Analysis and Control of Buck-Boost Converter with the Same Input Polarity Based on Novel Energy Factor Evaluation

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Abstract

This paper presents firstly a buck-boost circuit with the advantage that its output voltage polarity is the same as the input polarity. The circuit operation is presented and analyzed in different modes of operation.

The well known parameters used in evaluation of DC/DC converters like Total Harmonic Distortion THD, Power Factor PF, and Ripple Factor RF have no meaning in DC/DC converters, so it is to introduce efficient concepts to permit a fair evaluation of the converter.

This paper present other parameters that can be used to study the characteristics of the converter and gives a real and logic means of its operation. These main parameters are: pumping energy PE, storage energy SE, energy factor EF, and energy losses EL. In addition, the converter efficiency is not considered as 100 % as taken in most analyzing studies.

The positive DC/DC buck-boost converter is evaluated according to the new concepts and the system model is deduced for different cases of operation taking into account the resistance of the circuit inductor. The circuit is implemented practically and the presented obtained results show the correct operation under different modes of operation.

In addition the control design of the converter is built such that a PI controller with windup is considered. In order to test the effectiveness of the designed control algorithm, the system were exposed to different voltage reference values and the obtained results demonstrate that the system responses for all cases are very acceptable according to the criteria of the control system theory.

Keywords : Positive Polarity Buck-Boost Converter, Energy Losses (EL), Energy Factor(EF), Storage Energy (SE), Buck-Boost control.

الخلاصـــة

تقدم هذه الورقة أولا دائرة مغير القدرة خافض/رافع (Buck/Boost) مع ميزة أن قطبية جهد الخرج التيار الكهربائي لها هو نفس قطبية الإدخال. كذلك سيتم تقديم عمل الدائرة اضافة الى تحليل كافة الحالات في مختلف انماط عملها.

المتغيرات المعروفة والمستخدمة في تقييم مغيرات القدرة مثل عامل التموج (RF)، التشوه التوافقي الكلي (THD)، ومعامل القدرة (PF) في الحقيقة لا تمتلك المعنى الحقيقي لها والتي تفيد بشكل دقيق في تقييم مغيرات القدرة نوع جهد مستمر/مستمر، لذلك اضحى من الضروري ايجاد متغيرات ذات مفاهيم كفوءة في تقييم عادل و منطقي وعملي لمغيرات الطاقة من هذا النوع.

يقدم هذا البحث معايير جديدة والتي يمكن استخدامها لدراسة خصائص مغيرات القدرة (نوع مستمر/مستمر) وتعطي وسيلة حقيقية ومنطقية لعملها. المتغيرات الجديدة الرئيسية هي عامل الطاقة (EF)، ضخ الطاقة (PE)، تخزين الطاقة (SE)، خسائر الطاقة (EL). وبالإضافة إلى ذلك فإننا لم نفرض أن الكفاءة تساوي 100٪ كما هو الحال في معظم الدراسات وانما يتم أخذ المفاقيد بنظر الاعتبار عند التحليل.

في هذه الورقة، تم تقييم عمل مغير القدرة (جهد مستمر/ مستمر) ذات القطبية المتطابقة استنادا الى مفاهيم المتغيرات الجديدة و أن نموذج المنظومة تم تقييمه لحالات عمل مختلفة (تغيير زمن التوصيل للمفتاح) آخذين بنظر الاعتبار ان الملفات لها مقاومة وبالتالي هنالك فقد في القدرة. تم تنفيذ الدائرة عمليا وعرضت النتائج المستحصلة بحالات العمل المختلفة خلال عرض البحث حيث تؤكد عمله بشكل ممتاز.

وبالإضافة إلى ذلك تم تصميم السيطرة على عمل المغير حيث استخدمنا وحدة تحكم نوع تناسبي/ تكاملي (PI) مع تقنية الانطلاق (windup) ومن أجل إختبار فعالية نظام السيطرة تم تعريض النظام إلى حالات متعددة من جهد العمل المطلوب (جهد المرجعية) (Reference Voltage) حيث أثبتت النتائج التي تم الحصول عليها فعالية وحدة تحكم لمتابعة جهد المرجعية.

الكلمات المرشدة : مغير القدرة خافض/ رافع بنفس القطبية ، خسائر الطاقة (EL) ، عامل الطاقة (EF) ، تخزين الطاقة (SE)، السيطرة على مغير القدرة خافض/ رافع .

1. Introduction

The main goal of switching DC/DC converter is to supply a DC regulated voltage to the DC load in addition to the minimization of the dimensions of the input transformer when the input is an AC source. The DC/DC conversion technology is a rapid growth and a statistic study, which is still incomplete reveals that there are approximately five hundred circuitries of DC/DC converters. (Fang Lin LuO, 2008)

Buck, Boost, Buck-Boost, and Cuk are the main classical types of DC-DC converters.

The classical Buck–Boost converter can operate for stepping up and down DC-DC converter, but it is important to note that the converter works in the third quadrant mode of operation. The output voltage can be found from equation (1).

$$Vo = -\frac{K}{K-1}\,Vi \qquad \text{.......................................} (1)$$

Where, Vi and Vo are the input and output voltages, respectively. K is defined as the duty cycle (t_{on}/T), where T is the reciprocal of the converter chopping frequency f and t_{on} is the switching ON time (Muhammad Rashid, 2007; Nagalakshmi. and Bindu, 2015).

The classical Buck-boost converter suffers from main problems: there is no possibility to obtain an output voltage of the same polarity of the input voltage, low output voltage with high output current (which has widespread requirements in computer peripheral equipments and industrial applications) is not available, positive and negative output voltage in the same time is not available, low voltage transfer gain, interlink between input and output, and single quadrant operation mode (Luo, 2000; Hart- Daniel, 2011; Itoh and Fuji, 2008).

Since there are large number of DC/DC converters had not been clearly classified until 2001, prof. Luo *et.al*., have classified them mainly in six generations (Luo and Ye, 2005; Lin, *et.al.,* 2009).

In this paper, a positive output DC-DC buck-boost converter circuit is presented. The circuit is analyzed for different modes of operation and related necessary formulas are deduced. The evaluation of the converter is also presented according to new concepts that depend on the energy analysis in the circuit. The control design of the converter is also presented in this paper. The converter circuit is simulated and implemented practically. In addition, the results of the converter operation as well as the controlled system are stated in this research.

2. Positive Polarity Buck-Boost DC/DC Circuit operation and analysis.

Figure (1) shows the circuit diagram of the positive output Buck-Boost converter and the equivalent circuit for the two modes of operation when the switch is closed and open respectively.

The performed voltages of the presented converter circuit are from positive voltage to positive voltage based on the use of Level Voltage technique LV. The circuit can produce a less than the input voltage (step-down) and greater than the input voltage (step-up) DC-DC conversion. The main switch (S) in these circuits is controlled by a P.W.M. signal of repeated frequency f and switch on (conduction) according to its duty cycle (K). The time period of repeating frequency (f) is T = 1/f, so that the switch ON state period is K*T and the it is switched off along the period (1 – k)*T (Timothy, 2002; Kayalvizhi *et.al.,* 2005).

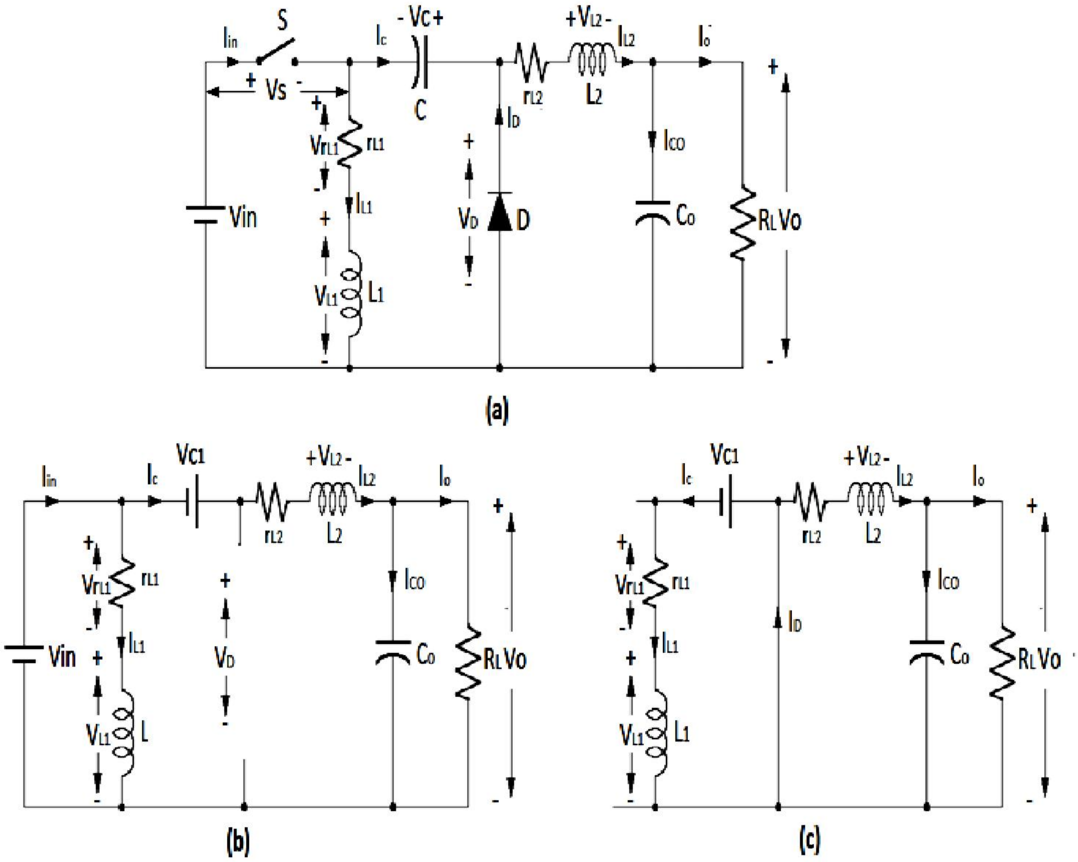


Figure (1) Circuits diagram of positive output converter and its modes.

a) Circuit diagram. (b) Circuit during Switch-on. (c) Circuit during Switch-off.

2.1. Operation analysis when switch (S) is closed.

Figure (1-b) shows the circuit when the switch (S) is closed for a time (KT), where the diode during this time is reverse-biased and the inductor voltage across the V_{L1} is expressed by eq.(2) (Ray-Lee Lin, *et.al.,* 2009)

$$V_{L1} = V_{in} - V_{rL1} = L_1 \frac{di_{L1}}{dt} \quad \rightarrow \quad \frac{di_{L1}}{dt} = \frac{V_{in} - V_{rL1}}{L_1} \quad \ldots\ldots (2)$$

$V_{rL1} = I_{L1} * r_{L1}$ is the voltage across the resistance r_{L1} of inductor L_1, since the derivative of the current is a positive constant, the current increases in linear form as depicted in eq.(3).

$$\frac{di_{L1}}{dt} = \frac{\Delta i_{L1closed}}{KT} = \frac{V_{in} - V_{rL1}}{L_1} \rightarrow \Delta i_{L1closed} = \frac{V_{in} - V_{rL1}}{L_1} KT \quad \ldots\ldots\ldots. (3)$$

Also the voltage across L2 is,

$$V_{L2} = Vc1 + V_{in} - Vo - VrL_2 = L_2 \frac{di_{L2}}{dt} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$V_{rL2} = I_{L2} * r_{L2}$ is the voltage across the resistance r_{L2} of the inductor L_2. Also the current increases linearly, then

$$\Delta i_{L2closed} = \left(\frac{Vc1 + V_{in} - Vo - V_{rL2}}{L_2}\right) KT \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

2.2. Operation analysis when switch is open

Figure (1-c) shows the circuit diagram during this mode of operation, when the diode becomes forward-biased to carry the current in the inductor also the peak-to-peak variations of the current across the inductors L1 and L2 are: (Ray-Lee Lin, *et. al.,* 2009)

$$\Delta i_{L1_{open}} = \frac{(-V_{C1} - V_{rL1})}{L_1}(1-K)T \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$\Delta i_{L2_{open}} = \frac{(-V_o - V_{rL2})}{L_2}(1-K)T \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

In steady-state operation requires that the variation of current during the switch ON and open equals to zero, i.e.

$$\Delta i_{L1_{closed}} + \Delta i_{L1_{open}} = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

and,

$$\Delta i_{L2_{closed}} + \Delta i_{L2_{open}} = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

By substituting the expression of $\Delta i_{L1_{closed}}$ and $\Delta i_{L1_{open}}$ in Eq (8) and simplify the expression in eq. (10) is obtained,

$$V_c = \left(\frac{K}{1-K}\right)V_{in} - V_{rL1}\left(\frac{1}{1-K}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

The same method is applied for $\Delta i_{L2_{closed}}$ and $\Delta i_{L2_{open}}$ are substituted into Equation (9); the following expression is obtained,

$$\left(\frac{Vc1 + V_{in} - Vo - V_{rL2}}{L_2}\right)KT + \frac{(-V_o - V_{rL2})}{L_2}(1-K)T = 0$$

Simplifying this last expression, eq.(11) is obtained.

$$Vo = K\,Vc + K\,V_{in} - V_{rL2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Substituting eq.(10) into eq.(11), the final voltage gain of the converter is obtained as,

$$\frac{V_o}{V_{in}} = \frac{K/(1-K)}{1+\frac{r_{L1}}{R_L}(\frac{K}{1-K})^2 + \frac{r_{L2}}{R_L}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

If it is assumed that $r_{L1} = 0$ and $r_{L1} = 0$ the converter voltage gain is,

$$\frac{V_o}{V_{in}} = \left(\frac{K}{1-K}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

Therefore, this circuit combines the capabilities of the buck and boost of the input voltage and of the same polarity. This is the main advantage of the circuit over the classical buck-boost converter.

So the advantages of positive Buck-Boost Voltage converter are: giving positive output, large voltage amplification, simple in structure, very small voltage ripple in comparison with classical converter, overcoming the effects of parasitic elements, and high efficiency.

3. Evaluation of DC/DC Converters Based on New Concepts

When talking about the evaluation of DC-DC converters it is found that the major studies depend on the evaluation of the classical factors like: ripple factor, power factor, efficiency, and Total Harmonic Distortion. But, really these factors;

firstly have no meaning and secondly are not the best description for the characteristics of the switching converters (Gabriel, *et. al.,*2012).

In order to present more accurate study of the switching converter specially a DC/DC converters, a new parameters have been considered like SE, PE, EL, EF, damping time constant τd, and time constant τ. Clearly, these parameters are absolutely different from these classical or traditional used (Kayalvizhi R.,*et.al.* ,2005; Onwuchekwa, C.N., 2011).

Using these parameters the converters' characteristics can be described accurately and success, including the main fundamental features; the stability of the system, unit-step response, and impulse-response for different values of disturbances.

- **Pumping Energy (PE).**

As known, the energy in the converter is transferred from the source to the passive elements of the circuit which are considered as storage elements (inductors and capacitors), then PE can be used for input energy calculation in switching period as,

$$PE = \int_0^T P_{in}\, dt = \int_0^T v_1 i_1\, dt = T\, V_1 I_1 \quad \ldots\ldots\ldots\ldots\ldots\ldots (14)$$

Where : V_1 and I_1 are input voltage and current respectively, and T is the switching period.

- **Storage Energy (SE).**

SE is very important parameter in DC/DC converters which gives a good relationship between the converter characteristics and stored energy in the converter. The inductors stored energy W_L and that stored in capacitors Wc are expressed as,

$$W_L = \frac{1}{2} L\, i_L^2 \qquad and \quad W_c = \frac{1}{2} C\, V_C^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (15)$$

Where i_L is the inductor current and Vc is the capacitor voltage.
If the number of inductors is n and there are m capacitors in the circuit, the total SE can be calculated as,

$$SE = \sum_{j=1}^{n} W_{Lj} + \sum_{i=1}^{m} W_{ci} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

- **Capacitor – Inductor Storage Energy Ratio (SER).**

SER describes the relation between the energy in the capacitors to that in the inductors, that is

$$SER = \frac{\sum_{i=1}^{m} W_{ci}}{\sum_{j=1}^{n} W_{Lj}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

- **Energy Losses (EL)**

The major analysis of DC/DC converters assumes that the converter has no power losses (100% efficiency), practically this assumption is not correct, and so it is important to take this parameter into account. The power flow of the converter is,

$$P_{in} = P_{out} + Pr + Pp + Pd \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (18)$$

Where: P_{in}, P_{out} , Pr , Pp , and Pd are input power, output power, the losses in the resistances, passive elements power loss, and device power loss respectively.
Then,

$$EL = T \times P_{losses} = T\ (P_{in} - P_{out}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)$$

And the efficiency of the converter is calculated as,

$$\eta = \frac{P_{out}}{P_{in}} = \frac{P_{in} - losses}{P_{in}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (20)$$

- **Energy Factor (EF)**

EF gives a clear idea about the energy distribution of the converter and it is a very important factor. It is independent of the conduction duty cycle K and proportional to the switching frequency F (T=1/F). EF is the relation between the stored energy and the pumping energy and can be given by,

$$EF = SE / PE \quad \text{.....................................} (21)$$

- **Time constant (τ)**

This parameter gives idea about the transient response of the DC/DC converter and it is independent of the switching period T. If the losses are taken into account i.e. $\eta <$ 100% , the time constant is defined as

$$\tau = \frac{2T*EF}{1+SER}\left(1 + SER * \frac{1-\eta}{\eta}\right) \quad \text{..........................} (22)$$

- **Damping Time constant (τ_d)**

It is also a new concept in the DC/DC converter world. It is related to the transient characteristics of the converter and is defined as,

$$\tau_d = \frac{2T\times EF}{1+SER} * \frac{SER}{\eta + SER(1-\eta)} \quad for\ \eta < 1 \quad \text{..........} (23)$$

- **Time constant Ratio (ξ)**

The time constant ratio is other concept, it is independent on switching frequency. It represents the ratio between τ_d and τ , and so it is defined as

$$\xi = \frac{\tau_d}{\tau} = \frac{SER}{\eta\left(1+SER\frac{1-\eta}{\eta}\right)^2} \quad for\ \eta < 1 \quad \text{...................} (24)$$

4. Converter Mathematical Modeling.

Using the EF parameters described earlier the mathematical model of all types for converters. It can be written as,

$$G(S) = \frac{M}{\tau\,\tau_d\,S^2 + \tau\,S + 1} \quad \text{..................................} (25)$$

Where,

$$M = \frac{K/(1-K)}{1+\frac{r_{L1}}{R_L}\left(\frac{K}{1-K}\right)^2 + \frac{r_{L2}}{R_L}} \quad \text{...................................} (26)$$

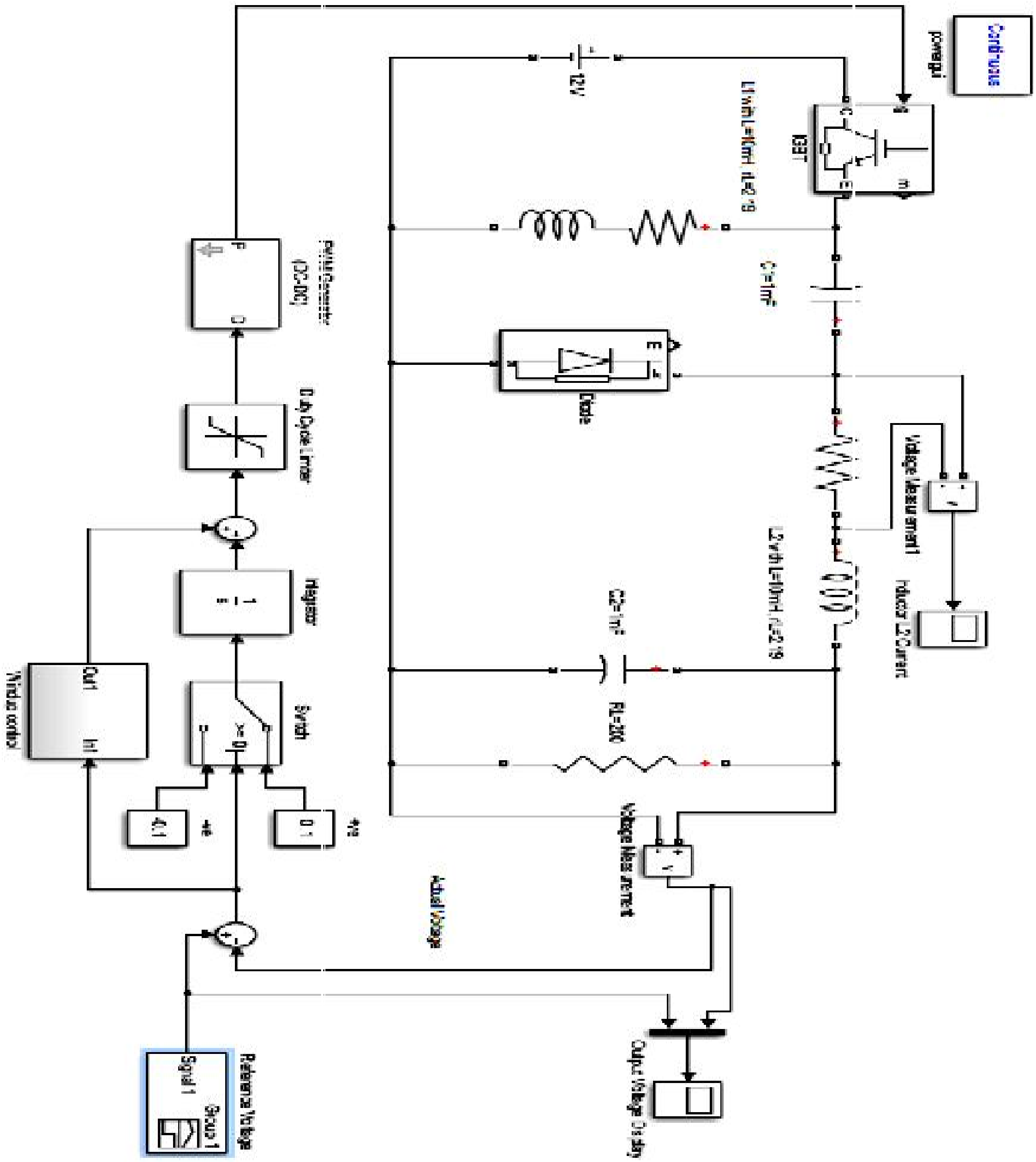
Where M is defined as the gain of the transferred voltage (M =Vo/Vin), and S is the S-domain Laplace operator.

5. Converter Controller design.

In order to let the converter output voltage to track the required reference voltage, a controller is used. In case of the converter presented in this paper a PI controller with windup technique is used (R.Kayalvizhi, et.al. ,2005; Taghvaee, M.H., et. al. 2013). The idea of winup technique is that the proportional gain jump to a certain value which is proportional to the desired and the source voltages according to the gain of the converter. Once the value of output voltage is closer to the desired value of about 10% the integrator action starts working and causing the acceleration of the converter output toward the reference voltage and eliminate the steady state error.

The controller goal is to generate the control signal which varies from 0 to 4.9 V. In order to generate the PWM gate signal of the IGBT switch, the control signal is compared with a saw tooth signal of 5V amplitude, 10 KHz which represents the switching frequency. The function of the limiter is to ensure that the control signal does not exceed the value of 4.9 V (which reflects the value of duty cycle < 1) since the control signal has no meaning.

The case study of the converter circuit presented in this paper has the following parameters:
Vin=12 V, L_1= L_2=10 mH, r_{L1}= r_{L2}= 2.19 ohm, C1= C2 = 1000 uF, R_L = 200 ohm, and switching frequency (f) = 10 KHz.
According to the strategy used in designing the controller, figure (2) shows the block diagram of the controlled converter.



6. Results

The results presented in this paper are grouped in three sections:

6.1. Converter evaluation and modeling results.

In this section the converter evaluation results are presented according to the mentioned concepts of energy factor parameters. In which case three values of duty cycle of K=30% (buck operation), K=50% (unity gain operation), and K= 60% (boost operation) are used. In order to calculate the energy factor parameters and then find the transfer function of the converter, equations (14)-(26) are applied for the case of K=30% for example, the following results are obtained.

- the voltage transfer gain M as follow,

$$M = \frac{\frac{K}{1-K}}{1+\frac{r_{L1}}{R_L}\left(\frac{K}{1-K}\right)^2+\frac{r_{L2}}{R_L}} = \frac{\frac{0.3}{1-0.3}}{1+\frac{2.19}{200}\left(\frac{0.3}{1-0.3}\right)^2+\frac{2.19}{200}} = 0.423$$

- Vo = M x Vin = 0.423 x 12 = 5.0771 V
- Io = Vo / R_L = 5.0771 / 200 = 0.0254 A
- I_{L1} = Io x M = 0.0254 x 0.423 = 0.0109 A
- I_{L2} = Io = 0.0254 A
- $V_{C1}=(M*Vin)/(1+(r_{L1}/R_L)* M^2)$= 5.0671 V
- V_{C2}= Vo= 5.0771 V
- $W_L=0.5*I_{L1}^2*L_1+0.5*I_{L2}^2*L^2 = 3.8139x10^{-06}$ J
- $W_C=0.5*C_1*V_{C1}^2+0.5*C_2*V_{C2}^2$ = 0.0257 J
- $P_{loss}= r_{L1}*I_{L1}^2 + r_{L2}*I_{L2}^2$ = 0.0017 W
- Po = Vo x Io = 0.1289 W
- I_{in} = (Po + Ploss) / Vin = 0.019 A
- η = Po / (Vin x Iin)= 0.9872 = 98.72 %
- PE= Vin*Iin*T = $1.3055x10^{-5}$ W
- SE=W_C+W_L = 0.0257 J
- SER=W_C / W_L = $6.7454x10^3$
- EF= SE / PE = $1.9708x10^3$
- $\tau = \frac{2xTxEF}{1+SER}\left(1+SER*\frac{1-\eta}{\eta}\right)$ = 0.005167 sec.
- $\tau_d = \frac{2T\times EF}{1+SER} * \frac{CIR}{\eta+SER(1-\eta)}$ = 0.0045 sec.
- $\xi = \frac{\tau_d}{\tau}$ = 0.8738
- The system transfer function is

$$G(S) = \frac{M}{\tau\,\tau_d\,S^2+\tau\,S+1} = \frac{0.4231}{2.332\,x\,10^{-5}\,S^2+0.005167\,S+1} \quad \text{....... (27)}$$

Equation (27) represents the transfer function of the converter based on the values of components that have been selected for its design. Find the transfer function of the system is the main goal for the controller design; where through transfer function the designed system can be analyzed and find out whether it is stable or not. In addition, finding the system transfer function help in design the converter control algorithm using any of the well known designing control methods. Comparing eq. (27) with the general expression of second order system in eq.(28),

$$G(S) = \frac{G\,x\,Wn^2}{S^2+2\,\xi\,Wn\,S+Wn^2} \quad \text{................................ (28)}$$

It is found that Wn = 207.07 rad/sec. Since $\tau_d < \tau$ then the system can be considered stable and with low overshoot. In general, whenever τ_d more smaller than τ, the system is more damping. Equation (27) is simulated and the response is shown in figure (3). It is clear that the system is stable.

The same procedure is repeated for K=50% and 60% and the obtained results are shown in table (1) . The simulation test results for K=50% and 60% in addition to that for K=30% are presented in figure (3).

Figure (4) shows the relation between the duty cycle and the efficiency for different values of inductor DC resistance.

Table 1. Results of DC/DC Buck-Boost Positive output converter based on Energy factor concepts (Vin=12V, L1=L2=10mH, C1=C2=1000µF, $r_{L1}= r_{L2}$=2.19Ω, R=200Ω,f=10KHz.

Factor	$\boldsymbol{K = 30\%}$	$\boldsymbol{K = 50\%}$	$\boldsymbol{K = 60\%}$
η (%)	98.72	97.86	96.56
PE (J)	1.3055e-05	7.0457e-05	1.5643e-04
SE (J)	0.0261	0.1365	0.2955
SER	6.8329e+03	3.9587e+03	2.406e+03
EF	1.9964e+03	1.9374e+03	1.8892e+03
τ (sec)	0.0052	0.0086	0.0136
τ_d (sec)	0.0045	0.0045	0.0045
$\zeta = \tau_d/\tau$	0.8629	0.526	0.3319
Wn (rad./sec)	207.05	160.6673	127.650
G(S)	$\frac{0.423}{2.363*10^{-5}\,S^2+0.005233\,S+1}$	$\frac{0.9786}{3.874*10^{-5}\,S^2+0.008582\,S+1}$	$\frac{1.448}{6.137*10^{-5}\,S^2+0.0136\,S+1}$

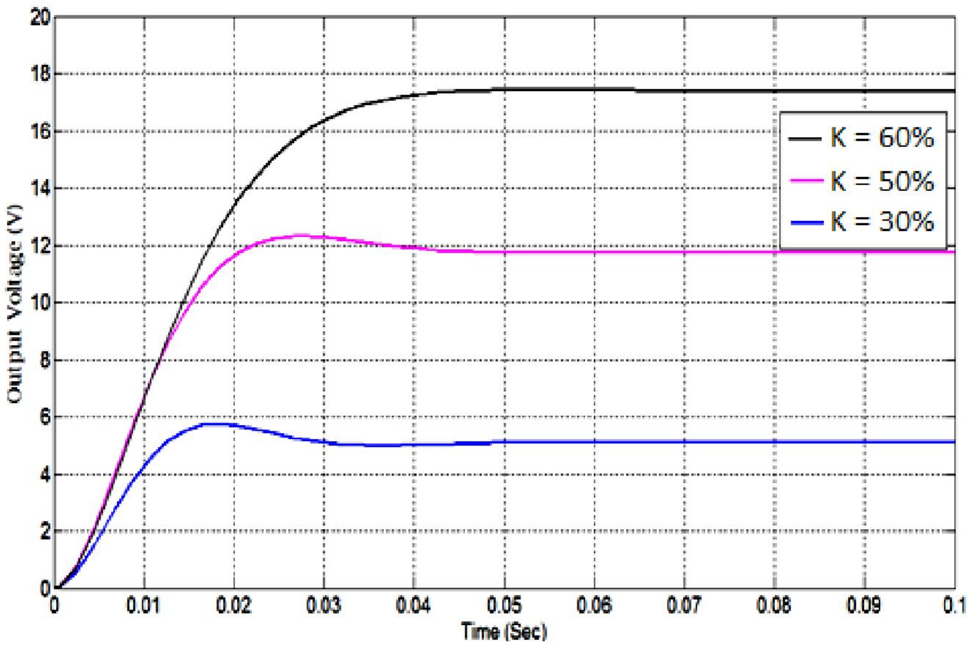


Figure (3) step response of the presented converter in cases of K=30%, 50%, and 60%.

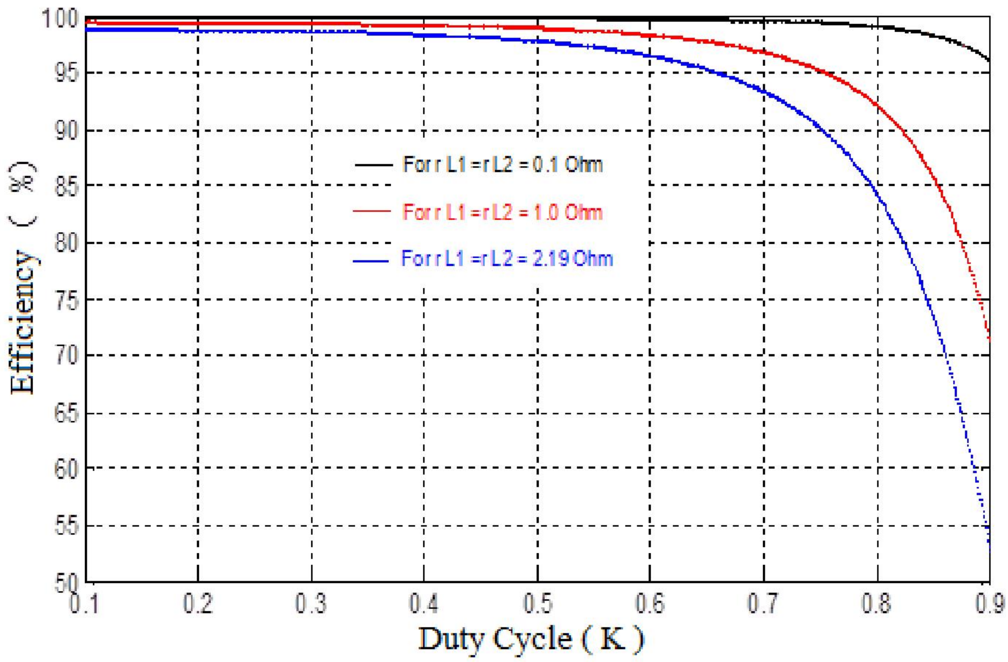


Figure (4) shows the influence of inductors' resistances (r_{L1} and r_{L2}) on converter efficiency for a wide range of duty cycle (K).

6.2. Experimental Results.

The converter circuit is set up practically (see figure 5) for the same elements values in the laboratory, the switch used is IGBT IRGBC30S and the output voltage of the converter are represented for K=30%, 50%, and 60% as shown in figures (6) – (10).

Figure (5) Experimental converter circuit setup.

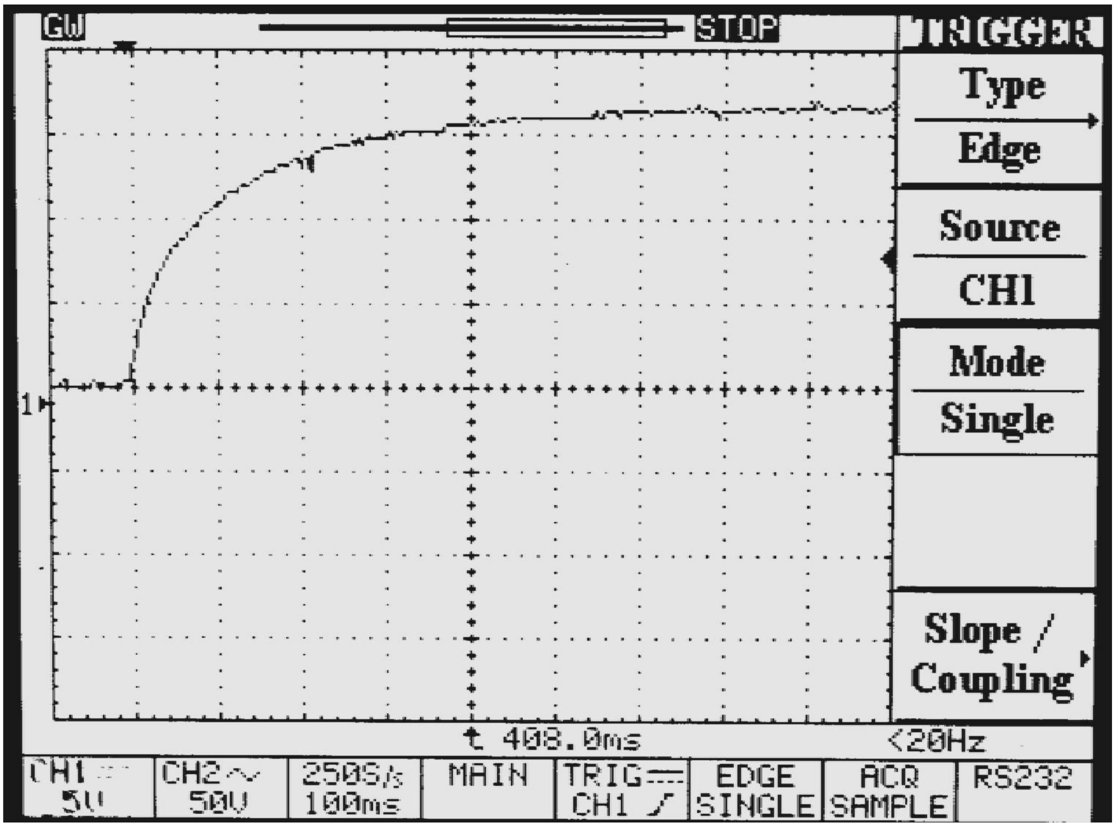


Figure (6) Practical output voltage of the converter. (K=30%, Vin=12 V, 20ms/div, 2V/div.)

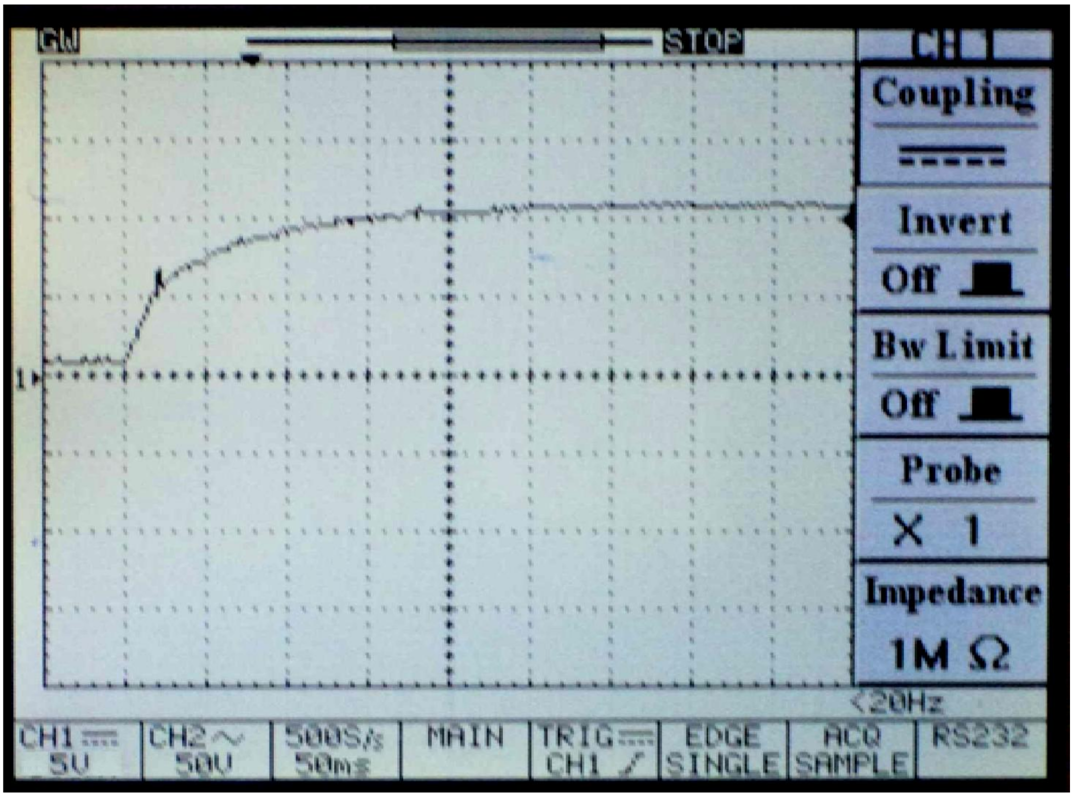


Figure (7) Practical output voltage of the converter. (K=50%, Vin=12 V, 20ms/div, 5V/div.)

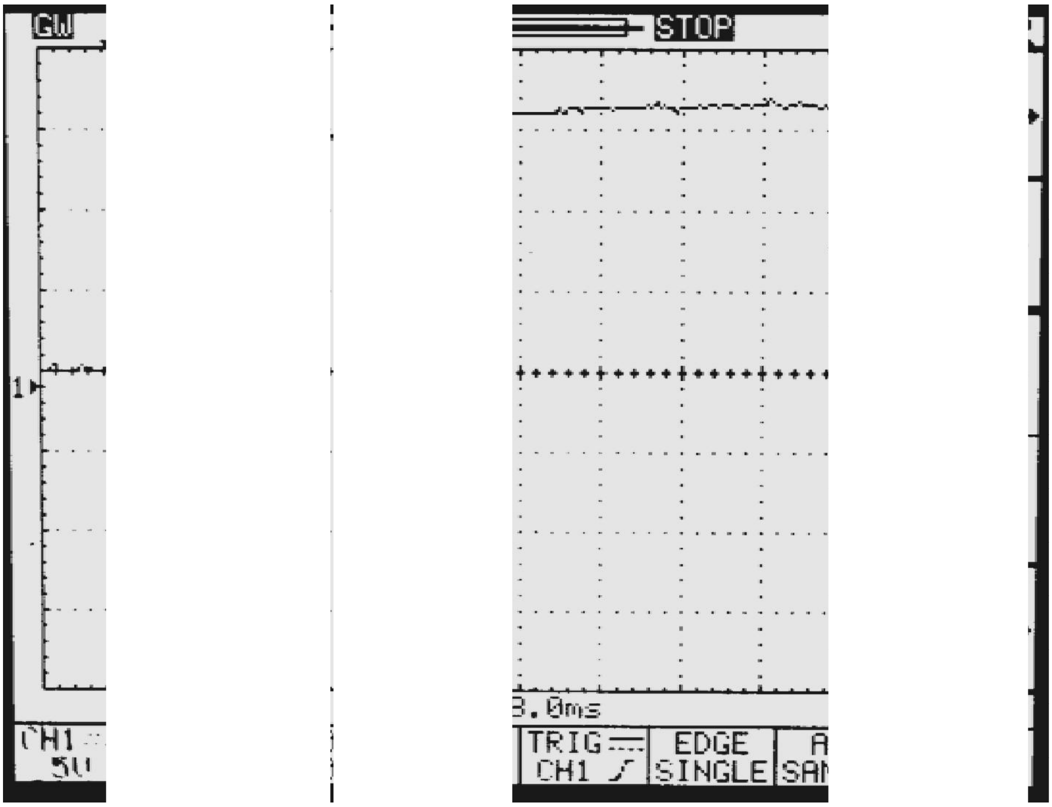


Figure (8) Practical output voltage of the converter. (K=60%, Vin=12 V, 20ms/div, 5V/div.)

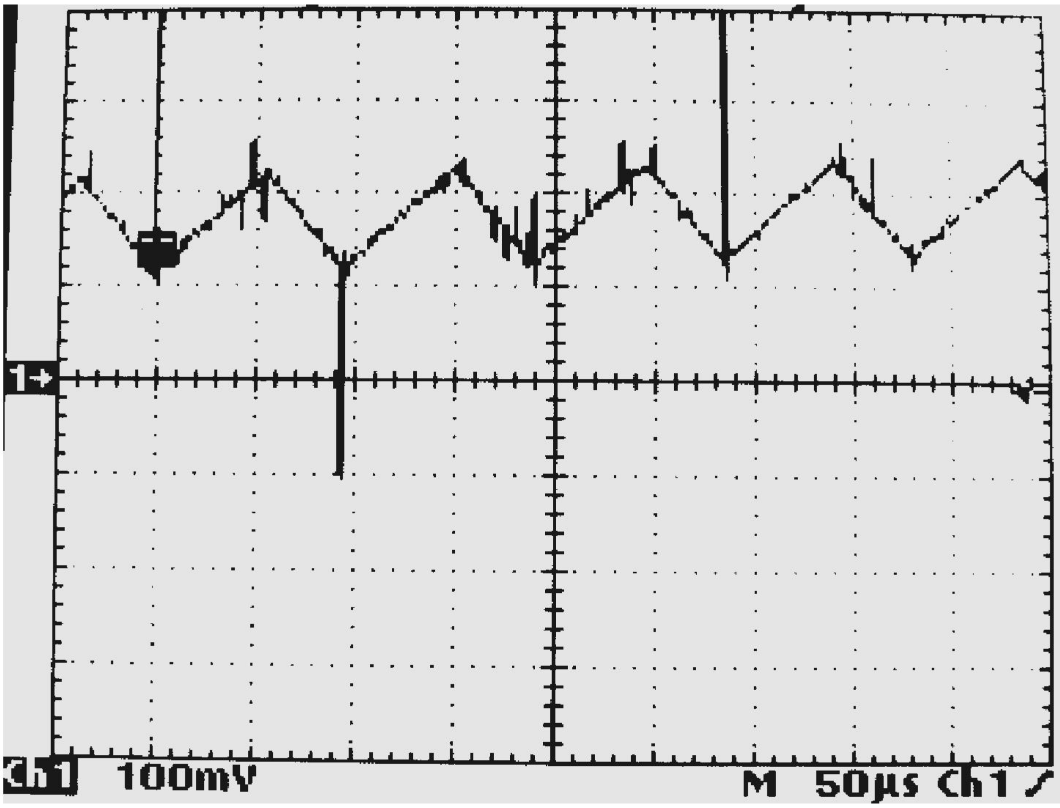


Figure (9) Waveform of the inductor (L2) current. (K=60%, Vin=12 V, 20ms/div, 0.1A/div.)

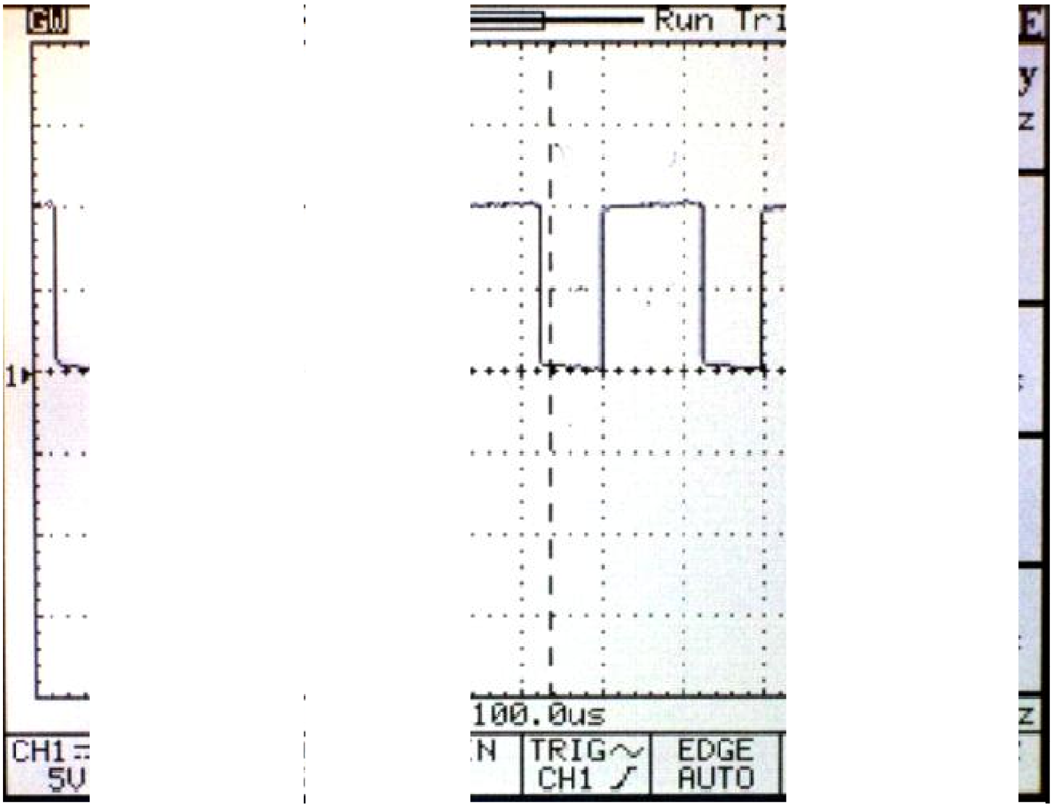


Figure (10) Switch control Signal. (K=60%, 50µs/div &5V/div.)

6.3. System control results.

The converter controller designed above is implemented for different values of required desired voltage as shown in figure (11) and the presented results demonstrates the effectiveness of the controller to follow the reference voltage in each case. Also figure (12) shows the variation of duty cycle during the control procedure for the same situation of figure (11).

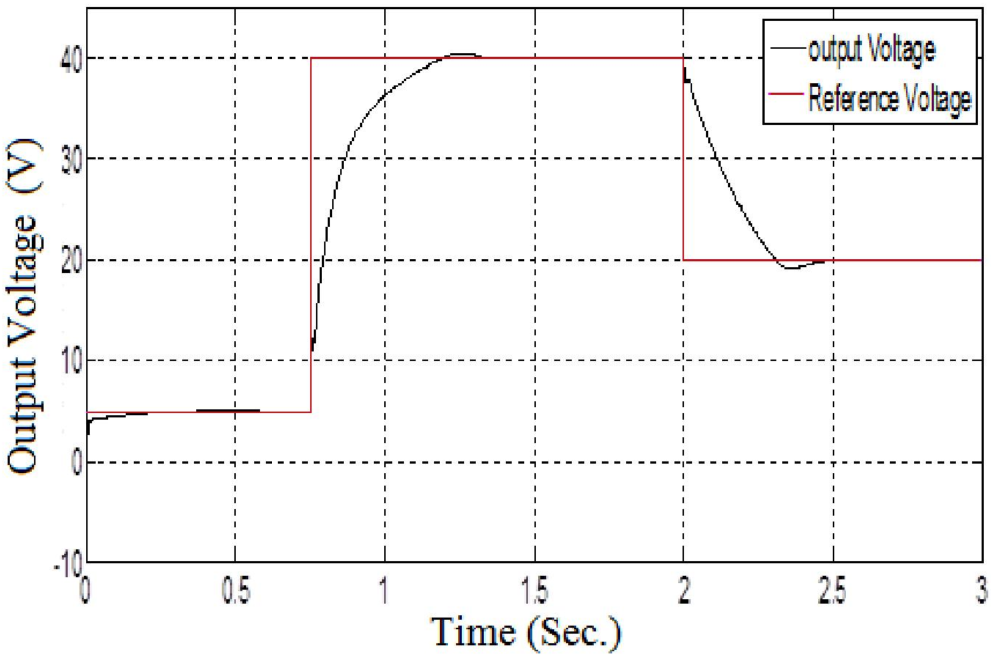


Figure (11) the controlled output voltage under different steps of desired voltage (5 V, 40 V, and 20 V)

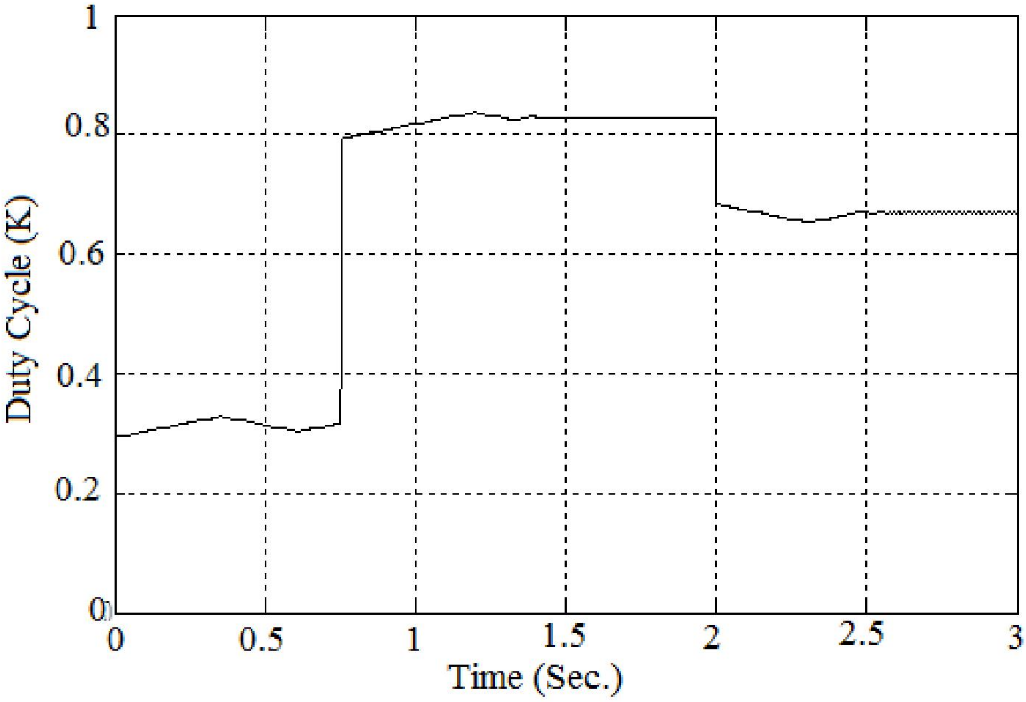


Figure (12) The evolution of duty cycle (K) during the control operation of figure (11).

7. Conclusions

The Buck-Boost circuit presented is characterized by similarity of polarity of input/output voltage, simple in construction, very small voltage ripple in comparison with classical Buck-Boost, capability of overcoming the effects of parasitic elements, and high efficiency.

In the converter analysis the resistances of the inductors (real case) are taken into account so the efficiency does not considered as 100%.

The estimation of the converter based on the energy factor with the parameters (EF, SE, PE, ..etc) is presented in this paper, these parameters firstly help us to understand the operation of the converters; secondly, they facilitate accurate and fair modeling of the converter; then the system controller can be designed easily.

A prototype of the converter is considered and the new parameters are deduced and then the model is obtained. The model is simulated using MATLAB, the converter circuit is implemented practically and the result obtained demonstrates fair operation and closer to the simulated results.

The control algorithm of the converter is designed and PI controller with windup in which the initial value of duty cycle is estimated which considered as proportional element of the controller, then the integrator element is entered in order to eliminate the steady state error. According to the obtained results the controller operates correctly and follows the desired output voltage.

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