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DC/DC Buck-Boost Converter Efficiency and Power Dissipation Calculation at Operating Points Not Included in the Datasheet

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***Abstract*—Applying traditional circuit analysis techniques, this paper proposes a new approach to model the steady state operating conditions of the DC/DC buck-boost power converters. The developed approach can be more or less considered new because it is not present in the literature, sometimes it can be considered general because it is valid for the other two basic topologies (Buck and the Boost types converters). It's easy to apply and can be applied immediately from the datasheets of the components used to construct the converters without additional measurements. In this paper work the efficiency of the converter is determined analytically using the determined characteristic parameters of the model and its main relationships.**

Keywords—DC-DC power conversion; modeling; power converter; buck-boost converter

I. INTRODUCTION

The efficiency calculations shown in the literature for ideal (no losses) DC/DC converters are enough for multiple applications. However, nowadays he need for greater efficiency demands precise special models that take non-idealities and, therefore, efficiency losses into account [1]. Remembering this aim, the present work will be focused on the search for a general static model of the buck-boost type DC/DC power converters. This model is to be easily applicable and immediate from the data sheets of the converters components and no measurements are needed.

This type of converter is very famous nowadays because they are the main part of renewable energy-based electric sources.

There are so many types of DC-DC converters which operate over a wide range of input and output voltages. However, the given datasheets provide special efficiency curves for certain operating points [2]. Sometimes the same component can be used in other type of converters with different operating conditions and output voltages, and it is required to know the efficiency or power dissipation at such operating conditions and output voltages. the dissipated power (power losses) at any operating condition and output voltage and the efficiency profile of the converter at any operating condition and output voltage, it is always preferred to have a quick and easy method to obtain the converter efficiency without using any laboratory measurements.

The three main causes of power dissipation in a DC-DC converter are [3]:

- Inductor conduction losses
- Power Dissipated in the MOSFET
- Power loss in the filter capacitor
- Diode conduction loss

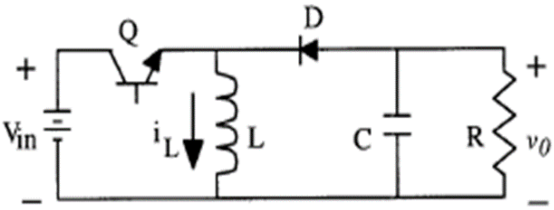

Fig. 1. The main construction of the Buck-Boost Converter

To calculate the power losses and efficiency of DC to DC buck-boost converter Fig.1, the equivalent circuit of the buck-boost converter with parasitic resistances is used, as shown in Fig. 2, where R_s is the equivalent resistance of the MOSFET during the ON-State period, r is the inductor equivalent series resistance, r_C is the capacitor equivalent series resistance, R_D and V_γ are the diode forward resistance and threshold voltage respectively [4].

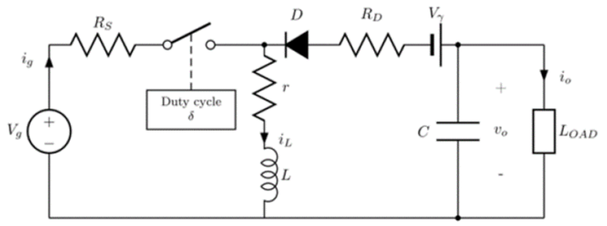

Fig. 2. Buck-boost converter circuit with main non-idealities (losses).

II. Power Dissipated in the Inductor

Figure 3 shows the current through the inductor in the DC-DC buck-boost converter.

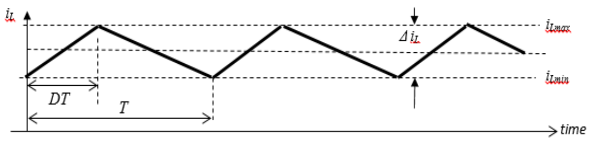

Fig.3. Current through the inductor in the DC-DC buck-boost converter. (Continuous mode of operation CCM) [5]

The peak-to-peak value of the ripple current through the inductor L is Δi_L which is only 0.375% of the R.M.S. value of the inductor current so it can be neglected.

The average value of the inductor current I_L is equal to the sum of the dc input current I_I and the dc output current I_o. Hence, one arrives at the peak value of the switch current

$$I_L \approx I_I + I_O = \frac{I_O}{1-D} \qquad \ldots(1)$$

So I_{Lrms} value will be,

$$I_{Lrms} \approx I_I + I_O = \frac{I_O}{1-D} \qquad \ldots(2)$$

Knowing that the inductor conduction loss,

$$P_L = rI_{Lrms}^2 = \frac{rI_O{}^2}{(1-D)^2} = \frac{rP_O}{(1-D)^2 R_L} \qquad \ldots(3)$$

III. Power Dissipated in the MOSFET

Assuming r_{DS} to be the resistance of the MOSFET switch during the ON-State period. The two major losses in it are conduction and switching losses, to evaluate the conduction loss, assuming that the inductor current I_L is ripple-free and equal to the DC current $I_i + I_o$, so the current of the main switch can be approximated as follows [6]

$$i_S = \begin{cases} I_L = I_i + I_o = \dfrac{I_o}{1-D} & , \; for \;\; 0 < t \le DT, \\ 0, & , \; for \; DT < t \le T, \end{cases} \qquad \ldots(4)$$

being its rms value

$$I_{Srms} = \sqrt{\frac{1}{T}\int_0^T i_S^2\, dt} = \frac{I_O}{1-D}\sqrt{\frac{1}{T}\int_0^{DT} dt} = \frac{\sqrt{D}\, I_O}{1-D} \qquad \ldots(5)$$

The MOSFET conduction loss is

$$P_{r_{DS}} = r_{DS} I_{Srms}^2 = \frac{Dr_{DS}I_O{}^2}{(1-D)^2} = \frac{Dr_{DS}P_O}{(1-D)^2 R_L} \qquad \ldots(6)$$

The switching losses can be assumed independent of output voltage, so it remains constant with any changes in output voltage.

I.V POWER LOSS IN THE FILTER CAPACITOR

The current of the output capacitor [7],

$$i_C = \begin{cases} -I_O, & for \;\; 0 < t \le DT, \\ I_i = \dfrac{DI_O}{1-D}, & for \;\; DT < t \le T, \end{cases} \qquad \ldots(7)$$

So, its rms value will be,

$$I_{Crms} = \sqrt{\frac{1}{T}\int_0^T i_C^2\, dt} = I_O\sqrt{\frac{D}{1-D}} = I_L\sqrt{D(1-D)} = I_S\sqrt{\frac{1-D}{D}} \qquad \ldots(8)$$

And the loss of power of the capacitor,

$$P_{rC} = r_C I_{Crms}^2 = \frac{Dr_C I_O^2}{1-D} = \frac{Dr_C P_O}{(1-D)R_L} \qquad \ldots(9)$$

II.V DIODE CONDUCTION LOSS

The diode current can be approximated by,

$$i_D = \begin{cases} 0, & for \;\; 0 < t \le DT, \\ I_L = I_I + I_O = \dfrac{I_O}{1-D} & for \;\; DT < t \le T, \end{cases} \qquad \ldots(10)$$

$$I_{Drms} = \sqrt{\frac{1}{T}\int_0^T i_D^2\, dt} = \frac{I_O}{1-D}\sqrt{\frac{1}{T}\int_0^{DT} dt} = \frac{I_O}{\sqrt{1-D}} \qquad \ldots(11)$$

Loss of power due to R_F,

$$P_{RF} = R_F I_{Drms}^2 = \frac{R_F I_O^2}{1-D} = \frac{R_F P_O}{(1-D)R_L} \qquad \ldots(12)$$

The average value of i_D equal to,

$$I_D = \frac{1}{T}\int_0^T i_D\, dt = \frac{I_O}{(1-D)T}\int_{DT}^T dt = I_O \qquad \ldots(13)$$

So, the loss of power accompanying with the V_F will be,

$$P_{VF} = V_F I_D = V_F I_O = \frac{V_F P_O}{V_O} \qquad \ldots(14)$$

Hence, the total diode power loss is,

$$P_D = P_{VF} + P_{RF} = V_F I_O + \frac{R_F I_O^2}{1-D} = \left[\frac{V_F}{V_O} + \frac{R_F}{(1-D)R_L}\right] P_O \qquad \ldots(15)$$

Summing all the above calculated losses we get the total losses of the converter which can be written as [8]:

$$P_{Total\ Losses} = P_L + P_{rDS} + P_{rC} + P_D + Other\ Losses \qquad \ldots(16)$$

Other losses mean the MOSFET switching losses, quiescent current losses etc. Knowing both the total losses and converter output power P_o, the total percentage efficiency at any output voltage can be simply calculated with [9].

$$\eta = \frac{P_0}{P_o + P_{Total\ Losses}} \quad \dots (17)$$

III.V EXPERIMENTAL AND CALCULATED RESULTS

A laboratory experimental prototype shown in Fig. 4. has been used to verify the operation of the implemented DC/DC buck-boost converter which is shown in Fig. 5 through different tests at the steady-state and dynamic operation conditions, these tests have been executed for both buck and boost modes of operation (Figures 6-9) thus to experimentally verify the performance and the strength of this sliding mode controller in controlling this type of DC/DC converters.

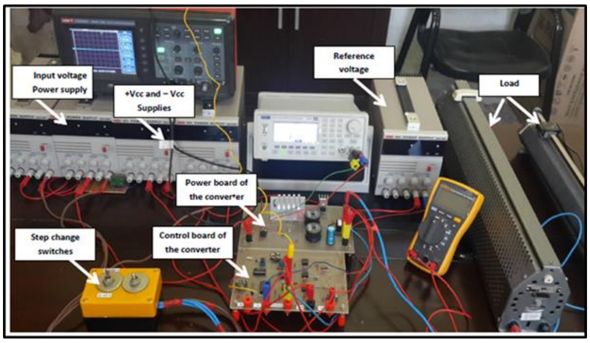

Fig. 4. The Experimental setup of the PWM-based SMVC-buck-boost converter

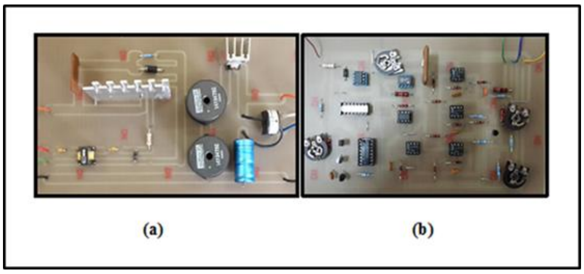

Fig. 5. (a) Experimental setup of the buck-boost converter
(b) Experimental setup of the SM controller

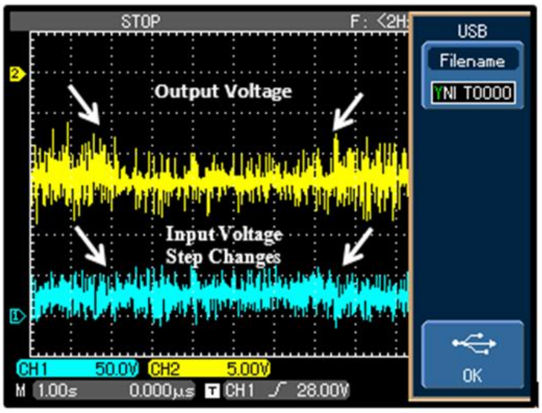

Fig. 6. Input and output voltage profiles, buck mode, two step changes in supply voltage 24V to 20V then to 24V, V_o = -12V, R_L = 140Ω, D = 33%

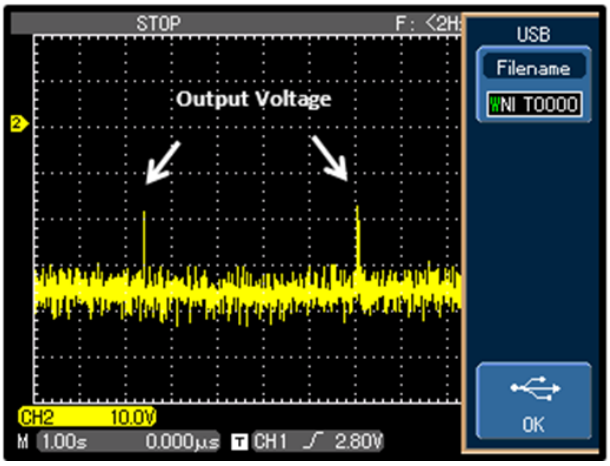

Fig. 7. Output voltage profile, boost mode, two step changes in supply voltage 24V to 28V then to 24V, Vo = -36V, RL = 140Ω, D = 60%

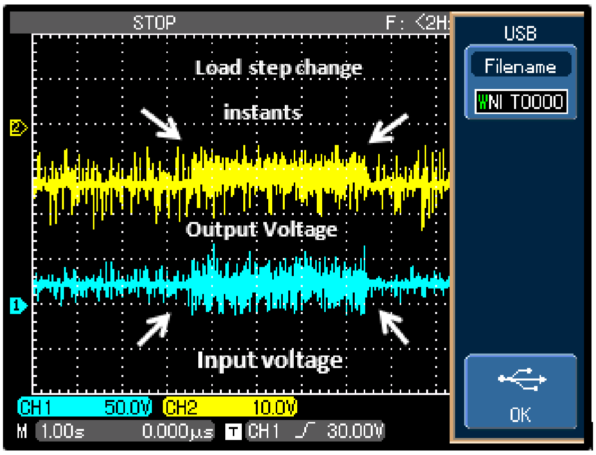

Fig. 8. Input and output voltage profiles, buck mode, two step changes in load resistance 140Ω to 14Ω then to 140Ω, V_{in} = 24V, V_o = -12V, D = 33%

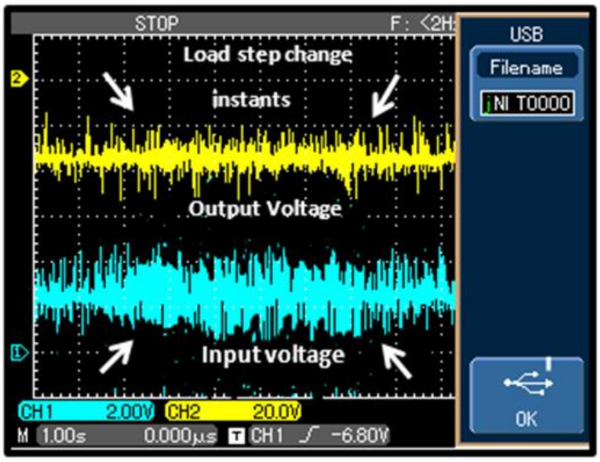

Fig. 9. Input and output voltage profiles, boost mode, two step changes in load resistance 140Ω to 14Ω then to 140Ω, Vin = 24V, Vo = -36V, D = 60%

An experimental calculation of the efficiency of the converter depending in measuring the average values of the input-output currents and voltages is shown in Fig. (10).

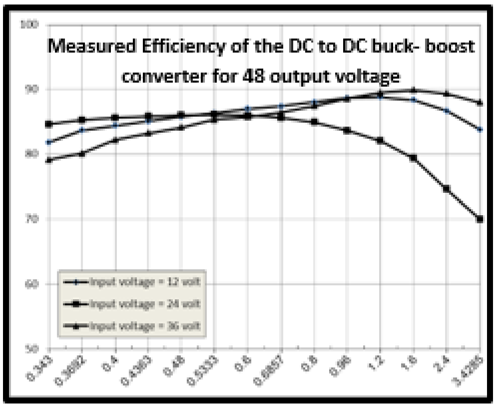

Fig. 10. Measured Efficiency of the DC to DC buck-boost converter for 48 V output voltage

For different loading with (25A, 80V and 0.077 and 0.100 Ohm, N-Channel Power MOSFETs is used with V_{in} = 12 V and V_o = 36 V at 4 A The datasheet does not give any efficiency graph with such operating conditions. However, the data sheet does provide an efficiency graph with V_{in} = 12 V and V_o = 24V at 4 A. The 24-V efficiency data can be used to calculate the 36-V efficiency.

The procedure in this calculation can be summarized as follow:

1. Calculate the total power loss for the 24-V output $P_{Total\ Losses}=P_L+P_{rDS}+P_{rC}+P_D+$ *Other Losses*
2. Calculate the MOSFET total conduction loss P_{rDS} for 24 V output as shown in eq. (6).
3. Calculate the diode conduction loss P_D using eq. (15).
4. Calculate the power loss in the filter capacitor P_{rC} using eq. (9).
5. Calculate the power dissipated in the Inductor P_L using eq. (3).
6. Calculate the other losses.
7. Calculate the total power loss for the 36-V output $P_{Total\ Losses}$ by equation (16).

TABLE I shows the efficiency measured at V_o = 36 V and different output currents on the IRF542 MOSFET based DC/DC buck-boost converter.

TABLE I.

Io(A)	Measured Efficiency(%)	Calculated Efficiency(%)
0.2	90.23	88.98
0.4	91.78	90.95
0.6	92.13	91.88
0.8	91.11	90.33
1.0	90.23	89.01
1.2	88.66	88.12

XI CONCLUSIONS

To calculate the DC/DC buck-boost converter efficiency at any output voltage given that the power supply's efficiency is known at any other output voltage. So this provides a quick and easy method to calculate the efficiency of a buck-boost converter at different conditions other than what is given by the standard tables and characteristics in datasheets. Also accurate results can be found by this method without the need to build an experimental prototype and test it.

REFERENCES

[1] Betcy Mariam David, and Sreeja K.K., “A Review of Sliding Mode Control of DC-DC Converters”, International Research Journal of Engineering and Technology, Vol. 2, No. 4, PP. 1382-1386, July 2015.

[2] TamalBiswas, G KPanda, P KSaha, and S Das, “Design of PWM-Based Sliding-Mode Control of Boost Converter with Improved Performance”, International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 4, No. 2, PP. 817-824, February 2015.

[3] Siew-Chong Tan, Y. M. Lai, Chi K. Tse, and Chi Kin Wu, “A Pulsewidth Modulation Based Integral Sliding Mode Current Controller for Boost Converters”, 37th IEEE Power Electronics Specialists Conference, Jeju, Korea, PP. 1612-1618, June 2006.

[4] . Siew-Chong Tan, Y. M. Lai, Chi K. Tse, Chi Kin Wu, and Martin K. H Cheung, “A Fixed-Frequency Pulsewidth Modulation Based Quasi-Sliding-Mode Controller for Buck Converters”, IEEE Transactions on Power Electronics, Vol. 20, No. 6, PP .1379-1392, November 2005.

[5] R. A. Abdulhalem, Haroutuon A. Hairik, and Asmaa J. Kadhem, “Experimental Prototype for PWM – Based Sliding Mode Boost Converter”, 1st International Conference on Energy, Power and Control (EPC-IQ), College of Engineering, University of Basrah, Basrah, Iraq, November 30-December 2, 2010.

[6] Abhilash Kumar, and Vinay Pathak, “Control Techniques used to Improve Performance of Dc-Dc Converter: A Review”, International Journal of Electrical, Electronics and Computer Engineering, Vol. 5, No. 1, PP. 82-87, 2016.

[7] Siew Chong Tan, Y. M. Lai, and Chi K. Tse, "A Unified Approach to the Design of PWM–Based Sliding Mode Voltage Controllers for Basic DC-DC Converters in Continuous Conduction Mode", IEEE Transaction on Circuit and Systems, Vol. 53, No. 8, PP. 1816-1827, August 2006.

[8] Pranita Singh, and Shubhi Purwar, “Sliding Mode Controller for PWM based Buck-Boost DC/DC Converter as State Space Averaging method in Continuous Conduction mode”, IEEE 2nd International Conference on Power, Control and Embedded Systems, 2012.

[9] Vatché Vorpérian, “Simple Efficiency Formula for Regulated DC-to-DC Converters”, IEEE Transactions On Aerospace and Electronic Systems Vol. 46, No. 4, PP. 2123-2131, October 2010.