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Research Article

Soft Switching DC-DC Converter Simulation Using Simulink/Simscape

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***Abstract*— Generally, switching losses of power electronics converters are proportional to their operating frequency. Consequently, for high frequency DC-DC converter, zero voltage switching (ZVS) technique is preferable over hard switching. If switches transition from OFF to ON occurs when the voltage across the switching element is zero, it reduces switching losses that is combined with heat and Electro Magnetic Interference (EMI). Such technique is defined as soft switching. Resonant components L-C are used to produce soft switching for the proposed topology. The values of the resonant components are found by applying related equations that were obtained according to the circuit topology. Moreover, very little electromagnetic interference (EMI) produces with this type of converters due to soft switched, which can make the proposed converter suitable for communication applications. In order to ensure efficient resonant converter, the research focuses on modelling a circuit with the fewest components. The converter is simulated and the model validates its viability, with two IGBT thermal models via MATLAB/SIMSCAPE program.**

***Index Terms*—Buck, resonant converter, thermal model, EMI, soft switching, Simscape.**

I. INTRODUCTION

BUCK regulation in DC-DC converters is accomplished by turning on the switching device for a predetermined duty cycle. For such converters, it is recommended to use high frequency for operate in order to minimize the converter's size. Hard switching converters experience significant power loss as a result of high frequency operation since switching losses account for a large portion of total converter losses and rise as switching frequency increases. Due to significant power loss caused by switching element, the hard switched converters efficiency is low. Electromagnetic interference (EMI) and switching stress are also made worse by high operating frequency. A soft switched or zero voltage switching circuit layout can resolve the issues with hard switched converters. Switching frequency for the proposed circuit arrangement is independent of switching losses, in order to raise the switching frequency to an extremely high value.

with modern civilization, power electronics (PE) equipment are widely utilized for producing and managing electricity in both industrial and domestic consumes [1]. The power converters are dominated by power transistors, specifically insulated-gate bipolar transistor (IGBT) modules, because of their good performance, low cost for high voltage levels, reliability, lightweight design, dependability for wind power inverters, and motor drives [2]. The life span of IGBT power modules is significantly impacted by the operational junction temperature of semiconductor devices [3]. The junction temperature is one of the most crucial variables to consider because it has a direct effect on power loss of Buck converter leading to overheating. Both wear and tear and failures may result from these factors. To attain precise measurement and prevent chip burning, the prediction of semiconductor chip junction temperature is essential [4].

Previous researches studied a variety of methods, including three-dimensional modelling and finite element simulation, were used to simulate the junction temperature. However, extracting the internal and structural data is not possible using the two aforementioned methods [5, 6]. The RC network model and loss calculation model, which are built on the basis of a data sheet, are then electro-thermally coupled in addition to the most popular method, which is to create a two-part simulation through coupling. The pertinent parameters of the Buck converter system are then entered into the loss calculation model to obtain the thermoelectric simulation [7]. In this study, the SIMSCAPE environment in MATLAB/Simulink may be used to directly predict the junction temperatures of all IGBTs by developing an impedance thermal model based solely on data from the manufacturer. The goal of this work was to design a junction temperature estimating method while getting beyond these limitations.

Via heat conduction between the substrate, heat sink, and air. Consequently, the complete heat transfer process of the IGBT module's thermal resistance may be broken down into only three parts. The heat sink's solid thermal resistance and convective heat transfer resistance to the ambient are measured after the IGBT chip's thermal resistance to the heat sink is first determined by contact thermal resistance [9], [10].

II. Model of thermal resistance

As equation (1) illustrates, the heat dissipation pathway diagrams reveal that the total thermal resistance of each layer in series [11] equals the thermal resistance between the chip and the heatsink.

$$R_{JA} = R_{JC} + R_{CH} + R_{HA} \quad (1)$$

The heat capacity and thermal resistance of each layer are represented by the following equation:

$$R_{TH} = \frac{L}{kA} \quad (2)$$

$$C_{th} = c\rho AD \quad (3)$$

In this case, the material's heat capacity (C_{th}), specific heat capacity (c), thickness (D), thermal conductivity (k), heat dissipation area (A), density (r), and thermal resistance (R_{th}) are all measured for each layer. For accurate T_J estimation and a realistic representation of its junction temperature, the three-phase inverter's IGBT module employs the junction temperature estimation methodology. The MATLAB/Simulink SIMSCAPE Environment can be used to simulate the Foster model, or thermal network model, in order to complete this objective.

Transient thermal impedance curves can be simulated by using limited number of thermal resistors and capacitors. The Cauer type and Foster type are frequently applied to RC networks. based on the heat transfer principle.

The internal physical structure of each layer cannot be accurately represented by the Foster network, despite its ease of usage [1۲]. Its parameters are easily computed by fitting the model to the thermal impedance curve. Foster's models are made by fitting the thermal response curves with the exponential equation below, but they are immutable, meaning that nodes inside of them have no real physical influence.

The exponential equation is used to fit the thermal response curves in order to generate the model [13-14].

III. ZVS Buck Converter Design

To achieve zero voltage across the converter's switch when it is turned on and off, Figure 1 is presented for ZVS operation[15]. The Buck converter circuit consists of diode D_1, resonant inductor L_1, and resonant capacitor C_1. The capacitor C_1 is linked in parallel with the switch S to achieve the technique. The very small internal switch capacitance C_j is added to capacitor C_1, the resonant circuit frequency is lightly impacted.

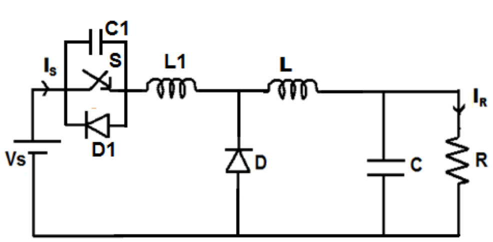

Fig 1. Graphical schematic of the ZVS Buck converter.

Based on the required load current and allowable voltage ripple, the buck output filter L, C are designed. The converter output impedance and switching frequency are taken into consideration when choosing the resonant capacitor. One can ascertain the resonant components L_1 and C_1 using,

$$|Z_o| = \left|\omega L_1 - \frac{1}{\omega C_1}\right| \quad (4)$$

$$f_r = \frac{1}{2\pi\sqrt{L_1 C_1}} \quad (5)$$

Where f_r represents the ZVS Buck converter's resonance frequency and Z_o is the circuit's impedance. Table 1 displays the designed parameter for the converter, which is derived from the above.

A 1.25 watt miniature prototype of a discrete regulated ZVS Buck converter has been designed with practicality case study, low power prototype was selected as it is harder to design ZVS within such ratings. In order to obtain a realistic figure for the load current, which came out to be 0.25 A, the load voltage was fixed at 5 V in order to maintain constant current level during tests. Using Ohm's law, a load resistance of 20 Ω was then computed.

TABLE I

Values for ZVS Buck converter design

No	Parameters	Design Values
1	Switching frequency f_S	20 KHz
2	Input Voltage V_S	12 V
3	Output Voltage V_o	5 V
4	Inductance L	1.5 mH
5	Capacitance C	47 μF
6	Inductance L_1	10 μH
7	Capacitance C_1	1 μF
8	Load Resistance R	20 Ω

By adjusting for each of these factors, the buck converter's input voltage is adjusted to 12 V because the input voltage must be higher than the output voltage of 5 V. The equations (4) through (5) are used to design the filter inductor, filter capacitor, resonant inductor, and resonant capacitor. Table 1 provides the values that were obtained.

IV. System Simulation

The simulation is performed using the SIMSCAPE environment and the MATLAB/Simulink 2023 package. Buck DC-DC converter with the parameters as listed in Table 1 models is shown in figures 2 for soft switching circuit.

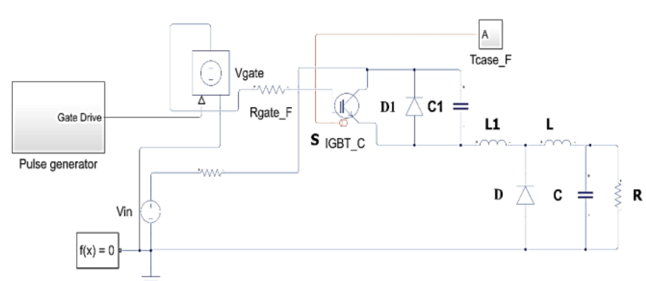

Fig 2. Simscape Proposed Model

While figure 3 illustrates the transistor voltage Vce versus the current through it Ice during soft switching condition. While, The converter input and output voltages are demonstrated in figure 4.

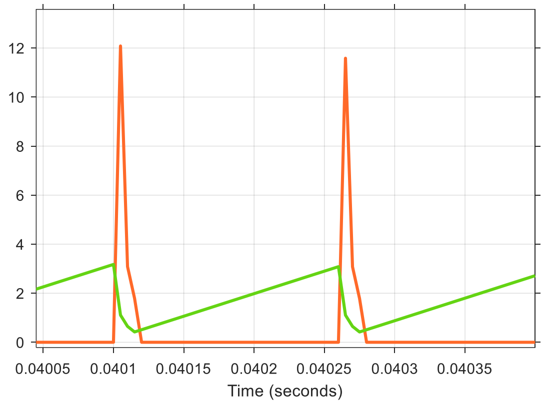

Fig 3. Soft switching Vce and Ice.

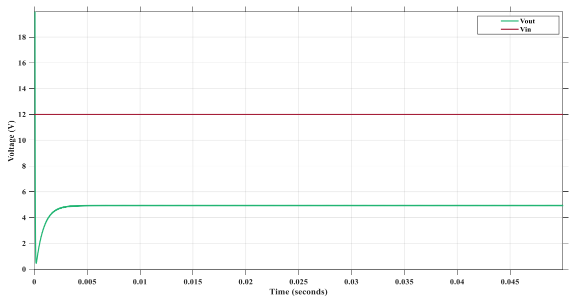

Fig 4. Input and output voltages.

Also, the junction temperatures for the two cases (hard and soft) are illustrated in figure 5. The small difference for both cases is due to low power rating.

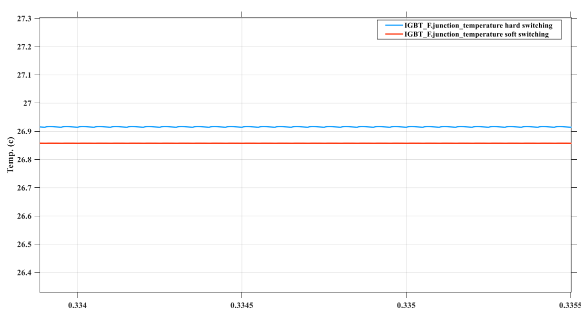

Fig 5. Soft and Hard switching junction temperature.

The switching losses for hard switching is presented in figure 6. It shows that the switching losses is fluctuating between 0.012 and 0.016 watt. A comparison between hard and soft switching losses are presented in 7. Where the soft switching loss is almost negligible, while the hard switching loss is close to 0.2 watt.

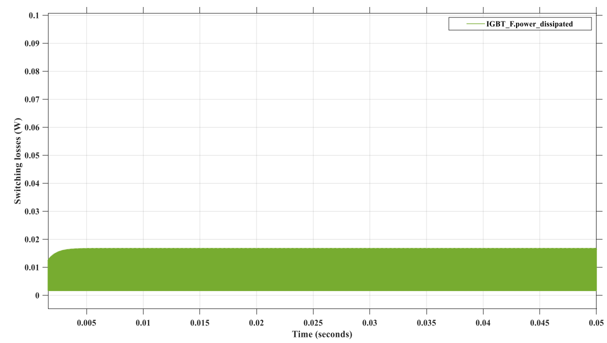

Fig 6. Hard switching losses.

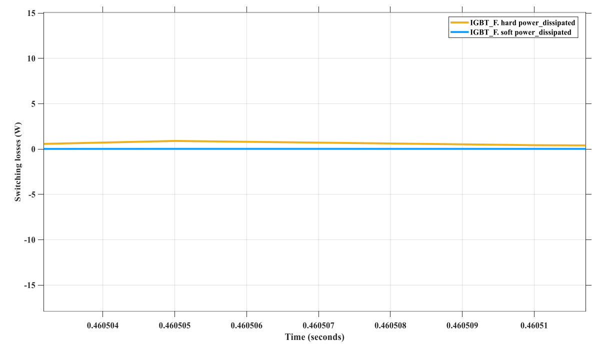

Fig 7. Soft and Hard switching losses.

Finally, the junction temperature for IGBT is measured according to Cauer and Foster thermal models. The results shown in figure 8, presents a difference of 0.25 ºC in junction temperature and one of the lines has jittery shaped line.

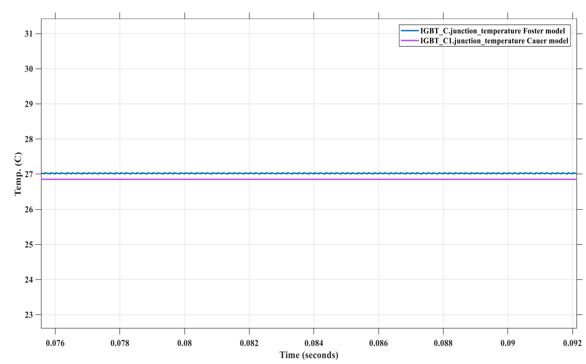

Fig 8. Cauer and Foster Models Junction Temp.

V. Conclusion

This research paper presented a simple soft switching DC-DC Buck converter, the topology is simulated using SIMSCAPE domain. The goal is to highlight the transistor losses and illustrate the junction temperature via two thermal models. The results are demonstrated, where the superiority of soft switching circuit in reducing the switching losses and junction temperature. The SIMSCAPE domain offered a new opportunity to improve the design of cooling system. Both Cauer and Foster models are used to analyse the thermal analysis, as it can be seen Foster method has higher response during inherent change of junction temperature and it can suit high frequency converters while Cauer model averages the junction temperature during thermal analysis. Consequently, Cauer model can cause error when it is used for high switching application or with circuits that have fatal inherent change of temperature.

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