academicJournals

Vol. 9(7), pp. 169-173, 15 April, 2014
DOI: 10.5897/SRE2014.5856
Article Number: BD683C543742
ISSN 1992-2248 © 2014

http://www.academicjournals.org/SRE

Scientific Research and Essays

Full Length Research Paper

Failure model and detecting method for MOSFET degradation in DC-DC power converters

Li-Feng Wu[1,2,3]*, Peng-Fei Dong[1,2,3], Yong Guan[1,2,3], Guo-Hui Wang[1,2,3] and Xiao-Juan Li[1,2,3]

[1]College of Information Engineering, Capital Normal University, Beijing 100048, China.
[2]Beijing Engineering Research Center of High Reliable Embedded System, Capital Normal University, Beijing 100048, China.
[3]Beijing Key Laboratory of Electronic System Reliable Technology, Capital Normal University, Beijing, 100048 China.

Received 2 March, 2014; Accepted 28 March, 2014

MOSFET is the most commonly used devices in DC-DC power converters, and its performance is important to the prognosis and health management of power. The paper proposes a degradation analysis model for MOSFET in DC-DC power converters. A method for detecting the degradation of MOSFET is also introduced. Simulations have shown that the method can predict deterioration in the performance of MOSFET. The simulation results are good agreement with the theory.

Key words: DC-DC converter, degradation, MOSFET.

INTRODUCTION

DC-DC power converters are widely used in telecommunications equipment, electrical equipment, control equipment, and so on, because they are light, small, thin, and low-cost (Rosas-Caro et al., 2010; Julio Cesar Rosas-Caro et al., 2012). Moreover, DC-DC power is a main component of electronic systems. However, the use of DC-DC power restricts the reliability of electronic systems and directly affects the working status of the entire electronic systems in other aspects such as accuracy and stability. According to statistics, electrolytic capacitors and MOSFETs have a higher degradation rate than other components in DC-DC power (Pang and Pong, 2010). In-depth studies have been conducted on the failure of aluminum electrolytic capacitors, discussing such problems as early failure, the failure mode and the failure mechanism, and the course of deterioration. Considering the impact of the parameters of the working environment (such as temperature, voltage, current, frequency, etc.), some researchers have analyzed the impact of the main parameters of aluminum electrolytic capacitors (such as capacitance, loss angle, leakage current, ripple current, etc.) on its life (Braham et al., 2010; Abdennadher and Venet, 2010; Buiatti et al., 2010; Sun et al., 2010). In the case of MOSFETs, several methods have been proposed to detect faults in MOSFET, for example, short-circuit and open-circuit faults. Previous work on MOSFETs has focused primarily on reliability designs (Azoui et al., 2011), predicting the remaining useful life of MOSFETs using off-line accelerated aging tests (Smet et al., 2011), and developing degradation models based on accelerated life tests (Oukaour et al., 2011).

*Corresponding author. E-mail: wooleef@gmail.com

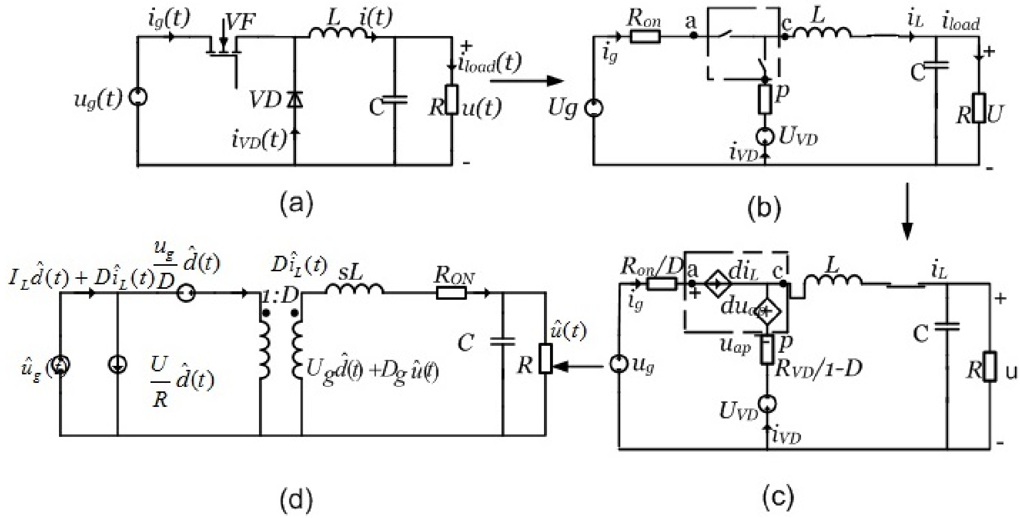

Figure 1. Equivalent Circuit Diagram of a Buck Converter: (a) ideal, (b) non-ideal, (c) large signal averaged model, (d) small signal circuit model.

With the development of technology, a novel technology called Prognostics and Health Management (PHM) has recently been attracting more and more attention. Many papers use on-line monitoring technology. Articles have been written proposing the use of algorithms to extract features to monitor MOSFETs and IGBTs in real time (Ginart et al., 2008). An online non-intrusive method of obtaining the degradation state of MOSFETs based on the Volterra series has been proposed (Wu et al., 2014); however, these methods are complex. In this paper, a failure model for MOSFET is presented and a simple method for estimating degradation of MOSFET in DC-DC power converters is proposed.

MODEL

The equivalent circuit diagram for a DC-DC Buck converter is shown in Figure 1. To achieve the ideal state (as shown in Figure 1(a)), it is possible to obtain transfer functions between the input and output of the converter (Chen, 2010).

The transfer function is as follows:

$$G_{ug}(s)=\left.\frac{\hat{u}(s)}{\hat{u}_g(s)}\right|_{\hat{d}(s)=0}=D\frac{R//\frac{1}{sC}}{sL+R//\frac{1}{sC}}=\frac{R}{LCRs^2+Ls+R}=\frac{K_1^{'}(\omega_0^{'})^2}{s^2+2\zeta^{'}\omega_0^{'}s+(\omega_0^{'})^2} \quad (1)$$

where $K_1^{'}, \omega_0^{'}, \xi'$ represent the amplification, corner frequency, and damping ratio, respectively:

$$K_1^{'}=D \quad (2)$$

$$\omega_0^{'}=\sqrt{\frac{1}{LC}} \quad (3)$$

$$\xi'=\frac{1}{2R}\sqrt{\frac{L}{RC}} \quad (4)$$

The MOSFET equivalent circuit consists of an ideal switch connected in a series with a resistance (Ron), as shown in Figure 1(b), while Figure 1(c) is the Buck converter large signal averaged model. The ideal switch and diode are replaced by a dependent current and voltage sources, respectively. The current of i_g can be expressed as Equation (5) when the MOSFET is turned on.

$$i_g = i_L \approx I_L \quad (5)$$

The effective value of i_g is:

$$I_{grms}=\sqrt{\frac{1}{T_s}\int_0^{DT_s} i_g{}^2 dt}=\sqrt{D}I_L=\frac{I_g}{\sqrt{D}}=\frac{\sqrt{D}}{1-D}I_{VD} \quad (6)$$

The power loss of MOSFET when turned on is obtained using following equation:

$$P_{R_{on}}=R_{on}I_{grms}^2=\frac{R_{on}}{D}I_g^2=DR_{on}I_L^2 \quad (7)$$

Therefore, it is well known that the equivalent resistance (Ron) is Ron/D, which is equivalent to DRon in the

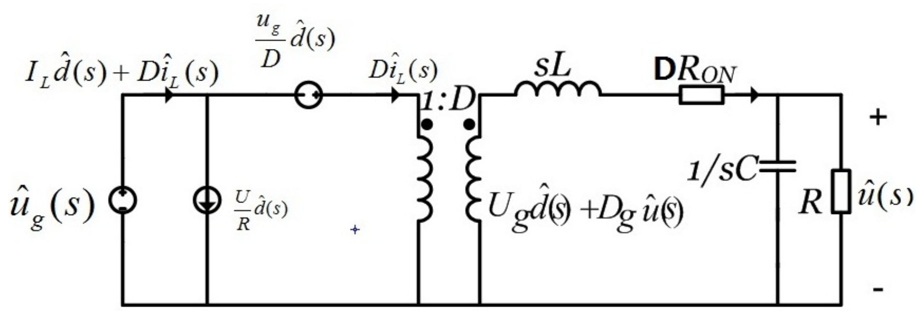

Figure 2. Small signal equivalent circuit diagram of the non-ideal Buck converter in the s domain.

inductor branch based on the energy conserved, according to Equation (7).

Methods

According to Figure 1(d), the small signal equivalent circuit diagram of the non-ideal Buck converter in the s domain has been established (Figure 2).

It is well known that the transfer functions can be expressed as follows:

$$G_{ug}(s)=\left.\frac{\hat{u}(s)}{\hat{u}_g(s)}\right|_{\hat{d}(s)=0}=D\frac{R//\frac{1}{sC}}{sL+DR_{ON}+R//\frac{1}{sC}}=\frac{\frac{D}{LC}}{s^2+(\frac{L+DR_{ON}RC}{RLC})s+\frac{DR_{ON}+R}{RLC}}$$

$$=\frac{K_1\omega_0{}^2}{s^2+2\xi\omega_0 s+\omega_0{}^2} \tag{8}$$

where K_1, ω_0, ξ represent the amplification, corner frequency and damping ratio, respectively:

$$K_1=D\frac{R}{R+DR_{ON}} \tag{9}$$

$$\omega_0=\sqrt{\frac{DR_{ON}+R}{LCR}}=\sqrt{\frac{1}{LC}+\frac{DR_{ON}}{LCR}} \tag{10}$$

$$\xi=\frac{L+CRDR_{ON}}{2\sqrt{LCR(R+DR_{ON})}} \tag{11}$$

Now, adding an excitation signal, the output will change. While the MOSET degradation occurs, the resistance Ron will increase, causing the output to change. The state of MOSFET through the output can be obtained.

$$U(s)=G_{ug}(s)R(s)=\frac{K_1\omega_0{}^2}{s^2+2\xi\omega_0 s+\omega_0{}^2}\bullet\frac{K_2}{s} \tag{12}$$

The u(t) can be obtained using the Laplace inverse transformation, which is shown as:

$$u(t)=\frac{K_1K_2}{\omega_0}[1-\frac{e^{-\sigma t}}{\sqrt{1-\xi^2}}\bullet\sin[\omega_d+\varphi]] \tag{13}$$

where ω_d, σ, φ can be expressed as:

$$\omega_d=\omega_0\sqrt{1-\xi^2}$$

$$\sigma=\xi\omega_0$$

$$\varphi=\arctan\frac{\sqrt{1-\xi^2}}{\xi}=\arccos\xi$$

Comparing Equations (2 to 4) and Equations (9 to 11), it is clear that these parameters will change with the degradation of MOSFET. Therefore, it is clear that the state of MOSFET can be obtained by detecting the transient response signal. From the response signal, the Ron is gained. According to the relationship between the degradation state (useful life) and the Ron (Celaya et al., 2012), the state can be detected. The method for detecting the degradation of MOSFET is shown in Figure 3.

RESULTS AND ANALYSIS

In order to verify the validity of the method, MOSFETs in different degrees of degradation are selected to be set in the Buck converter, and the output signals are shown in Figure 4. The results indicate that the Ron increases with the degradation of MOSFET, causing the transient response signal to change. Ron1 expresses the state before degradation, and Ron8 expresses the failure state. From the information of the output signals, including the amplification, corner frequency and damping ratio, the degree of degradation of MOSFET can be judged. By monitoring the changes of the feature signals, it is easy to indirectly measure the degree to which MOSFET has deteriorated. The relationship between the max amplitude and the Ron can be expressed, as shown in Figure 5.

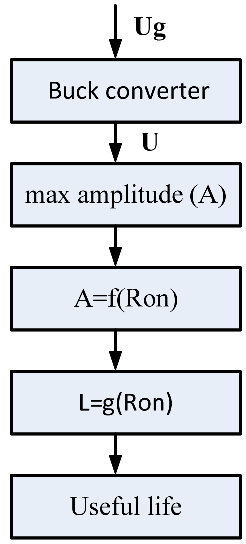

Figure 3. Chart on the method for detecting the degradation of MOSFET.

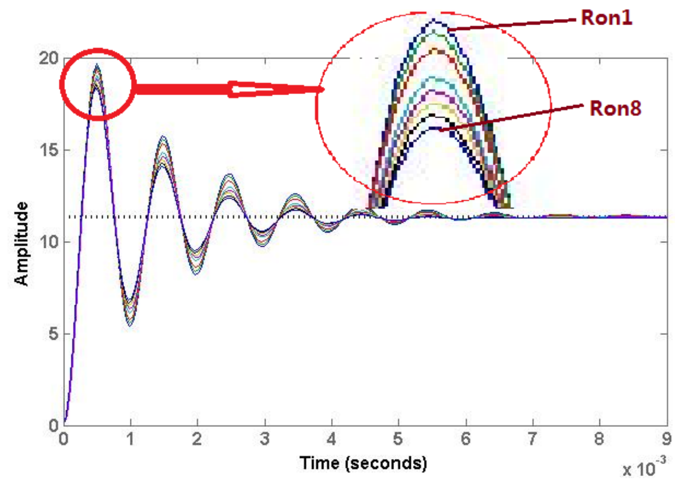

Figure 4. The transient response signal with the Ron increase caused by degradation of MOSFET.

According the relationship shown in Figure 5, the Ron can be gained, and the degradation of MOSFET can be predicted by taking advantage of the relation of L=g(Ron) (Celaya et al., 2012).

Conclusions

The simulation and the test results indicate that degradation process of MOSFET leads to an increase in the resistance. The change in the Ron is difficult to measure; it is easy to obtain the change in the response signal caused by the Ron. The degree of degradation is determined by analyzing the response signal collected in the test. Based on the trend of the changes, the remaining useful life of MOSFET in a DC-DC converter can be accurately predicted.

ACKNOWLEDGEMENTS

Financial support for this work was received from the National Natural Science Foundation of China (No. 61070049, No. 61202027), the National Key Technology R&D Project (No. 2012DFA11340), the Beijing Natural Science Foundation of China (No. 4122015), and the

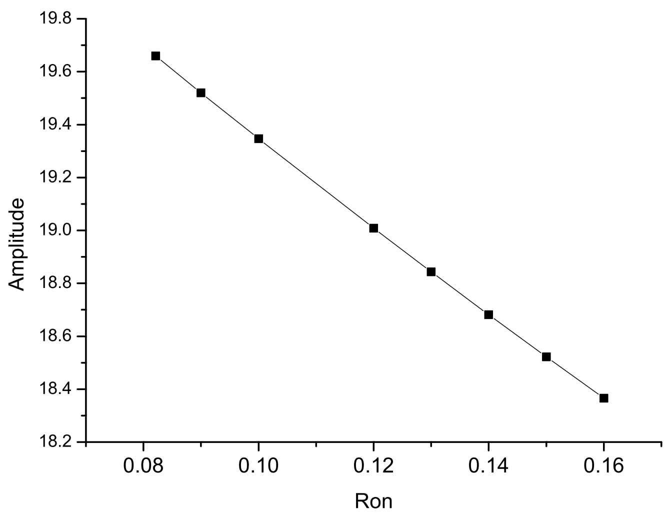

Figure 5. The relationship between the max amplitude and the Ron.

Beijing City Board of Education Science and Technology Development Project (No. KM201210028001).

Conflict of Interests

The author(s) have not declared any conflict of interests.

REFERENCES

Azoui T, Tounsi P, Dupuy P (2011). 3D Electro-thermal modeling of bonding and metallization ageing effects for reliability improvement of power MOSFETs. Microelectron. Reliab. 51:1943-1947. http://dx.doi.org/10.1016/j.microrel.2011.06.018

Braham A, Lahyani A, Venet P, Rejeb N (2010). Recent Developments in Fault Detection and Power Loss Estimation of Electrolytic Capacitors. IEEE T Power Electr. 25(1):33-43. http://dx.doi.org/10.1109/TPEL.2009.2026749

Celaya JR, Saxena A, Kulkarni CS, Saha S, Goebel K (2012). Prognostics approach for power MOSFET under thermal-stress aging. Reliability and Maintainability Symposium (RAMS), 2012 Proceedings – Annual. Date of Conference Jan. 2012.1-6. http://dx.doi.org/10.1109/RAMS.2012.6175487

Chen Y (2010). Practical simulation and testing technology of switching converter. Beijing: China Machine Press.

Ginart A, Roemer MJ, Kalgren PW, Goebel K (2008). Modeling Aging Effects of IGBTs in Power Drives by Ringing Characterization. In Proceedings of the International Conference on Prognostics and Health Management, Denver, CO, USA, 6–9 October, pp. 1-7.

Oukaour A, Tala-Ighil B, Pouderoux B (2011). Ageing defect detection on IGBT power modules by artificial training methods based on pattern recognition. Microelectr. Reliab. 51:386-391. http://dx.doi.org/10.1016/j.microrel.2010.08.006

Pang HM, Bryan Pong MH (2010). A life prediction scheme for electrolytic capacitors in power converters without current sensor. Proceedings of IEEE Applied Power Electronics Conference and Exposition- APEC: pp. 973-979.

Rosas-Caro JC, Garcia-Vite PM, Lozano-Garcia JM, Gonzalez-Rodriguez A, Castillo-Gutierrez R, Castillo-Ibarra R (2012). Generalized DC-DC multiplier converter topology. IEICE Electron. Exp. 9(19):1522-1527.
http://dx.doi.org/10.1587/elex.9.1522

Rosas-Caro JC, Ramirez JM, Peng FZ, Valderrabano A (2010). A DC-DC multilevel boost converter. IET Power Electron. 3(1):129-137. http://dx.doi.org/10.1049/iet-pel.2008.0253

Smet V, Forest F, Huselstein J (2011). Ageing and failure modes of IGBT modules in high-temperature power cycling. IEEE Trans. Industr. Electr. 58:4931-4941. http://dx.doi.org/10.1109/TIE.2011.2114313

Sun F, Wang Y, Cui J, Lin H (2010). Research on failure prediction method of electrolytic capacitor used in power conversion circuit. J. Electr. Mater. Instr. 24(1):29-33.

Wu L, Zheng Y, Guan Y, Wang G, Li X (2014). A Non-intrusive method for the degradation of MOSFETs monitoring. Sensors 14(1):1132-1139. http://dx.doi.org/10.3390/s140101132