TOPOLOGY AND CONFIGURATION SELECTION FOR DC/DC CONVERTERS IN SPACE ELECTRICAL POWER SYSTEMS BASED ON COMPARATIVE RELIABILITY EVALUATION

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ABSTRACT

Selection of DC/DC converter topology is one of the most challenging aspects in space Electrical Power Systems (EPS) design and development. It both highly, affects and is affected from EPS reliability requirements among the other EPS performance specifications. So ranking of DC/DC converters based on End-Of-Life (EOL) reliability is an undeniable need.

In this paper, reliability of four DC/DC converters including buck, forward, fly-back, and Push-pull, as candidates for a 5-years-long, Low-Earth-Orbit (LEO) space mission, are evaluated and compared. Converters are assumed having similar design requirements and supervision and control elements with different power conversion parts and negligible reliability-affecting excess circuits.

Standard process is undertaken in preliminary and critical design of converters for reliability improvement and prediction. To reduce the converters' parts stress regarding the particles radiation and the thermal cycling effects of the space environment, a derating process is applied to the primary design based on ECSS standard. Derated components are then selected in such a way to make possible calculating components failure-rates based on the MIL-HDBK-217F data and equations as the major EEE components failure-rate data reference. Reliability modelling and analysis for the converters is done by reliability block diagram (RBD) method, and the converters are then comparatively evaluated based on the analysis results. According to the results, buck converter is the most reliable one and push-pull is the least. Among the isolated topologies, fly-back is the best one from the reliability point of view.

KEYWORDS

Reliability, Mil-HDBK-217F, Derating, Failure Analysis, DC/DC converters, Converters topology

1. INTRODUCTION

Reliability and performance, up to EOL, are key requirements of any space EPS equipment. EEE components in space are degraded due to high levels of stress, mostly imposed by space particles radiation and thermal cycling. Design and development of an EEE-based space equipment, should address “Derating”, failure-rate calculations, and reliability analysis.
This paper presents an approach for calculating EEE derating and failure-rate for candidate DC/DC converters. Converters are due to work in a LEO satellite EPS for five years. Selected topologies are buck, forward, fly-back and push-pull. Steps undertaken in converters design and development are:

- Calculating converters EEE parts values based on the standard equations of the converters.
- Applying standard derating process to the calculated values, based on ECSS-Q-ST-30-11C.

- Selecting EEE components based on: a) addressing derating results so to operate at a reduced level of stress up to EOL and become significantly reliable, and b) in such a way to make possible calculation of parts failure-rates based on Mil-HDBK-217F and other guidelines.
- Failure-rates calculation and reliability analysis of the converters based on MIL-HDBK-217F.
- Comparatively evaluation of the converters.

2. CONVERTERS CONFIGURATION AND DESIGN

2.1. Page Layout and Margins. Selected Topologies and Configurations

Four selected DC/DC converters have topologies and configurations shown in figure 1.

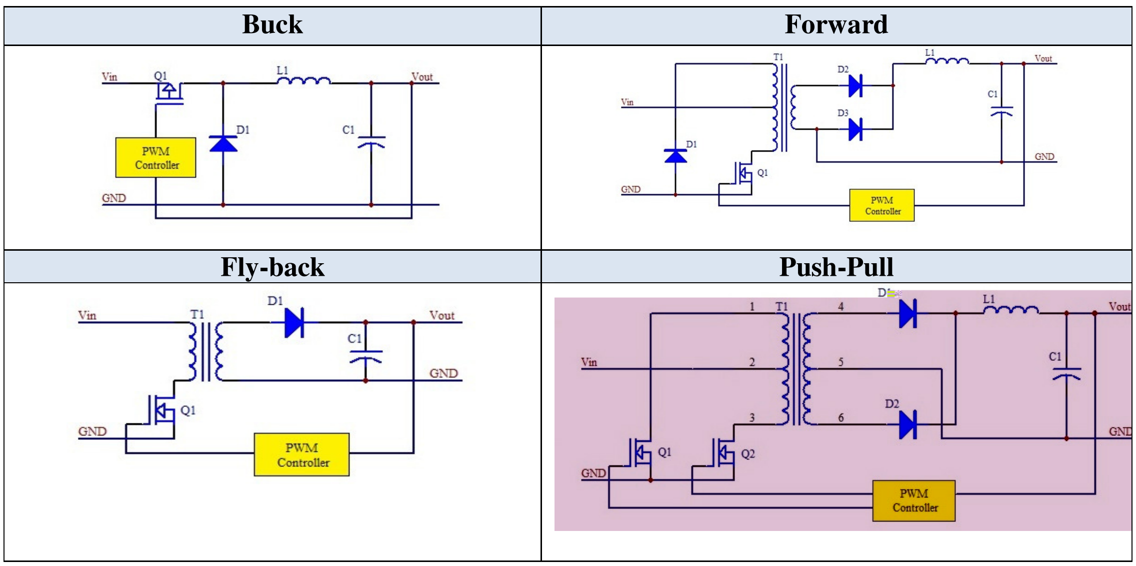

Figure1. Candidate DC/DC Converters types and Configurations

2.2Preliminary Components calculations

FOR THE PURPOSE OF PARTS VALUES CALCULATION, STANDARD PROCESS AND EQUATIONS ARE USED [1], [2], [3].

Converters are designed to operate under the following conditions:

22< Vi <34, Io=6A, Vo=5V, f_{SW}=50KHz, V_{ripple}=25mV

Calculated values for EEE components/parts of the four converters are shown in table1.

2.3. Derating

Derating corrections are made, based on “ECSS-Q-ST-30-11C”, the EEE components derating standard [4], on the primary values to address performance and reliability concerns by reducing stress level of parts. Parts values after derating are shown in table 2, column3.

2.4. EEE Components Selection

Standard parts (part numbers) or if necessary, a combination of parts with equivalent value of greater than or equal to the derated values are selected for final design. Priority is given to the part numbers being supported by MIL-HDBK-217F [5], to support and facilitate the afterwards failure-rates calculations. Selected part numbers are shown in column 4 of table 2.

Table 1.calculated values for EEE components/parts of selected converters

Converters	Parts	Part Values calculated primarily and before derating
BUCK	L1	75µH, 9A
	Q1	P-Ch MOSFET, VDS= 34V, IDSmax=9A
	D1	Schottky Diode, Ip=9A, Vr=34V, 3W
	C1	100µF, 5.1V Tantalum
PushPull, FlyBack, Forward	…	…

Table 2.Derated values, and selected part numbers for EEE components/parts of converters

Converters	Parts	Part Values After Derating	Nearest Standard Part Number Selected
BUCK	L1	75µH, 9A	TDK Military Component
	Q1	VDS=42.5 , IDS=12	STRH40P10
	D1	Schottky 15A, Vr=45V, 6W	JANS1N6844U3
	C1	110µF, 8.5V Tantalum	ST110-75T2MI
PushPull, FlyBack, Forward	…	…	…

3. RELIABILITY PREDICTION

Reliability prediction is done based on parts failure-rates analysis as addressed in MIL-HDBK-217F as follow, Having selected EEE part numbers in almost full conformance to the standard.

3.1. Components Failure-Rates Calculation

In conformance with MIL-HDBK-217F, failure-rates for the components are calculated based on the equations 1-4 below and parameters of table 3.

Diodes: $$\lambda_p = \lambda_b \times \pi_T \times \pi_S \times \pi_C \times \pi_Q \times \pi_E \quad \text{Failures}/10^6 \text{ hours} \qquad (1)$$

MOSFETs: $$\lambda_p = \lambda_b \times \pi_T \times \pi_A \times \pi_Q \times \pi_E \quad \text{Failures}/10^6 \text{ hours} \qquad (2)$$

Inductors: $$\lambda_p = \lambda_b \times \pi_T \times \pi_Q \times \pi_E \quad \text{Failures}/10^6 \text{ hours} \qquad (3)$$

Capacitors: $$\lambda_p = \lambda_b \times \pi_{CV} \times \pi_C \times \pi_Q \times \pi_E \quad \text{Failures}/10^6 \text{ hours} \qquad (4)$$

Table 2.Failure-rates of EEE parts of Buck convertor, based on MIL-HDBK-217F requirements

Part	Part Number	failure rate based on MIL-HDBK-217F								
		λb	πCV	πC	πQ	πE	πT	πR	πA	λP
L1	TDK Military	0.0015	-	[redacted]	0.03	1	1	[redacted]	[redacted]	0.0000450000
Q1	STRH40P10	0.06	[redacted]	[redacted]	2	0.5	1	[redacted]	1	0.060
D1	JANS1N6844U3	0.027	[redacted]	[redacted]	1.8	0.5	1	1	1	0.0243000000
C1	ST110-75T2MI	0.015	1.118	0.3	0.03	0.5	[redacted]	[redacted]	[redacted]	0.0000754650

3.2. Reliability Modelling

All elements of RBDs are assumed to be in serial connection. So, total failure-rate of each converter is obtained using components failure-rate.

3.3. Reliability Analysis

Reliability of converter is calculated from total failure-rate, for mission time of 43800 hours.

4. ANALYSIS RESULTS

Total failure-rates (per-hour) of converters and reliability values at EOL are shown in table 4.

Table 3.Total failure-rates and reliability of convertors

Converters	Fialure-Rate per hour	Reliability at EOL
Buck	0.0844205*10-6	0.996309
PushPull	0.193295*10-6	0.991564
FlyBack	0.0872626349*10-6	0.996185
Forward	0.1575182186*10-6	0.993124

5. CONCLUSIONS AND FUTURE WORK

Comparative reliability evaluation of four DC/DC converters including buck, forward, fly back and push-pull, designed for a LEO five-year mission, was presented in the paper. Converters reliability predictions were done by calculating failure-rates, based on MIL-HDBK-217F, for final selected part numbers. For obtaining of final part values of the converters, primary calculated part values were derated by applying ECSS EEE components derating standard "ECSS-Q-ST-1-30-11C", as to address EOL conditions. Results show that buck converter is the most reliable one and push-pull is the least. Also fly-back is more reliable than forward and very close to buck. Among the isolated topologies, fly-back is the best one from the reliability point of view. Topologies with higher number of isolation/semiconductor parts have lower reliabilities.

For more applicable results, state-of-the-art space DC/DC converters with their failure-rates can be considered. Also in continuation, variety of space converters can be evaluated.

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