A Simple Large Signal Model for Isolated DC-DC Converters

Presented and Authored By:
Wilson Eberle

Co-Authors:
Dr. Yan-Fei Liu and Dr. P.C. Sen
Presentation Overview

1. **Introduction**
   1. *Why we need to model converters*
   2. *Drawbacks of existing techniques*

2. **Deriving the Averaged Model for Isolated DC-DC Converters**

3. **Other Isolated DC-DC Converter Topologies**

4. **Experimental Results**

5. **Conclusions**
1. Introduction

- **Application:** low power DC-DC power supplies
- **Why Model?:** Switching converters are **time variant** and **non-linear**

![Diagram of Switching Converter with Compensator]

- **Need Switching Converter Model to Design Compensator**
- **Time Variant & Non-Linear Switching**
Why Model?

- Design compensator
- Understand and predict small signal dynamic behaviour in frequency domain
- Understand and predict large signal dynamic behaviour in time domain
Control Techniques

- **Voltage Mode Control**: output voltage controlled by duty ratio of high side switch
- **Current Mode Control**: output voltage controlled by peak switch current
- Non-linear and digital techniques gaining popularity, but current mode still most widely used
Modeling Approach

- **Average out the switching ripple**
- **Interested in low frequency behaviour**

![Diagram showing low frequency component of inductor current](image)

**Average Over One Switching Period**
Existing Techniques for Voltage Mode Control

Small-Signal AC Equivalent Circuit Method

e.g. Voltage Mode Buck

- Derived from perturbed and linearized state equations

Complicated, Small-Signal ONLY & Doesn’t Resemble Circuit!
Existing Techniques for Current Mode Control

Small-Signal AC Equivalent Circuit Method

e.g. Current Mode Buck

Complicated, Small-Signal ONLY & Doesn’t Resemble Circuit!
Existing Techniques for Voltage Mode Control

Averaged Circuit Modeling e.g. Voltage Mode Buck

- Low ripple assumption for $i_L$ and $V_o$
- Active switch replaced by dependent average current source
- Rectifier replaced by dependent average voltage source

Simple, Small & Large Signal & Resembles Circuit
Existing Techniques for Current Mode Control

Averaged Circuit Modeling e.g. Current Mode Buck

\[ i_Q = di_L = i_L \frac{i_C - i_L}{\frac{1}{2} m_1 T_S + MT_S} \]

Simple, Small & Large Signal & Resembles Circuit
Motivation

- **Existing Averaged Circuit Modeling:** only for simple single switch non-isolated converters!
- **Idea:** extend model to more complex multi-switch isolated converters
1. Introduction
2. Deriving the Averaged Model for Isolated DC-DC Converters
3. Other Isolated DC-DC Converter Topologies
4. Experimental Results
5. Conclusions
Proposed Model
Asymmetrical Half-Bridge

- 2 primary switches and 2 synchronous rectifiers
- Isolation step down transformer
- Q1 and Q3 operate during DTs
- Q2 and Q4 operate during (1-D)Ts
Proposed Model
Asymmetrical Half-Bridge

\[
\begin{align*}
\frac{N_{S1}}{N_p} i_F(t) + i_M(t) &= i_{Q1} = d \left[ \frac{N_{S1}}{N_p} i_F + i_M \right] \\

v_{DSQ2}(t) &= v_{IN}(t) = d v_{IN} \\

i_{Q3} &= d i_F \\

\frac{N_{S1}}{N_p} + \frac{N_{S1}}{N_p} (v_{IN}(t) + v_{CB}(t)) &= v_{DSQ4} = d \left[ \frac{N_{S1}}{N_p} + \frac{N_{S1}}{N_p} \right] (v_{IN} + v_{CB})
\end{align*}
\]
Proposed Model
Asymmetrical Half-Bridge
Proposed Model
Asymmetrical Half-Bridge

- Active switch & corresponding rectifier replaced by dependent average current source
- Second switch & corresponding rectifier replaced by dependent average voltage source
- Extend to current mode control with duty cycle as a function of control current
1. Introduction
2. Deriving the Averaged Model for Isolated DC-DC Converters
3. Other Isolated DC-DC Converter Topologies
4. Experimental Results
5. Conclusions
Proposed Model
Active Clamp Forward

\[ v_{DSQ2} = d\left[v_{IN} + v_{CR}\right] \]

\[ i_{Q1} = d\left[\frac{N_S}{N_P}i_F + i_M\right] \]
Presentation Overview

1. Introduction
2. Deriving the Averaged Model for Isolated DC-DC Converters
3. Other Isolated DC-DC Converter Topologies
4. Experimental Results
5. Conclusions
AHB Experimental Results:
400kHz, Vin=48V, Vo=5V, Io=6A

Small Signal Frequency Response of the Loop

13kHz bandwidth
45deg phase margin

13kHz bandwidth
47deg phase margin
AHB Experimental Results:
400kHz, Vin=48V, Vo=5V, Io=6A

Large Signal (Time Domain) Step Load Change

330mV undershoot  320mV undershoot
1. Introduction
2. Deriving the Averaged Model for Isolated DC-DC Converters
3. Other Isolated DC-DC Converter Topologies
4. Experimental Results
5. Conclusions
Conclusions

Model Proposed for Isolated DC-DC Converters:

- **Specific Advantages:**
  - Simple to derive
  - Circuit similar to switching converter
  - Large Signal
  - Easily adapted to peak current mode control

- Applicable to other isolated topologies

- Good agreement between model and experimental results for small and large signal cases
Thank You For Your Time

Modeling and other material at:

www.queenspowergroup.com