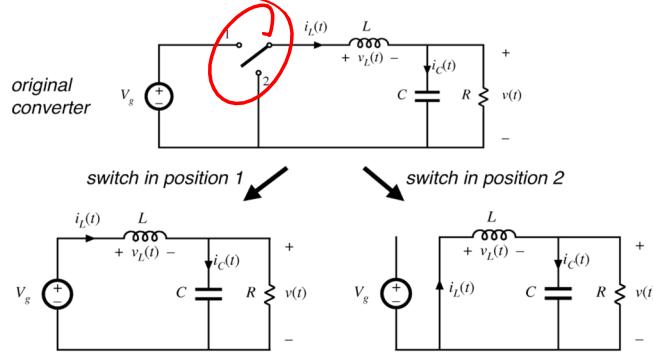


Nonlinearities in Power Electronics

1. Circuit reconfiguration

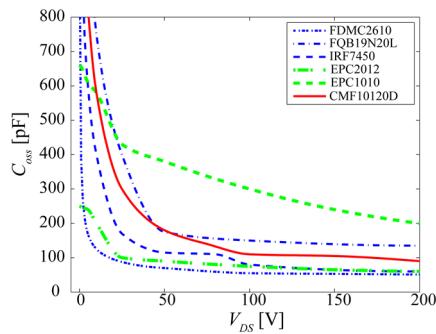


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Nonlinearities in Power Electronics

1. Circuit reconfiguration

2. Component Value Nonlinearities



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Nonlinearities in Power Electronics

- 1. Circuit reconfiguration
- 2. Component Value Nonlinearities
- 3. Switching Event Nonlinearities

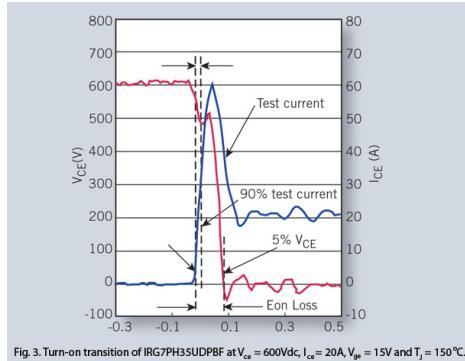


Fig. 3. Turn-on transition of IRG7PH35UDPBF at $V_{ce} = 600\text{Vdc}$, $I_{ce} = 20\text{A}$, $V_{gp} = 15\text{V}$ and $T_j = 150^\circ\text{C}$.

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Review of State Space Modeling

Diagram of a circuit element:

$$\frac{di}{dt} = \frac{i_c - I}{C}$$

$$\frac{dV_c}{dt} = \frac{v_c - v_i}{L}$$

$$\dot{x} = \begin{bmatrix} v_c \\ i_c \end{bmatrix}$$

$$u = \begin{bmatrix} v \\ I \end{bmatrix}$$

$$\frac{d}{dt} \begin{bmatrix} v_c \\ i_c \end{bmatrix} = \begin{bmatrix} 0 & \frac{1}{C} \\ -\frac{1}{L} & 0 \end{bmatrix} \begin{bmatrix} v_c \\ i_c \end{bmatrix} + \begin{bmatrix} 0 & \frac{1}{C} \\ \frac{1}{L} & 0 \end{bmatrix} \begin{bmatrix} v \\ I \end{bmatrix}$$

Matrix A: $\begin{bmatrix} 0 & \frac{1}{C} \\ -\frac{1}{L} & 0 \end{bmatrix}$

Matrix B: $\begin{bmatrix} 0 & \frac{1}{C} \\ \frac{1}{L} & 0 \end{bmatrix}$

Independent inputs: v , I

State derivatives: \dot{x}

States: x

Matrices that describe circuit connections

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Example: State Space Model of Buck

original converter

$$x = \begin{bmatrix} v_C \\ i_L \end{bmatrix}$$

$$u = V_g$$

switch in position 1

$$\dot{x} = \begin{bmatrix} \frac{1}{RC} & \frac{1}{L} \\ -\frac{1}{L} & \phi \end{bmatrix} x + \begin{bmatrix} 0 \\ 1 \end{bmatrix} u$$

$$\dot{x} = A_1 x + B_1 u$$

switch in position 2

$$\dot{x} = \begin{bmatrix} \frac{1}{RC} & \frac{1}{L} \\ -\frac{1}{L} & \phi \end{bmatrix} x + \begin{bmatrix} 0 \\ 0 \end{bmatrix} u$$

$$\dot{x} = A_2 x + B_2 u$$

Define $\delta(t) = \begin{cases} 1, & nT_s \leq t < (n+1)T_s \\ 0, & (n+1)T_s \leq t < (n+2)T_s \end{cases}$

$$\delta'(t) = 1 - \delta(t)$$

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Buck State Space Averaging

$$\dot{x} = [A_1 \delta(t) + A_2 \delta'(t)] x + [\delta(t) B_1 + \delta'(t) B_2] u$$

+ got rid of $\delta(t)$ (didn't like)
- error?

↓ Average

$$\dot{x} = [D A_1 + \delta A_2] x + [D B_1 + \delta' B_2] u$$

for Buck:

$$\dot{x} = \begin{bmatrix} \frac{1}{RC} & \frac{1}{L} \\ -\frac{1}{L} & \phi \end{bmatrix} x + \begin{bmatrix} 0 \\ Dv_g \end{bmatrix} v_g \rightarrow \begin{cases} \frac{dv_g}{dt} = \frac{-V_C}{RC} + \frac{i_L}{L} = \phi \\ \frac{di_L}{dt} = \frac{-V_C}{L} + v_g \frac{D}{R} = \phi \end{cases}$$

$I_L = \frac{V}{R}$
 $V = DV_g$

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Small Signal Model

$$\dot{x} = [\delta(t)A_1 + \delta'(t)A_2]x + [\delta(t)B_1 + \delta'(t)B_2]u$$

perturb & linearize ① $x = \hat{x} + \tilde{x}$

$$\dot{x} + \dot{\hat{x}} = [(\delta(t) + \hat{\delta}(t))A_1 + (\delta'(t) - \hat{\delta}'(t))A_2](x + \hat{x}) \\ + [(\delta(t) + \hat{\delta}(t))B_1 + (\delta'(t) - \hat{\delta}'(t))B_2](u + \hat{u})$$

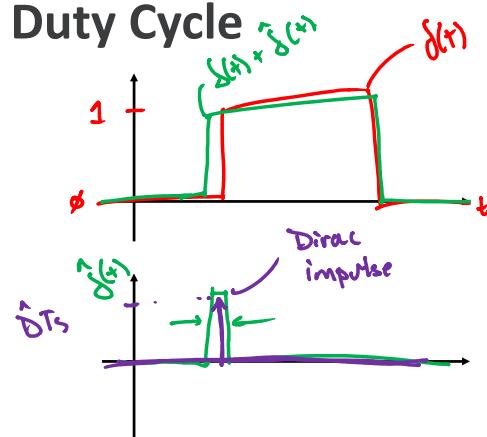
② Linearize (el: ignore 2nd order terms)
steady-state $\dot{x} = \dots$ (same thing from previous)

dynamic

$$\begin{cases} \dot{\hat{x}} = [\delta(t)A_1 + \delta'(t)A_2]\hat{x} + [\delta(t)B_1 + \delta'(t)B_2]\hat{u} \\ \quad + [(A_1 - A_2)x + (B_1 - B_2)u]\hat{\delta}(t) \end{cases}$$

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Effect of Changing Duty Cycle



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