A New General Mathematical Technique for Stability and Bifurcation Analysis of DC-DC Converters Applied to One-Cycle Controlled Buck Converters with Non-Ideal Reset

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Abstract

This paper brings two major contributions: the first investigates and draws conclusions about stability and bifurcation phenomena related to one-cycle controlled dc-dc converters when non-ideal reset is encountered. The second introduces a new general mathematical technique for deriving stability and bifurcation behavior in continuous conduction mode operated dc-dc converters. Up to now, one-cycle control analysis assumed the integrator is instantly reset and in these conditions it was demonstrated that one-cycle control is always stable. In the present work it is proven that even with an ideal converter, when the integration capacitor is discharged over a nonzero resistor the system becomes unstable at high duty cycles. The stability condition with respect to the control voltage is analytically derived using a new general proposed technique. This approach can be applied to any control such as: traditional current mode control, predictive current control, charge control, one cycle control or feedback loops employing different regulators. Moreover, it can be used with different types of modulation: leading-edge, trailing-edge or double-edge modulation. When applied to one-cycle controlled buck converters employing a non-ideal resettable integrator, it is proven that bifurcation phenomena are encountered. This behavior with period doubling instability is confirmed by Matlab and Caspoc simulations.

The control duty cycle $d$ for the OCC technique can be calculated (1) using the equation below:

$$ V_D = \frac{1}{T_S} \int_0^t E(t) dt = V_{ref} $$

A system be described by an iterative map of the form:

$$ x_{n+1} = g(x_n, \text{par}, d_n(x_n, \text{par})) = f(x_n, \text{par}) $$

(2)

It is known that the characteristic multipliers are the solutions of the equation:

$$ \det(\lambda - J_f(X)) = 0 $$

(3)

The Jacobian $J_f(x_n) = \frac{\partial f}{\partial x_n}$ can be calculated as

$$ J_f(x_n) = \frac{\partial g}{\partial x_n} + \frac{\partial g}{\partial d_n} \frac{\partial d_n}{\partial x_n} $$

(4)

From (2) it clearly follows that:

$$ g(x) = \phi_2 \phi_1 x_n + (\phi_2 \psi_1 + \psi_2) u $$

(5)

References