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TIME DOMAIN DIGITAL STATE-SPACE MODELING OF PWM CONVERTER

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Article presents a method of time-domain digital modeling of PWM converter operating in a continuous conduction mode. Digital values during switching period are introduced with an aim to simplify linearization. It is shown that continuous modeling of variations around steady-state operating point is not a necessary assumption for linearization. References 5.

Keywords: pulse-width modulated (PWM) converter, digital control, state-space model, digital value.

Discrete-time modeling of PWM converter was introduced by Packard [1]. Later it was shown how to present a Packard's model in a state-space form of description [4]. In the letter [3] it is shown how the well-known discrete-time modeling can be extended to take into account the sampling, modulator effects and delays in a digitally controlled converter. In [1,2,4,5] continuous model of variations in PWM is necessarily used for linearization. And continuous small-signal variation equations are integrated across one complete switching period including modulation to find the small-signal difference equations [1, 4]. The task of this article is a derivation of general method of digital state-space modeling of PWM converters.

Digital modeling means that system is quantized both in time and amplitude. Digital values during switching period are introduced, because, despite of modulation of the variables in time and in amplitude, digital values have the same dimension. So linearization of the power circuit can be significantly simplified.

PWM converter in a continuous conduction mode of inductor's current is considered. An assumption is made that electronic key is ideal, and circuit elements are linear with stable parameters. In a general case converter is defined by two various differential equations in two keys positions (single commutation on period)

$$dx(t)/dt = A_1 x(t) + B_1 u(t); \quad nT \le t \le nT + \gamma(n)T, \qquad dx(t)/dt = A_2 x(t) + B_2 u(t); \quad nT + \gamma(n)T \le t \le nT + T$$

where $u(t)$ – input voltage vector, A_1, A_2 – dynamics matrixes, B_1, B_2 – input voltage matrixes, T – switching period, $\gamma(n)$ – duty cycle on *n*-th switching period.

Derivation is made in such a sequence. 1. Determination of solutions of differential equations on n-th switching period for the intervals of commutation. 2. Determination of the value of state vector at the end of switching period $x(nT+T)$, using its value at the beginning of switching period $x(nT)$. 3. Linear approximation of exponential matrix. 4. Introduction of digital values on switching period around steady-state operating point and linearization of difference equations.

The final result is a state-space digital model of PWM converter in a general form of description:

$$\left[\hat{x}(n+1) - \hat{x}(n)\right]T^{-1} = A\left(X + \hat{x}(n)\right) + B\left(U + \hat{u}(n)\right) + B_\gamma \gamma(n),$$

$$A = \left(\Gamma A_1 + (1-\Gamma)A_2\right), \quad B = \left(\Gamma B_1 + (1-\Gamma)B_2\right), \quad B_\gamma = \left(A_1 - A_2\right)X + \left(B_1 - B_2\right)U \ ,$$

where X, U, Γ – steady-state values of state vector, input voltage and duty cycle respectively, $\hat{x}(n), \hat{u}(n), \hat{\gamma}(n)$ – changes of digital values of state vector, input voltage and duty cycle respectively during n-th switching period.

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Цифрове моделювання ШІП в часовій області в просторі станів

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Представлено метод цифрового моделювання ШІП в часовій області у режимі неперервного струму дроселя. Введено цифрові величини протягом періоду переключення з метою спростити процедуру лінеаризації. Показано, що неперервне моделювання варіацій навколо усталеного режиму роботи – це не обов'язкове припущення при лінеаризації. Бібл. 5.

Ключові слова: широтно-імпульсний перетворювач, цифрове керування, модель у просторі станів, цифрова величина.

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Цифровое моделирование ШИП во временной области в пространстве состояний

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Описан метод цифрового моделирования ШИП во временной области в режиме непрерывного тока дросселя. Введены цифровые величины на протяжении периода переключения с целью упростить процедуру линеаризации. Показано, что непрерывное моделирование вариаций около установившегося режима работы – это не обязательное допущение при линеаризации. Библ. 5.

Ключевые слова: широтно-импульсный преобразователь, цифровое управление, модель в пространстве состояний, цифровая величина.

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