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Posicast control within feedback structure for a DC–DC single ended primary inductor converter in renewable energy applications

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ABSTRACT

In this paper, modeling, analysis, design, simulation and control of a single ended primary inductor converter (SEPIC) are discussed for renewable energy applications. Because the traditional control methods such as proportional–integral–derivative (PID) and classical half-cycle Posicast controllers based on feedforward are sensitive to noise and variations in natural frequency, a Posicast control with feedback structure is proposed and designed to reduce or rejection undesirable sensitivity greatly, to suppress measurement noise and to eliminate the overshoot in the output response. The SEPIC converter is modeled using average value modeling analysis. Dynamic modeling and simulation are accomplished using MATLAB Simulink™ 7.2.

1. Introduction

One of the most applications of converters such as AC/DC converter, named rectifier, DC/AC converter, named inverter, and DC/DC converter, named chopper, is in renewable energy systems such as autonomous wind-solar hybrid power generation system [1,2], shown in Fig. 1. Among these converter, DC–DC converters have important roles for charging or discharging of batteries, adjusting DC-link voltage between rectifier and inverter and etc. Batteries are employed to store superfluous energy derived from wind blowing and solar irradiance during windy or sunny days and then to release during cloudy days or at nights. So, a DC–DC converter is used to charge or discharge the battery. Furthermore, they are also implemented in fuel cell [3,4], photovoltaic and solar system in order to extract the maximum power [5,6] and other applications such as electric vehicle [7].

Various DC–DC converters which can be applied in order to step up and step down output voltage are cascaded buck and boost converters, buck-boost converter, flyback converter, Cuck converter and SEPIC converter [8]. Two needed separate controllers and switches are the most drawbacks in the cascaded buck and boost converters. In the buck-boost and Cuck converters, output voltage is inverted. Furthermore, a required transformer in a flyback converter instead of just an inductor increases the complexity of the development. So, the best option for increasing and decreasing of output voltage is single ended primary inductor converter named SEPIC. A SEPIC is a DC–DC converter allowing the output voltage to change more than, less than, or equal to the input voltage without inverting. Output voltage of a SEPIC is controlled using duty cycle generated by control circuit and applied to the transistor. Thus, the most advantage of a SEPIC over the other converters is a non-inverted output voltage.

In order to control of a SEPIC converter, several controllers are used such as classical PID and Posicast controllers. The Posicast controller improves the steady state performance and damps resonant behavior of responses. It causes that gain parameter of the controller is easily determined and sensitivity to parametric uncertainty and load change have been reduced. Furthermore, Posicast control within a feedback system is proposed and utilized to damp oscillations in lightly damped control systems. It is designed as a feedback structure and dynamic compensator to deal overshoot in the system step response. Also, it is very efficient, robust to modeling uncertainty and is used to minimize vibration in various types of systems and to suppress high frequency noise [9].

In this paper, Mathematical model and description of the SEPIC converter based on average value modeling is accomplished in Section 2. Section 3 illustrates the Posicast control design based on feedback system. Posicast control with feedback structure is proposed and designed to reduce or rejection undesirable sensitivity greatly, to suppress measurement noise and to eliminate the overshoot in the step response of the SEPIC converter. Simulation results are discussed in Section 4. Finally, the conclusion is presented in Section 5.

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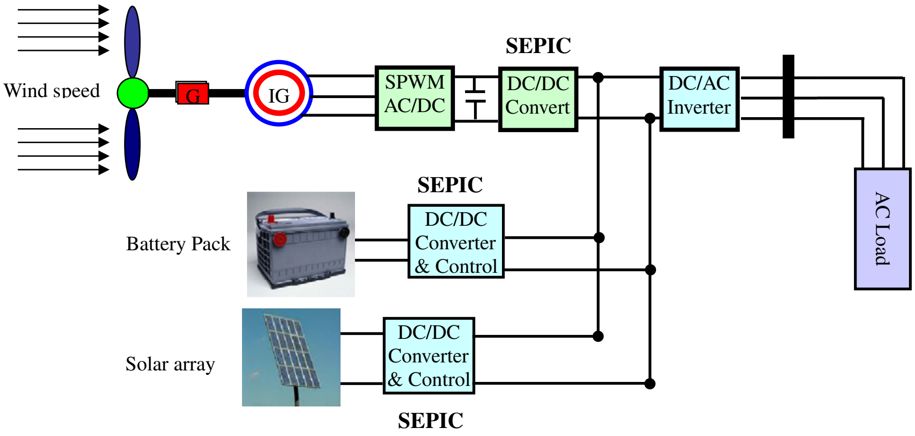

Fig. 1. SEPIC application in a hybrid renewable energy system.

2. Mathematical model of the SEPIC converter

The SEPIC converter is a kind of DC–DC converter that the output voltage magnitude is more or less than input voltage magnitude. The output voltage is adjusted using duty cycles applied to the transistor. State space equations analysis is utilized for modeling and analyzing of the SEPIC converter shown in Fig. 2. In this analysis, parasitic resistances of the inductors and capacitors are ignored. Based on the MOSFET is on or off, two situates are happen [8,9].

In the first state, the MOSFET transistor is on and the diode would not conduct. In this situation, the equivalent circuit is depicted in Fig. 3. Thus, state space equations are obtained as following

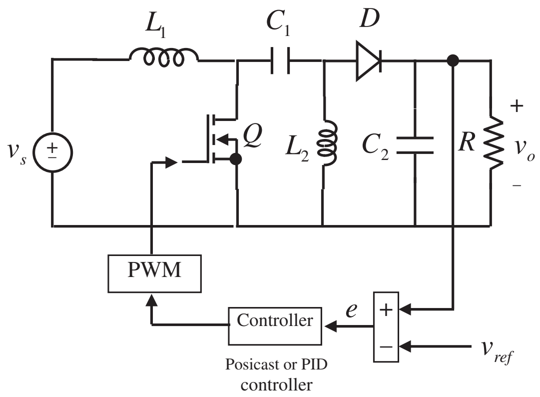

Fig. 2. SEPIC converter schematic.

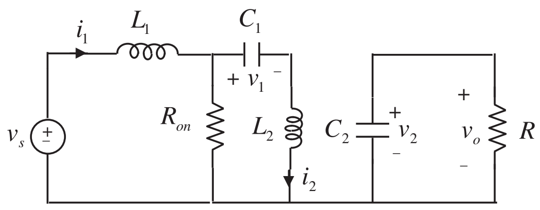

Fig. 3. SEPIC converter model when transistor is on and diode is off.

$$\underbrace{\begin{bmatrix} L_1 & 0 & 0 & 0 \\ 0 & L_2 & 0 & 0 \\ 0 & 0 & C_1 & 0 \\ 0 & 0 & 0 & C_2 \end{bmatrix}}_{K} d/dt \underbrace{\begin{bmatrix} i_1 \\ i_2 \\ v_1 \\ v_2 \end{bmatrix}}_{x} = \underbrace{\begin{bmatrix} -R_{on} & 0 & 0 & 0 \\ R_{on} & -R_{on} & -1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & -1/R \end{bmatrix}}_{A_1} \underbrace{\begin{bmatrix} i_1 \\ i_2 \\ v_1 \\ v_2 \end{bmatrix}}_{x} + \underbrace{\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}}_{B_1} \underbrace{\begin{bmatrix} v_s \\ V_D \\ 0 \\ 0 \end{bmatrix}}_{u} \tag{1}$$

$$x = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} = \begin{bmatrix} i_1 \\ i_2 \\ v_1 \\ v_2 \end{bmatrix} \tag{2}$$

$$Kdx/dt = A_1 x(t) + B_1 u(t) \tag{3}$$

$$v_o = v_2 \tag{4}$$

$$\underbrace{[v_o]}_{y} = \underbrace{[0 \quad 0 \quad 0 \quad 1]}_{C_1} \underbrace{\begin{bmatrix} i_1 \\ i_2 \\ v_1 \\ v_2 \end{bmatrix}}_{x} + \underbrace{[0 \quad 0]}_{E_1} \underbrace{\begin{bmatrix} v_s \\ V_D \end{bmatrix}}_{u} \tag{5}$$

In the second state, the MOSFET transistor is off and the diode will conduct. In this situation, the equivalent circuit is depicted in Fig. 4. Therefore, state space equations are calculated as following

$$\underbrace{\begin{bmatrix} L_1 & 0 & 0 & 0 \\ 0 & L_2 & 0 & 0 \\ 0 & 0 & C_1 & 0 \\ 0 & 0 & 0 & C_2 \end{bmatrix}}_{K} d/dt \underbrace{\begin{bmatrix} i_1 \\ i_2 \\ v_1 \\ v_2 \end{bmatrix}}_{x} = \underbrace{\begin{bmatrix} 0 & 0 & -1 & -1 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 1 & -1 & 0 & -1/R \end{bmatrix}}_{A_2} \underbrace{\begin{bmatrix} i_1 \\ i_2 \\ v_1 \\ v_2 \end{bmatrix}}_{x} + \underbrace{\begin{bmatrix} 1 & -1 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}}_{B_2} \underbrace{\begin{bmatrix} v_s \\ V_D \\ 0 \\ 0 \end{bmatrix}}_{u} \tag{6}$$

$$Kdx/dt = A_2 x(t) + B_2 u(t) \tag{7}$$

$$v_o = v_2 \tag{8}$$

$$\underbrace{[v_o]}_{y} = \underbrace{[0 \quad 0 \quad 0 \quad 1]}_{C_2} \underbrace{\begin{bmatrix} i_1 \\ i_2 \\ v_1 \\ v_2 \end{bmatrix}}_{x} + \underbrace{[0 \quad 0]}_{E_2} \underbrace{\begin{bmatrix} v_s \\ V_D \end{bmatrix}}_{u} \tag{9}$$

Using state space equations, small signal model for the control-to-output transfer function are obtained as follow