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Comparison between two controllers for a modular three level boost converter in renewable energy systems; indirect sliding mode and PI

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Abstract

Fuel cells and photovoltaic systems have many applications among renewable energy systems. DC converters play an important role in these systems. According to characteristics of renewable systems and nonlinear behaviour of the DC converters, control of them is essential. In this paper, the control of a DC modular converter is investigated. This converter is based on a three-level boost converter. This topology can increase the output voltage level compared to the input voltage level and balance the DC output voltage. There are two capacitors in each module of the converter and a capacitor is shared between two modules. The performance of the indirect sliding mode controller is compared with a classic PI controller. The system is simulated using MATLAB/ Simulink software. The simulation results are presented in several scenarios. The dynamics of the input powers and the voltage balance are studied. These tests are performed under changes in the input power, the resistance load and the input voltage. It is obvious that the proposed controller has good performance during operating point changes. The superiority of the proposed controller over the classic controller is shown for all tests. In transient mode, the linear controller is unable to balance capacitor voltages by changing the input power, input voltage and load.

Keywords: Modular converter, PI controller, Indirect sliding mode controller, DC voltage balance, Renewable energy systems

1. INTRODUCTION

According to climate changes, power generating from renewable energy sources are prominent. Fuel cells and photovoltaic systems are important sources among renewable energy sources. DC boost converters are used commonly in these systems. Control of the converter in renewable energy systems is very essential [1,2].

In this paper, a DC-DC modular three level boost converter is presented. This converter has two modules. Each module has two capacitors, a capacitor is common between two modules which helps to balance the output voltage. Two controllers are applied on this converter. One of them is indirect sliding mode controller and the other is PI controller. The optimization of parameters of PI controller is introduced.

2. Studied system and controllers

In this section, the studied converter and two controllers are introduced.

2.1. DC-DC modular converter

In this paper, a two modules DC-DC boost converter is proposed which is presented in [3]. Equations of the proposed system are introduced in (1) to (5).

$$\frac{di_{L1}}{dt} = (-r_1 i_{L1} + V_{i1} - (1-u_{11})v_{c1} - (1-u_{12})v_{c12})/L_1 \quad (1)$$

$$\frac{di_{L2}}{dt} = (-r_2 i_{L2} + V_{i2} - (1-u_{21})v_{c12} - (1-u_{22})v_{c2})/L_2 \quad (1)$$

$$\frac{dv_{c1}}{dt} = (i_{L1}(1-u_{11}) - i_{ch})/C_1 \quad (2)$$

$$\frac{dv_{c2}}{dt} = (i_{L2}(1-u_{22}) - i_{ch})/C_2 \quad (3)$$

$$\frac{dv_{c12}}{dt} = (i_{L1}(1-u_{12}) + i_{L2}(1-u_{21}) - i_{ch})/C_{12} \quad (4)$$

2.2. Indirect sliding mode controllers

The studied system comprises modular boost converter and the proposed controller [4]. To control the system, state variables of the system is gained from differential equations of the system. Then, the controller calculates the duty cycles of the converter according to reference of variable states and chosen control parameters. The objective of the control of the system is to control the inductors currents of the two modules boost converter and equivalence of voltages of all three capacitors. So, sliding surfaces are given in (6) to (9):

$$S_{i1} = i_{L1} - i_{ref1} + K_{i1} \int (i_{L1} - i_{ref1})dt \qquad (6)$$

$$S_{i2} = i_{L2} - i_{ref2} + K_{i2} \int (i_{L2} - i_{ref2})dt \qquad (7)$$

$$S_{V1} = V_{C12} - V_{C1} + K_{v1} \int (V_{C12} - V_{C1})dt \qquad (8)$$

$$S_{V2} = V_{C12} - V_{C2} + K_{v2} \int (V_{C12} - V_{C2})dt \qquad (9)$$

According to sliding surfaces, control laws and equations of the system, the four duty cycles of the two-module converter are obtained. The control parameters of the controller were chosen as $k_{ij} = \lambda_i = 1250\, rad/s$ and $k_{vj} = \lambda_v = 250\, rad/s$.

2.3. PI controller

In this section, steps of designing a PI controller for the studied converter are described. At first, the average model of the converter is given by the state variables and duty cycles. Then, the linearization is implemented. Transfer functions are given. Four transfer functions are defined: Two transfer functions for inductor currents and two transfers functions for voltages. The transfer functions are used to design the controller. Proportional and integral gains for currents and voltages are defined in the transfer function of PI controller. The transfer functions are given in (10)-(13).

$$FTOL\_i1_{i1ref} = FT_{i1_{d11}} \left(K_{p_{i1}} + \frac{Ki_{i1}}{s} \right) \qquad (10)$$

$$FTOL\_i2_{i2ref} = FT_{i2_{d22}} \left(K_{p_{i2}} + \frac{Ki_{i2}}{s} \right) \qquad (11)$$

$$FTOL\_\Delta V_{c1}\_\Delta V_{c1ref} = -FT_{vc12_{vc1d12}} \left(K_{p_{v1}} + \frac{Ki_{v1}}{s} \right) \qquad (12)$$

$$FTOL\_\Delta V_{c2}\_\Delta V_{c2ref} = -FT_{vc12_{vc2d21}} \left(K_{p_{v2}} + \frac{Ki_{v2}}{s} \right) \qquad (13)$$

Optimum PI parameters are obtained by pidTuner in MATLAB software. Control parameters of PI controller are given in Table 1.

Table 1. Control parameters of PI controller

	Proportional gain	Integral gain
Current	$K_{p_{i1}} = K_{p_{i2}} = 0.2243$	$Ki_{i1} = Ki_{i2} = 1088$
Voltage	$K_{p_{v1}} = K_{p_{v2}} = 0.009114$	$Ki_{v1} = Ki_{v2} = 2.75$

3. Results and Discussion

The behavior of the system for indirect sliding mode controller and PI controller is investigated in several scenarios. The dynamics of the input powers and balance voltage are investigated under variation of the input powers of two modules, input voltage, and resistance of load.

The waveforms of the capacitor voltages for both controllers are represented in Figure 1. More results are shown in main paper.

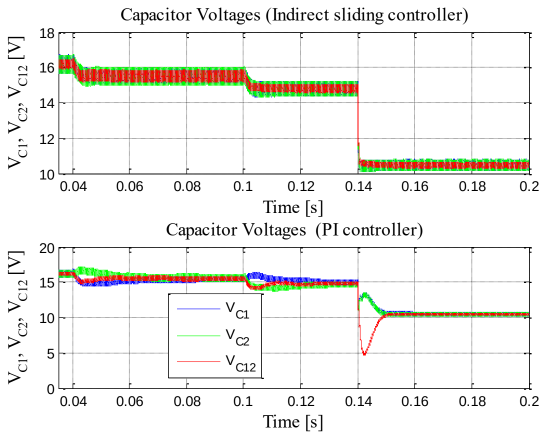

Figure 1. Waveforms of capacitor voltages: input voltage variation (first module) at 0.04 s, input voltage variation (second module at 0.1 s, load resistance at 0.14 s for two controllers.

4. Conclusion

The performance of two nonlinear and linear controllers for a two-module converter was investigated. The classic PI controller for this modular converter was designed. The results show that the nonlinear controller has better performance. In the transient mode, when the reference of the input powers, or input voltage, or load change, the PI controller is not able to balance the voltage of the capacitors.

5. References

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