Hardware based comparison of buck-boost converter topologies in MPPT systems

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Abstract

This paper presents a hardware based comparison of buck-boost converter topologies in MPPT applications. Buck-boost converters perform perfectly compared with the other DC-DC converter topologies without voltage conversion limitations. Comparative analyzes of classical buck-boost, sepic and cúk converters are made in terms of tracking capability, number of components that are used for power stage of these converters, control requirements, whether current of photovoltaic (PV) module is continuous or discontinuous and difficulties of measurement PV module current. Several simulations are performed by using perturb and observe (P&O) algorithm in MATLAB/Simulink environment under different solar irradiation conditions to conduct this research. With the help of this study, a basic technical guide for converter selection in MPPT applications is proposed.

1. Introduction

PV market has shown substantial progress and solar based electricity generation has been popular in recent years. As of end of the 2014, installed capacity of PV power generation reaches to 183GW approximately over the world. With improvements in solar cell efficiency, power processing units, legal regulations and incentive mechanism, it is foreseen that significant share of electricity may be provided by PV systems in the future [1-3].

PV systems consist of many components such as PV modules, power converter which is an inverter in a grid-connected system or a DC-DC converter in an island mode system. For these two types of system, MPPT is necessary operation strategy for extracting the available power from PV array. For island mode PV system, it is known that buck-boost converters have perfect performance compared with the other DC-DC converter due to their voltage conversion characteristic. In other words, since buck-boost converters regulate the input voltage from zero voltage to infinite voltage theoretically, MPPT is performed perfectly if the other operational principles of this type of converter are provided [4-8].

When considering the studies related to analyzes of converters in MPPT applications, there are rather limited studies in literature. In [5-7], a simplified analysis of three basic DC-DC converters is carried out and it is indicated that while buck and boost topologies have non-operation region in the voltage-current (V-I) characteristic curve of PV module, buck-boost converters perform in the entire region on the V-I curve. Similar study has been conducted in [4]. Practical approach is also developed among chosen converters. On the other hand, study conducted in [9], performance of converters in MPPT applications is shown by taken into account dynamics of converters. The study realized in [10] is proposed for sepic and cúk converters. In [11], comparative analyzes of sepic and buck-boost converters are performed in terms of experimental and simulative.

In this study, comparison of buck-boost converters is shown in MPPT applications under different solar irradiation. Classical buck-boost, sepic and cúk converters are performed with P&O algorithm. Comparison analyzes are carried out by seven indicators. These indicators are fluctuation of voltage and current of PV module, control requirements, number of components, tracking efficiency, whether current of PV module is continuous or discontinuous and difficulty level of PV module current measurement. Remains of the paper are as follows. Section 2 describes the mathematical background of the PV modules and buck-boost converters are presented. Main principle of MPPT application in buck-boost converter usage is explained. Moreover, all comparison indicators are emphasized in this section. Simulation results are presented in Section 3. Comparative analyzes of three converters are made in Section 4. In the last section, main outcomes of these studies are presented.

2. Buck-Boost Converters in MPPT Applications

MPPT performance of buck-boost converters is better than buck and boost converters due to their voltage conversion characteristic. When considering the MPPT performance of buck-boost converters theoretically, dynamic behavior of it is not required. Therefore, steady state equations are used. As shown in Fig. 1, classical buck-boost converter has five main components. The problematic thing seen from this circuit is the negative output voltage. As given in [12], output voltage of this converter is:

$$V_O = -V_{PV} \frac{D}{1-D} \tag{1}$$

V_O is the output voltage of buck-boost converter, V_{PV} is the voltage of PV module and D is the duty ratio of pulse width modulation signal (PWM).

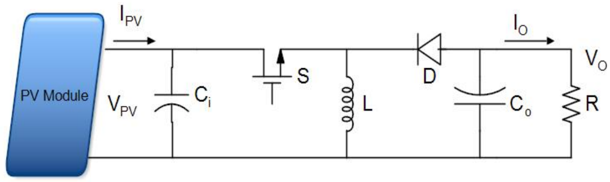

Fig. 1. Classical buck-boost converter (negative output)

Equivalent resistance (ER) seen from the input of this converter is easily calculated as given below:

$$R_{EQ} = R_{PV} = \frac{V_{PV}}{I_{PV}} \tag{2}$$

In (2), R_{EQ} or R_{PV} is the ER of PV module; I_{PV} is the current of PV module. By using (1) and (2), relationship between input and output of buck-boost converter can be obtained as given in (3).

$$R_{PV} = \frac{V_{PV}}{I_{PV}} = R\frac{1-D^2}{D^2} = \frac{V_O(1-D^2)}{I_O D^2} \tag{3}$$

Thanks to the (3), whatever environmental and loading conditions are, capability of MPPT is perfect as presented in Fig. 2. As shown in Fig.2.a-b, while duty ratio changes between 0-100%, ER of PV module changes between 0-∞ ohm. Therefore, it is worth noting that there is no limitation about impedance matching in buck-boost converter for MPPT applications.

The other buck-boost converters that are taken into account are sepic and cúk converters. These converters have same voltage conversion principle. They are also convenient for MPPT purposes. The main difference between these two converters is the polarity of output voltage.

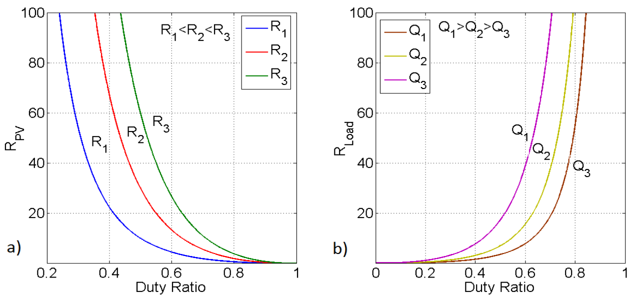

Fig. 2. R_{PV}-D and R_{Load}-D relationship

3. Simulation Results

In this section, simulation results of the buck-boost, sepic and cúk converters are presented in detail. One of the popular MPPT algorithms, P&O is used in these simulations. Two different scenarios are used for simulations. As listed in Table 1, constant irradiation and rapidly changing irradiation conditions are examined. In Fig. 3, a result of the constant irradiation condition is presented. Voltage, current and power of PV module are shown in this subplot. Moreover, Fig. 4 shows the detailed version of the first simulation. It is clear that these converters have the similar performance at steady state condition. However, cúk converter has minor fluctuation at steady state which may increase the tracking efficiency.

Table 1. Simulation conditions

	Solar Irradiance	Temperature	Resistance
Case 1	1000W/m^2	25°C	10Ω
Case 2	500-1000-500W/m^2	25°C	10Ω

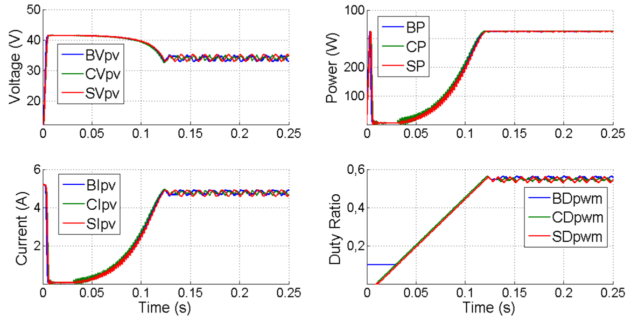

Fig. 3. PV module (Current, Voltage, Power) and Duty Ratio

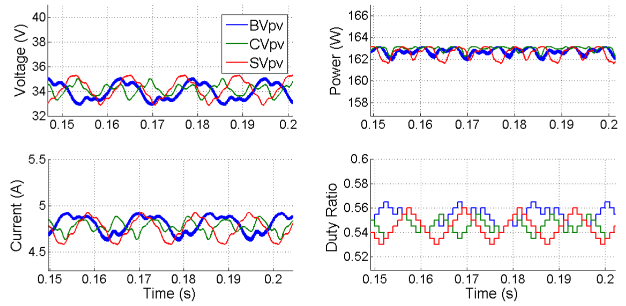

Fig. 4. PV module (Current, Voltage, Power) and Duty Ratio at steady state

In the second case, solar irradiance is increased from 500W/m^2 to 1000W/m^2 at t=0.08s. Then, it is decreased from 1000W/m^2 to 500W/m^2 at t=0.2s as presented in Fig. 5.

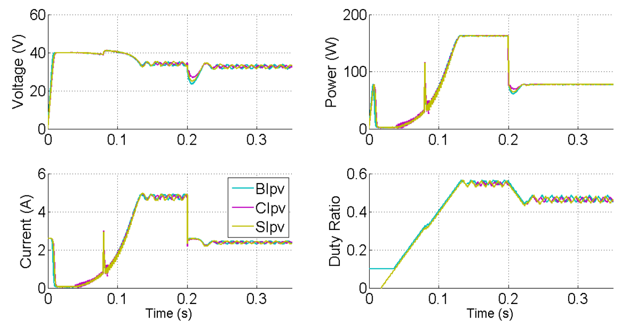

Fig. 5. Dynamic irradiance condition

At t=0.08s, maximum power point is not reached and power of PV module still increases. When solar irradiation changes rapidly, current and power of PV module show remarkable difference. However, after these peak changes in power and current as presented in Fig. 6, at t=0.14s, MPPT is accomplished. In this case, there is no remarkable difference in the performance of buck-boost, sepic and cúk converters.

At t=0.2s, current and power of PV module decreases harshly compared with the voltage. As shown in Fig. 7, cúk converter experiences minor changes which make this converter more convenient since fluctuations of the voltage, current and power are low. Furthermore, tracking efficiency is higher in cúk converter than that of the other converters since power of cúk converter decreases lower than the other converters. On the other hand, performances of sepic and buck-boost converters are so similar.

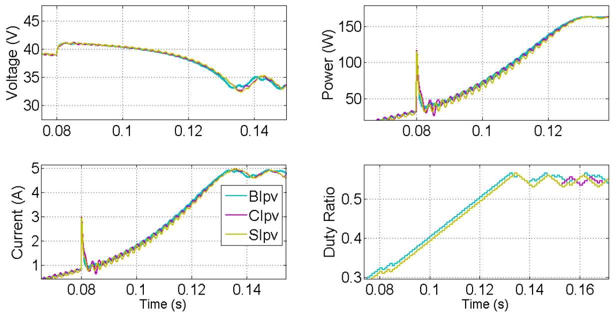

Fig. 6. Changes in PV voltage, current and power at t=0.08s

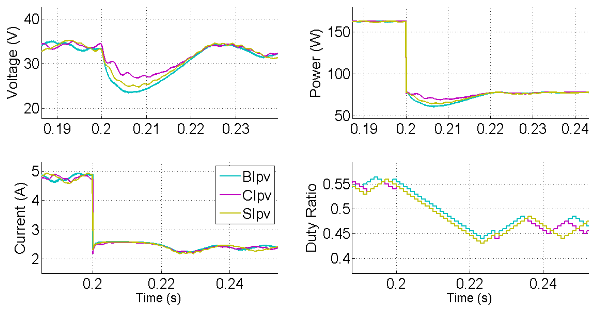

Fig. 7. Changes in PV voltage, current and power at t=0.2s

4. Discussion

In this section, buck-boost converters are compared in terms of seven indicators. These indicators are listed in Table 2. The first one is MPPT capability. As mentioned earlier, buck-boost converters do not have any limitation related to voltage conversion. Therefore, their MPPT capability is assumed as perfect.

Table 2. Comparison of buck-boost converter

Specification	Buck-Boost	Sepic	Cúk
MPPT Capability	Perfect	Perfect	Perfect
Number of component	Low	High	High
Control requirement	Isolated	Non isolated	
PV module current	Discontinuous	Continuous	
Current measurement	Hard	Easy	Easy
Fluctuations in changes	High	Medium	Low
Tracking efficiency	Low	Medium	High

The second indicator is the number of components that are used in converter's power stage. As known, power stage of classical buck-boost consists of a switch, a diode, capacitor and inductance. However, sepic and cúk converters have three capacitors and two inductances. So, classical buck-boost converters have the lowest number of components among them which reduces the cost of the power stage.

Control requirements are important for converter design. Control requirements in our perspective only means to switch driving circuit. While buck-boost converters need isolated drive circuit, sepic and cúk converters requires a basic IC for gate drive as boost converter has.

Current of PV module is important parameter for MPPT realization. Its status in terms of continuous or discontinuous is based on the converter topology or component. As shown in Fig. 8, input current of buck-boost converter is discontinuous due to the switch location. So, highly ripple in current makes the sensing its value harder. On the other hand, in sepic and cúk converters, there is an inductance in their inputs which makes the current continuous. As presented in Fig. 8, if value of inductance is enough high, current of PV module does not change in one switching period which makes the sensing of PV module current easy compared with the classical buck-boost converter. While average value of input current in buck-boost converter has to be calculated by a few sampling in a switching cycle which may increase the processing or convergence time, in sepic and cúk converters, there is no need to take a few measurements since current is assumed as constant within the switching cycle.

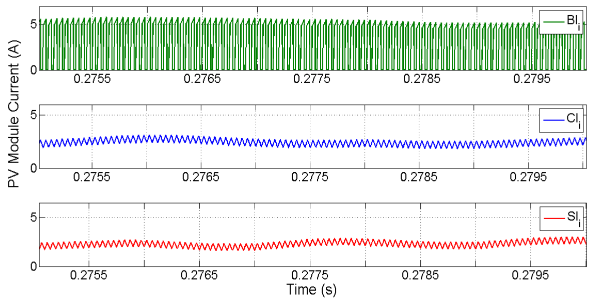

Fig. 8. Input current of converters

The last two parameters are fluctuations in power and tracking efficiency. In fact, these two parameters have inverse relationship. That is, if fluctuation in voltage or current of PV module is high, power is also fluctuated and tracking efficiency gets poorer. On the other hand, if there is no fluctuation theoretically, tracking efficiency will be high. These two indicators in this study are evaluated in rapidly changing irradiation conditions as presented in Fig. 9. It clear that power generated in cúk converter (CP) changes lower compared with the two converters as shown in Fig. 9 which is why tracking efficiency is high in this converter. The second converter performing the highest efficiency is the sepic. In this analysis, classical buck-boost is the last converter with lowest tracking efficiency.

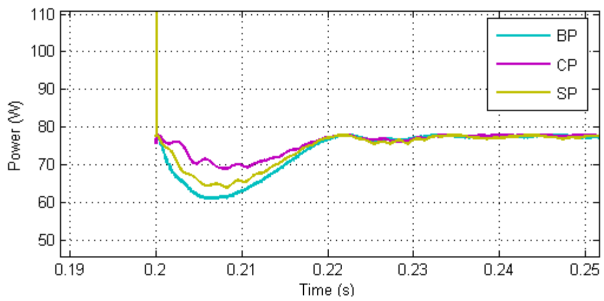

Fig. 9. Fluctuations under rapidly changing irradiation

5. Conclusions

Due to the significant developments in PV market, electricity generation from solar energy has been popular in recent years. MPPT in PV systems become more important for obtaining high efficiency.

As known, buck-boost converters with their voltage conversion characteristic have perfect performance in MPPT applications. However, comparison analyzes should be carried out by taking into account different aspects such as cost, feasible for realization, control requirements, current measurement and electrical performance etc.

While isolated gate drive circuits are necessary for classical buck-boost, number of components that are used in power stage of it is low compared with the sepic and cúk converters. On the other hand, sepic and cúk are not required isolated gate driving hardware which reduces the control complexity.

Measurement of PV module current is an important issue in MPPT applications. Input current of buck-boost converter is discontinuous and high ripple due to the switch's location. Therefore, measurement of this current is rather hard compared with the sepic and cúk.

Fluctuation and tracking efficiency are the last indicators that are taken into account in this paper. Fluctuations of cúk converters are low with respect to sepic and buck-boost converter under same conditions. Therefore, since more energy is transferred in cúk converters, high tracking efficiency is obtained in this converter compared with the other two converters.

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