Renewable and Sustainable Energy Reviews 76 (2017) 1230–1247

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Selection of non-isolated DC-DC converters for solar photovoltaic system

Dileep. G[a,*], S.N. Singh[b]

[a] Research Scholar, Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee, Uttarakhand 247667, India
[b] Senior Scientific Officier, Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee, Uttarakhand 247667, India

ARTICLE INFO

Keywords:
Solar energy
DC-DC converters
MPPT
PV system

ABSTRACT

Concerns over environment and increased demand of energy have led the world to think about alternate energy sources such as wind, hydro, solar and fuel cells. Out of these, photovoltaic (PV) power generation systems have become increasingly important all over the world due its availability, cleanness, low maintenance cost and inexhaustible nature. But power produced by the photovoltaic system is stochastic in nature due to the variation of solar irradiation and cell temperature throughout the day. In order to track the varying power, a DC-DC converter with maximum power point tracker (MPPT) is used. Different MPPT algorithms have been proposed for tracking peak power from the PV panel. Selection of adequate DC-DC converter is also an important factor since it has an influence on overall performance of the PV system. This paper presents a comparative study on the characteristics of different non-isolated DC-DC converters and highlights the various research works that has been done on DC-DC converters based MPPT PV system. Study shows that selection of converter also has an impact on the overall performance of the PV system. Based on the survey and comparative study, selection criteria to choose DC-DC converter for PV system is described in this paper.

1. Introduction

For economic development of any country energy is one of the major inputs. Number of industries, vehicles, domestic users has been increased by a large number in last decade; this in turn led to increase the global energy consumption also. Industries uses major share of energy produced in the world with a share of 33%, while residential, transport, service and other sectors follows with share of 29%, 26%, 9% and 3% respectively. Majority of energy is used in form of electricity and huge amount of electric energy is required by world to fulfill daily demand. By 2030 global electric energy demand is estimated to be doubled. Electric energy demands in fast developing countries are estimated to triple by this period. Majority of electric energy in the world is produced from coal with a share of 40.4% followed by natural gas, large hydro, nuclear, oil and renewable energy with a share of 22.5%, 16.2%, 10.9%, 5% and 5% respectively. Fossil fuel deposit on earth is depleting day by day and the atmospheric pollution and global temperature is increasing due to increased use of fossil fuels. Renewable energy tracking has become one of the interesting area in recent years due increased energy demand and issues related to environment. Out of all renewable energy sources, solar energy has gained much more attention due to its availability, cleanness and inexhaustible nature [1–4]. Tracking solar power is difficult due to non-linear current – voltage (I-V) characteristics of panel with a unique maximum power point (MPP) [5]. Power produced by PV panel varies with variation in atmospheric conditions such as solar irradiation and cell temperature. MPP of solar panel also varies with the variation in atmospheric conditions. So in order to extract maximum power, PV panel must be operated at a voltage corresponding to MPP (V_{MPP}). Maximum power point trackers are used to achieve this [6–10]. MPPT is an art of extracting maximum power from PV panel and it is regarded as the critical component of SPV system. Internal resistance of PV panel also varies with the variation in atmospheric conditions, but load resistance remains the same. Converter controlled with MPPT algorithm is used to achieve load matching and extracting maximum power from PV panel [11–13]. In order ensure that the PV system is operating near MPP, a DC-DC converter along with an MPPT controller is inserted in between the load and PV module [14]. Various MPPT algorithms such as short circuit current based [15,16], open circuit current based [17–21], ripple correlation control (RCC) [22–24], slide mode control technique [25–27], perturb and observe (P & O) [28–31], incremental conductance (INC) [32–37], fuzzy logic controller (FLC) [38–44], artificial neural network (ANN) based [45–49] approaches have been already proposed. DC-DC converters have drawn attraction these days, and are being used extensively with modern electronic systems. Since most of the renewable energy resources produce dc voltage, a DC-DC converter is used to transfer the power from source to load. For tracking solar and wind power, which are stochastic in nature,

* Corresponding author.
E-mail address: dileepmon2@gmail.com (D. G).

http://dx.doi.org/10.1016/j.rser.2017.03.130
Received 2 August 2016; Received in revised form 14 February 2017; Accepted 29 March 2017
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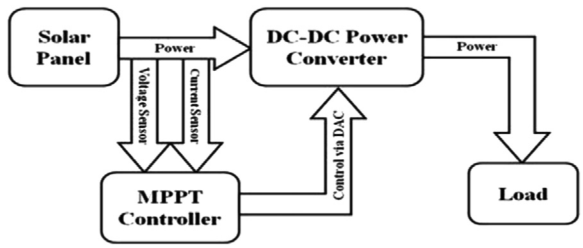

Fig. 1. SPV system with DC-DC converter and MPPT [51].

DC-DC converters are used as an impedance matching unit [50]. DC-DC converters act as an impedance matching unit in between the PV panel and load. By controlling converter duty ratio, input impedance of the converter is made equal to output impedance of the PV panel and load matching is achieved. Information regarding different converter topologies is mostly available on power electronics, simulation, and other electrical journals and detailed review on application of non-isolated DC-DC converter topologies on solar power tracking is not available. Since the application of non-isolated DC-DC converters on PV power tracking is increasing these days, it is the time to compile the work that has been already carried out in this area for the reference of researchers. This is the main motive behind this paper. This paper describes the working of different non-isolated DC-DC converters along with its merits and demerits on solar power tracking. At the end, a comparison of various converters is provided.

2. SPV system with DC-DC converter and MPPT

As shown in the Fig. 1, an SPV system consists of PV module, power conditioning unit (PCU) (in this case it is a DC-DC converter controlled by an MPPT tracker) and several loads. By varying the duty cycle of the DC-DC converter, load matching is achieved to transfer maximum possible power from PV panel to load. An MPPT controller with suitable algorithm is used to vary duty cycle of the converter. Current and voltage sensors are used to measure the value of panel voltage and current, and it is fed to the MPPT controller to determine the MPP [51].

3. PV characteristic curve

Characteristic curves of a PV panel are shown in Fig. 2. Both voltage-current (VI) and voltage-power (VP) curve of a PV panel is non-linear in nature. Open circuit voltage and short circuit current are two important points in VI characteristics of PV panel. Maximum voltage available from the solar cell is denoted by the open circuit voltage V_{OC} at this point, the PV current and power delivered from the panel is zero. V_{OC} of a particular solar cell depends on light generated current, saturation current and temperature of the cell. I_{SC} is the maximum current available from the solar cell and it is due to the generation and collection of photo generated carriers. I_{SC} of a solar cell depends on total cross sectional area, intensity of light, light spectrum, optical properties of panel such as absorption and reflection and collection probability. Power delivered from the panel at these points is zero. The point at which product of voltage and current is maximum in VI characteristics of a solar cell is defined as maximum power point (MPP). MPP is unique and it is located at the knee of VI characteristics as shown in Fig. 2 [52].

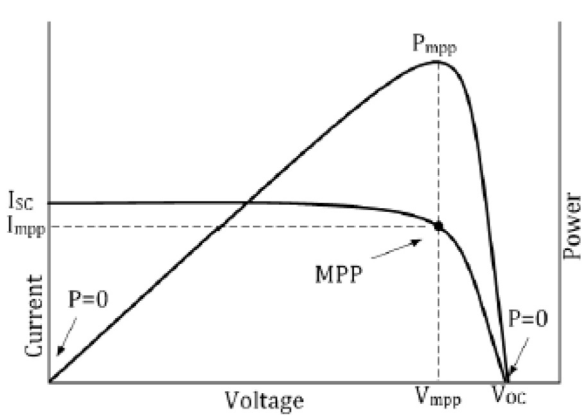

Fig. 2. Characteristics of PV module [52].

4. DC-DC converter

DC-DC converter is an integral part of SPV system now days. It acts as impedance matching unit between the load and PV panel. Buck, boost, buck-boost, cuk, SEPIC and zeta converters are commonly used along with MPPT controller for peak power tracking. Comparative study and survey of various DC-DC converters are presented in coming sections.

4.1. Buck converter

Buck converter is a type of DC-DC converter in which the output voltage is lower than the input voltage [53–58]. Since the output voltage is less than the input voltage it is also called as step down converter. This topology is used to charging battery or powering loads connected to the PV modules with higher voltage than their ratings. Circuit topology of a buck converter is shown in Fig. 3.

When converter switch is turned ON, diode gets reverse biased and it stop conducting current and inductor stores energy in it. During this period, the inductor current rises from minimum value to maximum value. When switch is turned OFF, energy stored in the inductor is transferred to the capacitor and load through freewheeling diode. Inductor current falls from maximum value to minimum value during this period. Voltage transformation ratio and resistance transformation ratio of buck converter is given in Table 1. Input side impedance and load impedance are denoted by R_i and R respectively. By varying the duty cycle, converter input impedance can be varied and matching with optimum panel resistance can be achieved for maximum power transfer. Since the duty cycle can be only varied between zero and one, buck converter can only reflect R_i between load resistance and infinity. It cannot reflect R_i between Zero and R. Therefore, buck converter does not achieve values above I_{MPP} of the PV module. Hence, MPP tracking of buck converter is limited to a region where $R >= R_{MPP}$ as shown in Fig. 4.

Chew and Siek [59] proposed a quad input dual output buck converter with reduced number of components for PV system to fed resistive load and battery charging application. They designed converter for a standalone PV system and it tracks peak power of three PV modules connected to the converter simultaneously. The proposed topology eliminates the number of components required thereby increasing the efficiency-cost percentage. Zhang et al. [60] presented a variable inductance based buck converter topology for solar micro grid application. When the solar irradiance increases the light gener-

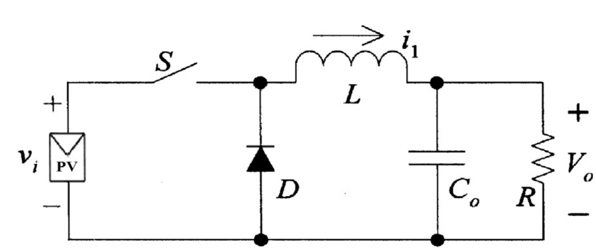

Fig. 3. DC-DC Buck converter.