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Fuzzy logic based MPPT controller for high conversion ratio quadratic boost converter

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ABSTRACT

In this study, a maximum power point tracking DC–DC quadratic boost converter for high conversion ratio required applications is proposed. The proposed system consists of a quadratic boost converter with high step-up ratio and fuzzy logic based maximum power point tracking controller. The fuzzy logic based maximum power point tracking algorithm is used to generate the converter reference signal, and the change in PV power and the change in PV voltage are selected as fuzzy variables. Determined membership functions and fuzzy rules which are design to track the maximum power point of the PV system generates the output signal of the fuzzy logic controller's output. It is seen from MATLAB/Simulink simulation and experimental results that the quadratic boost converter provides high step-up function with robustness and stability. In addition, this process is achieved with low duty cycle ratio when compared to the traditional boost converter. Furthermore, simulation and experimental results have validated that the proposed system has fast response, and it is suitable for rapidly changing atmospheric conditions. The steady state maximum power point tracking efficiency of the proposed system is obtained as 99.10%. Besides, the output power oscillation of the converter, which is a major problem of the maximum power point trackers, is also reduced.

Introduction

PV based electricity generation is increasing exponentially every year because of some reasons such as reduction of fossil fuel reserves, negative effects on environment of fossil fuels and increasing awareness on environment. In parallel to this development, the researchers are concentrating on developing new and advanced PV system technologies [1,2]. Mainly studies are focused on two major topics in order to obtain the maximum benefit from the PV system investment. The first research topic is designing new, high efficiency and low cost PV cells and modules, and contains studies on modules structure and materials. The second research topic covers studies on power electronics converter topologies and their control techniques. Different converter topologies and control strategies have been proposed for this aim [1–9].

PV panels generate specific power at certain operation conditions. The PV output voltage and current vary with environmental effects such as the solar irradiation, the ambient temperature, the pollution of the PV module surface, shadowing etc. As it is known, environmental conditions vary seasonally and on a daily basis. If these parameters change, also the amount of produced power changes. Therefore, the

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PV output parameters, according to the changing environmental conditions, must be continuously monitored. In addition, the generated power form a PV module is also related with the load level. Consequently, the PV module has nonlinear power versus voltage (*P*–*V*) and current versus voltage (*I*–*V*) characteristics and there is a unique operation point on these characteristics that provide the possible maximum power. This point is called as maximum power point (MPP) [1,2]. Since, the load level of the practical PV system and environmental conditions such as solar irradiation and ambient temperature continuously change, a proper control algorithm and power converter should be used to control the operation point and to keep the system at MPP. This control algorithm is called as maximum power point tracking (MPPT) algorithm. Many algorithms have been suggested for MPPT action [2–8]. In some studies, these control algorithms are grouped as online and offline methods. Some researchers group these methods as seeking and true seeking methods, while others group them as direct and indirect methods. The fundamental difference between these two groups is related to performing way of the MPPT process [3,4]. Online methods measure some parameters form the PV system continuously and control the system to track the maximum available power according to these measured data. Besides, offline methods use some predefined formulas, measurements or tables to perform same action. Although offline methods are usually fast, online methods perform more realistic MPPT process than offline methods. The most well-known online methods are incremental conductance (IC) and perturb and observe (P&O) techniques [1–4]. The fuzzy logic control based methods are the new approach, and they have become popular in recent years. Among the different intelligent controllers, fuzzy logic controller (FLC) stands out with its simple structure [5]. Furthermore, other artificial intelligence methods such as artificial neural networks, genetic algorithms, particle swarm optimization are also used in MPPT studies [6]. Soft switching MPPT converters are also proposed to achieve higher total system efficiency [9].

The output voltage of the PV panel is usually lower than required in typical energy applications such as motor drives, inverters, etc. Therefore, this voltage level must be increased for these type of applications. This required higher voltage level may be accomplished by series connection of PV panels. However, the number of series-connected PV panels must be within certain limits in practice due to some limitations such as PV voltage isolation, efficiency, shadowing effect, etc. On the other hand, conversion ratio of the conventional DC–DC converters is usually not suitable for the required voltage level of the aforementioned inverters for PV applications. (The conversion ratio is defined as the ratio of the output voltage to the input voltage.) Moreover, it is well known that, in conventional DC–DC boost converters, increasing duty cycle decreases the stability and increases the control difficulty. Therefore, while output voltage of boost converter increases exponentially with duty cycle, in practice the voltage conversion ratio between output and input voltage of the converter is recommended to be selected as a maximum four [10]. Although, another alternative to increase the conversion ratio is using the isolated DC–DC converter topology, this structure causes some problems such as cost, complexity, etc. [11]. Different DC–DC converter topologies with high voltage step-up capability have been investigated. The combination of the conventional boost converter with switched capacitors have been proposed to provide high conversion ranges. In this system, the output voltage level is related to the number of capacitors used in the circuit. However, voltage regulation action decreases the efficiency of the converter dramatically. Therefore, this topology is suitable and provides high efficiency, if an additional converter is used for voltage regulation [12]. In addition, the power switch suffers from high charge current. The DC–DC multilevel boost converter topology is proposed to overcome this drawback. This topology also combines the boost converter and switched capacitor action. The boost converter charges several capacitors in series with its output (same) voltage [13]. Thus, output voltage can be easily controlled with a number of series connected capacitors. Although this structure is very suitable to supply neutral point clamped multilevel inverters, the requirement that output capacitors should provide the whole load current limits its usage.

The coupled-inductor technique is also used to obtain high step-up converter [14]. However, the efficiency of this technique is low, and the leakage-inductor energy of the coupled inductor will cause voltage spike on the switch and increase switching losses [15]. Active and passive clamp circuits are utilized to recycle the leakage inductor energy, but clamp circuits increase the cost of the system. High step-up voltage gain can also be achieved with two cascaded boost converters. But this topology requires two controllers and two active switches. The quadratic boost converter (QBC) which is structurally similar to cascaded two boost converters has been proposed to provide high voltage conversion ratio. The QBC circuit is given in Fig. 1. The output voltage of the QBC is given as a quadratic function of the duty cycle of switching signal [16]. Since the QBC has only one active switch, additional driver circuit requirement is removed and more reliable and efficient converter is obtained. Therefore, the QBC is used in several applications where high voltage conversion ratio is required such as power factor correction applications and PV applications [17–19]. The output voltage of the fuel cell or PV module is usually low, and this low voltage should be increased to supply conventional AC loads or to export generated energy to the grid. Therefore, a robust, reliable and high efficiency converter design with high voltage conversion ratio is an important requirement. Although some studies have been presented on QBC control, the number of studies on MPPT quadratic boost converters is limited and a few simulation studies have been proposed [17,20,21].

In this study, a DC–DC quadratic boost converter with MPPT capability for PV systems which requires high voltage

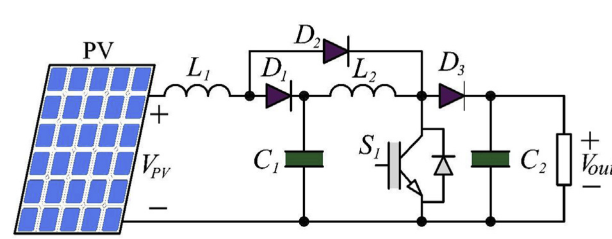

Fig. 1 – The PV supplied quadratic boost converter.

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