Chapter 17
Control and Conversion of Solar Power

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ABSTRACT

Solar energy conversion is one of the most addressed topics in the field of renewable energy. Solar radiation is usually converted into two forms of energy: thermal and electrical energy. Solar electricity has applications in many systems such as rural electricity, water pumping, and satellite communications. A solar power system consists of solar panels, dc-dc converters, controller, and load. Charging a rechargeable battery requires a regulated dc voltage. However, the voltage supplied by a solar panel can vary significantly depending upon the day, time, weather condition, and irradiation from the sun. Since solar power is unregulated, it cannot be supplied to the load directly. Solar power is harvested and stored by charging rechargeable batteries. A dc-dc converter is connected between the solar panel and the battery to charge the battery with a regulated voltage. Therefore, solar power can be properly converted and controlled to provide required electrical power to the load, and excessive power can be sent back to the electrical grid.

INTRODUCTION

In this chapter, the most recent development of digital power management and battery charging control will be introduced. Dc-dc converters convert unregulated input voltage into regulated output voltage. Digital PID (proportional-integral-derivative) type controllers can be applied to dc-dc converters for voltage regulation. Linear PID controllers for dc-dc converters are usually designed by classical frequency response techniques based on the small signal model of converters. To harvest solar power, rechargeable batteries are used to store energy. Because output voltage of a solar panel varies constantly, a dc-dc converter is needed to regulate the charging and discharging of the batteries. This chapter will introduce several types of dc-dc converters. Small signal model of the converters will be first obtained. PID controllers will then be designed

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and implemented. A solar battery charger will be designed and implemented. Experimental results will be presented and examined.

BACKGROUND

Solar energy conversion is one of the most addressed topics in the field of renewable energy. Solar radiation is usually converted into two forms of energy: thermal and electrical energy. Solar electricity has applications in many systems such as rural electricity, water pumping and satellite communications.

In the past, solar power was usually used for large-scale grid connected system and small remote photovoltaic plants or stand-alone systems (Bica, 2008). Recent technological development in thin-film photovoltaics (PV) is leading to new generations of consumer portable solar panels. These new solar panels are light weight, durable, flexible, and have been reported to achieve power efficiencies of up to 10%. The portable solar panels make solar power readily available for mobile power needs such as outdoor enthusiast, expeditions and campers. It also provides portable solar power for the military to extend the run time of military devices including satellite communications, two-way radios, laptop computers, thermal imaging cameras, GPS, and etc. Therefore, solar power is expanding beyond its traditional applications.

Solar power is harvested and stored by charging rechargeable batteries. Older solar battery chargers were mainly developed for stationary situations such as solar house and RVs. Lead acid batteries are usually used because light weight is not a major factor to consider. However, since the appearance of the foldable and light weight solar panels, the need to develop solar battery chargers for more portable batteries such as Nickel metal hydrid (NiMH) and Lithium-ion (Li-ion) batteries becomes essential.

Previous work has been done to compare battery charging algorithms for stand alone photovoltaic systems (Armstrong, 2008). Peak power from the solar panels was tracked for photovoltaic systems using various methods (Hua, 1998). To increase conversion efficiency, maximum power point tracking techniques as well as optimal control were studied and implemented (Boico, 2007; Masoum 2004).

Charging a battery requires a regulated dc voltage. However, the voltage supplied by a solar panel can vary significantly depending upon the day, time, weather condition and irradiation from the sun. In order to charge the battery with a regulated voltage, a dc-dc converter is connected between the solar panel and the battery. The output voltage, current and power can be regulated using feedback controllers (Mohan, 1995). In this chapter, the following dc-dc converters are discussed.

1. Buck converter (step-down)
2. Boost converter (step-up)
3. Buck-boost converter (step-down/step-up)
4. Cuk converter (step-down/step-up)
5. Sepic converter (step-down/step-up)

Of these five converters, buck converter and boost converter are the basic converter topologies. Buck-boost, Cuk and Sepic converters are derived based on the two basic topologies. In a dc-dc converter, the switching device such as transistor or MOSFET is switched on or off completely, therefore efficiency of dc-dc converters is generally higher than linear regulators.

A buck converter produces a lower output voltage than the input voltage. A boost converter produces a higher output voltage than the input voltage. Buck-boost, Cuk and Sepic converters are buck-boost type converters that produce an output voltage that is either higher or lower than the input voltage. A pulse-width-modulated (PWM) signal is sent to the switching device to regulate the output voltage. By varying the duty ratio t_{on}/T_s of the switch, the output voltage can be controlled.