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Impedance source converter for photovoltaic stand-alone system with vanadium redox flow battery storage

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Abstract

Photovoltaic stand-alone systems require an energy storage component to provide continuous energy to the load when the solar intensity is inadequate. A vanadium redox flow battery has many prominent attributes which make its integration with a photovoltaic stand-alone system highly attractive. This paper investigates a 3kW photovoltaic stand-alone system including solar panels, impedance source converter and vanadium redox flow battery. Impedance source converters are new type of DC-DC converters with buck and boost operating capability, offer greater range of DC output voltage, high reliability and reduce ripple currents. The equivalent circuit and the charging characteristics of the vanadium redox flow battery are provided. Impedance source converter acts as the power conditioning converter which receives the maximum power from the photovoltaic panel and maintains the constant voltage across the battery by controlling its duty cycle. The results are provided to study the charging behavior of the battery and to validate the advantages.

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Keywords: Energy storage; impedance source converter; photovoltaic; vanadium redox flow battery;

1. Introduction

World's energy consumption is forecasted to more than twice by 2050 and more than three-fold by the end of the century. Incremental improvements in conservation and energy efficiency measures in present energy system will not be sufficient to render this demand. Fossil fuels are the major source of energy that are being utilized today. But

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their continuous consumption leads harmful environmental effects such as pollution that endangers health of all creatures and greenhouse gases associated with climate change. Finding out of clean energy with adequate supply for the future is the most daunting challenge.

Nomenclature

V_{eql}	equilibrium cell voltage (cell potential at 50% SOC)
F	Faraday constant = 96485 C/mole
T	temperature impact on VRFB
R	universal gas constant = 8.314510 J/k.mole
n	number of cell stacks

The contribution of alternative renewable energy sources is being increased worldwide. Our ultimate source of clean, inexhaustible and abundant energy is the sun. But the major problem in solar power generation is the fluctuation in its output. Efficient electrical energy storage technologies, amongst which energy storage batteries are giving solutions to this problem especially for stand-alone or micro grid applications. The lead acid battery is the dominant energy storage technology for stand-alone photovoltaic system due to its relatively low cost. However, this battery is limited by the life cycle under deeply discharging conditions. The nickel cadmium batteries have drawn great attention due to its low self-discharge and non-freezing characteristics, but they are very expensive, highly hazardous, and low efficient. Another battery is nickel iron. It has very long life, but it has low efficiency, very high rate of self-discharge and high specific weight [1]. The vanadium redox flow battery (VRFB) has received considerable attention recently for the storage unit of photovoltaic stand-alone system. VRFB offers almost unlimited energy capacity using larger electrolyte storage tanks and it can discharge for long periods with no ill effects. VRFB technology has many advantages including long lifecycle, high storage efficiency, scalability, high round trip efficiency, rapid response, and low maintenance costs. Operation under rapidly changing conditions is possible without impact on efficiency, because the integrated pump ensures the availability of electrolyte at all times near the electrodes [2,3].

2. Vanadium redox flow battery

VRFB is an electrochemical cell used for electricity storage systems. Like other flow batteries, VRFB stores chemical energy and converts it into electrical energy by a reduction-oxidation (redox) reaction between vanadium ions dissolved in the electrolytes. VRFB cell has two compartments separated by a cation permeable polymer exchange membrane with electrolytes of vanadium dissolved in sulfuric acid solution in each compartment as shown in Fig. 1. The electrolytes are stored externally from the battery and must be pumped through the cell for all the chemical reactions. In the VRFB, two reactions are taking place simultaneously on both sides of the membrane. During the discharge cycle, $V^{2+}$is oxidized to V^{3+} with the release of electrons in the anolyte. These electrons are removed from the negative electrolyte and transported through the external circuit (either DC or AC) to the positive electrolyte. In the catholyte, V^{5+} in the form of VO_2^+ takes an electron from the external circuit and is reduced to V^{4+} in the form of VO^{2+} . Hydrogen (H+) ions are exchanged between the anolyte and catholyte to maintain charge neutrality. During the charging cycle the reduction occurs in the anolyte and the oxidation in the catholyte and the electron flow is reversed [4].
The reactions of the VRFB electrodes can be expressed by the equations (1) and (2).
Positive Electrode Reaction:

$$VO^{2+} + H_2O + e^- \leftrightarrow VO_2^+ + 2\,H^+ \tag{1}$$

Negative Electrode Reaction:

$$V^{3+} + e^- \leftrightarrow V^{2+} \tag{2}$$

Total cell reaction can be expressed in equation (3).