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ScienceDirect

Energy Procedia 112 (2017) 595 – 605

Energy Procedia

Sustainable Solutions for Energy and Environment, EENVIRO 2016, 26-28 October 2016, Bucharest, Romania

Output Analysis of Stand-Alone PV Systems: Modeling, Simulation and Control

Laurentiu Fara[a,b]*, Dan Craciunescu[a]

[a]*Polytechnic University of Bucharest, Splaiul of Independence Street no. 313, district no. 6, Bucharest 060042, Romania*
[b]*Academy of Romanian Scientists[2], Splaiul of Independentei no. 54, district no. 5, Bucharest 050094, Romania*

Abstract

A stand-alone PV system was studied, designed and simulated for an isolated mountain area in Romania. This PV system was developed for energy production, ensuring energy independence (electricity for lighting and supply of power for electric equipment with low consumption during a period of 70% from a year) of a house / chalet in an area where connection to the local grid is impossible or would require very high costs to developed electricity grid. A library of simple mathematical models for each element of such a stand-alone PV system, namely PV generator, battery, controller and load was established. The models of the PV system components are based on literature, but their implementation for analyses is developed using the MATLAB/Simulink software. It is discussed the interconnection of the subsystems and the performance of the PV system.

Peer-review under responsibility of the organizing committee of the international conference on Sustainable Solutions for Energy and Environment 2016

Keywords: Stand-alone PV system, MATLAB/Simulink, PV panels, battery, controller, load, performance

1. Introduction

Photovoltaic power systems have increasing roles in modern electric power energy mix due to the continuing decline in the world's conventional sources of energy. The major advantages associated with photovoltaic powersystems are: 1) they have no moving parts; 2) do not produce any noise; 3) require little or no maintenance,

* Corresponding author. *Tel.:* +4-072-668-4145;
E-mail address: lfara@renerg.pub.ro

Peer-review under responsibility of the organizing committee of the international conference on Sustainable Solutions for Energy and Environment 2016
doi:10.1016/j.egypro.2017.03.1125

are non-polluting; 4) are renewable; 5) are highly modular; 6) are highly reliable; 7) can be installed almost anywhere.

A stand-alone photovoltaic power system is a complete set of interconnected components for converting solar irradiance directly into electricity and generally consists of the PV generator, battery, charge controller, inverter, and the system load.

The stand-alone systems are those PV power generation plants which are not connected to the utility grid. The stand-alone PV system concepts available on the market are as follows, [1]:

- *Solar Home Systems:* all consumers and PV generator are coupled on the DC voltage
- *Small AC local grid with coupled components:* this PV technology emerged due to the needed supply (minimum power) AC loads by DC power sources and to charge the battery on the DC from different sources.
- *Modular AC coupled systems:* more flexible PV systems with modularly structured components are achieved by coupling all consumers and PV generator on the AC.

In this paper, the design of the various components of a photovoltaic power system for the purpose of mountain area use will be presented. Therefore, the energy requirements for a mountain areain Romania, as a practical case study,with a detailed step-by-step design procedure will be considered. The design of a stand-alone PV system will be developed using the MATLAB/Simulink software, [2].

The MATLAB and Power electronics application ranges from power supplies to robotic controls, industrial automation, automotive, industrial drives, power quality, and renewable energy systems, [3, 4].

Before the installation of a PV power plant, MATLAB finds applications in selecting the system based on the requirements and to choose particular components for the Solar PV applications. MATLAB helps for:1) selecting the matrix manipulations to grid inverter;2) plotting of functions and data;3) implementation of Maximum Power Point Tracking(MPPT) algorithms;4) creation of user interfaces for monitoring the Solar PV generator and for interfacing with inverter, [5, 6].

This article describes the procedure used for simulating the I–V characteristics and P–V power output of a PV system. It is important to understand how the PV array structure is defined in MATLAB. The main objective of this paper is to analyze the models for the elements of a stand-alone PV system: PV generator, battery, controller and load. The modeling of the PV system is based on modular blocks. The modular structure facilitates the modeling of the other system structures and replacing of elements, for instance a DC load instead of an AC load.

2. Methodology of design and simulation of a stand-alone PV system

2.1. Why we need a MATLAB/Simulink program for design and simulation

The software packages like PV-Spice, PV-Design Pro, Solar Pro, PV CAD, and PV system are available, but they have two limitations: 1) commercial, proprietary in nature and expensive; 2) do not support the interfacing of the PV arrays with actual power electronic systems.

There is a need for a flexible, interactive, and comprehensive simulation model, which can serve as the following.

- A basic tool for professionals and researchers to accurately predict the PV characteristics (including multiple peaks) and output power under partially shaded conditions, [7].
- A design aid for users who want to build actual PV systems, study the stability and interfacing without going into the details.
- A tool to study the effect of array configuration on the output power, [8].
- A planning tool that can help in the installation of efficient and optimum PV arrays.
- A tool to develop and validate the effectiveness of existing and new MPPT schemes.

These features are fulfilled by MATLAB/Simulink tool, which can be used to enhance the understanding and simulation of the I–V characteristics and P–V power output for stand-alone PV systems, [9]. It can be used to study the effect of temperature and insulation variation, varying shading patterns characterized by multiple peaks in the power–voltage curves, and the role of array configuration on the PV characteristics. A notable advantage of this approach is that the PV generator model can be interfaced with the models of actual systems (e.g., power electronic converters) making it possible to simulate complete PV systems and their interaction with other systems. The reason for using MATLAB is that it is available in most academic, research, and industrial organizations and is considered