Renewable and Sustainable Energy Reviews 73 (2017) 950–965

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

A review of technical issues on the development of solar photovoltaic systems

C. Lupangu, R.C. Bansal*

Department of Electrical, Electronic and Computer Engineering, University of Pretoria, Pretoria, South Africa

ARTICLE INFO

Keywords:
Energy policy
MPPT
Power quality
PV-battery energy management
PV systems

ABSTRACT

Today, photovoltaic (PV) plants are receiving a significant attention due to their intrinsic ability to directly transform solar energy in electrical energy. However, electricity generated from PV plants can rarely provide immediate response to load demand, as these sources do not deliver a regular supply immediately compatible with consumers' needs. Recently, an important attention has been devoted to the use of energy storage in grid-connected PV plants, with the objective of adding flexibility in load management and overcoming some important power quality problems of real distribution grids. This makes PV plants more useful and attractive. Several battery management techniques have been underlying as a way to create more price-responsive demand and as a way to integrate PV plants more effectively into power grid. However, the development of energy policies constraint the wider deployment of PV systems. In this paper, various sizing, modelling, maximum power point tracking (MPPT) methods have been reviewed for the efficient operation of grid-connected PV systems. Dispatch strategies for stored energy that maximize the financial value of battery-PV systems along with several optimization techniques are discussed. Power quality and control technology issues of grid-connected PV systems are also covered. The economic and environmental benefits of grid-connected PV systems are underlined and operational and maintenance issues of PV-battery power systems have been included. The present paper aims at reviewing some technical challenges on the current state of PV systems based on energy policies, various cell technologies, MPPT and converter/inverter technology, energy management and scheduling techniques, reliability, power quality and control systems issues.

1. Introduction

The main reason for climate change is the greenhouse gases released from the burning of fossil fuels. Almost 80% of greenhouse gases come from generation and consumption of electrical energy. World primary energy demand will increase almost 60% between 2002 and 2030; this is a 1.7% average annual increase, which further increases greenhouse gases leading to consideration climate degradation with global warming phenomena [1]. Sustainable and low-carbon energy technologies will play an important role in the energy revolution required to make the change in the path we are now on. Several types of renewable energy together with energy efficiency, carbon capture and storage, nuclear power and new transport systems need to be widely deployed if we are to achieve a global energy-related CO_2 target in the near future lower below today levels and deal consequently with global temperature rise problems [2]. Without an urgent and fully committed action, the International Panel on Climate Change (IPCC) has strongly underlined that, the effects of climate change will severely impacted and thus, irreversible across the world. Long-term average temperatures need to be decreased below 2 °C, likewise to pre-industrial levels. This will require sustained solutions and global commitments to lower all emission levels [3]. In relation to this, the International Energy Agency (IEA) is working closely with all shareholders to develop a series of technology roadmaps that enables governments, industry and financial partners together to identify the steps needed to accelerate the implementation of technology changes.

Photovoltaic (PV) energy is one of the most promising emerging technologies. The levelised cost of electricity of decentralized solar PV systems is falling below the variable portion of retail electricity prices that system owners pay in some markets, across residential and commercial segments [2,3]. More solar photovoltaic (PV) capacity has been added than in the previous four decades since 2010. A high rate of 100 MW (MW) of capacity installed per day in 2013 has been used to illustrate this raising phenomena of PV demand. A record of 177 GW of overall PV capacity took place in 2015 [2]. According to the IEA roadmap 2014 edition, the share of PV is estimated at 16% of

* Corresponding author.
E-mail addresses: lupangucedrick@yahoo.fr (C. Lupangu), rcbansal@ieee.org (R.C. Bansal).

http://dx.doi.org/10.1016/j.rser.2017.02.003
Received 29 February 2016; Received in revised form 8 November 2016; Accepted 1 February 2017
1364-0321/

global electricity by 2050, increasing significantly from the 11% goal as planned in the 2010 roadmap. An estimate of 17% of the whole clean electricity would come from PV generation while all renewables expect to produce 20% of global electricity. China will remain the leader in PV global market, and will account almost 37% of global capacity by 2050 [2,3]. A cost variation of USD 90 to USD 300/MWh has been evaluated for the newly PV built systems. The cost depends on several factors such as the solar resource; type, size and cost of systems; maturity of markets and costs of capital [3].

Photovoltaic energy sources can be used as stand-alone systems and grid-connected systems and their applications include water pumping, battery charging, home power supplies, street lighting, refrigeration, swimming-pool heating systems, hybrid vehicles, telecommunications, military space and satellite power systems, and hydrogen production. About 60% of the global market is allocated for decentralized systems, while centralized, utility-scale systems account for 40% of global market. Stand-alone or off-grid systems, which were previously dominant on a much smaller market, now contribute only 1% of global market. Crystalline silicon (*c*-Si) modules, whether single-(sc-Si) or multi-crystalline (mc-Si) currently dominate the PV market with around 90% share. Thin films (TF) of various sorts now represent only about 10% of the market, down from 16% in 2009, and concentrating photovoltaic (CPV), although growing significantly, represent less than 1% [2].

Likewise the wind energy, the solar resource is weather dependent, presenting therefore a serious challenge. It is thus crucial for the continuity of power supply to assess all flexible options such as demand-side response, storage, interconnections, and flexible generation to help meet the targets of PV generation by 2050 as envisioned by the IEA roadmap. PV should play his part among all balanced portfolio of all renewables. For instance, wind power tends to be stronger during winter and therefore compensate for low solar irradiance in temperate countries. Hydropower as renewable energy can considerably compensate solar PV in hot and wet countries. Solar thermal electricity with built-in thermal storage capabilities in hot and **arid** countries usually generate electricity during night time and can complement for the fluctuation of PV, supplying more solar energy to the systems– this make solar energy potentially the leading source of electricity by 2040 [2].

Solar PV sources cannot provide constant energy supply and introduce a potential unbalance in generation and demand, especially in off-peak periods when PV generates more energy and in peak period when load demand rises too high. Because of its intermittent and irregular nature, PV generation makes grid management a difficult task. Consequently, PV production into the grid is considered to be limited. One of the major challenges for PV systems remains in the matching of the intermittent energy production with the dynamic power demand [4]. A solution is to add a storage element to these intermittent power sources. Storage devices such as batteries allow intermittent sources like solar PV to address timely load demand and add flexibility in load management.

Although critical applications for storage have been clearly identified, dispatch strategies for stored energy that maximize the financial value of the combined renewable generation and energy storage systems are not well quantified or understood in an operational context and need to be further investigated [5]. Reliability is a key issue in the effective use of renewable PV energy and in smart grids, and therefore the demand for battery systems is increasing [6]. Aiming to provoke consumers to participate in demand response, several retail pricing schemes including time-of-use (TOU), critical peak pricing (CPP), real time pricing (RTP) have been proposed in the literature to optimize the economic benefits of PV battery systems. Yoon and Eltawil [7,8] have studied how the control of grid-connected PV system can help to enhance the efficiency of the system output, make the process more optimized and get high quality of electric energy.

The review of paper is organized as follows: Section 1 introduces the key parameters for the development of PV systems. Section 2 classifies stand-alone and grid-connected systems and illustrates some reliability challenges in PV systems. Section 3 highlights energy policy issues and, Section 4 deals various PV cell technologies. Section 5 illustrates the design & sizing and modelling. Section 6 illustrates MPPT and power electronic interface methods and Section 7 reviews the energy management and scheduling techniques. Section 8 briefly illustrates the conventional and artificial intelligence optimization methods and Section 9 illustrates the technical solutions to deal with grid quality and control issues. Section 10 reviews homogeneous and heterogeneous storage issues in PV systems and Section 11 illustrates some hybrid stand-alone and grid-connected PV systems. Section 12 presents economic and environmental considerations and Section 13 includes operation and maintenance issues, and finally, Section 14 concludes the paper.

2. Classification of stand-alone and grid-connected PV systems

Photovoltaic systems are subdivided into two categories, which are stand-alone and utility-interactive or grid-connected systems. This classification of PV systems relies upon their operational and functional requirements, their component configurations, and their connection to other electrical loads and power sources. Moreover, PV systems can operate independent or interconnected with the utility grid. They are designed to provide AC and/or DC power service, and can be connected with energy storage systems and other alternative energy sources.

As stated previously, Grid-connected PV systems are designed to operate in parallel and interconnected with the electric utility grid. The power conditioning unit (PCU) or the. inverter is the main component of grid-connected PV systems, which converts the DC power produced by the PV array into AC power consistent with the voltage and power quality requirements of the utility grid for either direct use on appliances or send to the utility grid to earn the feed in tariff compensation. When the grid is not energized, the PCU automatically stops supplying power to the grid. A bi-directional interface located at an on-site distribution panel or service entrance allows the AC power produced by the PV system to either supply on-site electrical loads or to back-feed the grid when the PV system output is greater than the on-site load demand. When the electrical loads are greater than the PV system output, especially at night and during cloudy periods, the balance of power required by the loads is received from the electric utility. This constitutes a safety feature when the grid is down for service or repair to ensure that the PV system will not continue to operate and feed back into the utility grid [9].

Grid-Connected PV system without a back-up energy storage (ES) are environmental friendly and frequently adopted by people due to less requirements for maintenance and cost. However, in the case of power outage during the night time or cloudy day, the system has to shut down the operation until the grid power is available.

Grid-Connected PV systems with a back-up ES are usually interconnected with the utility grid. This configuration provide several advantages such as selling the excess PV electricity production to the grid, battery system charging at off peak hours and buying power from the grid to feed the loads whenever the PV and battery power are not sufficient. Renewable PV sources cannot provide constant energy supply and introduce a potential unbalance in generation and demand, especially in off-peak periods when PV generates more energy and in peak period when load demand rises too high. Storage allows intermittent sources like PV to address timely load demand and adds flexibility in load management. Thus, there is an extra investment cost for the batteries for example. Nevertheless, by developing an optimal scheduling of the battery operation, the demand charges can be minimized resulting in overall benefits of the system. Batteries are a type of alternatives to function the PV system close to its maximum power point to feed electrical loads [9]. To prevent overcharging and