Journal of Energy Storage 17 (2018) 20–28

Contents lists available at ScienceDirect

Journal of Energy Storage

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

Simple moving average based capacity optimization for VRLA battery in PV power smoothing application using MCTLBO

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ARTICLE INFO

Article history:
Received 21 September 2017
Received in revised form 2 December 2017
Accepted 12 February 2018
Available online xxx

Keywords:
Solar photovoltaic
Battery energy storage system
Power system reliability
Techno-economic analysis
Multi-course teaching learning based multi-objective optimization

ABSTRACT

Rapid depletion of fossil fuel reserves and alarming increase of environmental pollution shift the researchers' attention towards renewable energy sources technologies like solar photovoltaic (PV). But solar radiation being affected by natural factors, result in uncertain power generation which leads to lower power system reliability. This paper proposes a smoothing strategy of generated PV power using gelled electrolyte valve regulated lead acid (VRLA) type battery energy storage system (BESS). The BESS stores the excess energy and releases it to meet the load demand in case of power surplus and deficit, respectively. The IEEE-RBTS is considered as the basic system for the study. But using large BESS incur humungous cost. Hence Multi-course teaching learning based multi-objective optimization technique (MCTLBO) is utilized to find out the optimal size of the PV panel, the BESS and the smoothening duration. Here, the objectives are to obtain minimum financial loss due to power outage as well as minimum BESS life cycle cost. MCTLBO is proposed here to improve the performance of the traditional teaching learning based optimization technique and it shows promising results. Factors affecting the power output of the PV panels are also considered here. The simulation is performed considering real time solar irradiance and temperature data of a city located on the eastern coast of India and the results obtained are both technically and economically viable in Indian context.

1. Introduction

Extending from 8°4′ N. to 36°6′ N., India receives abundant solar radiation of about 5000 trillion kWh per square meter per year. It has installed about 13.11 GW of solar PV plants of which Odisha, a state on the eastern coast of the country, contributes about 77.64 MW [1]. Odisha experience south-west summer monsoon for almost 4 months a year. Hence cloud cover, changes in ambient temperature along with variation of daylight hours affect the solar PV power generation to a greater extent. Additionally, constraints like thermodynamic limits, very low PV cell efficiency, effect of dust and shadow, power losses in various power electronic devices like converters and inverters used and in cables connecting the devices and very high and significant initial cost etc denigrates the technical as well as economical viability of the power generated. So, integrating solar PV panels into an existing conventional power distribution system lowers the power system reliability. In case of excess generation of solar power the system has to dump energy to keep the power system stable. And also high penetration of energy from PV units along with load variation arise many problems including voltage rise, high losses and low voltage stability [2]. These problems can be mitigated with the use of BESS which eventually leads to better power system reliability.

A lot of research has been done to control the energy system in PV fed power systems. A cost effective optimal size of PV and BESS units are determined for a stand-alone PV system to electrify rural households in India [3]. Optimal sizing of a grid connected PV-BESS is done for a residential customer of India has been done [4]. Optimal size of battery energy storage system of a grid-connected PV system is found out considering peak load shaving in [5]. Multi-objective particle swarm optimization (MOPSO) is utilized to minimize the annual operating cost as well as to maximize correlation coefficient [6]. The performance of hybrid differential evolution algorithm and harmony search algorithm is presented for optimal operation of a micro-grid [7]. Hysteresis energy management of a grid-connected PV/BESS is proposed to avoid frequent change of state of the BESS in order to smooth the power transmitted [8]. A PV power smoothing strategy is presented to

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https://doi.org/10.1016/j.est.2018.02.010
2352-152X/

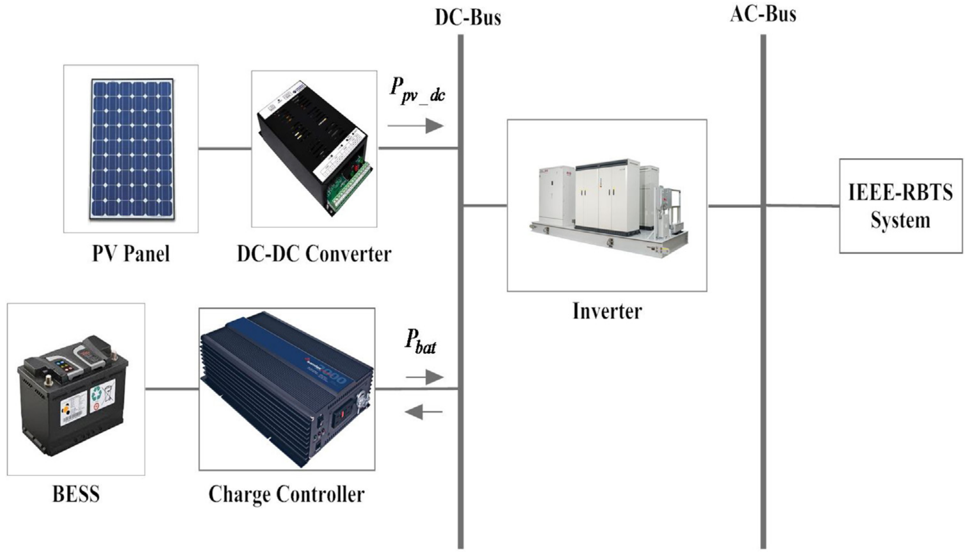

Fig. 1. Modelling of the system.

reduce the SCB power rating with the help of a hybrid energy storage system [9]. Problems associated with PV power fluctuation and methods to mitigate these issues are reviewed [10]. A control strategy is posited to use hybrid electric vehicles to smooth the voltage deviations of a PV-integrated distribution system [11].A strategy based on low pass filter principle is proposed to control the charging and discharging of BESS to smooth PV power generation [12]. The Various control strategies have been proposed to configure different energy storage systems like BESS [13,14], superconducting magnetic energy storage (SMES) [15], capacitor [16], flywheel [17], and fuel cell/electrolysers hybrid system [18], for smoothening renewable power generation.

The output of the PV panels connected to conventional power grid is always less than the load. Here the main purpose of the BESS is to smooth the generated PV power. In this paper, MCTLBO is utilized to determine the optimal sizes of PV panels, the BESS and the smoothing durations were determined so that they can supply to an IEEE-RBTS basic system [19] in order to incur minimum financial loss due to power outage and to obtain minimum life cycle cost of the BESS.

This paper is organized as follows. In Section 2, modelling of the system is described. Section 3 presents the smoothing strategy of the PV power. In Section 4 MCTLBO is explained. Section 5 details the problem formulation. The simulation results and analysis are illustrated in Section 6 and finally Section 7 concludes the paper.

2. Modelling of the system

The PV panel and BESS are connected to a common DC bus bar through a dc/dc converter and a charge controller respectively. The IEEE-RBTS basic system is connected to an AC bus bar. There is an inverter connected in between the DC and AC bus. This inverter converts the dc power generated by PV panels as well as the power supplied by the BESS into ac power. The charge controller provided between the BESS and DC bus is a bidirectional converter and allows the BESS to charge and discharge in case of power surplus and deficit respectively. The basic configuration of the system, which is used for this study, is given in Fig. 1.

2.1. System overview

- The PV and the BESS modules are assumed non-linear.
- All the system components along with the load impose algebraic constraints.
- The BESS module used here is made up of gelled electrolyte valve regulated lead acid cells, which is hybrid in nature with at least two modes of operation i.e. charging and discharging.
- A hybrid converter is used with high frequency state transition. In this study an average model has been used for simplicity's sake.

2.2. Modelling of PV system

The PV panel output dc power in kW is calculated as follows [20]:

$$P_{pv\_dc}(t) = A_{pv} \times \eta_{pv} \times \eta_{pt} \times N_{pv} \times f_{man} \times f_{dirt} \times f_{cell} \times \eta_{pv\_inv} \times E_{ir}(t) \times 10^{-3} \quad (1)$$

where η_{pv} = PV generator reference efficiency = 15%, A_{pv} = area of the PV panel = 1.67m^2 (for 250W rating), η_{pt} = efficiency for perfect maximum power point tracker = 100%, $E_{ir}(t)$ = global horizontal irradiance (GHI) at hour t in W/m^2, N_{pv} = number of PV panels. The de-rating factor due to temperature (f_{cell}) is given by

$$f_{cell} = [1 - T_{co} \times (T_m - T_{ref})] \quad (2)$$

where T_{co} = temperature coefficient = 0.005, T_{ref} = reference temperature = 25 °C. The module temperature (T_m) is calculated as follows:

$$T_m = T_{amb} + (\frac{NOC - 20}{800}) \times E_{ir}(t) \quad (3)$$

where nominal operating cell temperature (NOC) = 47.6 °C, T_{amb} = ambient temperature in degree Celsius, f_{man} = 97% (de-rating factor for manufacture tolerance is 3%), f_{dirt} = 95% (de-rating due to dirt is 5%), η_{pv_inv} = 97% (cable loss between the panel and inverter is 3%). AC output at the AC bus bar $P_t(t)$ is calculated as follows:

$$P_t(t) = P_{pv\_dc}(t) \times \eta_{inv} \times \eta_{inv\_sb} \quad (4)$$

where η_{inv} = inverter efficiency = 97%, η_{inv_sb} = 99% (AC cable loss between the inverter and primary switch board i.e. 1%).

The GHI data has been collected from the Indian Meteorological Department (IMD) of the location of Bhubaneswar for the year