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A multi-objective approach to integrate solar and wind energy sources with electrical distribution network

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Abstract

Solar and wind energies are the need of the hour worldwide and their high penetration in electricity power grid cause sensible amount of problems (stick to the grid code of respective country) due to randomness and uncertain generation pattern. Therefore reinforcement of intermittent renewable energy sources requires due attention to achieve optimum economical as well as operational benefit. This paper presents a novel techno-economic optimization method for proper location and size selection of multiple solar and wind generation units in distribution network. Multi-objective particle swarm optimization technique (MOPSO) is adopted to generate potential solutions by trade-off between payback year, reduction of power loss and voltage stability level of the network. The strategic planning method has been tested on a typical Indian rural distribution network. It is shown that the proposed method offers the workable solution to get the desired result.
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1. Introduction

The increasing concern on global warming, exhaustible nature of fossil fuel and high rise of oil prices prompted renewable energy sources (RESs) to play more significant role in the energy-planning endeavour because of its promising economic, environmental, and social benefits. The development of solar and wind energy conversion units has grown rapidly in the recent years and these two are the most promising renewable power generation technologies in India (Khare et al., 2013). However common downside of solar and wind energy application is uncertain and random generation pattern of sources and dependence on weather and climatic changes. The problems associated with stochastic generation can be moderated by amalgamating the sources with distribution network. But the interaction of RESs with grid makes the systems more difficult to analyze (Haesen et al., 2007).

Being the basic purpose of power injection, appropriate connection of the intermittent RES units in the network can yield several other benefits too. While proper allocation of photovoltaic (PV) array and wind turbines (WTs) enhances the voltage stability and reduce power losses of the network wrongly located RESs can cause several negative effects (Franco and Salza, 2011; Hung et al., 2013). As of consequence, simultaneous placement and sizing of PV array and WTs has become utmost challenge for distribution grid operators.

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In last few years, considerable effort has been devoted for sizing and optimization of autonomous solar and wind system (Arun et al., 2009; Askarzadeh, 2013; Celik, 2003; Kaabeche et al., 2011; Kaldellis, 2002; Karaki et al., 1999; Vrettos and Papathanassiou, 2011; Yang et al., 2007). But few contributions are available related to design of grid connected renewable energy system without battery storage. The new system configuration has potential for contributing towards environmental, social and economic sustainability (Yanine et al., 2013). An evolutionary programming based methodology is presented by Khatod et al. (2013) for placement of PV array and WTs in distribution network. Seasonal variation of generation and loads are considered to minimize active energy loss. Alsayed et al. (2013) have investigated combined PV–WT sizing problem with multi criteria decision making algorithm (MCDA). Environmental and economical attributes are weighted based on their entropy variation due to change of generation and load. Later (Alsayed et al., 2014) they have exploited non-dominated sorting genetic algorithm (NSGA) along with MCDA to generate non-dominated solutions. But technical and network operational criteria are not sufficiently discussed. The study also lacks to incorporate practical case of variable demand and stochastic generation pattern. So Multi-objective planning of grid linked solar–wind system without energy storage reflecting fluctuating generation and load scenario is still not highlighted by researchers.

The studies on grid interactive system design approaches consider PV array and WTs as purely active energy sources. However RESs operated at suitable power factor (pf) can help to amplify the voltage profile and reduce power losses of the network. The lack of attention to reactive power capacity of energy sources may lead to poor technical performance of the network, thus improper allocation of RESs (Zou et al., 2012). The active and reactive power sharing of voltage source inverter based PV array and WTs play a vital role in grid interactive system planning.

In a scenario of large scale penetration of intermittent RESs, the distribution companies (DISCOs) need to adopt appropriate means to compensate the effects of the uncertain power availability. The situation may become worse in peak load hours. The strategic use of demand side management (DSM) is an option that should be considered in the system planning, due to the cost-effective possibility to adjust the consumption in response to the variations of power production (Moura and Almeida, 2010).

This paper includes the shortcomings of earlier works and proposes a novel system design method deploying suitable combination of solar and wind generations in distribution network. The stochastic natures of resources are accounted and addressed with probability distribution functions and incorporated in techno-economic optimization problem regarding the system planning. The planning problem is synthesized with pf mode of RESs and wide ranges of technical and operational constraints. A multi-objective particle swarm optimization (MOPSO) based solution strategy is proposed to generate optimal location, type and size of RESs translating the planning problem.

2. Modeling of intermittent RESs

Solar and wind power generations are highly influenced by meteorological conditions such as wind speed, solar irradiance, ambient temperature and so forth. So the characteristics of solar radiation and wind conditions at installation location should be analyzed at the primary stage for efficient utilization of PV arrays and WTs.

2.1. Renewable resource model

Probability distribution functions (PDF) can be used to characterize stochastic behavior of renewable resources (wind speed and solar irradiance) in a statistical manner.

2.1.1. Solar irradiance modeling

The probabilistic nature of solar irradiance is considered to follow Beta PDF (Atwa et al., 2010; Karaki et al., 1999). Beta distribution for solar irradiance s^t (kW/m^2) over time segment 't' is given by

$$f_s^t(s) = \frac{\Gamma(\alpha^t + \beta^t)}{\Gamma(\alpha^t).\Gamma(\beta^t)}.(s^t)^{\alpha^t - 1}.(1 - s^t)^{\beta^t - 1} \quad \text{for } \alpha^t > 0;\ \beta^t > 0 \tag{1}$$

where α^t and β^t are the shape parameters at 't'; and Γ represents Gamma function.

Shape parameters of Beta PDF can be calculated using mean (μ_s^t) and standard deviation (σ_s^t) of irradiance for corresponding time segment.

$$\beta^t = (1 - \mu_s^t).\left(\frac{\mu_s^t(1 + \mu_s^t)}{(\sigma_s^t)^2} - 1\right) \tag{2}$$

$$\alpha^t = \frac{\mu_s^t * \beta^t}{(1 - \mu_s^t)} \tag{3}$$

2.1.2. Wind speed modeling

In order to describe stochastic behavior of wind speed in a predefined time period, Weibull PDF has been chosen (Karaki et al., 1999; Khatod et al., 2013). Weibull distribution for the wind speed v^t (m/s) at tth time segment can be expressed as

$$f_v^t(v) = \frac{k^t}{c^t}.\left(\frac{v^t}{c^t}\right)^{k^t - 1}.\exp\left(-\left(\frac{v^t}{c^t}\right)^{k^t - 1}\right) \quad \text{for } c^t > 1;\ k^t > 0 \tag{4}$$

The shape parameters k^t and c^t are calculated as follows.

$$k^t = \left(\frac{\sigma^t}{\mu_v^t}\right)^{-1.086} \tag{5}$$

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