Optimal Photovoltaic System Design with Multi-Objective Optimization

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ABSTRACT

Recently, several parts of the world suffer from electrical black-outs due to high electrical demands during peak hours. Stationary photovoltaic (PV) collector arrays produce clean and sustainable energy especially during peak hours which are generally day time. In addition, PVs do not emit any waste or emissions, and are silent in operation. The incident energy collected by PVs is mainly dependent on the number of collector rows, distance between collector rows, dimension of collectors, collectors inclination angle and collectors azimuth, which all are involved in the proposed modeling in this article. The objective is to achieve optimal design of a PV farm yielding two conflicting objectives namely maximum field incident energy and minimum of the deployment cost. Two state-of-the-art multi-objective evolutionary algorithms (MOEAs) called Non-dominated Sorting Genetic Algorithm-II (NSGA-II) and Generalized Differential Evolution Generation 3 (GDE3) are compared to design PV farms in Toronto, Canada area. The results are presented and discussed to illustrate the advantage of utilizing MOEA in PV farms design and other energy related real-world problems.

Keywords: Generalized Differential Evolution Generation 3 (GDE3), Multi-Objective Optimization, Non-dominated Sorting Genetic Algorithm-II (NSGA-II), Photovoltaic (PV) Collector Arrays, Renewable Energy

1. INTRODUCTION

Solar energy is one of the most widely used renewable energies; because it is emission free and it is easily deployable. Several sun-based energy generation methods exist, such as, photovoltaic farms (PV), concentrated solar power plants, and solar thermal electricity plants. These systems can be used for meeting the global energy crisis due to rising world-wide demands and insufficient supply of electricity throughout the world by deploying the appropriate systems in the required areas. For example, PV are inefficient in very hot areas, such as desert, but are more efficient in mild to cold areas. In this article, PV panels are selected because of mild-cold weather conditions in Canada. Although Canada produces enough electricity to fulfill
the national demand, nevertheless solar energy is of special interest due to PV non-polluting properties.

Concentrated solar systems like the paraboloid trough heat transfer fluid/steam systems can typically generate full rated electrical output for 10-12 hours a day (Schlaich et al., 2005). Other solar power generation systems include large solar updraft towers which can produce large amounts of electricity via utilizing air flow created by heated air which drives pressure staged turbines (Price et al., 2002). In spite of these available large-scale technologies, photovoltaic panels are the most popular method of harvesting solar energy, because they directly convert the Sun’s rays into electrical power. In addition, photovoltaic panels can be deployed anywhere and can provide a relatively stable electrical output. However, there are several drawbacks; they are subject to changing output efficiencies based on external factors such as shade, cloudy weather, covered by sands, and others.

Photovoltaic systems consist in converting solar radiation (sunlight) directly to electricity. There are two types of solar radiations on the Earth: direct and diffuse radiations. The sunlight is filtered through the Earth’s atmosphere. Then, the solar radiation is received directly from the Sun without having been dispersed by the atmosphere is called direct radiation. When the sun’s radiation is changed by the atmosphere due to clouds, water vapor, and other molecules, it is called diffuse radiation. Therefore energy absorbed by the PV panels are the sum of the amount of direct and diffuse radiations received in a given day.

In this article, we propose the use of two state-of-the-art MOEAs, namely, NSGA-II and GDE3 to optimize the deployment of solar PV farms. The objectives consisted in maximizing the total incident solar energy and minimizing the cost of PV panel deployment in a specific field. The cost was limited to initial investment because the paper focused only on the PV configuration setup. However, a real PV farm requires overhead costs such as maintenance costs, residual fees, energy storage component fee and others. Six decision variables composed the optimization problem, namely, the number of collector rows, the distance among collector rows, the dimension of collectors, the collectors inclination angle, and the collectors azimuth angle.

The remainder sections of this article are organized as follows: Related work, description of the designed mathematical model of PV panels, the description of the two algorithms used in this experiment and their fixed settings of the control parameters, the experimental results, and conclusions. A list of symbols used in this article can be found in Appendix A, and Appendix B provides the monthly averaged direct beam and diffuse irradiance, monthly averaged hourly solar and azimuth angles due south in Toronto.

2. RELATED WORK

In the last few decades, there has been a large number of studies on single-objective and multi-objective real-life applications (Talbi, 2009). However, most real-life problems are multi-objective problems by nature because they involve variant conflicting objectives. The development of efficient multi-objective metaheuristics such as evolutionary multi-objective algorithms played an integral role in the design of complex energy systems. This section presents the most recent optimization works applied to design solar energy systems.

Varun (2010) implemented a genetic algorithm for maximizing the thermal performance of flat plate solar air heaters to optimize various systems and operating parameters. The basic values like number of glass covers, Irradiance and Reynolds, plate tilt angle, and emissivity of plate are optimized for maximizing thermal performance.

Thiaux et al. (2010) applied NSGA-II algorithm to optimize the load profile impact on stand-alone photovoltaic system gross energy requirement. Yang et al. (Yang et al., 2007) developed a hybrid optimized solar-wind system. They optimized the components’ capacity sizes
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