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Research Paper

COMPARISON OF VARIOUS ALGORITHMS FOR PV PERFORMANCE

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ABSTRACT

This research focuses on the accurate estimation of photovoltaic (PV) system parameters through the integration of computational intelligence and modern optimization approaches. The proposed framework involves acquiring relevant PV performance data, formulating a suitable mathematical model, and implementing population-based optimization methods to minimize the error between experimentally observed and computationally predicted outputs. Several optimization techniques, including the Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Grey Wolf Optimizer (GWO), and Pufferfish Optimization Algorithm (POA), are investigated to evaluate their effectiveness in solving nonlinear parameter estimation problems. From a computer science perspective, the study concentrates on algorithm design, intelligent optimization mechanisms, data analysis, numerical computation, and performance benchmarking. Particular attention is given to the potential of POA to identify optimal parameter values in complex search spaces characterized by nonlinear relationships and multiple interacting variables. The investigation also explores the relevance of these optimization strategies to artificial intelligence, predictive analytics, computational modeling, and sustainable information technologies. The findings aim to contribute to the development of reliable PV simulation models and data-driven decision-support systems that can assist in renewable energy forecasting, system performance evaluation, and efficient energy resource management.

1.INTRODUCTION

The increasing worldwide demand for electricity, coupled with mounting concerns about ecological damage, climate change, and the depletion of non-renewable energy resources, has accelerated the development and adoption of alternative energy-generation technologies. In this context, solar photovoltaic (PV) systems have emerged as a promising solution for producing electricity in an environmentally responsible and sustainable manner. These systems utilize semiconductor-based devices to transform incident sunlight directly into electrical energy without requiring mechanical energy-conversion stages. Their modular architecture, scalability, relatively modest servicing requirements, and progressively declining deployment costs have contributed to their widespread adoption in domestic installations, business establishments, industrial facilities, and utility-scale electricity generation plants.

Despite these advantages, the electrical behavior of photovoltaic devices is governed by complex nonlinear relationships and is strongly influenced by changes in external operating conditions. Factors such as incident solar radiation intensity, cell operating temperature, nonuniform illumination, partial shading, and variations in the surrounding environment can significantly influence the current–voltage

(I–V) and power–voltage (P–V) responses of PV modules. Therefore, constructing a reliable mathematical model of a photovoltaic system is essential for characterizing its electrical performance, predicting energy output, developing effective control strategies, and improving the operation of energy-management systems.

The mathematical representation of a PV device incorporates several electrical parameters that collectively determine its terminal characteristics. Depending on the equivalent-circuit configuration, these parameters may include light-generated current, diode reverse saturation current, series resistance, shunt resistance, diode ideality factor, and other model-dependent variables. Accurately estimating these quantities remains a demanding computational problem because of the nonlinear behavior of photovoltaic devices, the interaction between model parameters, and the complexity of their influence on the resulting electrical characteristics. Small inaccuracies in the estimated parameter values may lead to substantial discrepancies between measured experimental data and model-generated predictions. For this reason, the reliable extraction of photovoltaic model parameters has gained considerable attention as an important research problem in solar energy modeling, performance analysis, and renewable energy system optimization.

2.Relevance to Artificial Intelligence and Data Analytics

The growing volume of information obtained from renewable energy installations has opened new avenues for incorporating artificial intelligence (AI) and data-oriented computational methods into the analysis of modern energy systems. Photovoltaic installations produce diverse operational measurements, including electrical voltage, current, power output, solar irradiance, module temperature, and other relevant performance indicators. The systematic examination of these measurements enables researchers to develop more effective techniques for performance estimation, operational supervision, fault diagnosis, and control-system enhancement.

Intelligent optimization methods, including the Pufferfish Optimization Algorithm (POA)[1], Genetic Algorithm (GA)[2], Particle Swarm Optimization (PSO)[3], can be employed to determine appropriate photovoltaic model parameters from experimentally acquired data. These computational approaches use different search mechanisms to explore possible solutions and identify parameter combinations that minimize the deviation between observed measurements and model predictions. Their implementation illustrates the integration of algorithmic intelligence, numerical optimization, and data-processing techniques in addressing complex engineering challenges.

Furthermore, accurately calibrated photovoltaic models can provide a reliable computational foundation for machine-learning-based energy applications. These representations can be integrated into solar power prediction models, abnormal-condition detection systems, energy scheduling and management solutions, and adaptive control architectures. By combining dependable mathematical modeling with intelligent computational techniques, it becomes possible to improve the analysis of PV system behavior and support the development of more efficient, data-driven renewable energy solutions.

3.Problem Description and Mathematical Modelling

The estimation of photovoltaic (PV) model parameters is established by examining the nonlinear dependence of the cell output current on its terminal voltage. In this study, the Single-Diode Model (SDM) is selected as the equivalent electrical circuit to describe the operating characteristics and current–voltage behavior of the photovoltaic device. Based on this model, the relationship between the terminal voltage and the generated output current is expressed mathematically through the following nonlinear equation:

$$I = I_{ph} - I_0 \left[\exp \left(\frac{V + IR_s}{nV_t} \right) - 1 \right] - \frac{V + IR_s}{R_{sh}} \quad (1)$$

[2]

Final Problem Formulation

Hence, the overall computational task can be mathematically represented as follows:

$$\mathbf{x}^* = \arg \min_{I_{ph}, I_0, R_s, R_{sh}, n} \sqrt{\frac{1}{N} \sum_{i=1}^N [I_i^{meas} - I_i^{calc}(I_{ph}, I_0, R_s, R_{sh}, n)]^2} \quad (2) \quad [2-10]$$

4.Comparison of various algorithms

To improve the accuracy of photovoltaic (PV) parameter extraction beyond the capabilities of conventional estimation procedures, evolutionary-based computational methods have been explored as alternative optimization strategies. One prominent technique is the Genetic Algorithm (GA), a stochastic search approach that derives its operating principles from evolutionary processes observed in nature. The method progressively refines a population of potential solutions using selection, recombination (crossover), and mutation operators. Unlike gradient-dependent optimization procedures, GA can investigate complex search regions without requiring derivative information from the objective function. Owing to this characteristic, it has been employed in photovoltaic parameter identification for different equivalent-circuit configurations, including single-diode and double-diode models. The primary objective of these applications is to determine suitable electrical parameter values that reduce the difference between experimentally recorded PV characteristics and theoretically computed responses, thereby improving the reliability of the mathematical model.

Particle Swarm Optimization (PSO) is another computational intelligence technique employed for determining the unknown electrical parameters of photovoltaic (PV) systems. Its working mechanism is inspired by the coordinated motion and collaborative learning patterns observed in groups of organisms. In this approach, a collection of potential solutions, referred to as particles, explores the search domain and updates its position according to individual search history and information shared by neighboring or other population members. The relatively straightforward implementation and limited algorithmic complexity of PSO make it a suitable choice for various engineering optimization problems. In PV modelling applications, this technique has been investigated for extracting equivalent-circuit parameters and minimizing the deviation between measured data and simulated photovoltaic responses, thereby enabling accurate reconstruction of current–voltage (I–V) and power–voltage (P–V) curves.

In addition to established optimization methods, several swarm-based and evolutionary computational approaches, such as Differential Evolution (DE) and Artificial Bee Colony (ABC), have been investigated for extracting unknown parameters from photovoltaic (PV) models. Each technique follows its own strategy for generating candidate solutions, exploring the search space, and refining parameter estimates during the optimization process. These methods are particularly relevant to complex objective functions involving nonlinear relationships, multiple local optima, and intricate solution landscapes. Their integration into photovoltaic research has expanded the available computational approaches for parameter identification and provided additional alternatives for improving the accuracy and reliability of PV equivalent-circuit models.

Recent developments in computational optimization have encouraged the investigation of innovative nature-inspired algorithms as alternatives to traditional metaheuristic techniques. These approaches are designed to strengthen the balance between global search and local refinement, improve solution convergence, and minimize the risk of becoming trapped in locally optimal regions. The Pufferfish

Optimization Algorithm (POA) is one such population-based method, formulated using behavioral characteristics associated with pufferfish. It employs a distinctive computational procedure to explore the solution domain, evaluate alternative candidates, and progressively improve the quality of the obtained results. Owing to its search-based framework, POA can be investigated for solving computationally demanding optimization problems characterized by nonlinear mathematical relationships, interdependent decision variables, and extensive search domains. In photovoltaic applications, this can provide a basis for examining its effectiveness in estimating unknown equivalent-circuit parameters and improving the agreement between simulated and experimentally observed PV characteristics.

The performance assessment of established optimization algorithms using standard test functions suggests that the Pufferfish Optimization Algorithm (POA) could provide an effective solution for computationally demanding optimization tasks. Its search mechanism is intended to balance global exploration with the detailed refinement of promising solutions, facilitating the identification of suitable parameter values with improved precision. The capabilities of POA can be evaluated in terms of estimation accuracy, convergence speed, and repeatability of results by comparing its performance against conventional approaches such as the Genetic Algorithm (GA) and Particle Swarm Optimization (PSO). The results of this comparative investigation can help determine the suitability of POA for identifying photovoltaic model parameters and addressing other engineering problems involving complex nonlinear objective functions. Where numerical evidence confirms consistent improvements across the selected evaluation criteria, the comparative advantage of POA over the reference algorithms can be demonstrated through quantitative analysis.

5. Analysis of Various Algorithm Performance

The performance of optimization algorithms plays a significant role in determining the accuracy and reliability of photovoltaic (PV) model parameter estimation. Various computational techniques, including the Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Pufferfish Optimization Algorithm (POA), can be employed to identify the unknown electrical parameters of PV equivalent-circuit models. Each method follows a distinct search strategy and exhibits different characteristics in terms of convergence, computational requirements, solution accuracy, and search efficiency.

The Genetic Algorithm utilizes evolutionary operators such as selection, crossover, and mutation to generate improved candidate solutions. However, its effectiveness depends on parameter configuration and population diversity. Particle Swarm Optimization updates candidate solutions using individual experience and collective information, offering a relatively simple implementation but potentially converging prematurely in complex search spaces. The Pufferfish Optimization Algorithm introduces a nature-inspired search mechanism designed to explore the solution domain and refine candidate solutions effectively.

A comparative assessment of these methods can be performed using benchmark functions and PV experimental datasets. Performance indicators such as root mean square error (RMSE), mean absolute error (MAE), convergence rate, and computational time provide quantitative measures for evaluating their effectiveness. POA may demonstrate improved performance if it achieves lower estimation errors and more consistent convergence than GA and PSO. Nevertheless, the final ranking should be established through repeated simulations and statistical analysis to ensure reliable and reproducible conclusions.

6. Conclusion

The comparative analysis of Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Pufferfish Optimization Algorithm (POA) highlights the importance of selecting suitable computational techniques for accurate photovoltaic (PV) parameter estimation. Although GA and PSO provide established approaches for solving nonlinear optimization problems, POA offers an alternative nature-

inspired search strategy for exploring complex solution spaces and identifying optimal parameter combinations. The performance of these algorithms can be evaluated using error metrics, convergence behavior, computational time, and solution consistency. POA can be considered a promising technique for PV model parameter identification, particularly when experimental results demonstrate improved accuracy and convergence compared with GA and PSO. Therefore, a systematic comparison using benchmark functions and measured PV data is essential to validate its effectiveness and practical applicability. The findings can contribute to the development of reliable photovoltaic models, supporting improved performance prediction, system analysis, and renewable energy management.

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