Bio-Inspired Strategies for Minimizing Distortion in DC-AC Converters

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The global shift towards sustainable energy sources, such as solar and wind power, underscores the critical role of power converters in renewable energy systems. These converters are essential in converting direct current (DC) generated from renewable sources into alternating current (AC), suitable for use in homes and distribution through the grid. The efficiency and performance of these converters have far-reaching implications for the effective integration of renewable energy into the existing grid infrastructure. However, the classic strategies for controlling and designing power converters exhibit unstable behavior under varying environmental conditions and changing energy demands. This letter shows some essential concepts and techniques explored in the research field of bio-inspired optimization algorithms and their implementation for the improvement of power converters in the field of renewable energies.

Today, humanity faces significant challenges, not the least of which is global warming. One way to tackle global warming is by adopting renewable energy-based energy generation technologies, which requires improving them and making them more stable and efficient (Owusu, P. A., & Asumadu-Sarkodie, S., 2016; Tomin, N., et al. 2022).

A fundamental part of the generation technologies based on renewable energies is power converter devices, whose primary function is to increase the stability of the generation of these energy sources. One way to improve the performance of these power converters is by improving their design and control strategies. There are different techniques, both classic and modern. Classical approaches are based on well-tested and studied mathematical methods. However, these classical have the disadvantage when the system becomes complex and non-linear, performing poorly. As an alternative, in recent years, various methods have emerged based on nature; these techniques are called bio-inspired algorithms (Pop, C. B. et al. 2022). These algorithms mimic mechanisms and strategies of nature and translate them into mathematical language for their integration into computational methods for optimal design. This letter introduces bio-inspired algorithms and their application in direct current to alternating current power converters and other fields.

While bio-inspired algorithms are not something new in computational algorithms, their application to various engineering fields, including renewable energy systems, is gaining interest in the scientific community. An optimization algorithm is a computational technique that finds the best possible configuration of a system, and, in this sense and focusing on nature-based optimization algorithms, there is an algorithm of great interest, based on the hunting behavior of gray wolves, called Grey Wolf Optimizer (GWO) (Faris, H., et al. 2018).

In the following content, some applications of the GWO algorithm are shown. Some results were obtained from its application in power converters compared to other bio-inspired algorithms and classical techniques (Aguila-Leon, J., et al. 2023a), where this algorithm generally performs better in computation time and efficiency of energy systems (Aguila-Leon, J., et al. 2023b).

As mentioned above, bio-inspired algorithms can be applied to design and control problems in engineering systems. As is well known, renewable resource availability varies depending on environmental conditions. This variability of renewable energy sources makes it crucial to implement power converters that, through different control strategies, try to keep the current and generation voltage parameters as stable as possible to meet the energy demand; a power converter needs a controller to achieve this. There are several types of controllers, for example, system error-based PID drivers, fuzzy logic drivers that rely on a set of rules and trigger functions, and more.

The problem with controllers is that they need to be tuned before being used; for example, in the case of PID, finding the proper values of the proportional, integral, and derivative gain constants is crucial for good performance. Generally, the problem of tuning a controller can be reduced to a combinatorial problem that maximizes the system's performance, and that's where bio-inspired optimization algorithms have a chance. The work in Aguila-Leon, J., et al. (2023a) shows how an MPPT controller based on a discrete PID optimized by GWO outperforms other MPPT techniques such as INC and P&O.

OPTIMIZING POWER CONVERTERS USING THE GREY WOLF OPTIMIZER (GWO)

Power converters are critical for the implementation of renewable energy-based generation technologies. Speaking specifically of photovoltaic systems, where the availability of the resource depends on various factors such as the season of the year, cloud cover, and even fortuitous events such as sudden shadows on the panels, power converters are of utmost importance to extract the maximum possible power and convert from direct current to alternating current (Aguila-Leon, J., et al. 2023a; Kummara, V. G. R., et al. 2019).

In the field of solar photovoltaics, there are two widely used control methods to find the Maximum Power Point (MPP): Perturb and Observe (P&O) and Incremental Conductance (INC). Both methods are based on small changes in voltage and current in the power converter in such a way as to maximize the possible extractability of the photovoltaic array; however, since both methods are based on successive approximations to the MPP, they tend to generate instabilities near that point of operation. The GWO and other optimization algorithms are viable techniques that enable tuning MPPT controllers with improved performance near the end of Maximum Power (Aguila-Leon, J., et al. 2023a; Aguila-Leon, J., et al. 2021).

From a research approach point of view, implementing optimization algorithms requires some knowledge and experience, not only in algorithm design but also in the system to which it will be applied for improvement. The first step for a proper application is to identify the process variables; once the controlled variable (or variables) and the manipulated variables have been identified, the most appropriate type of controller must be chosen, as well as the identification of the adjustment parameters for it. An optimization algorithm requires formulating an objective function, the mathematical function or model output, that will be used to evaluate whether the system has improved in each iteration of the algorithm.

To evaluate the system's performance, various criteria are used, mainly based on the error, such as the Root Mean Squared Error (RMSE). Minimizing the RMSE to a certain threshold or tolerance value works as a stop criterion for the algorithm, indicating that it has found the best possible solution to the optimization problem within the adjusted parameters. Adjusting the parameters of an optimization algorithm is extremely important, as they limit the search space and can directly impact the quality of the solution and the time and computing power required.

Among the novelties in research in the field of optimization algorithms is precisely what is known as meta-optimization, which is adding an external layer of optimization to the optimization algorithm, in other words, to optimize the optimizer. This approach allows the main optimization algorithm to be fine-tuned to fully adapt to the optimization problem, resulting in better solutions. However, applying meta-optimization today is complicated by the complexity of the calculations and the computation time required.

This approach has been explored by the authors, where through the GWO, the adjustment parameters of a PSO (Particle Swarm Optimization) algorithm applied to a PID-based MPPT controller for a solar photovoltaic array have been optimized. The results showed a 14.14% improvement in the GWO-optimized PSO MPPT controller compared to the standard PSO MPPT, which meant 18.14% more energy was extracted.

Another optimization approach, in addition to meta-optimization, is multi-objective optimization. This type of optimization is based on having two or more criteria to improve, maximize, or minimize. It can be done with basically any optimization algorithm. In the work shown in Aguila-Leon, J., et al. (2023b), the authors performed a multi-objective optimization test to reduce the total harmonic content (THD) and keep the RMS voltage signal stable in a DC-AC power converter. The results showed an 87.64% improvement in the reduction of the THD in the converter output current signal compared to the same unoptimized converter.

COMPARATIVE ANALYSIS AND ASSESSMENT FOR BIO-INSPIRED OPTIMIZATION ALGORITHMS

An optimization problem has two types of solutions: the global optimal solution and the local optimal solution. The global optimal solution is the ultimate solution to the problem, i.e., no other solution is better. In the case of locally optimal solutions, note the word in the plural; they are the set of possible solutions that, although they are not the best of all, are close to the global solution and can lead to a better performance of the system compared to the classical design of control methods.

An optimization algorithm can find a global solution to a problem that would be very unusual or deliver a local solution, which is more common. Whether we have a global or a local solution depends on two factors: the complexity of the optimization problem and how good or bad the optimization algorithm is for that optimization problem. Considering the above, comparative performance analysis and studies of optimization algorithms are a fundamental part of their application and research.

A comparative study of the performance of an optimization algorithm should include at least aspects such as computation time, best solution found, and RMSE. These aspects should be compared with at least two other optimization algorithms (as well as different adjustment parameters for each) as well as with other techniques so that after the comparative analysis, it can be determined which of the algorithms is best for the application, and under what conditions it is.

GENERAL REMARKS

This letter briefly introduces the concept of optimization and bio-inspired optimization algorithms and their application to engineering problems in power converter design, showing the fundamental concepts for their implementation and evaluation methodology. Some results of examples obtained in publications on power converters improved by optimization algorithms were shown. We can conclude that bio-inspired optimization algorithms are a very attractive alternative to classical techniques and methods, especially for complex and non-linear systems, such as energy systems, which integrate diverse generation technologies based on renewable energies, given their fluctuating and variable nature. The results of related works to the application of bio-inspired optimization algorithms have shown their ability to adapt well to variable conditions in complex systems, which translates into a potential and significant improvement in the performance of these systems. However, there is still much work to be done to improve optimization algorithms, whether through meta-optimization, algorithm hybridization, or multi-objective optimization. In this regard, it is essential to have a common methodological framework that allows the performance of these algorithms to be evaluated, analyzed, and compared with classical techniques. Researching and developing improvements in these algorithms can lead to significant advantages, such as improved energy efficiency in the field of renewable energies.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest within this research, authorship, and/or publication of this article.

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