Chapter 12
Increasing Energy Efficiency by Optimizing the Electrical Infrastructure of a Railway Line Using Fireworks Algorithm

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ABSTRACT

This chapter proposes the application of a discrete version of the Fireworks Algorithm (FWA) and a novel PSO-FWA hybrid algorithm to optimize the energy efficiency of a metro railway line. This optimization consists in determining the optimal configuration of the Energy Storage Systems (ESSs) to install in a railway line, including their number, location, and power (kW). The installation of the ESSs will improve the energy efficiency of the system by incrementing the use of the regenerated energy produced by the trains in the braking phases, as the ESSs will store the excess of regenerated energy and return it to the system when necessary. The results for this complex optimization problem produced by the two algorithms are excellent and authors prove that the novel PSO-FWA algorithm proposed in this chapter outperforms the standard FWA.

1. INTRODUCTION

Most real-world optimization problems deal with a large number of decision variables. These multi-dimensional problems being NP hard cannot be solve in reasonable amount of time. In recent years, the application of metaheuristic algorithms to solve complex optimization problems has shown a great deal of success. The metaheuristic techniques differ from the mathematical programming techniques in that they do not use the gradient of the objective function. The scalability, robustness, rapid convergence, and

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domain-independence of the meta-heuristic algorithms make them an attractive choice for optimization applications in diverse field (Vasant, 2013).

Most of the meta-heuristic algorithms are nature-inspired. Rather than follow a rigid and rigorous mathematical formulation, they solve the problems by using a set of operators which are computational metaphors of natural processes. Some of the prominent metaheuristic techniques are based on Swarm Intelligence. Social insects such as ants, bees, termites, and wasps can be viewed as powerful problem-solving systems with sophisticated collective intelligence. Composed of simple interacting agents, this intelligence lies in the networks of interactions among individuals and between individuals and the environment (Bonabeau, Dorigo, Marco, Theraulaz & Théraulaz, 1999; Eberhart, Shi, & Kennedy, 2001).

Particle swarm optimization (PSO) and Fireworks Algorithm (FWA) are two robust Swarm Intelligence optimization algorithms. This chapter introduces a novel hybrid PSO-FWA algorithm designed to handle a complex engineering optimization in the railway energy sector. PSO imitates the social behavior of insects, birds, or fish swarming together to hunt for food. It is a population-based approach that maintains a set of candidate solutions, called particles, which move within the search space. In every iteration, the exploration of the search space is guided by a combination of the personal best solution of a particle (pbest) and the swarm best solution (gbest). PSO implementation is intuitive, it relies on very few external control parameters, and delivers a rapid convergence (Shi, 2001, May; Shi & Eberhart, 2001, May; Schutte & Groenwold, 2005; Clerc, 2010; Liu, Yang & Wang, 2010).

The Fireworks Algorithm (FWA) is a recent Swarm Intelligence optimization algorithm. Deriving its inspiration from the fireworks exploding in the night sky, the FWA is found to be a competitive meta-heuristic algorithm (Tan & Zhu, 2010). The FWA algorithm begins with random initial positions of N fireworks. Before the fireworks explode generating sparks, the amplitude and the number of the explosion sparks are calculated. Fireworks with higher fitness values will have a smaller explosion amplitude and a larger number of explosion sparks, while fireworks with lower fitness values will have a larger explosion amplitude and a smaller number of explosion sparks. In addition, random sparks are also generated based on a Gaussian mutation process. A new population of N fireworks is selected at the end of each iteration. This may include the original fireworks, as well as the regular and Gaussian sparks. The elitist strategy is maintained by always inserting the current best location in the new population.

The original FWA has gone through some significant changes over the years. For instance, adaptive FWA (Li, Zheng & Tan, 2014, July), dynamic search FWA (Zheng, Janecek, Li & Tan, 2014, July), guiding spark FWA (Li, Zheng & Tan, 2016), FWA with differential mutation (Yu, Kelley, Zheng & Tan, 2014, July), enhanced FWA (Zhang, Zheng, Zhang & Chen, 2015; Liu, Zhang & Zhu, 2017, April), and discrete FWA (Luo, Xu & Tan, 2018, July) are found in literature. FWA for multi-modal optimization (Li & Tan, 2017), FWA for multi-objective optimization (Mnif & Bouamama, 2017, September; Taowei, Yiming, Kun & Duan, 2018, October) biogeography-based hybrid (Zhang, Zhang & Zheng, 2014, July), hybrid FWA with differential evolution (Zheng, Xu, Ling & Chen, 2015), hybrid with Simulated Annealing (Ye & Wen, 2017, December), hybrid with Generating Set Search (Kim et al., 2017) have also been proposed. FWA optimization applications in power grid systems (Qian & Hu, 2019, March; Lei, Fang, Gao, Jia & Pan, 2018, October; Huang, Li, Zhu, Wang, Zheng & Wang, 2016, September), routing problems (Hu, Wang, Wan, Wang & Hu, 2018, October) and medical systems (Shi, Xu, Zhu, Lu, Zhang, Xu & Zhang, 2015, October; Shi, Xu, Zhu & Lu, 2016, October) are also proposed in the FWA literature.

This chapter proposes the application of a discrete version of the Fireworks Algorithm (FWA) and a novel PSO-FWA hybrid algorithm to optimize the energy efficiency of a metro railway line. The optimization consists in determining the optimal configuration of the Energy Storage Systems (ESSs)