Global optimization approaches to design a hybrid railway power station

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ABSTRACT

Due to increased railway traffic and higher levels of power demand, development of rail networks has become a costly investment. Also, power supply to meet a railway power substation energy consumption proves to be a central issue. As a result, new promising solutions are being implemented worldwide like integrating renewable energies. These facilities, coupled with energy storage devices to tackle the intermittency issue of green energies, are known as hybrid railway power substations (HRPS). A HRPS can in this way satisfy the power demand while reducing costs and having a positive environmental impact [1].

To maximize the efficiency of the HRPS, the size of its components (solar panels, wind turbines, storage capacity,...) have to be properly designed while considering their usage over a long period of time. The use of the storage device will also have an important impact on the energy bill, especially if the daily evolution of electricity prices and seasonal changes are considered. The energy stored is adjusted every 10 minutes during the conception cycle to minimize the overall cost. Thus, the optimization of dimensional and command parameters are strongly coupled. The global optimization problem falls in the category of Plant/Controller optimization problem which proves to be a challenging topic in a wide variety of disciplines [2].

The optimization problem of the HRPS can be solved in several ways. In the case of a linear (or piece-wise linear) cost function, an all-at-once linear programming optimization can easily find the global optimum. On the other hand, if the number of total variables becomes important and the cost functions are nonlinear, different approaches should be explored.

The main objective of this study is to compare three non-linear global optimization methods over a simplified HRPS case study with a piece-wise linear cost function. The solution found by linear programming will serve as a reference and the proposed methods will be assessed based on their precision and computation time. This work is based on the case study proposed in [3], where decomposition methods are compared.

The first approach is an all-at-once optimization using a nonlinear programming algorithm : sequential quadratic programming (SQP).The second uses an iterative scheme, by solving the design and command problems separately. The third approach adopts a bi-level process where an outer loop only modifies the HRPS design while the role of the inner loop is to provide the optimal control for each design given by the external one. Tab.1 compares the different approaches in terms of computation time (CT) in seconds and deviation to the optimal cost (D) on several cycles with a number of time steps (TS) ranging from 50 to 50000.

Tab. 1 : Comparison of approaches for HRPS optimization.

	Simultaneous Approach		Iterative approach		Bi-level Approach	
TS	CT	D	CT	D	CT	D
50	2.3	2.83e-4	2.8	1.98e-3	34.1	1.45e-4
500	38565	6.00e-3	31.7	1.87e-3	411	2.50e-4
5000	Non convergence		78.1	3.74e-3	2852	2.9e-4
50000	Non convergence		3556	5.70e-3	30154	2.8e-4

The design problem for both cases is solved using a direct optimization algorithm while optimal command is provided by a nonlinear energy management strategy. An improved version of a dynamic programming (DP) algorithm is introduced to accurately find an optimal command. The impact of the control strategy's precision on global optimization results is assessed.

The main perspective of this work is to compare the different approaches on a nonlinear HRPS case study, considering real life nonlinearities that have been neglected like the delivery cost of electricity.

Keywords : global optimization, optimal command, energy management, hybrid railway power substation, multi-source systems

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