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► **To cite this version:**

Maxime Poyard, Stephane Brisset, Florent Delhay, Julien Poujet. COMPARISON OF OPTIMIZATION FORMULATIONS TO DESIGN AN HYBRID RAILWAY POWER SUBSTATION. 13th International Workshop on Optimization and Inverse Problems in Electromagnetism (OIPE), Sep 2014, Delft, Netherlands. hal-01913813

HAL Id: hal-01913813

<https://hal.science/hal-01913813>

Submitted on 6 Nov 2018

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COMPARISON OF OPTIMIZATION FORMULATIONS TO DESIGN AN HYBRID RAILWAY POWER SUBSTATION

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Abstract. This paper presents the design of a Hybrid Railway Power Substation by optimization. Two formulations are investigated to obtain the structural characteristics and the energy management strategy that minimize the total cost of HRPS during an operating period of one year. Energy formulation associated with sparse matrices allows optimizing on a wide time period with a short time step.

Keywords: Hybrid railway power substation, multi-sources system, energy storage, design, optimization, linear programming.

INTRODUCTION

Because of the rail network development, power demand of railway power substation (RPS) becomes increasingly important [1]. The integration of renewables energies could compensate this need and reduce pollution. Nevertheless the known intermittency factor of these energies makes difficult to estimate the amount of produced power [2]. By introducing a storage device, the hybrid RPS (HRPS) may operate without the grid and could ensure a good power quality [1]. The storage device should be accurately used according to the consumed power, the produced power and the evolution of prices fixed by power supplier [3]. To enhance the design of HRPS, the energy management strategy should be suitable in the long term. However, a high number of unknowns is induced by these temporal variables and thereby two different formulations are investigated within the linear programming. By taking into account economical aspects, the optimal design of each source and the energy management strategy are known for a time step of ten minutes during one year.

1-MODEL AND OPTIMIZATION PROBLEM

The studied HRPS is presented in Fig. 1, it is composed of photovoltaic panels, wind turbines and a storage system connected to the substation through an AC bus. Renewable energy production are illustrated by one-way power flows on Fig. 1, depends of the photovoltaic panels surface S_{pv} and the swept surface of wind turbines S_w . For the storage device, the quantity of maximal energy E_{max} defines the capability of storage, then power $P_{sto}(t)$ or energy $E_{sto}(t)$ can both express the temporal fluctuation of storage device for the optimization process.

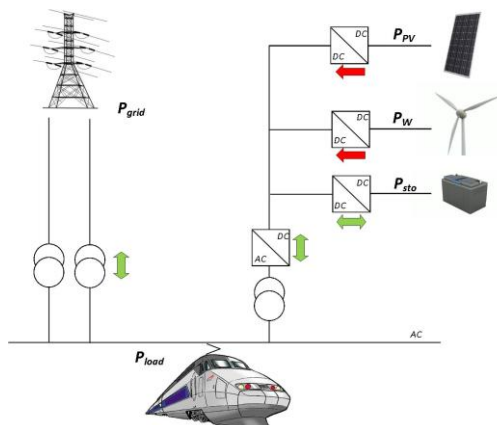


Figure 1. Overview of Hybrid Railway Power Substation.

According to measurements of wind speed and solar irradiation and for a given consumption during one year, all power flows of this multi-source system have to satisfy the power balance given in (1) [4]. The power from the grid P_{grid} is decomposed in two parts, the power received P_{grid}^+ and the power sent P_{grid}^- .

$$(1) \quad P_{grid}(t) = P_{grid}^+(t) + P_{grid}^-(t) = P_{load}(t) - P_{sto}(t) - P_{PV}(t) - P_W(t)$$

The objective function is expressed in (2) for an annual operating mode by considering investments cost of each device and also the purchasing C_{grid}^+ and selling C_{grid}^- of electricity [3].

$$(2) \quad C = \Delta t \cdot \sum_1^T [C_{grid}^+(t) \cdot P_{grid}^+(t) + C_{grid}^-(t) \cdot P_{grid}^-(t)] + C_{sto}^E \cdot E_{max} + C_{sto}^P \cdot P_{max} + C_{PV} \cdot S_{PV} + C_W \cdot S_W$$

In Table 1, two optimization problems are proposed through energy and power formulations of storage device. In power formulation, the stored energy is computed from the initial state of charge and also from the power stored at previous time steps. On the contrary, energy formulation considers only the maximal power of the storage. Dimensional variables of HRPS and grid power flow are the same on both optimizations.

Table 1. Description of each optimization problem formulation

Formulation	power	energy
Variables	common	$S_{PV}, S_W, E_{max}, P_{max}, E_{init}, P_{grid}^+(t), P_{grid}^-(t)$
	specific	$P_{sto}(t)$
Constraints	energy bounds	$0 \leq E_{init} - \Delta t \cdot \sum_1^t P_{sto}(i) \leq E_{max}$
	power bounds	$0 \leq E_{sto}(t) \leq E_{max}$
Constraints	power bounds	$-P_{max} \leq P_{sto}(t) \leq P_{max}$
	periodicity	$-P_{max} \cdot \Delta t \leq E_{sto}(t-1) - E_{sto}(t) \leq P_{max} \cdot \Delta t$
	$\sum_1^T P_{sto}(i) = 0$	$E_{sto}(T) = E_{init}$

2-COMPARAISON OF FORMULATIONS

For both optimization problems, linear programming is used. However it requires specific matrices to express equality and inequality constraints. Due to a time step of ten minutes, each temporal variable induces 52560 unknowns for one year cycle, therefore sparse matrices are employed. On Table 2, both formulations are compared according to the size of equality and inequality matrices and the memory required to store them.

Table 2. Comparison of memory requirements for both formulations

Formulation	power		energy	
	Expression	Memory	Expression	Memory
Size of matrices	$(5 \cdot T + 1) \times (3 \cdot T + 5)$	332 GB (full)	$(4 \cdot T + 2) \times (3 \cdot T + 5)$	266 GB (full)
Number of nonzero	$14 \cdot T + T^2$	67 GB (sparse)	$14 \cdot T + 4$	18 MB (sparse)

Fig. 2.a. and Fig. 2.b. present respectively the nonzero elements of equality and inequality matrices for power and energy formulations during one day. On Fig. 2.a., the power formulation induces a higher number of nonzero elements which makes difficult the storage of matrices for a high number of unknowns. By employing energy formulation, the memory required is greatly reduced and the optimization of HRPS is achievable in about one minute.

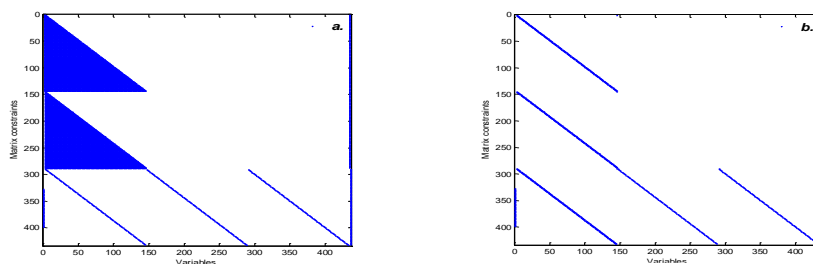


Figure 2. Comparison of matrices for one day

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