OPTIMAL POWER FLOW WITH STORAGE: APPLICATION TO DC RAILWAY ELECTRIFICATION SYSTEMS

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Abstract. This paper describes a methodology to design a new electrical railway system using optimization. An Optimal Power Flow (OPF) model of the railway, including energy storage system, is presented. Then, an application case is described. Finally, the problem has been implemented in the GAMS optimization environment. This non linear problem is solved with the Interior Point optimization method (KNITRO). The performances of the optimization process and results are discussed.

Keywords: GAMS, Energy storage systems, Interior Point Optimization Method, Optimal Power Flow, Railways.

INTRODUCTION

Increasing traffic is a challenge for railway networks. In order to meet the demand of the railway operators, more trains with a greater capacity have to be planned.. Thus, the electrical railway infrastructures need improvements in order to sustain more demanding exploitation and energy consumption. One of the challenging aspects is to provide a good power quality to every electric train. This is a condition to use the rolling stock at their standard performances.

In order to achieve these goals, new electrification infrastructures have to be designed, introducing power electronics, energy storage and direct integration of renewable energies.

Due to the increasing complexity of these new infrastructures, traditional engineering methods based on designers expertise and simulation tools reach their limits. The paper presents a railway network model. This one deals with the loads moving according to the train schedules. It also takes into account energy storage elements. Then, an application to an existing railway is presented. The optimization models have been implemented and solved using commercial available optimization tools (GAMS [1] with KNITRO [2] solver).

OPTIMAL POWER FLOW MODEL OF THE DC NETWORK

One of the main features of railway feeding networks is the motion of the loads, inducing frequent topologies changes. A suitable modeling method of the system has been previously developed [3]. This method provides an equivalent fixed topology model, where length of the transmission lines and loads on each node are defined as parameters. Their values are computed in order to describe the behavior of the network according to the practical train timetables from operator's dedicated electro-kinematical simulation tools.

Due to the problem characteristics, the transient dynamics of the network are neglected, therefore electrical system dynamics are represented as successive static states. The steady state linear network equations are built using the modified nodal analysis [4]. Additional non linear equations are used for the trains operating as power loads (1), where current I_c is computed according to the voltage V_c, and train consumed power P_c. Voltage and power are of course time-dependent. Storage unit dynamics are represented using energy W_s as a state variable whose evolution is described by differential equation (2).

(1) $$P_c(t) = V_c(t) \times I_c(t) \qquad \forall t$$

(2) $$W_s(t+\Delta t) = W_s(t) + \Delta t \times P_s(t)$$, where Δt is the chosen discretization time step.

Each equation is included as equality constraint in a standard non linear optimization problem. Additional inequality constraints are applied on physical characteristics such as stored energy values (3) or voltage values (4).

(3) $$W_s^{\min} \le W_s(t) \le W_s^{\max} \qquad \forall t$$

(4) $$V_k^{\min} \le V_k(t) \le V_k^{\max} \qquad \forall t$$

The complete optimization model will be detailed in the full paper.

APPLICATION CASE

The application case is based on a section of Paris suburban mass transit system (*Réseau Express Regional*), between the stations of Brétigny and Dourdan. This section is electrified using a DC 1500V overhead system. Train circulations are regularly spaced with a 120km/h top speed and close stops. Its total length is 24.2km. Electrification consists of three feeding and four paralleling substations.

Each feeding substation is assumed to have a short-term storage unit attached. In the paper, optimization tools are used for optimal control in order to provide storage set points.

The objective is to minimize the total energy consumption for a typical traffic peak.

The study time is 4 hours long, and the fast load variations occurring in railway applications impose the choice of a one second time step, which is significantly less than the ten-minute time step of traditional electrical transmission network studies. 14400 time steps are therefore considered. For each time step, three storage set points and states of charge have to be computed, jointly with 31 nodal voltages, 34 sources currents, leading to a problem with more than one million variables and constraints.

IMPLEMENTATION AND RESOLUTION

The model for optimization has been written using GAMS modeling language and solved using KNITRO Interior Point method implementation.

Optimization results

The storage set points computed by the optimization process are presented in Figure 1.

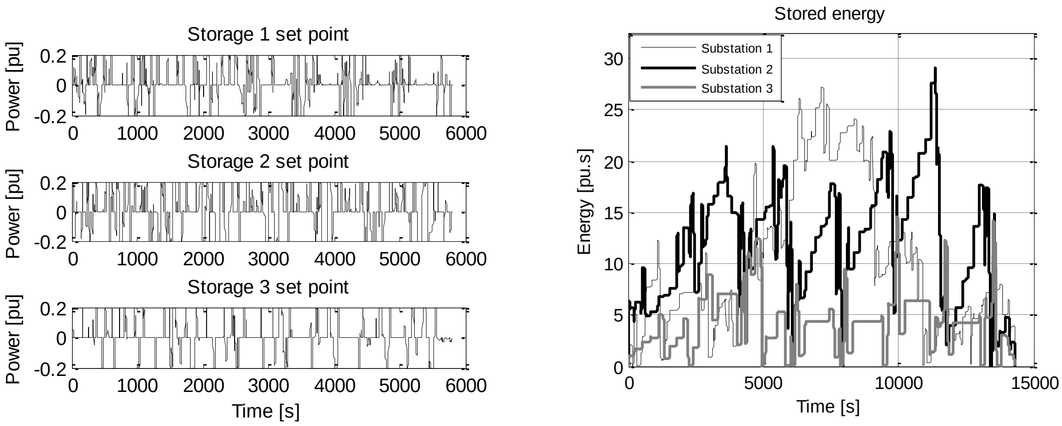

Figure 1. Optimal set points of storage units

A gain of 5% in energy consumption on the optimized cycle is achieved while using storage compared to the initial infrastructures.

Optimization process performances

The global optimization process shows good performances. Running on a server with two Xeon E5506 CPUs, the optimizer takes about 7 hours to converge on a local optimum. The memory overhead is around 10Gb. Due to the relatively low computing resource consumption the optimization process could be run on modern workstations provided enough RAM is available.

CONCLUSIONS

In the paper, an optimization model of a railway network is presented. The model is then applied on a typical engineering case, using commercially available optimization tools. The optimization process finds a more energy efficient solution and shows good performances on large scale problems. The first results prove that the authors are now able to optimize a real railway electrical system despite of its increasing complexity. In the future, a more accurate optimization model will be defined, and to the optimization process will be extended to AC feeding systems.

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