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Improving power supply design for high speed lines and 2 × 25 systems using a genetic algorithm

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ABSTRACT

The railway's electrical system is a complex system the design of which requires an in-depth detailed survey of the main modules of which it consists. Not only is it highly complex, but it is also strongly non-linear. A number of research methods have arisen to secure the best possible design to facilitate the task. CITEF (Railway Technology Research Centre, Technical University of Madrid) has developed a methodology using an optimisation method with a railway simulator (HAMLET), which meets this objective.

The methodology takes account of the fact that a good design must meet a number of major requirements. It must meet current electricity regulations, it must meet the budget imposed, it must observe environmental zones as far as possible and contemplate maintenance-sensitive zones, and finally it must identify areas posing particular difficulties in terms of connecting electrical elements to the main grid.

Coordination between a genetic optimisation algorithm and a high-performance railway simulator gives the methodology a considerable analysis capacity. The 2 × 25 system requires a high computation capacity, and it was for this reason that the genetic algorithm AMGA-II was selected. Extension of the methodology to 2 × 25 systems called for adaptation of the railway simulator, a new approach to the characteristics of the genetic system, and adaptation of the mathematical model calculating costs by means of the objective functions and restrictions.

The methodology was able to adapt to these complex and strongly non-linear systems, and provide a range of optimum solutions with a genuine compromise between the costs of installation and operation (Capex and Opex), a minor impact on critical zones and electrical validation for railways operating AC 2 × 25 systems.

1. Introduction

The problems involved in addressing the best possible design of a power supply system for railways have led a number of research groups to adopt a number of work methods to improve the process.

There is one major aspect on which attention must be focused. This type of system is very much non-linear. This means the solution furnished must clearly delimit capacity and the objectives it can meet, and it must also be a sturdy system in terms of reliability. The main aspects that must be addressed by the designer of dual-system electrical setups are many and varied: the infrastructure of the railway line, the operation plan and the rolling stock to be used, the signalling system, the initial characteristics of the components of the electrical system and, last but not least, the budget for each project. This generates a large number of possibilities. All these characteristics mean there is no pure analytical or simple method to determine an optimum sturdy design.

The two diagrams in Fig. 1 set out to explain the difference between the traditional method and the methodology proposed in this paper. Fig. 1a shows the habitual design process. At the outset the expert needs to gather all the necessary information on the project. After this phase has been completed, the designer can pinpoint information concerning the main modules, i.e. the infrastructure of the railway line, the rolling stock, the initial power supply system envisaged, and the signalling system. When all this information has been obtained, the only feasible way of ascertaining whether or not the initial design is correct is to use a railway simulator. When the simulation has been configured, run and completed, the designer will be able to analyse the results of the design proposed, in order to explore other possible solutions. At this point the process moves into a loop, and the user tests system designs until a satisfactory design is found. The great complexity of the overall system means that the designer will only be able to analyse a small proportion of the range of solutions. The method is also extremely costly in terms of the time taken. An average-sized simulation of a dual-system setup can take around 2 h, excluding the time required to configure the new

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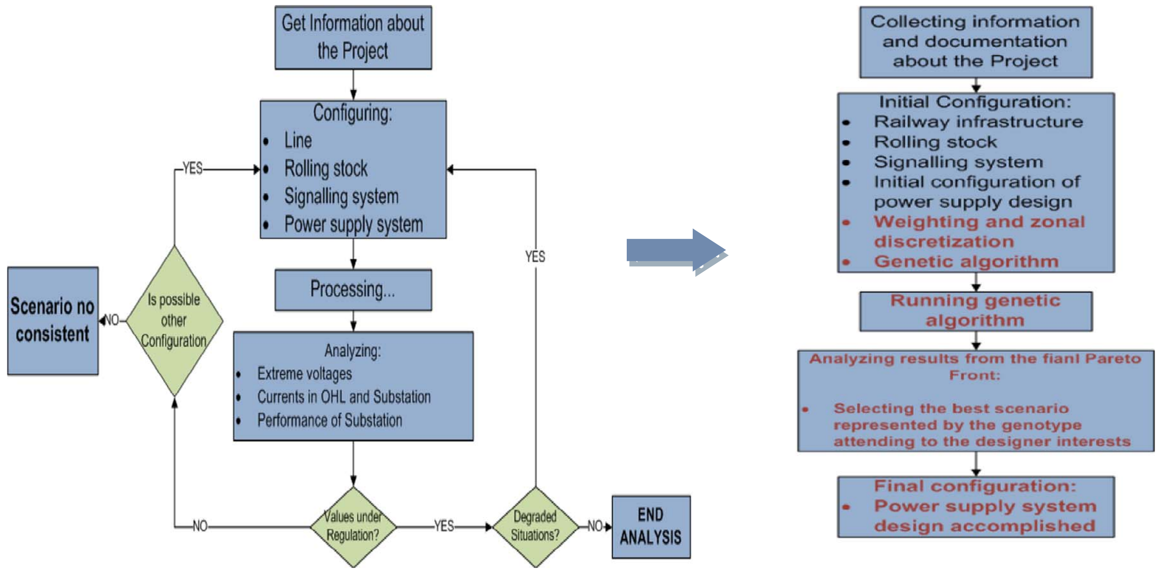

Fig. 1. Comparing processes to create a power supply system. (a) iterative process without the optimisation method; (b) with the optimisation method.

design and analyse the results.

This means it is extremely important to focus on automating this type of process. Automation must be in accordance with the process shown in Fig. 1b. Design of the electrical system thus becomes a much faster and efficient process, taking account of the complexity of the system, exploring many more possibilities and making decisive changes to furnish enhanced designs for the project being analysed.

The first phase is the same in both processes. Compiling data and information concerning the project is just as necessary in both cases. The second phase addresses the initial configuration and a simulation of a first approach to the power system. This phase has a new feature: configuration of the parameters used in the methodology, and of the genetic algorithm. This means the turning point between one method and the other emerges after the second phase. During the next step the designer launches the methodology and awaits completion. This is where the differences between the two approaches are greater and much more important. The methodology conducts an automatic search through the global solutions space, and eventually concludes its task with a set of optimum solutions defined in a final Pareto front. This model calculates values for opposing target functions based on installation costs and operation costs (Capex and Opex). Finally the expert must decide which design is best suited to the needs of the project, depending on the capacity of the designs proposed by the best individuals in the Pareto front, with a view to better management of the costs of installation/operation. This is, in fact the major difference between the models - this is an automatic model, which provides a much greater analytical capacity.

Implementation of all the modifications and of integration in the methodology for adaptation to dual-system setups, and of course the advantages afforded by the methodology, will be set out below.

2. Literature review

One of the main criteria driving the growing implementation of railway systems was the major focus on high-speed transit systems by the governments of a number of countries. Deploying this kind of system requires civil engineering work, rolling stock and signalling as a power system, it is very costly, and has a considerable impact on the areas affected by the infrastructure. This type of infrastructure adds a substantial amount to the budget, and therefore requires careful planning of construction and a proper viability plan [1]. One of the most important areas of surveys and design in relation to this type of project is implementation of the power supply system. For high-speed networks the system normally used is AC (Alternating Current) 2×25, also called “dual system” [2]. This system is essentially chosen for its long-distance fitness capacity. The design of this kind of system is no easy task, and requires careful management of information, calculations and simulations [3,4]. This methodology attempts to optimise the design process to furnish a final set of possible solutions that are cost-effective and also technically viable. An initial approach to this problem was proposed in an interesting paper by Chen et al. [5]. It applies a classical optimisation method, Mixed Integer Programming, to install electric vehicle charging stations in Seattle. It is interesting in that it addresses the major non-linearity of such a system and transfers this to its mathematical model.

The importance of securing a sturdy reliable method to improve the design process has led to work undertaken on a number of lines of research in recent years. Batistelli et al. [6] describe a method to study the basic working conditions of 2×25 systems. The model provides a tool to calculate the currents passing through the catenary, to provide a greater insight into the characteristics of the 2×25 system studied. Knestchke [7] developed a method for proper positioning of the number of autotransformers and traction substations. The ultimate objective is proper spacing between the main components and controlling the harmonics of the final system obtained. Brenna et al. [8] describe and analyse the importance of the autotransformers in a good planning design in a 2×25 railway system. They have been working with the flow currents from/to the autotransformers and the calculations of the inductances between the wires. Using these calculations and models is able to determine better the influence of the power supply system to other interacted, like signalling system or to the nearby systems.

The study and method created by E. Pilo [9] are very interesting indeed in a number of aspects. The main component of his Ph.D. Thesis [10] is a proposed simplification for 2×25 models. In connection with other relevant aspects, another highlight is addressed in [11]. Pilo works with MIP (Mixed Integer Programming) to obtain the best solution in terms of numbers and positioning of both autotransformers and traction substations. In this case the theoretical model applied operates on the premise of an analysis of the electrical viability of the system on the basis of a number of snapshots selected from the initial operation plan for the rail system analysed. The last step was the integration of an algorithm based on artificial intelligence to optimise the design [12]. The author works with objective functions in order to quantify each scenario. In short, it could be said that his paper is the closest to this methodology, and in many sections it is the starting point on which it is based. Introducing the importance of the neutral zones is the work