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Computer aided design tool for the study of electric traction fixed installations and train operation

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Abstract

The complexity in design and dimensioning of electric traction fixed installations necessitates the development of a methodology for dimensioning based on numerical simulation models. This solution gives faster and more reliable results than those obtained by the empirical and inaccurate methods previously used.
A computer aided design tool implementing this methodology is presented in this paper. Various elements such as truck data, catenary, traction substations, rolling stock, train composition, railway network and schedule conditions are considered. The analysis of the resulting simulated output allows optimisation and selection of the best solution for the power supply system of a railway network, as far as traction substations and overhead line systems are concerned.
Therefore, the final choice of the electrical energy supply system that fulfils the technical requirements and ensures the programmed traffic, should be submitted to the analysis of a minimum cost criterion, regarding available feeding points of the energy supplier network.

1 Introduction

The dimensioning of traction substations and overhead line systems is the main point of railway system electrification. They must fulfil several technical requirements in order to obtain a correct behaviour of the electrical supply system.

From a generic point of view, for a given voltage level, the number of traction substations needed to feed the electric traction system depends on its length.

A short number of substations will lead to greater spacing between them. This involves increasing the substation rated power and also using a larger equivalent section of the overhead line system in order to keep power losses and voltage drops within acceptable limits.

Conversely, a larger number of substations allow the substation rated power and the section of the overhead line system to be reduced. Moreover, loads are distributed more evenly. As far as costs are concerned, a larger number of substations usually involves greater equipment and infrastructure investment as well as increased maintenance costs.

These reasons justify a detailed study in order to compare several hypotheses, which can be performed with computer aided design tools.

2 Proposed Methodology

The proposed computer aided design tool is a software package developed for DC or AC supply systems [1] – [5].

Four modules compose this software package:

- Database Management;
- Train Movement Simulation;
- Traffic Simulation and Load Flow;
- Harmonic Analysis.

The first step in the proposed methodology is to determine the number of traction substations needed to feed the electric traction system, taking into account background experience in previous electrification projects. From the number of traction substations it is possible to determine the pre-location of traction substations using an "equal-energy" criterion. This method, the input data for which can be obtained from the *Train Movement Simulation* module, is a first approach to obtain locations of the traction substations, bringing near substations feeding larger loads in order to achieve an appropriate distribution of the overhead line voltage.

These calculated locations would be corrected taking into account existing connection points to the public energy supply network and the track constraints usually required for substation implantation (horizontal and straight track).

The above mentioned aspects and the electrical characteristics of the overhead line define the fixed nodes of the electric traction system, enabling the *Traffic and Load Flow Simulation* module to be run.

The analysis of these simulation outputs (substation load diagram and the pantograph voltage limits) allows the dimensioning of the traction substation, satisfying the required train loads as well as the UIC 610,0 standard (pantograph voltage conditions).

Several simulations of different alternative network solutions should be performed in order to find the best solution from an economic and technical point of view. At this stage, costs related to the substation incoming lines should be considered.

The *Harmonic Analysis* module is a simulation tool that allows the consequences of harmonics generated by the trains to the overhead line system and through the traction substation to the supply public network, to be previewed. This is a very up-to-dated subject and this module allows analysing the worst possible conditions to be analysed.

3 Software Package Developed

3.1 Database Management Module

The *Database Management* module manages the use of a subprograms set, which allows the database files needed to run the simulation programs to be built, accessed and viewed. This module includes the following databases (DB): Track DB, Fixed Electric Installations DB, Rolling Stock DB and Traffic and Electrical Network Management DB.

Use of this module enables track geometrical and electrical data, vehicle characteristics, scheduled paths and the network layout to be defined for the simulations to be made.

As an example of the Rolling Stock DB, figure 1 represents a view of a traction effort versus speed curve used in the vehicle simulation.

3.2 Train Movement Simulation Module

The *Train Movement Simulation* module analyses single vehicle movement on a specific path. It executes an electromechanical simulation that corresponds to a chosen vehicle type, moving on a selected physical path belonging to a railway network and considering a certain time schedule for a specific and predefined journey. This means, when one simulation runs, the large amount of data has already been inputted in the previously described module. Simulations are then executed by selecting only the conditions that must be considered in this specific run.

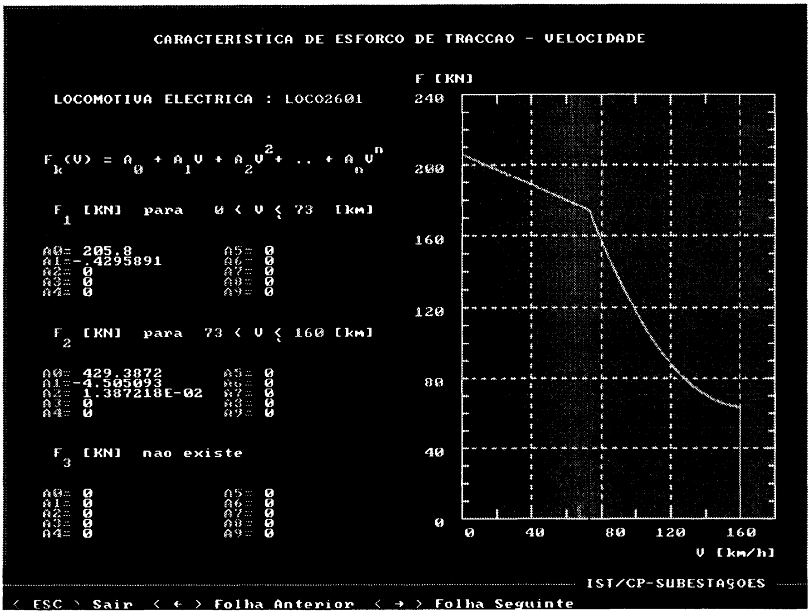


Figure 1: Rolling Stock DB - traction effort versus speed curve.

Among outputs, this module presents the simulated speed-time curve, energy consumption and the pantograph current and voltage evolution concerning this individual movement, fig. 2.

3.3 Traffic Simulation and Load Flow Module

To use this module it is only necessary to select a previously created network, which, in turn, considers information such as network system topology, train type and traffic schedule. The user inputs an integration time and a time-window within which the software performs the traffic simulation. This means that, all the trains that belong to the transportation network are being considered simultaneously, no matter what moving conditions they have.

From each simulation time a “picture” of the system is obtained, regarding:

- fixed nodes – nodes which consider the energy supplier company, transmission lines, traction substation transformer and overhead line system (catenary);
- mobile nodes - electric vehicles.

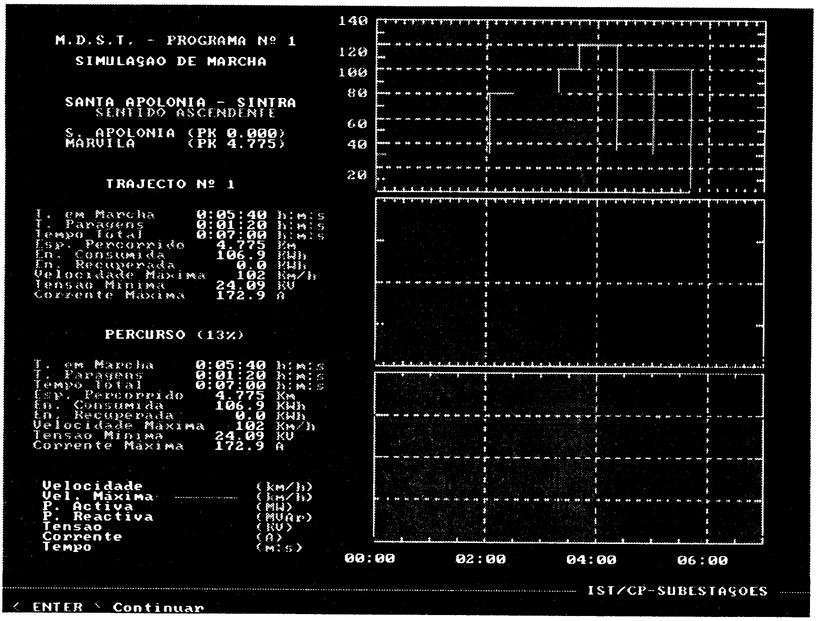


Figure 2: Screen sample generated by the *Train Movement Simulation* module

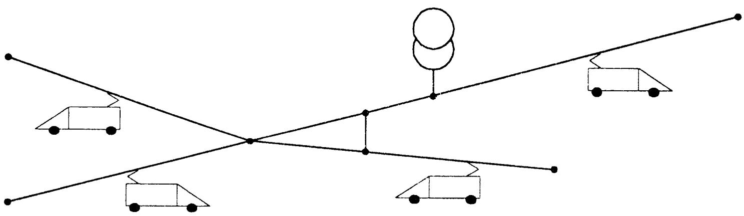


Figure 3: Network in analysis with fixed nodes and mobile nodes

Depending on the movement laws of each train type, the next "picture" of this system will certainly show different node positions (because of mobile nodes changing position).

Because of this, for each simulation's new time value, a different "Network Admittance Matrix" and train "Power Demands" is defined.

Concluding this "picture" analysis, the network "Load Flow" (Newton-Raphson method) is run leading to the load diagram of the traction substation (power and current), the power factor evolution at the traction substation and the worst pantograph voltage drop value, fig. 4.

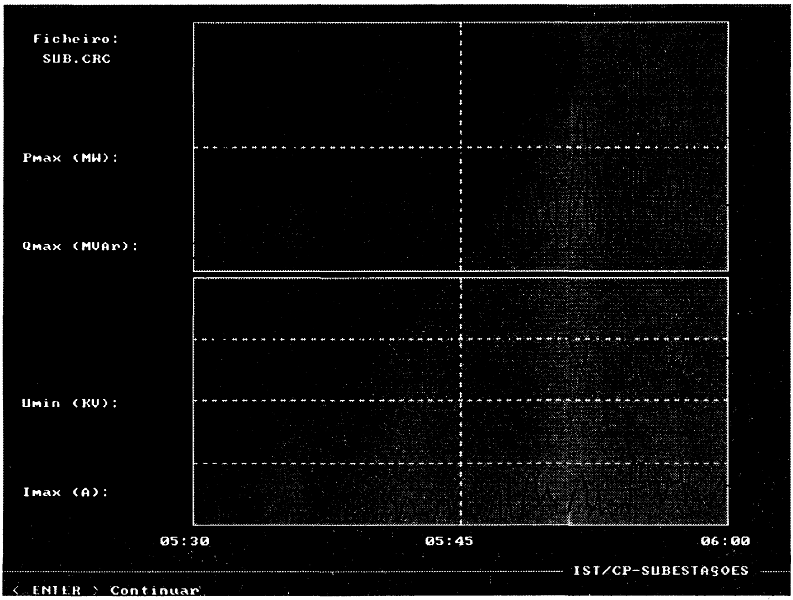


Figure 4: Screen sample generated by the *Traffic simulation and Load Flow* module

Usually, the schedule table for dimensioning the electric traction system is referred to the situation in which the maximum number of vehicles is circulating.

Substations' dimensioning is possible by using the load diagrams obtained in this module. The voltage level that feeds each vehicle (voltage value at the mobile nodes) can enable decisions to be made for the re-dimensioning of the supply system.

3.4 Harmonic Analysis Module

The use of power converters in traction motor feeding circuits introduces harmonics to the catenary, and through the traction substation into the supply public network. The *Harmonic Analysis* module is a simulation tool that enables the possible harm caused by this phenomenon to be previewed. Four different topologies of traction motor feeding circuits used in railway rolling stock can be analysed.

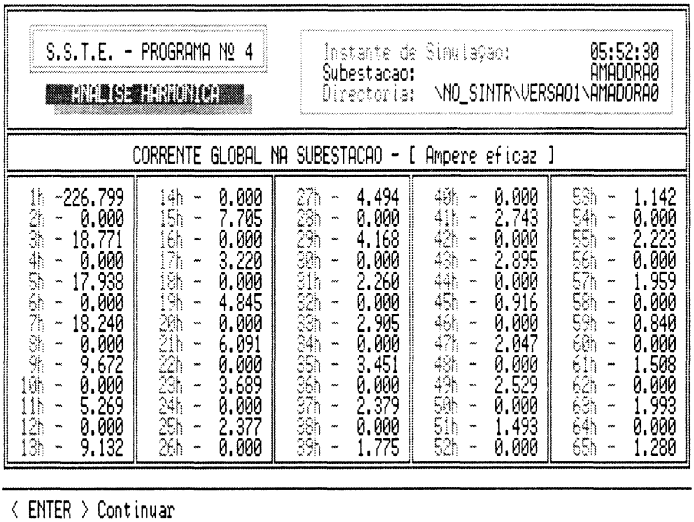
This module considers the mathematical models of different traction topologies; by using those models and the pantograph voltage value (which results from the previous "Load Flow") the equivalent harmonic current generator for the vehicle load conditions at that moment is obtained. The harmonic current calculation is performed using FFT (Fast Fourier Transform) analysis.

Topology 1 regards trains with single-phase series commutation motors. In topology 2 the traction circuit is composed mainly of a transformer, an on-load tap changer and a non-controlled full-wave single-phase rectifier. Topology 3 regards trains whose traction circuit is composed mainly of a transformer and series connection of two mixed asymmetrical rectifier bridges. Finally, in topology 4, the basic traction circuit comprises a four-quadrant converter (AC/DC), an intermediate stage with DC voltage and three-phase power inverters that feed the asynchronous motors.

At the AC voltage side, a sinusoidal voltage source with 50 Hz is presumed. The module objective is to calculate the current from the network. This current has a certain harmonic content, being the module purpose to determine the harmonics generated by the current.

Topology 4 is widely used nowadays in drives with regenerative braking [6], allowing the return of power into the traction system network. During the recuperation stage, the energy returned is a result of using the kinetic energy of the moving vehicle. Electric traction units, with enormous inertial masses being displaced, feature major kinetic energy flows suitable for recuperation and return to the catenary, in order to be used by other vehicles running close by or even to be returned to the network of the energy supplier company.

Figure 5 shows a screen sample with harmonic components analysis at the substation point.



1h - 226.799	14h - 0.000	27h - 4.494	40h - 0.000	53h - 1.142
2h - 0.000	15h - 7.705	28h - 0.000	41h - 2.743	54h - 0.000
3h - 18.771	16h - 0.000	29h - 4.168	42h - 0.000	55h - 2.223
4h - 0.000	17h - 3.220	30h - 0.000	43h - 2.895	56h - 0.000
5h - 17.938	18h - 0.000	31h - 2.260	44h - 0.000	57h - 1.959
6h - 0.000	19h - 4.845	32h - 0.000	45h - 0.916	58h - 0.000
7h - 18.240	20h - 0.000	33h - 2.905	46h - 0.000	59h - 0.840
8h - 0.000	21h - 6.091	34h - 0.000	47h - 2.047	60h - 0.000
9h - 9.672	22h - 0.000	35h - 3.451	48h - 0.000	61h - 1.508
10h - 0.000	23h - 3.689	36h - 0.000	49h - 2.529	62h - 0.000
11h - 5.269	24h - 0.000	37h - 2.379	50h - 0.000	63h - 1.993
12h - 0.000	25h - 2.377	38h - 0.000	51h - 1.493	64h - 0.000
13h - 9.132	26h - 0.000	39h - 1.775	52h - 0.000	65h - 1.280

Figure 5: Screen sample with harmonic analysis at the substation point

4 Conclusions

This paper proposes a computer aided tool for the design of electric traction fixed installations, based on numerical simulation models. Implemented databases allow the testing of this tool on the Lisbon Railways Track Subsystem.

Four modules compose the developed software package: *Database Management* module, *Train Movement Simulation* module, *Traffic Simulation and Load Flow* module and *Harmonic Analysis* module.

This methodology and the structure data supported allows future developments such as:

- prediction to power peaks and energy consumption costs;
- inclusion of algorithms for optimal energy consumption in individual train movements;
- calculation of the unbalance generated in the public energy supply network, according to different power transformer types;
- comparison between a deterministic analysis method versus a probabilistic approach.

This methodology is suitable for railway engineers involved in dimensioning and analysing an electric traction network (AC and DC supply systems).

Acknowledgement

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