METHODS AND TOOLS FOR PREDICTING WORKING MODES OF RAILROAD POWER-SUPPLY SYSTEMS

L.A. Zaytseva*, V.V. Zaytsev†

*†Rostov State University of Transport Communications, Lenin Street, 44/6, Apt. 23, 344038 Rostov-on-Don, Russia
†vadim@cs.vu.nl, fax: +31(20)5987653

Keywords: power supply, electrification, breakdown mode, modelling.

Abstract

This research is dedicated to design and implementation of a computer application for predicting the functioning of a railway power supply system (both on developing stage and in operational state). The process of creating a model for simulation of train movements is described in detail. Two working modes are considered in required hardware reliability estimation: a normal mode (standard conditions) and a breakdown mode (when one of the substations is down). Model analysis and implementation of the results obtained show their trustworthiness. While exploring model behaviour, we could determine minimum time interval between trains, estimate maximum possible current, voltage losses, as well as other parameters.

1 Introduction

During the last decade railway electrification was a hot topic in Russia. A lot of attention has been paid to economic efficiency of the solutions proposed for newly electrified zones. Total cost of ownership should be as low as possible without hindering reliability, requirements for which always remain high.

In order to make the best choice in railway power supply, usually several variants are examined. The most economic and considerably reliable one is chosen for deployment. Computer model can be used to predict how the real power supply system will work. Such a model is considered in the following sections of the paper.

The model should simulate train movements and power supply system behaviour in several admission modes for trains, as close as possible. By admission mode two parameters are basically meant here: time interval (or gap) between trains and train grouping and positioning.

The most difficult type of problem is modelling train movements on single track railway section. It is quite common on single track sections to let several trains going in one direction run together in one pack (with a fixed gap in between), and only then let the trains go in the other direction. The time interval between trains inside such a pack can be minimal, which leads to load increase for the traction network. A computer model allows for predicting power supply system working conditions with any train positioning on a single track railway section.

The working modes of a power supply system depend also on a feeding scheme of a particular section. The primary mode on a single track section is feeding from both sides. With such a scheme, two adjacent railway substations simultaneously feed one railway section. This section is called *the inter substation zone* and is in this case the only zone which is being fed.

In the case of a breakdown or maintenance work it is possible that one railway substation becomes switched off or unplugged. A scheme like this always has higher currents and voltage losses. Therefore, it may pose certain limitations on trains' admission.

For a double track railway section and two-side feed it is common to make an additional connection of traction networks of two tracks by means of a so-called *sectioning post* (Figure 1). The sectioning post allows to make currents in these two traction networks equal. This decreases voltage and power losses; thus, the sectioning post should normally be operational.

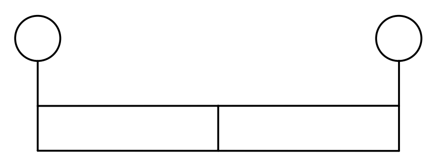

Figure 1: Primary feeding scheme for a double track section.

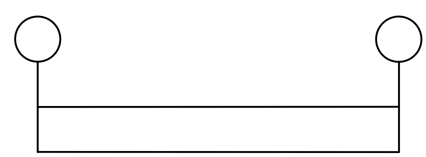

Figure 2: Separate feeding of two tracks.

When a sectioning post goes down (or is switched off), the scheme looks more like Figure 2 and is called the separate feeding scheme.

We have seen two possible feeding schemes in normal mode. By “normal mode” we mean any situation where all railway stations remain operational (as opposed to “breakdown mode”, when one of them is down).

2 Modelling

The problem solution consists of following issues:

1) Create a computer model capable of predicting power supply system working conditions.

2) The model should have direct correspondence to the real railway section prototype and should simulate its features as accurate as possible.

3) The model should calculate power supply system working conditions both in normal and emergency modes.

4) The model should give recommendations on limitations of train positioning and movements in emergency mode. (If deemed necessary, it is possible to decrease the number of trains on an inter substation zone or to increase the time interval between trains).

2.1 Choosing a modelling method

There are several different methods for calculating power supply system parameters. One big group of methods uses average traffic estimation. Calculation in this case is based on mean and mean-square values of train currents, feeder currents, feeder wing currents and substation currents (average values are counted for every 60 km zone).

These methods are used in railway section power supply systems design only when the train schedule is totally unknown. In this case the only data one can rely on is the number of trains in a day and a railway section profile. The latter parameter determines power expenses and train currents.

The other group of methods is used when train schedule is available or when there is enough information about train positioning rules for the model to generate a schedule similar to a real one. Here we can consider separate time moments: for every moment there is a scheme created (so-called “moment scheme”). The coordinates of all the trains make part of such a moment scheme, as well as the currents they consume.

The latter group of methods gives more accurate results when a condition is met that the number of moment schemes within a day is more than 1440 (number of minutes in 24 hours). Obviously, so much calculation could pose significant burden should it be executed by hand—of course, this is absolutely not a problem for a computer model. This was one of the main reasons for us to use a method from the second group. Input data is an array of train currents collected on real trains or calculated with taking section profile (200 metres accuracy) and train’s weight into account. The train schedule or the positioning rules are also defined.

2.2 Modelling the normal mode

Let us first consider modelling single track railway sections. Note the main parameters that should be determined by the working model:

- Maximum traction network currents
- Maximum voltage losses

The current in traction network should not exceed the bound permissible by heating norms. Voltage losses should not be too large because train speed depends on the voltage. According to the Russian standards, if the voltage in traction network is 27.5 kV, minimal possible voltage on a locomotive should be 21 kV (which means the losses should never exceed 6.5 kV).

On design stage the type and diameter of a traction network is determined according to these three criteria:

- Costs
- Maximum traction network current
- Maximum voltage losses

It is common to start the research from the least possible traction network diameter. Then it is increased until all three choice criteria are met.

On this stage a special train positioning is used: a pack of cargo trains is formed with a minimal possible gap in between and sent to one direction. Most cargo trains in this pack have average weight, but some of them (usually one or two) have maximum weight allowed for the inter substation zone.

It should be noted that the number of trains in a pack, as well as the number of “heavy” trains is determined by a special standard document that fixes their dependency from the overall number of trains on that particular direction. This document is always a very important part of research on Russian railway power supply systems design (see Table 1).

Number of trains in a day		Time interval (minutes)	Number of cargo trains in a pack
Cargo	Passenger		
Up to 24	Up to 20	20	2
	More than 20	15	3
24–36	Up to 20	12	4

	More than 20	10	6
37–48	Up to 20	9	5
	More than 20	8	7
49–72	Up to 20	8	7
	More than 20	6	10
More than 72	Up to 20	7	8
	More than 20	5	12

Table 1: Determining the number of cargo trains and the time interval between subsequent trains in a pack.

Additionally, the model takes care of:

- different ordering of average cargo trains and heavy cargo trains
- displacement interval (the time difference between arrival on the inter substation zone of trains from one direction and the other)
- feeder length (the length of the feeding wire which connects railway substation with traction network)

It is worth mentioning that some railway sections place substations on some distance from the railway. If the length of the feeders is long enough to influence the voltage on the locomotive, this should be taken into account.

It is also possible to have one railway substation placed at a distance with a feeder length of several kilometres, while the other one is placed directly on a railway. This leads to the currents of the substation with a shorter feeder length to be always greater than the currents of the substation with a longer feeder. In order to compensate the currents it is possible to artificially increase the length of a feeder on the substation which is “too close” to the railway (Figure 3).

Figure 3: Artificial increase in feeder length.

Taking all section peculiarities into account is a distinct feature of our model: it also allows to change the length and resistance of a feeder.

In order to completely simulate trains moving on a real life railway section, the model utilises data about points where the trains coming from different directions can pass by each other.

During simulation railway substation currents and voltage losses are calculated every minute. Later their maximums are determined and produced.

2.3 Modelling the breakdown mode

If one of the railway substations goes down, it complicates the situation for power supply system significantly. The main goal is then to not let breakdown mode become emergency mode. The biggest complication is that in AC systems the inter substation zone can only be fed from one side (Figure 4) —adjacent inter substation zones are fed from different phases.

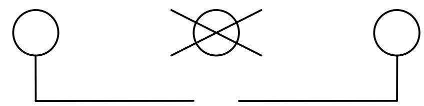

Figure 4: Switching to one-sided feeding when one railway substation is down.

When one substation falls off, it can also result in a brief break in train traffic. Trains in this case can be accumulated at one of the stations. In order to repair this omission when the traffic is restored, the trains are sent with minimum possible gaps. This mode is called *full use of carrying capacity of a railway section*.

Thus, on design stage heating of the traction wire should be checked in two conditions:

- separate feeding of tracks on double track zones
- train traffic with minimal time intervals between trains

Apparently, the currents of two adjacent railway substations rise significantly when one-sided feeding scheme is launched. Yet it should be impossible for these currents to hit the maximum limit, otherwise the traction network wire will experience a breach in mechanical durability.

Increase of currents in traction network not only complicates power supply system working conditions, but also causes high electromagnetic impact on communication lines located close to the railway.

The voltage losses increase, too. It makes sense to assume that the minimal voltage level in traction network will be experienced in proximity of the switched off substation (at the end of console feeding zone).

Uncontrolled drop in voltage level can lead to disconnection of locomotives. Therefore it is particularly important to predict how the power supply system will operate in the breakdown mode.

A breakdown mode cannot hold on for long (it usually takes up to several hours). It is possible to limit the number of trains moving inside the inter substation zone and to increase time intervals between trains.

With a model which takes the section profile into account, it is possible to research breakdown modes for every single substation. The model calculates voltage levels in traction network and currents along the whole length of it. It is also possible to change train speed and time intervals between trains Θ. During simulations, the model counts the voltage on each of the electric locomotives and chooses the minimum. The minimum value is then compared to the allowed absolute minimum—if the voltage is too low, the time interval is increased by one minute:

$$\Theta_i = \Theta_{i-1} + 1 \tag{1}$$

Then the model starts the simulation over. This stepwise optimisation of time intervals between trains yields in the time interval which is minimal acceptable for a fixed train speed.

Another outcome is an array of currents on all elements of inter substation zone (with an accuracy of 3 km). These currents can be used to calculate electromagnetic influence on adjacent communication lines.

2.3 Model algorithm

The model runs in an Internet browser. All data available from the railway experts about the section profile is already incorporated in it, as are the abovementioned formulae and methods. First, the user chooses the inter substation zone from a predefined list of zones on which the data is available to the application. This choice determines all train currents and positions of intermediate stations. Then, it is possible to provide additional input data: fix the train speed, choose the number of trains in a pack, minimum time interval between trains, traction network type, its resistance, displacement interval, etc. Data is checked for validity, and the simulation process starts, visualising every step. Every “minute” a moment scheme is calculated: the current of each substation and the voltage on each locomotive are determined, saved and compared to the allowed bounds.

When the last train leaves the inter substation zone and there are no more trains waiting to be let in, the simulation stops. All simulation outcomes such as maximum voltage loss, maximum current and the time interval between trains that meets all the conditions are displayed.

This is how the model works for the simplest possible configuration. We have dealt with more complex real life situations, for example, they can combine double track and single track zones, they can have more than two different types of trains, etc.

3 Conclusion

It has been shown why and when it is necessary to predict different functioning modes of a railway power supply system. Predicting normal working mode is needed when designing a system (when electrifying new railway section). Predicting breakdown mode is needed for train traffic management on the fly in the case of a non-working railway substation.

The principles of creating the model with taking the section profile into account were substantiated. A working computer application that allows for checking railway power supply system reliability was implemented. The results of the research were used in several big electrification projects. The program itself is still being used for educational purposes in Rostov State University of Transport Communications.