A SIMULATOR FOR POWER SUPPLY SYSTEMS OF D.C. TRANSIT RAILWAYS

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ABSTRACT

There are many software simulation packages available in the railway traction industry, which are used by different organisations to address various aspects of problems in railway systems engineering. The ALSTOM Multi Train Simulator (MTS) is a suite of computer programs, which are used to assist the design optimisation of d.c. railway power supply systems. At ALSTOM Drives & Controls, the MTS has been used extensively in the engineering of large projects such as the Manchester Metrolink, Ankara Metro and the Jubilee Line Extension. This paper describes the features and capabilities of the simulator, its applications in engineering and the most recent developments on the simulator which have been driven by such applications.

1. INTRODUCTION

Simulation techniques for railway systems have been well established over the last two decades [1,3,8]. The techniques have been widely used to study all aspects of railway operations and designs. Some examples are: studies of energy savings by the introduction of new traction drive technology [2], system optimisation for new and existing transit railways [6,9], system earthing strategy and its effects on rail potential and stray current [4,5,10], the effects of voltage controlled rectifiers with various output characteristics can also be modelled. Virtually all elements that affect the system can be included in the simulation and all necessary data can be obtained from the simulation results [8].

The ALSTOM MTS has been developed to study railway operations with particular emphasis on power supply systems.

An important aspect of any computer programme is that of validation. Having been developed over a period of some two decades, the ALSTOM MTS has been validated using a combination of different methods. As the program is modular in construction, each module can be checked and validated individually. Initially, the program was validated against manual calculations, and latterly against an actual operational railway which provided excellent correlation with the simulation results [6,9]. In the case of the a.c. load flow module, test results were checked against those obtained from a propriety software package and excellent correlation was observed.

2. FEATURES AND CAPABILITIES

Briefly the simulator is capable of the following:

- Complex track configurations including mainline with branches and loops
- Interactive d.c. traction and a.c. supply network load flows
- Dispatch of trains by headway control or time table control
- Mixed fleets of train operation on the same line
- Use of voltage controlled rectifiers, inverters or resistor banks. Assessment of energy savings.
- D.C. track rail earthing optimisation

The simulator has been continuously developed to suit the requirements of different projects. Extensive post processing programs for both numerical and graphical outputs have been developed to produce the right format for documentation. Both numerical summaries and graphical outputs are made available from the simulation. Details of how the MTS output results are organised are contained in [8]. Figure 2 shows a typical substation load cycle from the simulation (time based). Figure 3 shows a typical graphical output from the simulation for train performances (distance based).

The following sections describe in more detail some aspects of the MTS features.

3. GENERALISED TRACTION MOTOR MODELS

Over many years, d.c. motors have been the work horses for electric traction due to their desirable characteristics. Consequently, when the MTS was first developed, only d.c. motors were modelled [2,3].

With the rapid advancement in power electronic technology, the use of a.c. motors has become normal practice due to their many advantages over the d.c. motor. It is apparent that the d.c. motor modelling techniques in the MTS had to be expanded to enable the modelling of a.c. motors. This was first prompted by the studies for the Skytrain project in Vancouver, where linear induction motors (LIM) are used for traction drives and then followed by the studies for the Jubilee Line Extension project [9]. The MTS modelling capability was enhanced to address both d.c. and a.c. motors. This is achieved by making the motor modelling programs “off line” from the MTS. Each type of motor is modelled individually, whilst a common output data structure is maintained [7].

The MTS is further improved by reading different motor data for different track sections. For example, motor characteristics are different in open track and tunnel sections. In the Vancouver Skytrain system, linear motors exhibit different characteristics in sections that have laminated back iron from those with solid back iron. Laminated back iron is used in sections that require higher traction output from the motors.

4. MIXED FLEET OPERATIONS

The MTS was initially developed to study urban transit railway operations where trains are usually despatched at a fixed time interval (or headway). The train despatch was controlled by specifying headways which may be different in different sections of the track. An enhanced feature of random delay time for each train was added later on. Another feature was added to cater for the different numbers of passengers in different sections of track.

In suburban railways, it is more likely that train dispatch is controlled by time tables than by headways. In order to simulate this type of railway operation, time table control was added to the MTS, so that the user has the choice between the two. Also in such operations, trains are likely to be a mixed fleet, for example, a passenger train may be an express or a local service, and freight trains may also operate. The MTS was further developed to cater for such operations.

Where mixed fleet operations are considered, facilities for train overtaking are also incorporated.

5. INTERACTIVE A.C. AND D.C. LOAD FLOWS

Usually, the d.c. traction system is studied in isolation from the a.c. power supply network by assuming that the convertors are supplied at nominal voltages. Proprietary software packages are available for a.c. network load flows, which solve load flows at a given steady state load condition. This is usually done by assigning a notional load figure at traction substations (e.g. The rms currents at the substations over a simulated load cycle derived from a d.c. system simulator) and other load centres.

There are two major drawbacks of this approach. One concerns the voltage regulation on both the d.c. and a.c. sides. The results obtained could be optimistic, which is undesirable in the design of the power system. The other concern is that of cable ratings on the a.c. side, as steady state load flows only produce indicative cable loading.

This demands that the simulator should have the capability of studying both d.c. and a.c. networks interactively. Subsequently the MTS was developed to combine the solutions of d.c. and a.c. networks interactively. As a result, more accurate results are obtained on both a.c. and d.c. sides. Duty cycles on the a.c. side (eg. for a cable) can be predicted as well as on the d.c. side.

The a.c. load flow algorithm uses a fast decoupled method as described in [11]. The a.c. network data preparation can be in a physical format such that bus couplers and switches can be represented as zero impedance links in the base network. This allows rapid studies of line outages and busbar re-configurations. A pre-processor routine identifies “islands” and allows the load flow of each island to be carried out one at a time in a loop. Up to a maximum of 10 electrical islands can be processed, provided that there is generation and load in each island. Tap changers fitted to both distribution and converter transformers are also modelled. Additionally, shunt elements such as cable stray capacitances and installed filters are modelled when required.

6. HARMONIC FLOWS IN A.C. NETWORK

A separate module was developed to solve the harmonic flows in the a.c. power network. This module is “off line” from the main simulator as a post processing program. This is because the harmonics do not have a substantial effect on the power frequency load flows.

The harmonic load flow solution is a deterministic non-iterative problem. The harmonic current injections are calculated as a function of traction loading [12]. Infeeds and generation are modelled as a shunt reactance representing the fault MVA. The effect of auxiliary loads at the traction substations can optionally be included. As fault level calculation is necessary to determine the system reactances looking from each traction substation in turn, the fault levels at all a.c. busbars are output separately to a file.

7. COMPLEX D.C. NETWORKS

Usually a railway line is a double track, “straight” line. As the system expands, one or more branches may be added to the existing line (the mainline). A loop may be present at the end of the line or other locations. The combinations of such features are endless.

Due to the nature of the d.c. system, the mainline and the branches and loops are usually connected electrically. Therefore, the whole system should be treated as an integral entity. The simulation should reflect all factors in the system.
The ALSTOM MTS has been developed to solve such networks. The configurations that can be studied are illustrated in Figure 1. If a given network is a combination of these features, it can be dealt with by the simulator with sensible applications.

8. RAIL POTENTIAL AND STRAY CURRENT CONTROL

Most d.c. railways use the running rails as the traction current return conductor. The disadvantages associated with such an arrangement are:

- Rail potential rises or falls above certain thresholds and may be hazardous in the forms of touch and/or step voltages.
- Stray current may cause or accelerate electrochemical corrosion to metallic structures in the vicinity of the system.

The control of rail potential and stray current is an important aspect of all d.c. railway power system design. There are many measures that have been adopted in the attempt to mitigate the harmful effects of the two problems. Among them the choice of earthing strategies within the d.c. system has a profound influence on both rail potential and stray current control.

The tasks of controlling both rail potential and stray current are conflicting, therefore a balance has to be struck between the two. This calls for a comprehensive study before a final strategy can be determined. Subsequently a computer program was developed to simulate the performances of systems against defined criterion, namely maximum rail potential, total stray current and gross leakage charge [4,5,10]. With this program, different earthing strategies can be studied for a given system before a final decision is made. The earthing schemes include

- totally floating earth
- directly connected earth
- diode earth
- floating earth with Rail Potential Control Devices

In the case of Rail Potential Control Devices, the studies can be used to optimise the device settings (voltage, current and time). A detailed description of this capability is contained in [10].

9. SPECIAL FEATURES AT SUBSTATIONS

Special features at substations include voltage controlled rectifiers (VCR), inverters and resistor banks.

VCRs are used in some railways to enhance the regulation of d.c. voltages. Inverters are used in some railways to recoup excessive energy generated by braking trains in regenerative mode in the d.c. system that cannot be absorbed by other trains. Resistor banks are installed in some railways to do similar things as inverters, the difference being that the resistor banks do not convert energy back into a.c. supply networks.
These special features were added to the MTS when they were required and are now integral parts of the simulator.

The incorporation of inverters in the MTS enables assessments of likely energy savings to be carried out. Similarly, train coasting has been incorporated in the MTS to assess energy saving and journey time.

10. CONCLUSION

Over the years, the ALSTOM MTS has proven to be an essential tool in the design optimisation of d.c. railway power supply systems. The advancement in technological developments demands that the MTS be maintained up to date. There is no doubt that further developments of this suite of programs is a continuous theme, which will be determined by tracking the technological advancements in all areas of d.c. railways.

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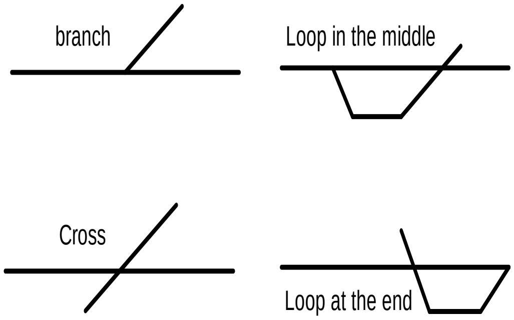

Figure 1. Track configurations that can be studied

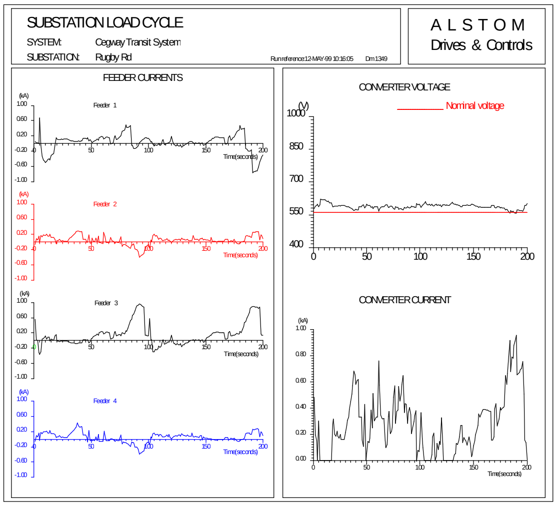
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Figure 2. A typical substation load cycle plot

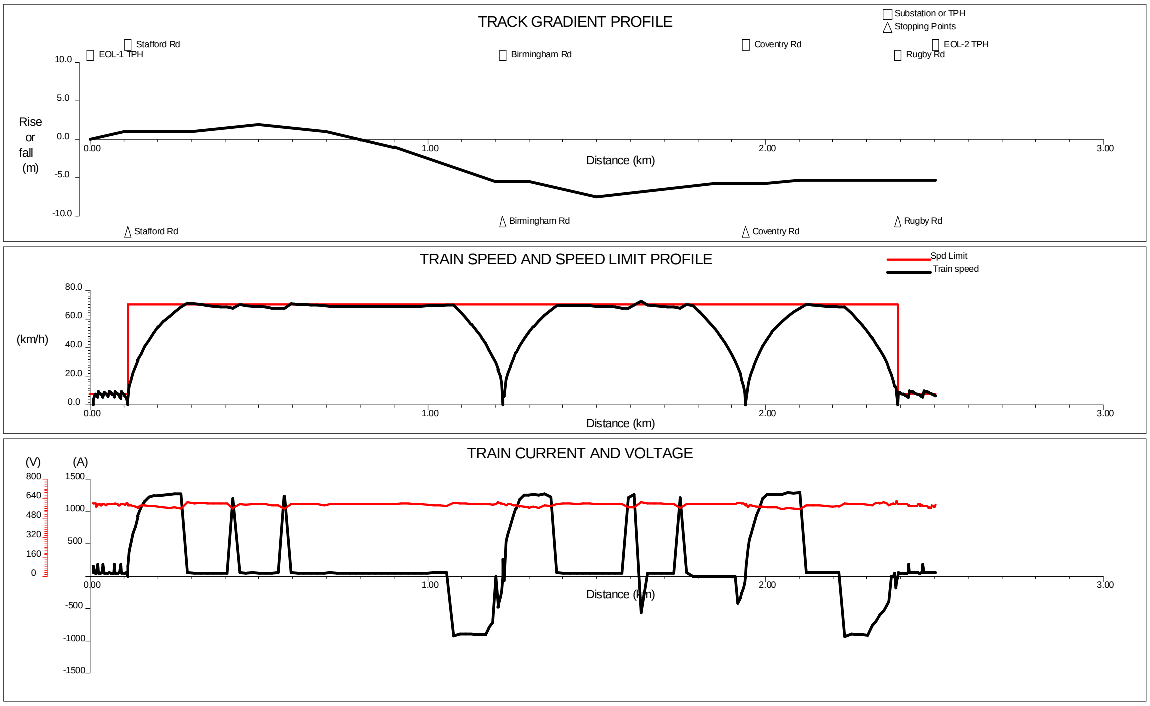

Figure 3. A typical train performance plot