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Comparison of physical modelling and CAD representation of compensated railway systems

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ABSTRACT

A 25kV, 75km single phase traction feeder with two SVCs has been modelled both on a physical simulator and on a CAD package (SABER). The controls of the SVCs, which use a phase locked loop technique, have been included in both simulation models. Some of the simulated results are given; comparisons made with the results obtained from each model show very good agreement.

INTRODUCTION

Many main line railway electrification systems use 25kV ac to transmit electrical power to the locomotives. At this voltage level the railway system is usually divided into electrical sections of about 25km length. Longer sections result in excessive voltage drop (more than 25%) with severe loss of performance to the most distant locomotives. In many countries, particularly those of Northern Europe and the USA, it is relatively easy to feed track lengths of 25km from existing electrical supply networks. In more sparsely populated regions there is not a sufficiently large number of potential feed points and, in order to achieve a 25km feeder length, additional three phase power lines must be installed. This is an expensive process which can affect the economic viability of electrification. There is therefore a need to investigate methods that could be used to extend the feeder length beyond 25km.

The large voltage drops which occur in 25kV power supplies are mainly due to the flow of reactive currents generated by the locomotives. These voltage drops can be minimised by providing local reactive power support in the form of Static Var Compensators (SVCs). Earlier theoretical studies (Morrison et al.[1]) have shown that, with 2 SVCs on a feeder, a length of up to 75km can be achieved, which is a significant improvement over the uncompensated length. However, this requires the SVCs to operate and maintain stability in very difficult conditions.

To study the performance of a feeder with 2 SVCs requires a reliable model of a complete feeder with the SVCs and several locomotives. A complex time domain model can be constructed but it is desirable to have independent validation of the results in some other form.

This paper describes the use of comprehensive time domain analysis, to model a system with 4 locomotives and 2 SVCs all operating interactively, and its comparison with a physical model of the same system.

SYSTEM DESCRIPTION AND PARAMETERS USED

The system studied and the parameters used in the study are given in Figure 1. A 75km single track section is shown with X/R ratio of about 3. In order to enable easy comparison with the physical model, the feeder is divided into 4 equal lengths with a busbar at each break point where trains may be connected. The train loads are conventional electrical locomotives as shown in Figure 3.

For these studies, one SVC was located at the middle and the other at the end of the feeder. Each of the SVCs is composed of a Thyristor Controlled Reactor (TCR) and a fixed shunt capacitor. The shunt capacitor is arranged as a single arm filter, tuned at about the 3rd harmonic. This is an economic arrangement which, for a single SVC, has been shown to be adequate to meet the requirements for harmonic attenuation in railway applications (Hu et al. [2]). The ratio of the rated reactive power of each of the SVCs (12.4MVAr) to the short circuit level at the end of the track section is 0.7, which is very high compared with normal industrial application of SVCs. Under these conditions it is important to model the controls of the SVCs, which are of the phase locked loop type (Ainsworth [3]).

THE CAD MODEL OF THE SYSTEM

The CAD simulation model of the system is shown in figure 2 and the values of the components calculated from the system parameters are given in table 1. In the model the feeder is represented by four π-equivalent circuits and the locomotive loads are modelled as controlled single-phase converters. The main power circuit of the locomotive is given in figure 3(a) which is a half-controlled bridge connected in cascade with a diode bridge. Two kinds of locomotive models were created and used in this study. The first model, shown in Figure 3(b), is a simplified model which contains only a diode bridge and a current source at the dc side. This simplified model can be used to simulate the working conditions of the locomotives at full conduction. The second model is a full representation of

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the locomotive circuit, which is useful when a locomotive operates under partial conduction. When several locomotives are running together as a consist, they are modelled as one equivalent locomotive with appropriately modified load current and transformer inductance. The SVCs in the system are modelled in full, including the controls of the TCR.

The CAD package used in the study is called SABER, which is a comprehensive, flexible, time domain analysis system. One of the big advantages of this package is that it leaves much freedom to the user to create his own components and sub-circuits used in the system simulation, by using a special language, MAST. In the CAD model of the compensated railway system, the basic components such as the resistors, inductors, capacitors and the single phase ac source are provided by a library. However, some of the special parts, particularly the thyristors, the power transformers and the controls for the SVCs, are created using the various features of the package.

PHYSICAL MODELLING

A physical model of a power system is one where real system inductance, capacitance and resistance are modelled with inductors, capacitors and resistors (Ainsworth et al. [4]). Likewise, converters are modelled with small scale converter units, which have identical control to the real converters. Therefore, a physical model is a small scale version of the real system having identical voltage and current waveforms to the real system.

Physical modelling has many qualities which are different from other forms of analysis. However, as far as the work here is concerned, it is used as an alternative means of modelling to provide confidence in the CAD modelling results. Since physical modelling is conducted in a totally different manner from CAD modelling it is assumed here that if the results of a time domain model and a CAD model agree, they are almost certainly both correct.

The physical model of the system with 2 SVCs is the same as shown in figure 2 and the values of the components used for the model system are also given in table 1. Since the behaviour of the physical model is virtually the same as the real system, the SVC controllers can be made indentical to those found on a commercial SVC. Simplified control systems have been used for the locomotives but care has been taken to ensure that both the steady state and transient performance are accurately modelled.

SIMULATION RESULTS AND COMPARISON

In order to evaluate the different simulation models of the compensated railway system, a number of cases with different load conditions have been simulated using each model. A few of the results are presented here.

Figure 4 illustrates the locomotive current waveforms when 2 locomotives are operating; one locomotive is assumed to be operating above base speed and has two bridges fully conducting while the other has one bridge under partial conduction. Figure 4(a) can be compared directly with figure 4(b), which is taken under identical conditions, from the CAD model. The comparison is very close.

A typical comparison between the voltages and currents produced by physical and CAD models is shown in figures 5(a) and 5(b) respectively. Figure 5(a) is the waveform of the system under part load conditions obtained from the physical model of the system. The load condition for this case is one fully loaded locomotive at each of the load points 1 and 3 (figure 1) with both locomotives working at full conduction. There is no load at the load points 2 and 4. In figure 5(a) the system supply current, the two TCR currents and the two SVC voltages (ie voltages at points 2 and 4) are plotted. The simulated results for the same working conditions produced by the CAD model are given in figure 5(b). The agreement is very close. Slight differences, particularly for high order harmonics such as 23rd and 25th may be observed by a close examination. There are several reasons for this. The supply voltage used for the physical model is not perfectly sinusoidal and constant; the tolerances on some of the component values selected for the physical model and the changes in their characteristic parameters at high frequencies result in slight differences in the firing angles of the TCRs in the two models and hence in the generation of high order harmonics in particular. Also the CAD model seems to provide less damping for the high frequency oscillations caused by the switching action of the TCRs and the locomotives in the system. In view of these differences, the correlation of the results is extremely good.

CONCLUSIONS

A 75km feeder with two SVCs has been successfully modelled by a physical simulator and a CAD package SABER. It has been shown that very good agreement has been achieved between the results obtained from each model.

It is concluded that both the physical and CAD models are accurate and either may be used to evaluate system performance. Further, it is demonstrated that CAD models of complex groups of converters produce results that stand up to verification by other means.

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Table 1 The parameters of the model system

Element	Real value	Physical model
V_s	27.5kV	40V
L_s+L_t	27.1mH	26mH
R (line sec.)	3.17 Ω	2.2 - 3.2 Ω
L (line sec.)	25.8mH	25mH
C (line sec.)	0.375μF	0.39μF
L_{tcr1}	194.7mH	187mH
C_{svc1}	45.8μF	48μF
L_{f1}	26.3mH	25mH
L_{tcr2}	184.3mH	177mH
C_{svc2}	45.8μF	48μF
L_{f2}	26.3mH	25mH
$L_{loco.}$(each)	46.7mH	45mH
$I_{loco.}$(each)	136A	0.257A

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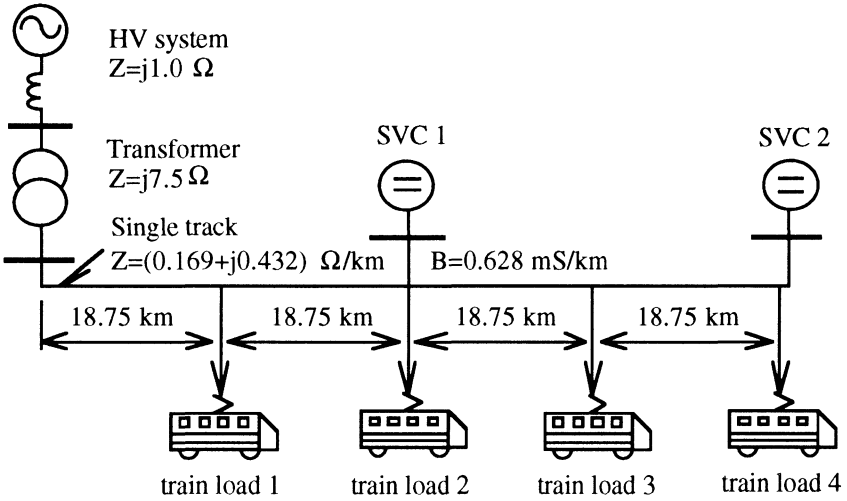

Figure 1. System Schematic Layout for the Study

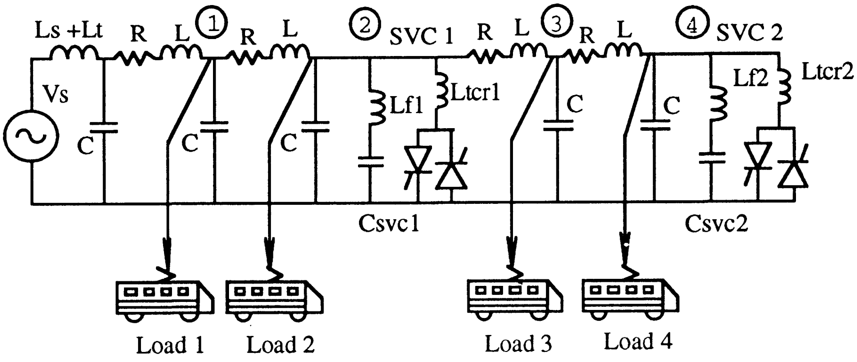

Figure 2 Simulation model of the system

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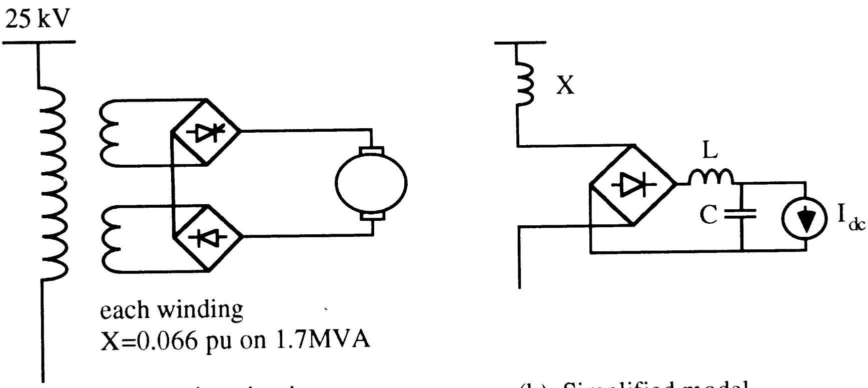
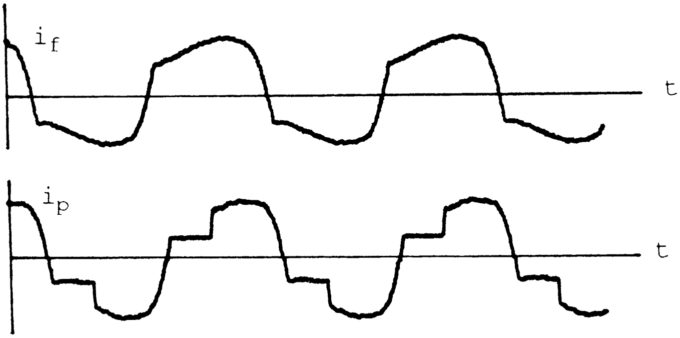
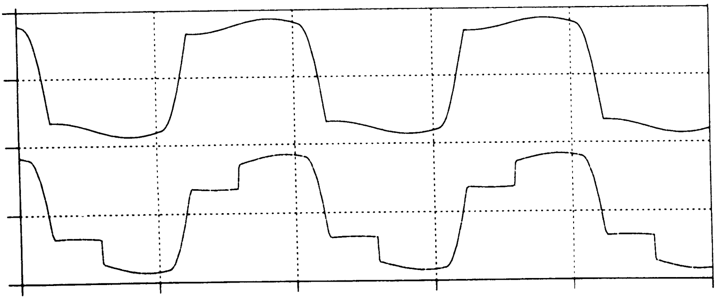


(a) Locomotive circuit (b) Simplified model

Figure 3. Locomotive circuit and its simplified model



(a) Physical simulation



(b) CAD simulation
i_f --- Full conduction current, i_p --- Partial conduction current

Figure 4. Locomotive supply current waveforms

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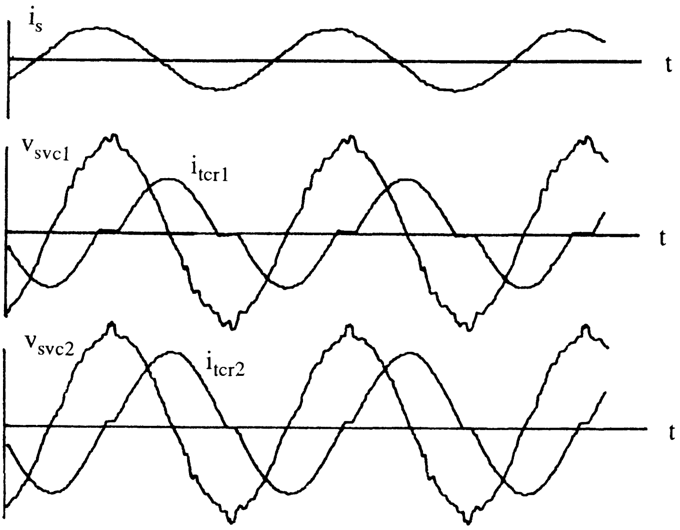
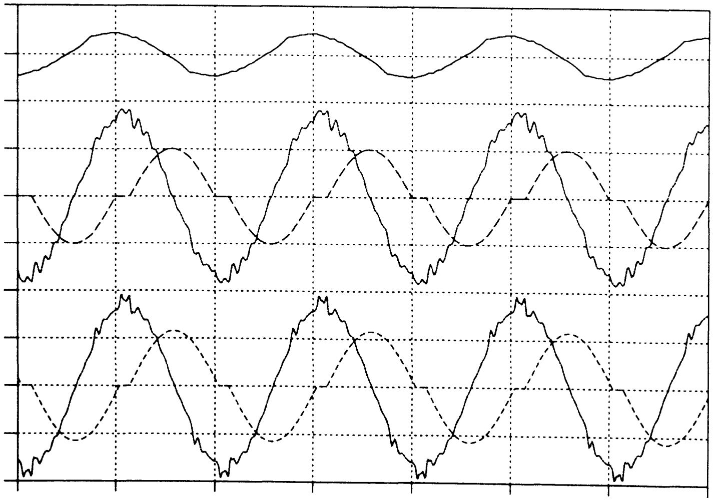


(a) Physical simulation results of the system



(b) CAD modelling results of the system
i_s --- System current, i_{tcr1}, i_{tcr2} --- Currents of the TCR 1 and TCR 2, v_{svc1}, v_{svc2} --- Voltages of the SVC 1 and SVC 2.

Figure 5. Simulation results of the system with light load condition