Multi-train simulation of DC rail traction systems with regenerative braking

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Plan

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- Properties of a good simulation tool.
- Simulation of railway systems and SimuX.
- The user interface and the data input.
- An Object-oriented perspective.
- Implementation of simulation
  - Train movement simulation.
  - Solution of the power network.
- Report generation.
- Summary

Why simulation?

- ✓ The cost of construction of a rail traction system is high.
- ✓ Making modifications on a constructed system is difficult, time-consuming and costly.
- ✓ Therefore, simulation is an important part of the design and optimization of rail traction system.
- ✓ Simulation is also helpful in testing the proposed changes in the operating conditions (e.g. Decreasing headway times, changing the types of vehicles) of the system.

Properties of a good simulation tool

A good simulation tool must have the following properties:

1. **Correctness:** Simulation results should reflect the real system.
2. **Fastness:** Simulation results should be produced quickly.
3. **Flexibility:** Parameter changes and changes in the interconnection of subsystems should be allowed.
4. **Interaction:** A nice user interface
5. **Standardization:** Compatability with available standards.
6. **Report generation:** Representing simulation results efficiently.

Simulation of Railway systems

Simulation of railway systems include specific problems.

Simulation of Railway systems

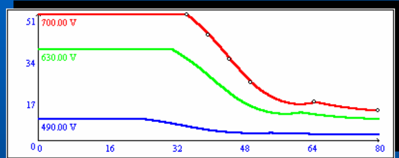
Railway systems are composed of

a. Electrical
b. Mechanical
c. Social

components.

A Simulator is expected to cover these aspects.

Simulation of Railway systems



Simulation of railway systems is difficult as it usually involves the solution of **multiple nonlinear equalities**.

Simulation of Railway systems

Another difficulty arise in the simulation of railway systems is that the system is **composed of many (hundreds of) components** and the relation betwen these components **(the topology of the system) changes in time.**

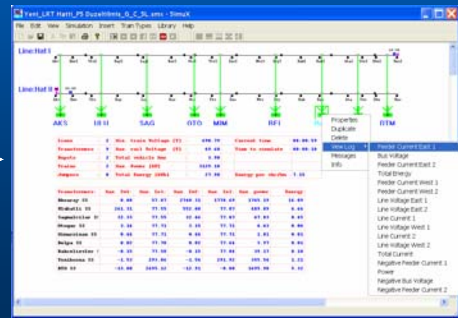
What is SimuX?

- ✓ **SimuX (SimulatorX)** is a rail traction power system simulator, that tackles the above mentioned problems and have the properties of a good simulator.

User interface and data input

A good simulator should allow easy manipulation of data as well as providing mechanisms to input data conveniently (Martin [8]). For this purpose SimuX provides a visual interface to allow easy edition of the track.

SimuX main screen

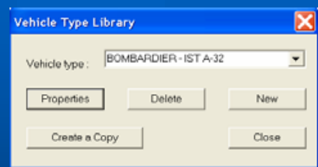


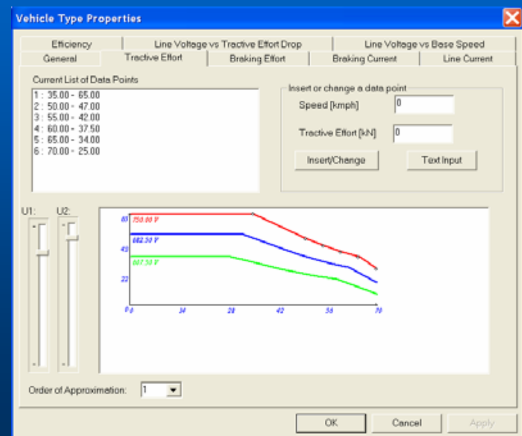
Use of libraries

In order to support standards and simplify data entry several items can be stored in libraries to be used again and again. Among these items the following are the most important:

- ✓ Vehicle Types
- ✓ Power Line Types
- ✓ Rail Types

Use of libraries (Vehicle Types)



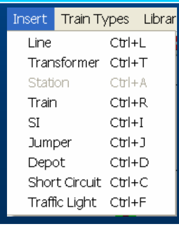


User interface and data input

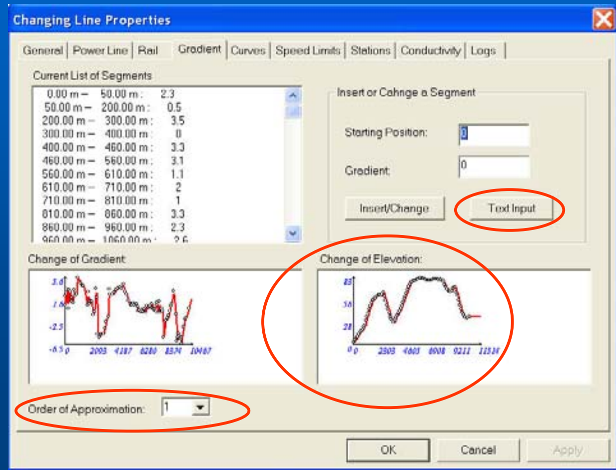
The following items can be entered by the help of dialog boxes:

- ✓ Lines
- ✓ Transformer Substations
- ✓ Trains
- ✓ Depots
- ✓ Passenger Stations
- ✓ Isolation Points (SI)
- ✓ Jumpers (between catenary systems or rails)
- ✓ Short Circuits
- ✓ Traffic Lights

As these items are entered they are visually represented on a scaled version of the track, and allowed to be edited or deleted later on.

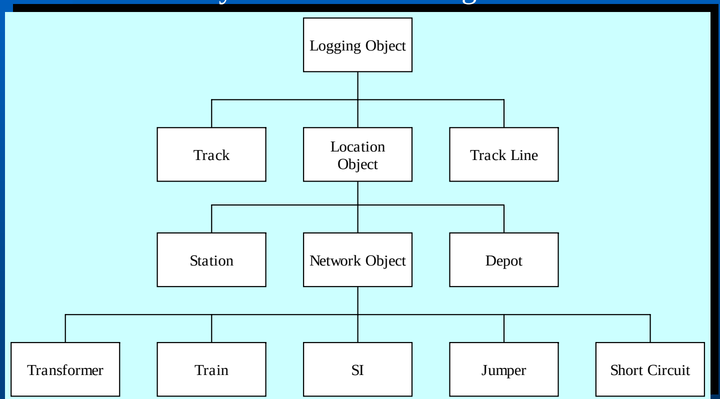


User interface and data input (Lines)

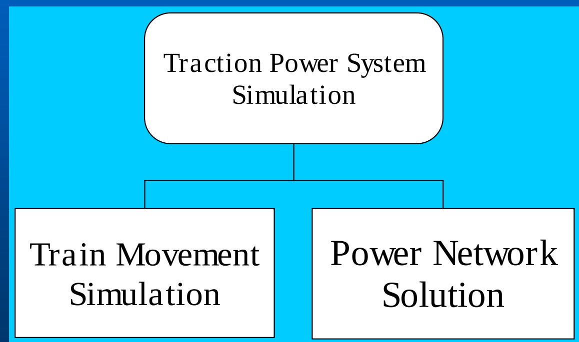


SimuX Class Hierarchy

Class hierarchy used in SimuX is given as follows:



Simulation



Train Movement Simulation

In train movement simulation, the trains are assumed to be rigid bodies moving along the track with no slipping or sliding, and obeying **Newton's third law**:

$$Ma = F - F_R - F_G - F_C$$

Train Movement Simulation

The following algorithm can be used:

1. Using characteristics of the train (e.g. max. speed and comfort rate), and signalling mechanisms (fixed block or moving block) determine the target acceleration.
2. Find the corresponding required tractive effort.
3. Using the motor characteristics and the line voltage determine the maximum tractive effort (or maximum braking tractive effort) possible with the current speed of the train.

Train Movement Simulation

4. Determine the actual acceleration and corresponding electrical power requirement (or regeneration) of the train.
5. Determine the new position of the train to be used in next iteration.

Network Solution

There are several methods to solve a rail traction power network.

A direct matrix approach where the network matrix is formulated using nodal analysis is adopted by SimuX.

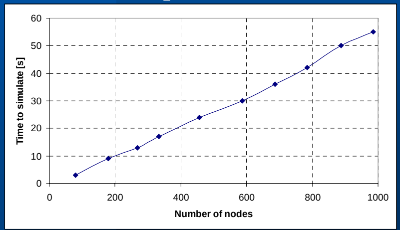
Here, the network is assumed to be formed by resistances and pure voltage or current sources at a given time. Difficulties involved are:

1. Large dimensions
2. Dynamic topology
3. Regenerative braking

Network Solution

In the solution of the power network SparseLib, which allows LU factorization of positive definite sparse matrices, is used.

It is possible to show that computational complexity involved is linear with respect to nodes.



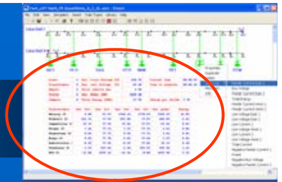
The number of nodes on a typical power network vs. the time to simulate the network for two minutes (with 100ms sampling time) using SimuX on a Pentium III – 1GHz computer.

Report Generation

The data processed by a simulation tool is meaningless if the user cannot visualize and interpret it.

SimuX proposes several mechanisms to visualize the output data.

Front end



Gives dynamic information on all critical values.

Lines :	2	Min. train Voltage [V] :	689.19	Current time :	08:03:25
Transformers :	9	Max. rail Voltage [V] :	49.63	Elapsed time :	00:01:52
Depots :	2	Total vehicle kms :	13.75		
Trains :	2	Max. Power [kW] :	3129.18		
Jumpers :	0	Total Energy [kWh] :	68.36		

Transformers:	Max. Iw1:	Max. Ie1:	Max. Iw2:	Max. Ie2:	Max. power	Energy
Aksaray SS	0.00	57.86	2740.31	1775.59	1745.19	29.00
Ulubatli SS	261.31	81.47	1216.95	81.81	985.26	18.94
Sagmalcilar S!	85.09	81.47	85.44	81.81	96.65	1.58
Otogar SS	85.09	81.64	85.44	81.64	8.85	0.12
Mimarsinan SS	85.26	81.64	85.26	81.64	1.61	0.03
Belpa SS	85.26	81.71	85.26	81.57	12.43	0.07
Bahcelievler !	85.34	83.10	85.19	83.37	122.56	0.68
Yenibosna SS	85.13	1307.93	85.40	292.14	1001.69	6.06
DTM SS	1428.75	2697.22	56.72	0.00	1697.27	11.89

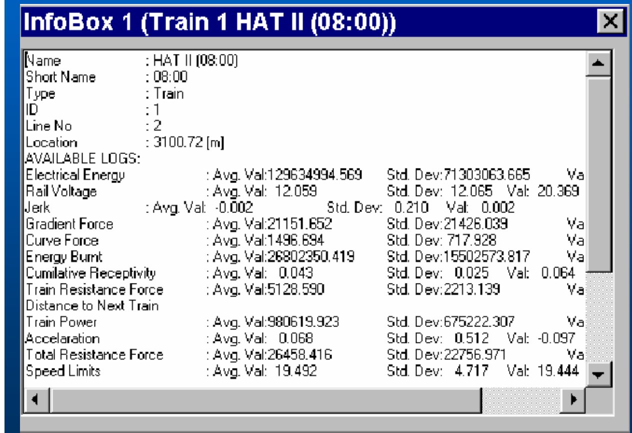
Message Boards

Show important events in the simulation.

Message Board 1 (All messages)

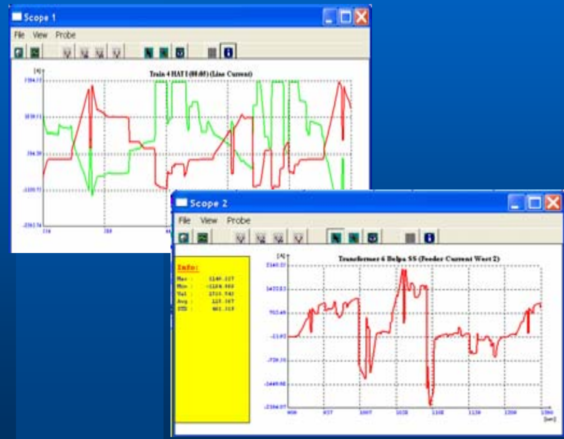
ID	Time	Sender	Message	Extra Info.
15	08:04:23	Train 2 HAT I (08:00)	Train leaves station.	Station 1015 YenI
14	08:04:04	Train 2 HAT I (08:00)	Train arrives station.	Station 1015 YenI (17026.24 [m])
13	08:03:25	Track	Simulation Started.	
12	08:03:25	Track	Simulation stopped	
11	08:03:21	Train 1 HAT II (08:00)	Train leaves station.	Station 2003 Ulu
10	08:03:03	Train 1 HAT II (08:00)	Train arrives station.	Station 2003 Ulu (2006.42 [m])
9	08:02:57	Train 2 HAT I (08:00)	Train leaves station.	Station 1016 DtmI
8	08:02:40	Train 2 HAT I (08:00)	Train arrives station.	Station 1016 DtmI (17799.04 [m])
7	08:01:33	Train 1 HAT II (08:00)	Train leaves station.	Station 2002 Emn
6	08:01:13	Train 1 HAT II (08:00)	Train arrives station.	Station 2002 Emn (950.40 [m])
5	08:00:41	Train 2 HAT I (08:00)	Train leaves station.	Station 1017 HavI
4	08:00:02	Train 2 HAT I (08:00)	Train arrives station.	Station 1017 HavI (18969.00 [m])
3	08:00:00	Depot 2	Train leaves depot.	
2	08:00:00	Depot 1	Train leaves depot.	
1	08:00:00	Track	Simulation Started.	

Information Boxes



Give brief info on selected items.

Scopes

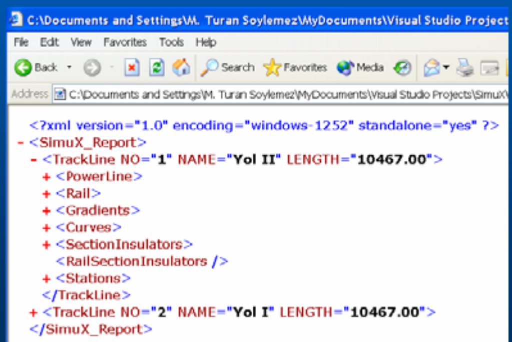


Scopes allow visualization and detailed examination of all logged data.

It is possible to export data to **MATLAB, Mathematica or Excel.**

Report Generation

It is important for a simulation tool to create reports in different formats including XML.



Summary

- **Simulation is an important part in the design and or analysis of rail traction power systems.**
- **Simulating railway systems is difficult due to high dimensions and nonlinearities involved.**
- **SimuX is a railway system simulator developed for simulating all kinds of aspects of DC fed rail systems.**
- **Properties of a good railway system simulator are discussed in the example of SimuX.**