An Integrated Simulator for AC Traction Power Supply of Railway Vehicles

1. The link with the chosen Topics and Sub-Topics

The authors' 1st choice Topic is 6 Infrastructure and Sub-Topic 6.4 Electric power/catenary facilities, because the research is on the development of a simulator for the AC traction power supply of railway vehicles and 6.4 is the Sub-Topic most directly related to electric power facilities.

2. The reason for the research

In constructing new high speed railway lines or increasing the number of trains in operation, electric power calculations are an important issue. Therefore, a new integrated simulator was developed for AC traction power supply of the Shinkansen and other railway vehicles. The simulator provides essential information for rating substations, catenaries, and protective equipment.

3. The methodology

The simulator calculates energy consumption of individual trains during running, and solves load voltages and currents in any branch of AC traction feeding circuits (such as in catenaries, feeders, and transformers).

3.1 Calculation of energy consumption of an individual train during running

Diagrams of trains, specifications of respective types of rolling stocks, positions of gradients, curves, stations, and tunnels enable the determination of the position, velocity, and traction current of each individual train at every second, with equations of motions implemented. High speed trains running at speeds exceeding 200 km/h required correct approximation of running resistance.

Then the running resistance quadratic velocity equations for both tunnel sections and open sections are switched. In addition, recent Shinkansen trains have the capability of constant velocity running and braking control with continuous curves to stop at stations. A simplified adjusting notch algorithm and the reverse velocity curve fitting algorithm were developed for these purposes.

3.2 Method of solving multiple conductors for AC feeding circuits

A well-proven solving engine for multiple conductors is used to analyze voltage and current distribution, to guarantee numerical accuracy. The engine has over 30 years of history internally at RTRI, and calculates all the basic parameters of the Shinkansen with autotransformers (AT, 25 kV x 2). The engine uses a common mathematical technique that handles AC feeding circuits (such as for catenaries, feeders, rails, protective wires, and earth conductors) as parallel conductors with self-induction and mutual induction.

Automatically, the feeding circuit is divided into nodes and branches along a rail route from a substation to the end. Each node is a changing point of circumstances (such as a substation or AT, geometry of conductors, tunnels, changing resistivity of earth, and presence of a train) that has a parallel conductor which has potential (matrix V in Equations 1 to 3 below) and input current (G) and admittance (Y). Every branch is a set of homogenous circumstance conductors that have passing current (I) and their own impedances (Z). The Z matrix consists of self-impedances and mutual impedances between each conductor which is derived from the conductor's geometry position, radius of conductor, resistance of direct current, feeding frequency, and earth resistivity, using the equations of Carson-Pollaczek. Each train is located on a specified node as a constant current source between the trolley and rail. These concepts are described in Fig. 1 and Equations 1 to 3. Then the engine determines voltages and current of every node with the inverted impedance matrix and equation using Schechter's L-U algorithm.

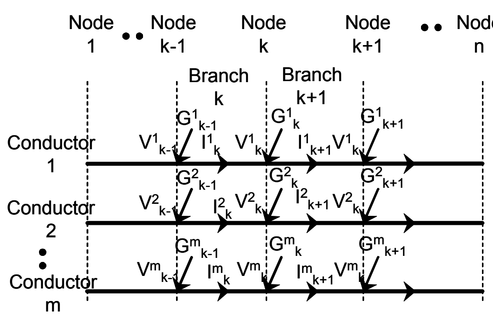

Fig. 1: Example of nodes and branches.

$I_2 + Y_1 \cdot V_1 = G_1$ (1)
$I_{k+1} - I_k + Y_k \cdot V_k = G_k$ (2)
$-I_n + Y_n \cdot V_n = G_n$ (3)

In Japan, some traction substations have FACTS (flexible alternating-current transmission system) devices such as SVCs (static VAR compensators) or STATCOMs (static synchronous compensators) for balancing power or suppressing voltage fluctuation. This program has an additional function to describe such FACTS devices.

4. Results

To evaluate the accuracy of this simulator, the data calculated using this simulator was compared with field data of measurements taken on the Shinkansen. Figure 2 shows favorable results of comparison. In this case, the shapes of energy consumption are very similar. Further investigation to be discussed in the full paper shows remarkable results of suppressing voltage fluctuations with FACTS device calculated.

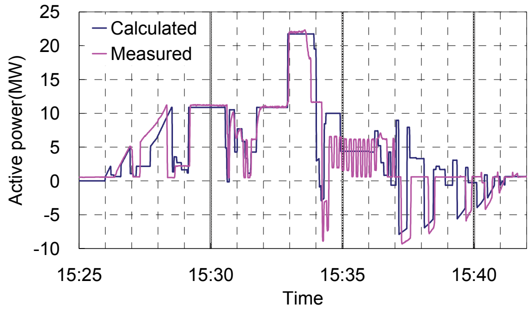

Fig. 2: Comparison of measured field data and calculated data.

5. What is new about the research?

This simulator is an integration of calculating energy consumption of an individual train during running, and accurate calculation of the feeding circuit. Easy-to-use operation and a well-proven internal algorithm produce reliable results. It emulates sophisticated technology such as the digital ATC system for the Shinkansen and constant velocity operation. It can also handle some FACTS devices such as SVCs.

6. Potential for implementation

An integrated simulation tool for AC traction was developed, and the data evaluated by the simulator proved the reliability of this tool. The algorithm for this simulator can be adopted and used in further development of such tools.

7. Impact on railway business

This simulator can be used as a standard analyzing tool for various applications in power supply of railway vehicles. For example, for the construction of the Taiwan High-speed Rail system, which went into revenue service in 2007, additional works with this tool developed by the Japanese enabled EMC calculations of induced voltage on telephone lines along the railway route.

8. Potential for international collaboration

The simulator developed in this work has been validated to be accurate in calculations of AC traction power supply of railway vehicles, and can be useful in promoting international standardization. The authors are interested in attending WCRR 2019 to meet with various experts from around the globe to discuss possibilities for collaboration on these issues.