Promoting Electric Public Transport

TROLLEY Project

Outputs 4.2.3. Variants of Technical Organizing

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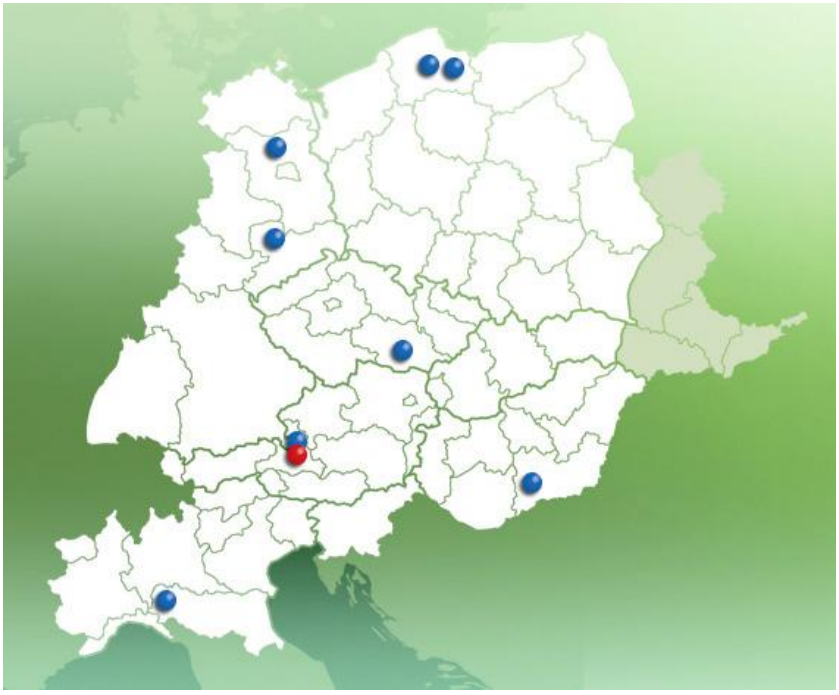
Status: Released

Short Version



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List of Abbreviations:

GUW..... track substation
FD ..... contact wire
RiS ..... copper-silver alloy grooved contact-wire

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I. Preface

The principal purpose of this project is the development of a solution for the power supply of trolley bus lines across open land track sections.

The measurements during the test journeys served the determination of the bus data as input data for the simulation, as an energy-based line analysis and for verification of the simulation, as well as for the inclusion of the geometrical data of the bus network. Furthermore, weak spots in the network are supposed to be identified by the measurements. On the following pages, the individual kinds of test rides will be explained.

II. Determination of the bus data

Various bus parameters are necessary for the simulation as input data. The bus data obtained from the data sheets to this end only concerns the unladen mass and the allowed overall mass. All other data were determined from test journeys. The maximum performance, the efficiency factor during the acceleration and while braking, the rolling resistance, the offset performance and the performance regulation are all included in this.

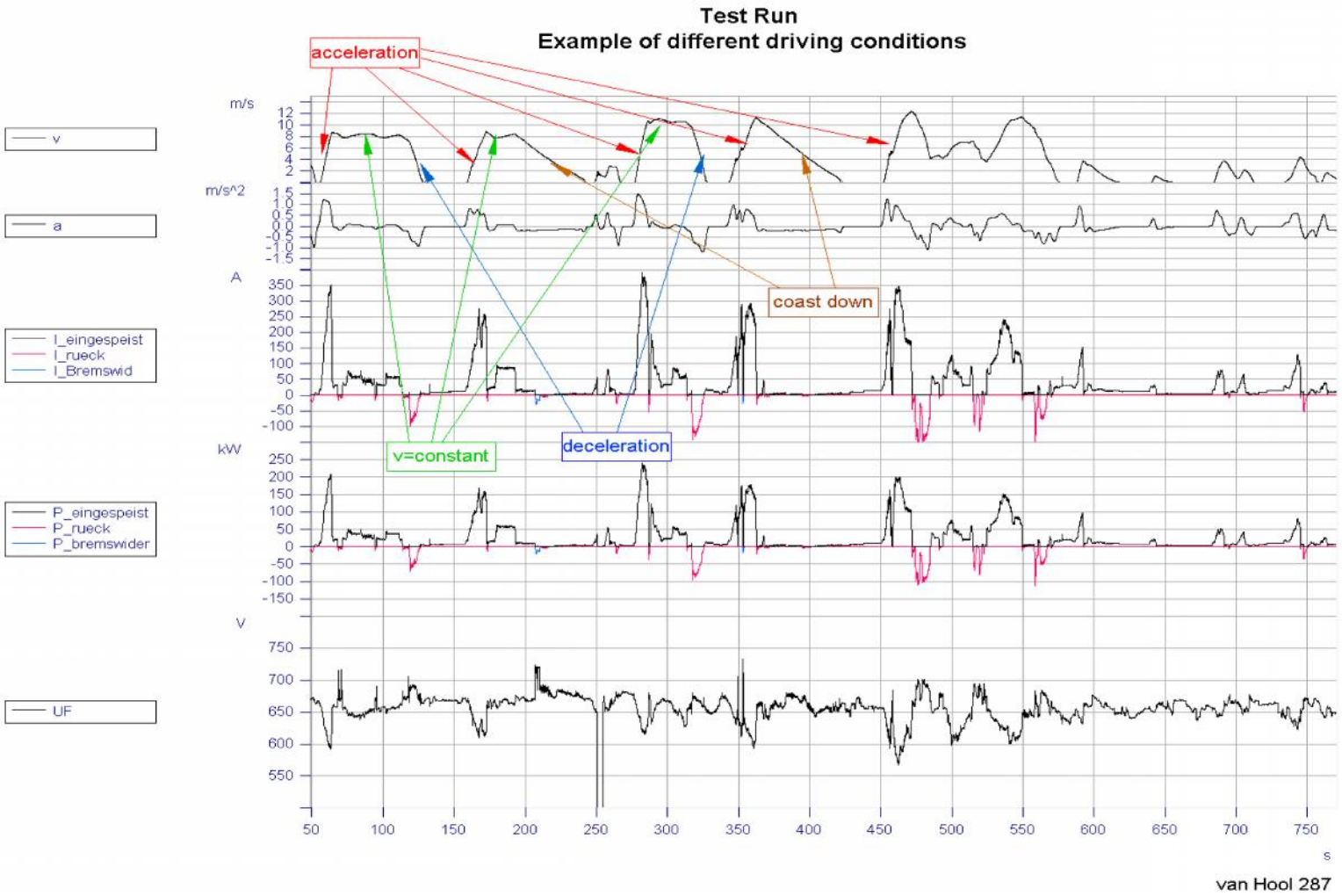

Fig. 1: Test run overview

Parameter Determination

a) constant acceleration until reaching the
b) maximum output,
c) Power reduction from the limit speed v_{ab}.

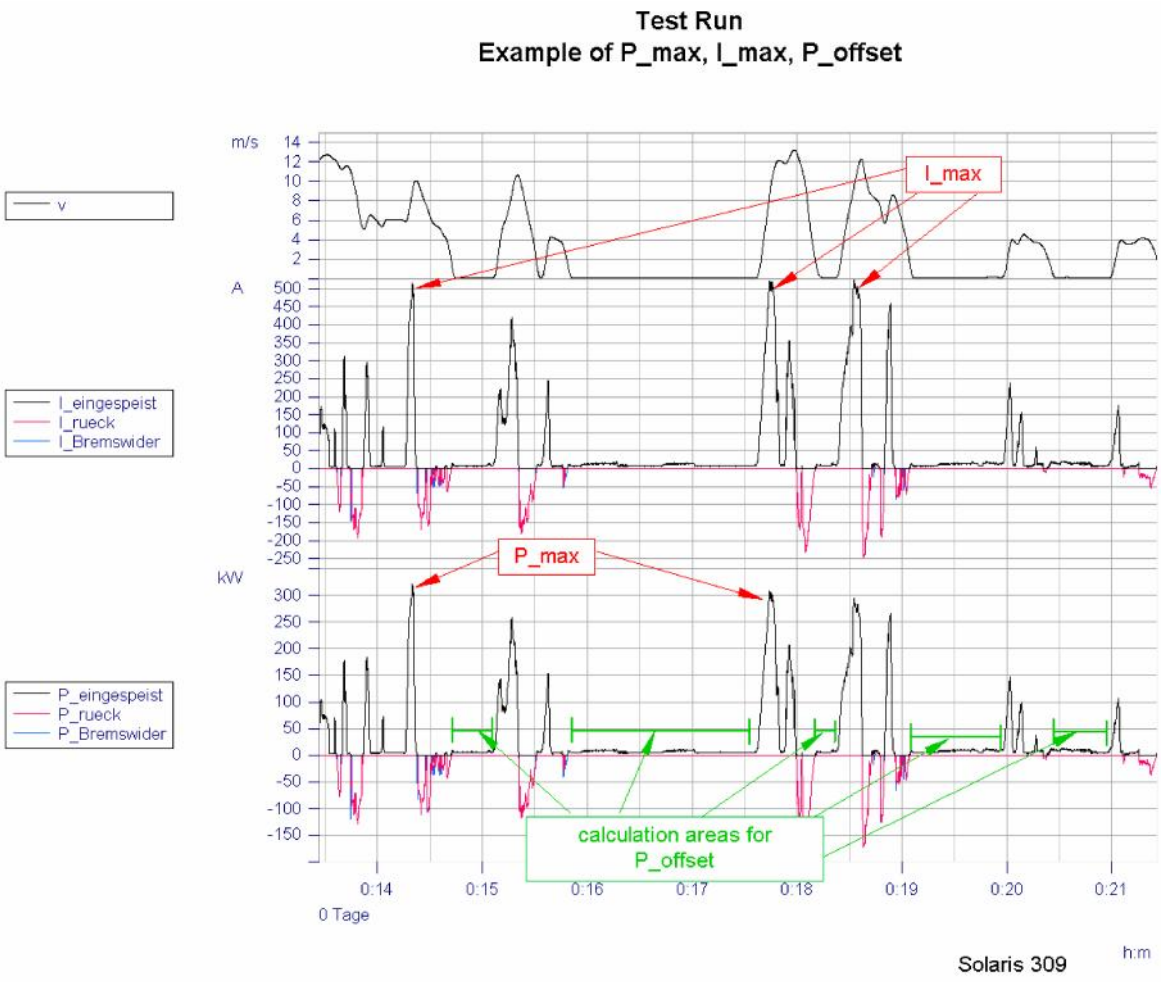

Fig. 2: P_max, I_max, P_offset

Poffset, Offset output with heating switched off

The offset output is that proportion of the total output which does not serve the actuator. Auxiliary units like capacitor, fan, control unit, light etc. are supplied by it.

P_{offset} was determined by calculating the average output during the downtime during the test journey. These areas are identified as an example in Fig. 2.

The offset output affects the calculations of the efficiency. Furthermore, it has a direct influence on the simulation, because it determines there, of course, the energy consumption during all stationary phases.

Fig. 6 shows how problematic the measurement of the offset output is. It differs clearly between the left and right standstill area (2.7 kW and 6.5 kW). There is a coasting phase in the middle where the offset output amounts to only 0.5 kW. These differences would mean different efficiencies from $\eta=0.80$ to $\eta=0.91$. Therefore, it was not the mean output but the offset output, immediately before or after the acceleration process, which was used for the efficiency calculations.

The long-term measurements show that the offset output during coasting, with 0.5 kW... 1 kW, is probably significantly smaller than at a standstill. Furthermore the offset output increases about 3 sec. before starting by some kW. For the simulation, a uniform offset output was used for stationary phases as well as for the coasting phases.

Rolling resistance

The rolling resistance corresponds to the friction coefficient. It is calculated from the coasting phases as the quotient of the delay during coasting and the gravitational acceleration $R=-a_{roll}/g$. Since the rolling resistance is speed-sensitive, it was determined in each case as a mean value from some coasting processes for the following speed ranges (van Hool-Bus).

- 0...3m/s
- 3...6m/s
- 6...9m/s
- 9...12m/
- 12...13m/s

Efficiency factor

The efficiency of the bus drive was determined both when feeding in as well as during regenerative feedback. The efficiency while feeding was determined from the starting process. It is calculated from the mechanical energy which the bus gains when dirivng off and the electrical energy which the bus consumes for the acceleration. The offset output is not considered.

Bus parameters and the extension section to Esch

The parameters for the simulation were determined on a test track in urban areas at a maximum of 50 km/h and without gradient and were used unchanged for the simulation on the extension track section. The bus manufacturers have yet to address the following questions:

- Is the maximum performance uphill also available for a longer time of up to 2 min.? In town, the speed range for the maximum performance during acceleration is already exceeded after approx. 5 seconds.
- Does derating uphill start at the same speed and does it have the same magnitude as on a straight line?
- Can the back-fed electricity become as big as the fed-in electricity or is it limited beforehand? Without limitation, regenerative feedback electricity of up to 500A would flow when braking at a stop downhill.
- When braking downhill, is the pneumatic brake switched on? In the simulation, this is not considered.

III. Infrastructure

On every line, the contact wire voltage, the overall electricity and the speed was recorded in a van Hool-Bus across the whole day. In parallel, the position of the bus was recorded by means of a GPS receiver in addition.

These measurements serve to obtain line parameters as input data for the simulation. To this end, the speed profile of the bus was evaluated at various times of the day and in various line segments. Furthermore, these measurements serve for line analysis. To this end, the energy consumption per km as well as its diurnal fluctuation is determined for every line.

Long-term measurements of the lines

During long-term measurement, voltages, electricity, speed and acceleration of the bus were recorded during the whole day consecutively in intervals of 90ms. In parallel, there was a recording of the bus position by means of the GPS logger at one second intervals.

First, the measurement series were assigned bit by bit to the individual journeys between the terminals. From these measurement series, the following variables were calculated in the line analysis:

energy values

- fed in power, regenerated power and power used in the braking resistors /km
- Offset power with heating

line characteristic variables

- Line length
- Average speed
- Average acceleration during start-up and braking
- Journey time and delay
- Breakdown of the line into individual track sections with different traffic density
- Number of stops in individual track sections and at times of the day with different traffic density
- Top speeds in individual track sections and at times of the day with different traffic density

The simulation can then be verified with the results of the line analysis. In Fig. 3 the energy fed in, the regenerated energy and power used up in the brake resistors is shown as an average over the whole day for all lines.

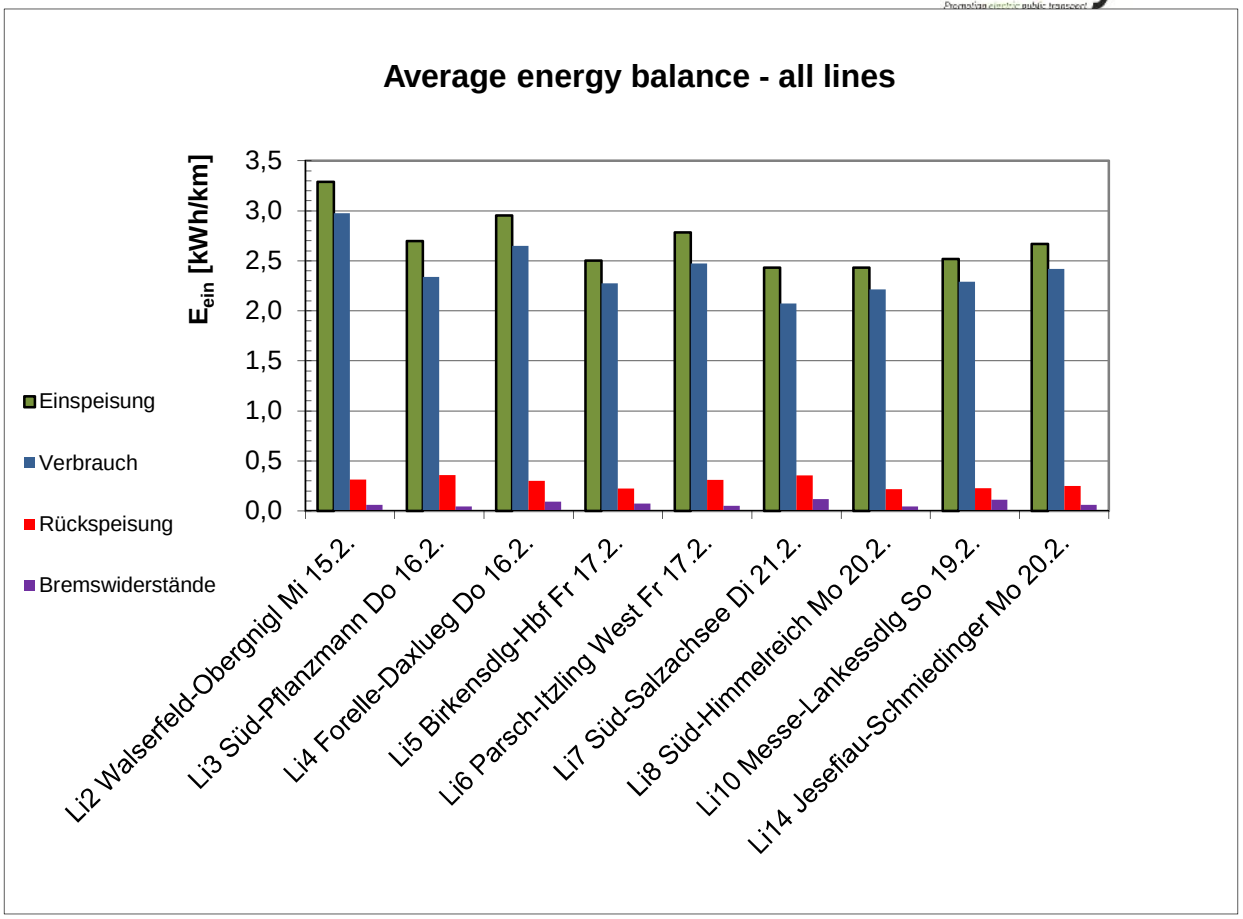

Fig. 3: Average energy balance all lines

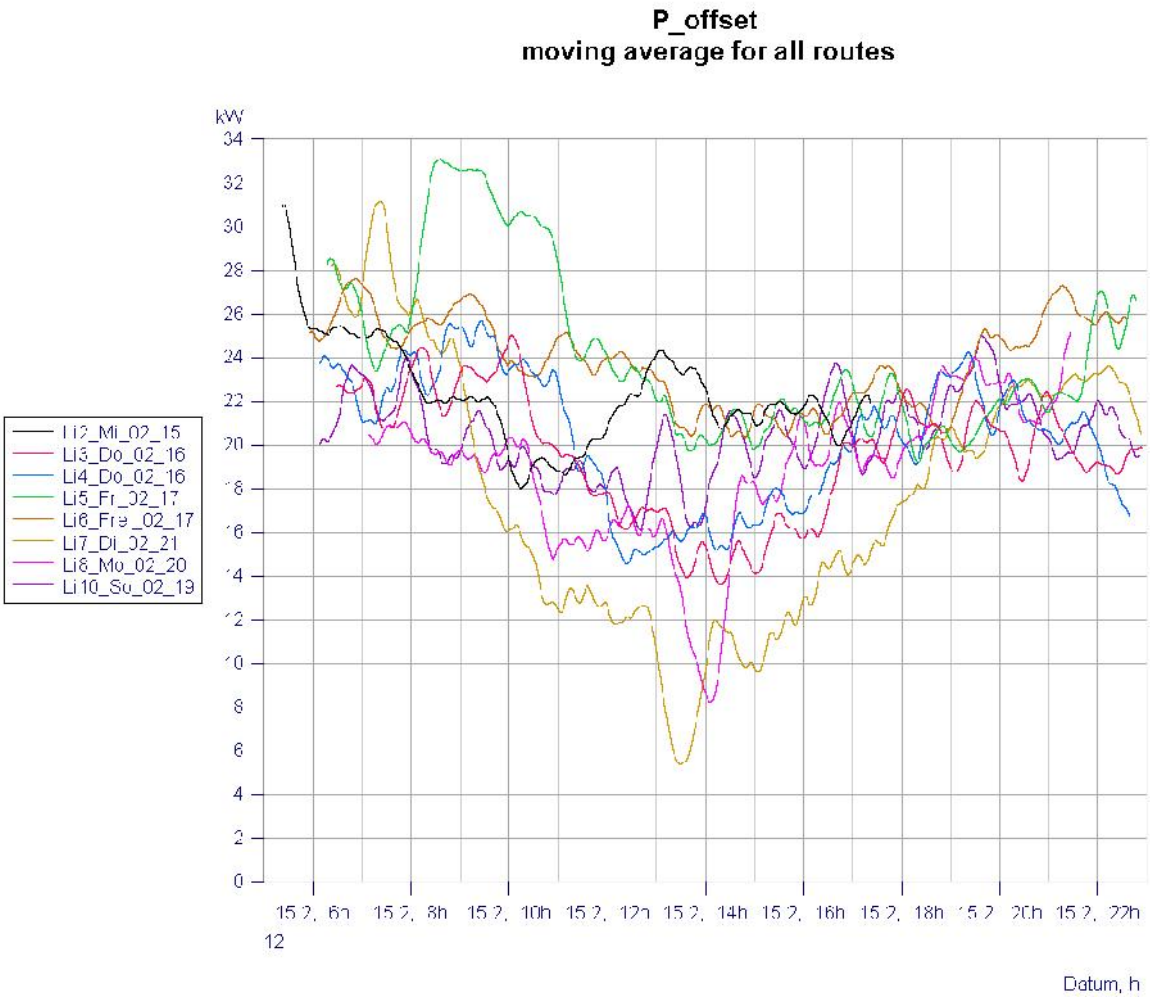

Fig. 4: Offset output for all lines

Lines with high consumption and/or with high fed-in energy also have a big offset output. This means that high energy consumption can also be traced back to a high heating output.

Lines with high average speed have a lower energy consumption per km. This, in turn, is due to the offset output, which can increase the energy consumption per km at low speed. Although the offset output varies greatly from line to line, the lower power requirement at lunch time is clearly recognizable.

Line characteristic variables

Mean speeds and accelerations

The mean speed of every line was determined without considering the waiting periods in the terminals (Fig. 5).

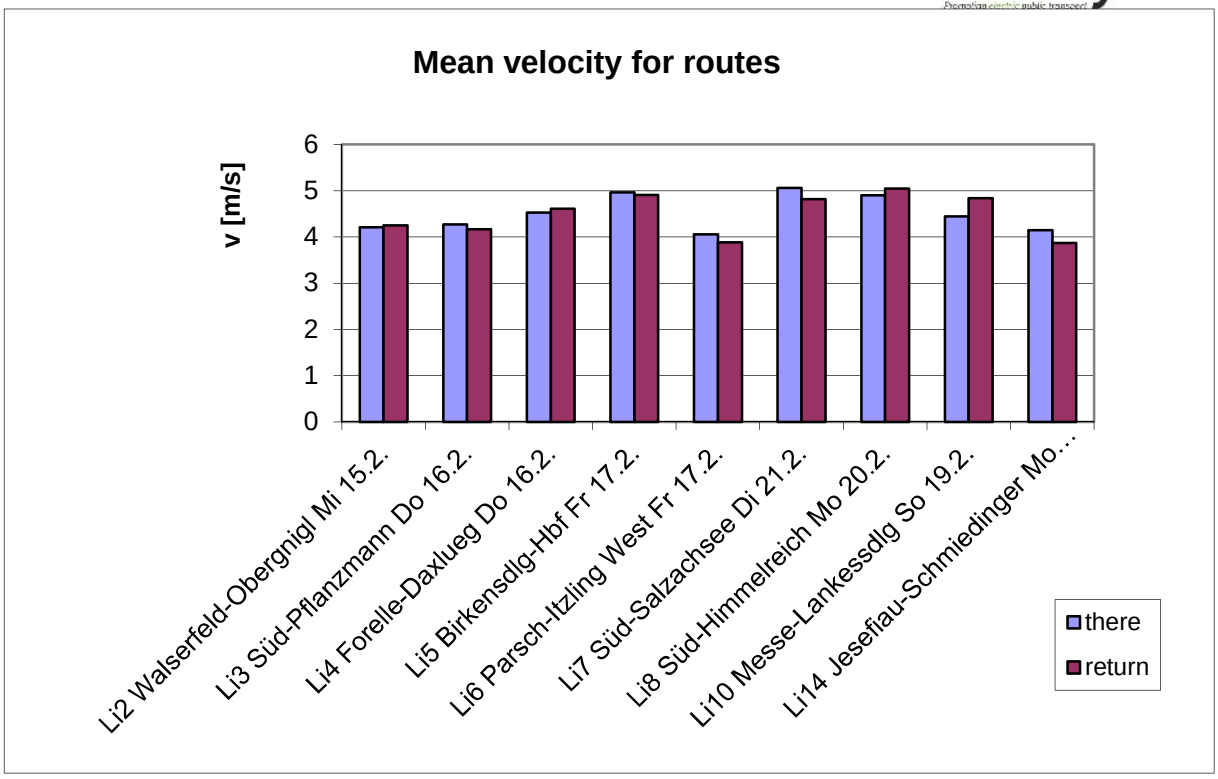

Fig. 5: Mean speed of the lines

The mean accelerations were determined from the long-term measurement of line 4.

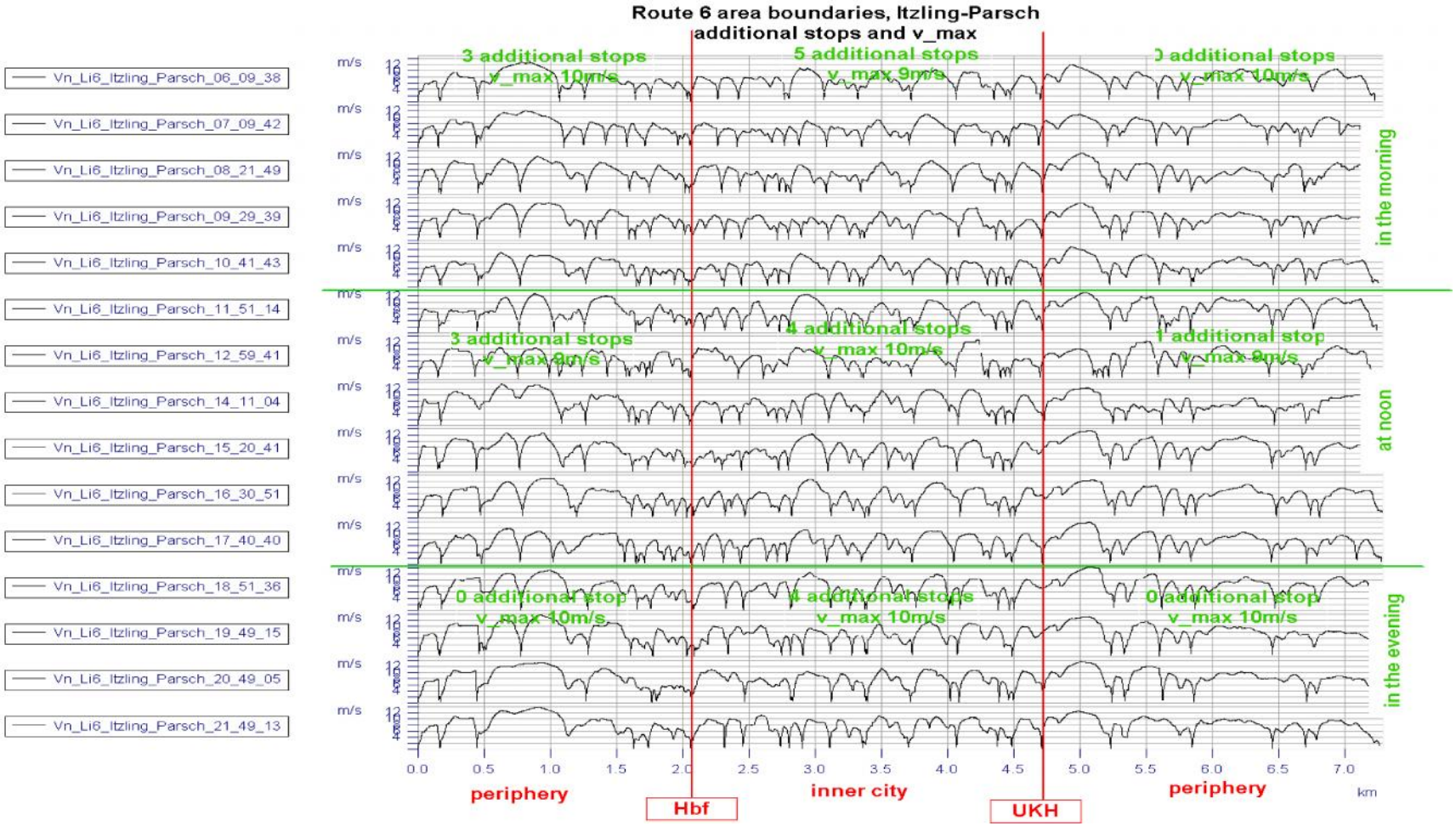

Fig. 6: Speed line 6

In accordance with Fig. 6 the number of additional stops and v_{max} was determined for all lines in every area. Number of additional stops (black) and "mean" top speed (red) in m/s. Additional stops and v_{max} are always shown for the three day sections, specified in the form of morning / (after) noon / evening.

Line	suburbs	inner city	outskirts
2 one way	Walserfeld - H.-Schmid-Platz 1/1/0 12/13/12	H.-Schmid-Platz - Mirabellplatz 15/17/12 10/11/11	Mirabellplatz - Obergnigl 0/0/-1 9/11/10
2 return	Obergnigl - Mirabellplatz 0/-2/0 9/10/11	Mirabellplatz - H.-Schmid-Platz 16/12/13 10/10/11	H.-Schmid-Platz - Walserfeld -2/-1/-2 12/13/12
3 one way	Süd - Justizgebäude 0/2/-1 13/12/13	Justizgebäude - Hbf 5/8/5 10/8/10	Hbf - Pflanzmann -1/1/0 10/10/10
3 return	Pflanzmann - Hbf 0/0/-2 9/10/9	Hbf - Justizgebäude 6/8/5 8/8/8	Justizgebäude - Süd 1/1/0 13/13/12
4 one way	Forelle - Esshaver Str. 1/1/0 10/11/11	Esshaver Str. - Sterneckstr. 5/6/1 10/9/10	Sterneckstr. - Daxlueg -2/1/0 12/11/12
4 return	Daxlueg - Sterneckstr. 1/0/-4 11/11/10	Sterneckstr. - Esshaver Str. 3/5/-1 9/9/9	Esshaver Str - Forelle 2/2/1 12/11/12
5 one way	Birkensiedlung - Justizgebäude -2/-1/-1 11/13/12	Justizgebäude - Hbf 4/6/4 11/9/9	
5 return	Hbf - Justizgebäude 4/6/4 10/10/9	Justizgebäude - Birkensiedlung -3/0/-1 12/13/12	
6 one way	Parsch - Unfallkrankenhaus 1/1/-1 9/9/11	Unfallkrankenhaus - Hbf 3/4/3 8/8/10	Hbf - Itzling 1/3/0 10/11/11
6 return	Itzling - Hbf 3/3/0 10/9/10	Hbf - UKH 5/4/4 9/10/10	UKH - Parsch 0/1/0 10/9/10
7 one way	Süd - UKH 2/0/-2 13/13/14	UKH - Hanuschplatz 3/1/0 10/9/10	Hanuschplatz - Salzachsee 2/3/0 11/10/11
7 return	Salzachsee - Hanuschplatz 7/6/4 9/9/10	Hanuschplatz - UKH 2/1/1 10/11/11	UKH - Süd 2/2/-2 13/13/14
8 one way	Süd - Justizgebäude 2/3/1 12/12/11	Justizgebäude - Schwedenstr. 3/4/2 9/8/8	Schwedenstr. - Himmelreich -1/-1/-5 12/12/10
8 return	Himmelreich - Schwedenstr. 0/1/-4 10/12/10	Schwedenstr. - Justizgebäude 5/5/3 9/9/9	Justizgebäude - Süd 1/2/1 12/13/12
10 one way	Messe - Hanuschplatz 2/4/1 9/10/9	Hanuschplatz - UKH 1/2/2 9/10/9	UKH - Lankessdlg. -1/1/2 10/11/11
10 return	Lankessdlg. - UKH -1/0/0 11/11/10	UKH - Hanuschplatz 0/1/0 9/9/10	Hanuschplatz - Messe -3/1/0 10/10/10
14 one way	Josefiau - Justizgebäude 3/_/_ 11/_/_	Justizgebäude - Kiesel 4/_/_ 8/_/_	Kiesel - Schmiedingerstr. 3/_/_ 10/_/_
14 return	Schmiedingerstr. - Kiesel 10/_/_ 9/_/_	Kiesel - Justizgebäude 5/_/_ 9/_/_	Justizgebäude - Josefiau 2/_/_ 11/_/_

Tab. 1: Area boundaries, additional stops and maximum speed

Voltage curve

Every acceleration of the bus leads to a drop of the contact wire voltage in the bus as a result of the electricity need. The cause is the voltage drop on the overhead contact system (OCS) and to a lower extent the internal resistance of the substations. The contact wire voltage must not drop to less than 420 V. As an example, the contact wire voltage was examined for line 7.

Power measurements and contact wire resistance

During three night journeys, the entire trolley bus network was driven through. All line courses were recorded by means of GPS, including the height data. All stops, crossroads, supply points, isolators, connectors and electrical shunts were marked. These data serve for constructing the network in the simulation program.

Furthermore, contact wire voltage and bus electricity was recorded. Since there were no other buses at night, conclusions can be drawn from the current and voltage at the bus about the contact wire resistance, including the internal resistance, of the substation. With a change of the bus electricity during acceleration or braking by the amount ΔI, the voltage in the contact wire changes by ΔU. For the sum total of overhead contact system (OCS) resistance and internal resistance of the substation, the following applies at every point x in track sections

$$R_{U} \quad (x) + R_{F \;\; hr} \quad {}_{ht}(x) = \Delta U(x)/\Delta I\,(x).$$

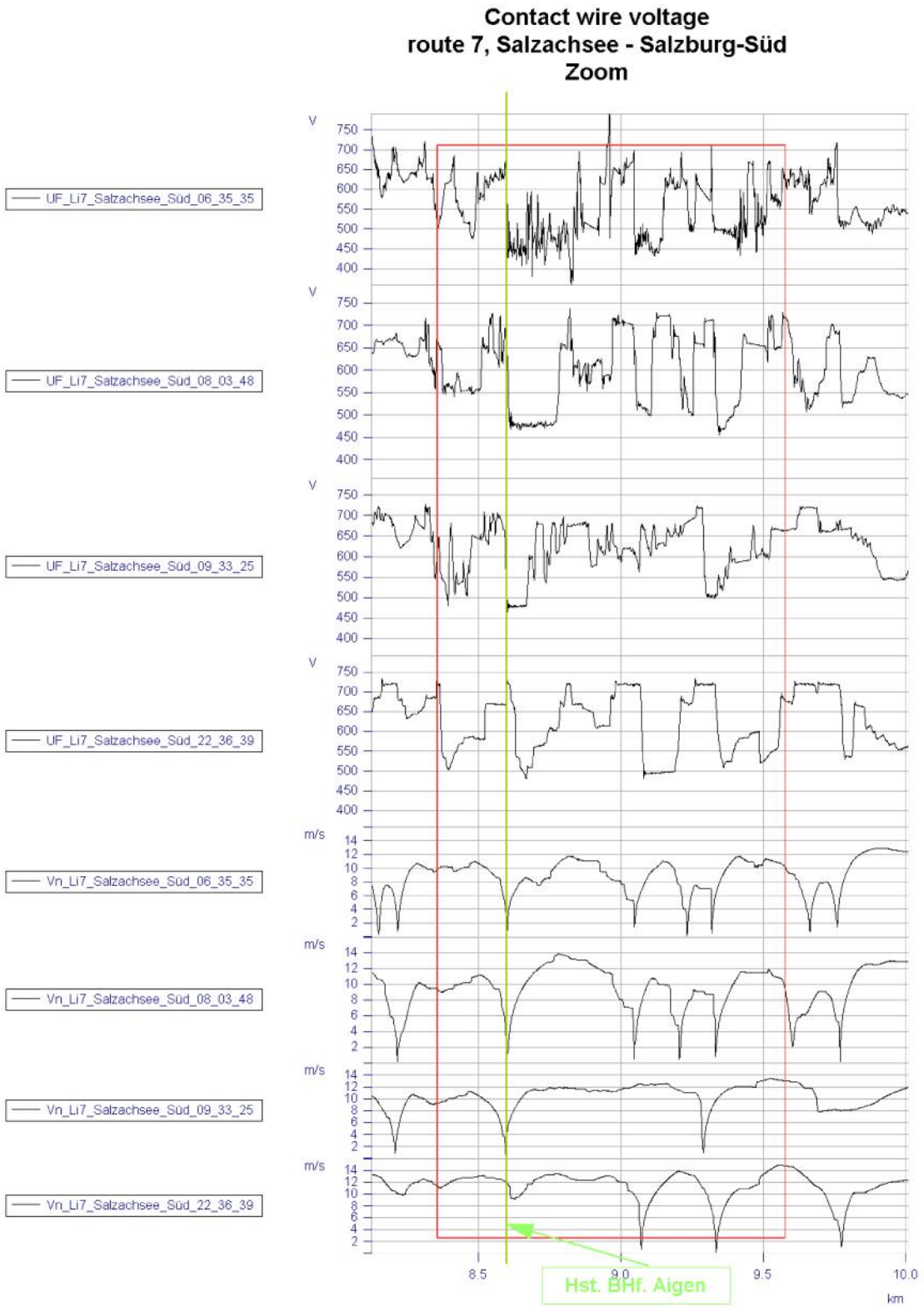

Fig. 7: Contact wire voltage line 7, expanded

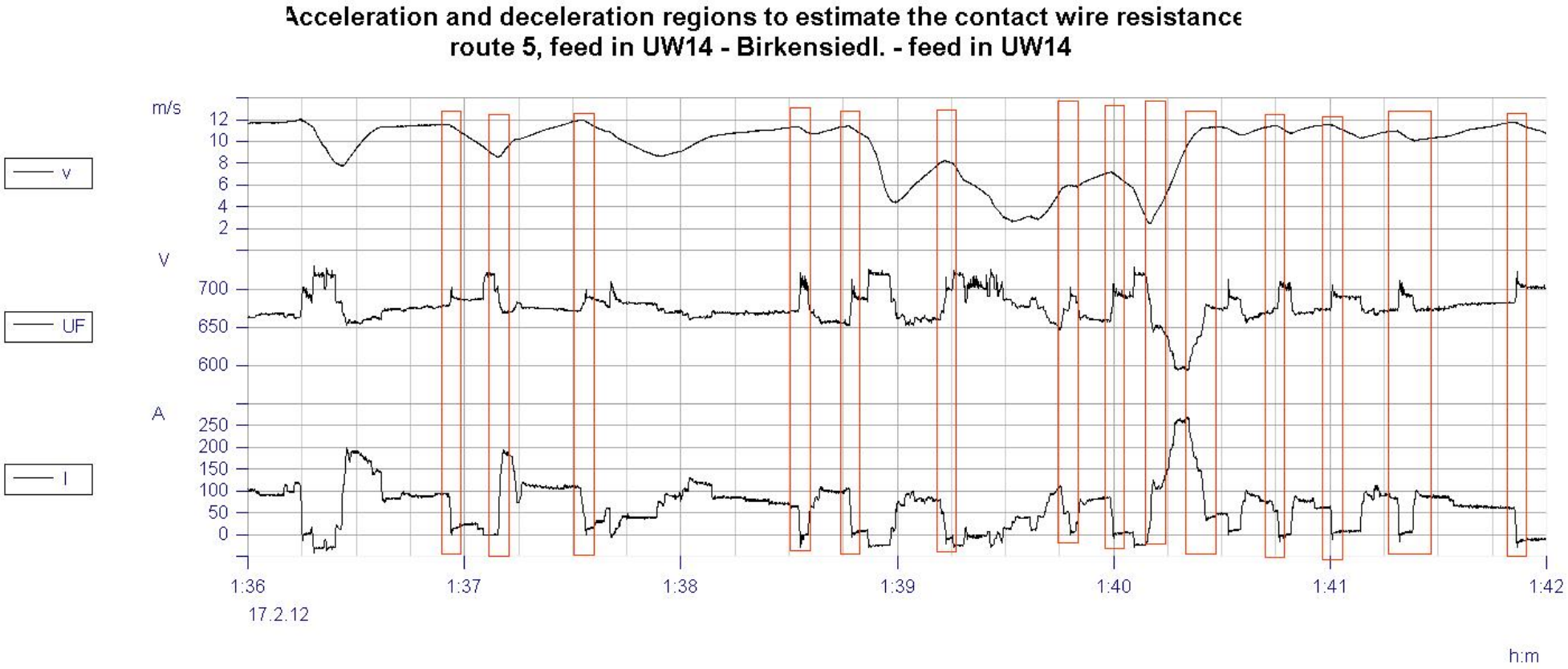

Fig. 8: Night journey line 5, U/I for resistance calculation

Voltage and current variations in the red areas were used for the resistance calculation. For this line section, this results in the following overhead contact system (OCS) resistance in Fig. 9:

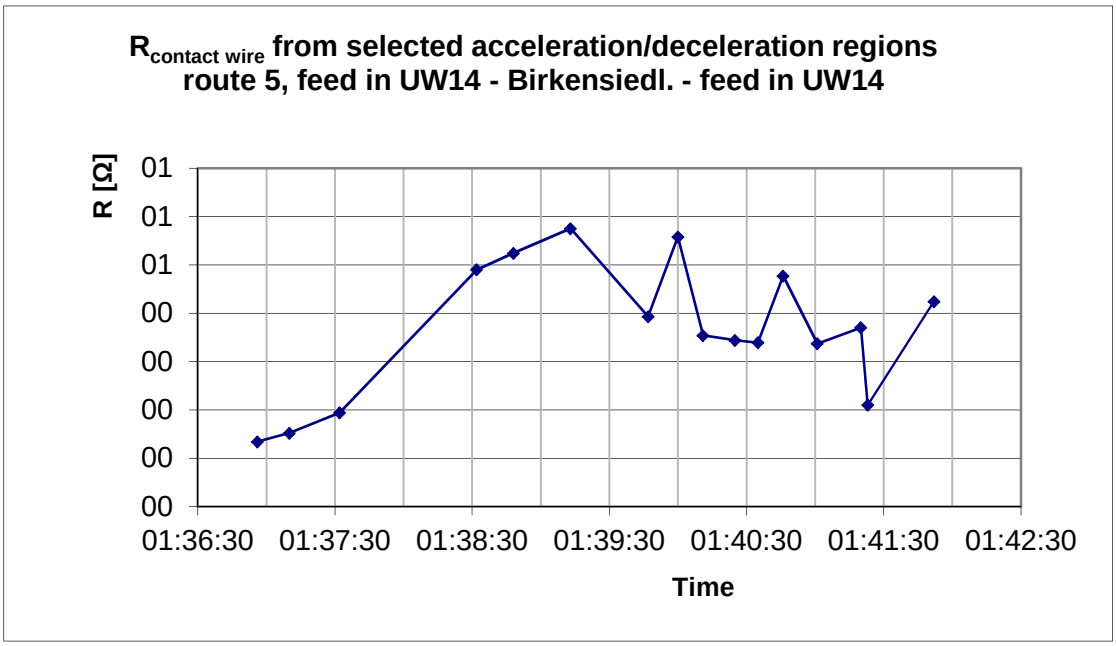

Fig. 9: Overhead contact system (OCS) resistance Line 5

The overall resistance of the contact wire and the internal resistance of the substations is now available in Fig. 9 for the measurement times. Since the substation has an internal resistance of only 0.02Ω, the curve in Fig. 9 basically shows the overhead contact system (OCS) resistance. If the voltage and electricity measured values of all substations are available in addition, the cross sections for the line segments between the individual measuring points could be calculated in a further step. However, the measurement accuracy obviously will not suffice. The resistance variations in the right part of Fig. 9 are too great. In order to be able to calculate the cross section in every measuring segment, the exact knowledge of the position of all connectors, supply points and shunts is necessary. Since, during network measurement, these positions were determined during the journey, their accuracy is not high enough.

Formula symbols

	Unit	Designation
v	m/s	Bus speed
v_{ab}	m/s	Bus speed above which the engine power is throttled by ΔP
a, a_{anf}, a_{brems}	m/s²	Acceleration (when starting / braking)
g	m/s²	Gravitational acceleration = 9.81m/s²
U_F	V	Voltage at the contact wire
I	A	Total bus current
I_{ein} $I_{rück}$ $I_{Bremswid}$	A	Fed in, regenerative and braking resistor current
P	W	Output
ΔP	Ws/m	Power amount that is throttled back above v_{ab}
P_{offset}, P_{heiz}	W	Offset output (the power demand of the bus which does not serve the actuator), heating output P_{heiz} is part of P_{offset}
P_{ein}, $P_{rück}$, $P_{Bremswid}$	W	Fed in output, regenerative output and output consumed in the braking resistors
E_{ein}, $E_{rück}$, $E_{Bremswid}$	Ws	Fed in energy, regenerative energy and energy consumed in the braking resistors
η_{ein}, η_{rueck}		Efficiency factor during input and regeneration
R		Friction coefficient

Tab. 2: Formula symbols

IV. Simulation of trolleybus networks

With the complexity of electric grids like that of an Trolley bus network, the influence of the numerous parameters and the interaction variety of the variable consumers, if at all, is at most only qualitatively predictable. In order to gain a quantitative idea, too, it makes sense to make use of a computer simulation. The analytical focus is on the preparation of energy balances and network losses (overhead contact system (OCS) losses, braking resistors), the review of the capacitive limit of the electrical network and its stability and the support of the planning process for proposed route extensions. It should be pointed out that, although

many time-related parameters are received because these contribute on many different ways to the energy balance, the software is not supposed to issue traffic forecasts, etc.

Parameters

A list of all essential parameters involved in the simulation can be found below.

Network Parameters

This is based on the power grid, the geometrical data of which were obtained by GPS.

- Wear of the contact wire
- Specifications of the substations

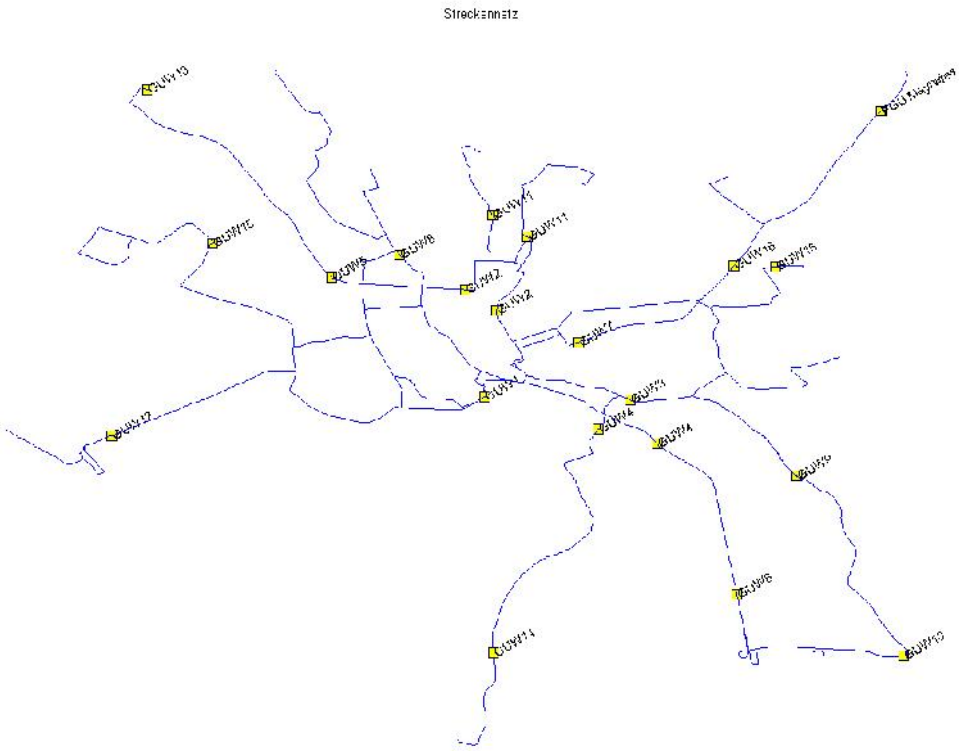

Fig. 10: Representation of the Trolley bus network Salzburg in the simulation; here with GUW‘s

Track section parameters

- line courses and stops
- maximum speeds
- additional stops

Vehicle parameters

- manufacturers' data sheets
- missing data determined by measurements

Traffic modes

- Normal mode (typical traffic situation)
- Ideal mode (the extra stops are not considered)
- Traffic jam mode (special load situation for the network, high amount of additional stops, stop'n'Go simulated)

V. Applying the simulation to the Salzburg trolleybus network

Content focus here is on the planning of track section extensions. However, one should first look at the total grid and become familiar with the load histograms of GUW's. Afterwards, the quantitative correspondence and the validity of the simulation will be shown with the help of a line analysis.

The Salzburg-Trolley bus network is a 600V mains that, however, is operated at a higher nominal voltage (approximately 670V). In general, this should not drop by more than 30% because with such a contact wire voltage at the bus, the converters in the bus may be damaged. For assessing qualitative grid reliability, the specified criterion is a 10% drop, i.e. the mains voltage should always be higher than 540V.

All GUWs are situated along the same medium voltage line with 10kV. This is subject to to the usual day-night fluctuations. Individual load curves of individual GUW allow illustration in the form of histograms of the relative frequency of the power output provided.

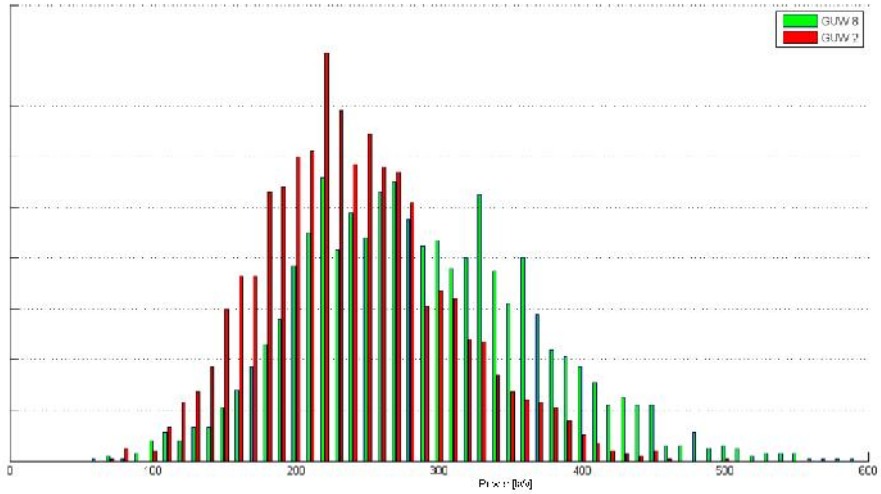

Fig. 11: Load Histogram (output) GUW 2 & 8

In Fig. 11, it is evident that GUW 8 & 2, despite very similar overall infeed energy, are loaded, nevertheless, very differently. The load curve of the GUW 8 is wide, with a power window at 200-350kW and peaks of up to 600 kW. However, GUW 2 is characterised by a slimmer distribution curve with a maximum between 200-250kW.

Similarly, the voltage drop at the GUW can be illustrated as a histogram (Fig. 12). The voltage drop originates with power demand on the transformers installed in the GUW. Here, the magnitude of the voltage drop depends on the impedance of the transformer which can be determined from the characteristic data of the type plate and of the rectifier. This variable is summarised for the simulation as an internal resistance of the substation.

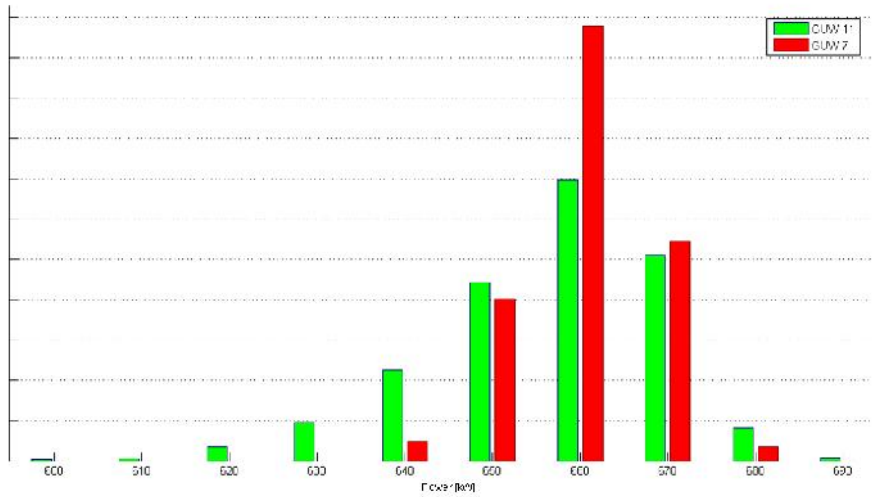

Fig. 12: Load Histogram (voltage) GUW 7 & 11

There is a transformer with an apparent power of P_S=1000kVA and a relative short circuit voltage of u_k=6,77% installed in GUW 11. The characteristics of the transformer of the GUW 7 are P_s=800kVA and u_k=6.3%. G_F=1.35 is the rectifier factor. The following applies for the impedance (approximated the equivalent circuit diagram):

$$Z = \frac{u_k\ (U_N/G_F)^2}{100\%\ P_S}$$

At U_N = 670V one obtains for GUW 11 Z_{11}=0.017Ω and for GUW 7 Z_7=0.019Ω. Without consideration of the rectifier, one would therefore get an estimate for the voltage drop on the GUW with the help of

$\Delta U = Z$.

With an electricity peak of I = 800A, the voltage drop on the GUW GUW 11 would therefore be ΔU = 24V and ΔU = 28V for the smaller GUW 7.

It should be noted that GUW's with higher power rating have higher idling losses with the same construction method as a rule.

Application for line analysis

On account of precise long-term measurements of the lines, these are suited well to carry out an energetic validation of the simulation results and and all the more to get an assessment of the validity of the simulation for planned route extensions.

The extent of utilization of the bus and the wear of the overhead contact system (OCS) wire were not recorded. This leads to fundamental degrees of freedom that cannot be treated precisely. Hence, both parameters were specified for all lines equally firmly, although differences are bound to be present in the extents of utilization of the lines. Also, the time proportion of coasting during the driving time affects the energy balance and was considered.

Although the track section characteristics of the individual lines are very different from each other, the temporal proportion of coasting while the bus is on the road is in a narrow area of 24 %-32 %. Here, the coasting proportion was determined during which the bus measurement data were searched for the times where the torque-generating current i_Q is negative, however, the current at the contact wire is positive.

Individual differences between the buses and drivers also come into it because for the long-term measurement, unfortunately, the same buses and drivers could not always be used. And although the long-term measurement was always carried out with the same bus type, differences can be made out on account of the different usage and maintenance of the buses.

For comparison the simulation was carried out in all three traffic modes. For the traffic jam mode, additional stops were inserted automatically every 300m. A comparison between measurement data and simulation results is shown in Tab. 3 exemplarily for line 4.

Here, $E_{aufgenommen}$ is the energy absorbed by the bus from the mains. Furthermore, $E_{rekuperierbar}$ is the energy provided by the engine in generator mode, no matter whether this was fed back or consumed in the brake resistors.

Line 4 - Forellensiedlung - Daxlueg	measurement data	Simulation		
		NORMAL - Mode	IDEAL - Mode	TRAFFIC JAM- Mode
E_infeed [kWh/km]	2.98	3.18	2.90	3.97
E_recuperable [kWh/km]	0.40	0.38	0.33	0.81
E_eff [kWh/km]	2,58	2.80	2.57	3.16
E_rekuperierbar / E_ infeed %	13.42%	12.0%	11.5%	20.4%
v [m/s]	4.39	4.38	5.44	3.75
duration [min]	46.1	46.2	37.2	54.0
track length [m]	12141			
track requirements [kWh]	36.2	38.6	35.2	48.2
Offset power [kWh]	15.1	15.2	12.2	17.7
Traction power [kWh]	21.0	23.4	23.0	30.4
Line 4 - Daxlueg - Forellensiedlung				
E_ infeed [kWh/km]	2,80	2,97	2,65	3,68
E_recuperable [kWh/km]	0,43	0,43	0,38	0,83
E_eff [kWh/km]	2,37	2,54	2,28	2,84
E_recuperable / E_ infeed %	15,34%	14,6%	14,2%	22,7%
v [m/s]	4,48	4,29	5,42	3,85
duration [min]	46,1	48,1	38,1	53,6
track length [m]	12379			
track requirements [kWh]	34,7	36,8	32,9	45,5
Offset power [kWh]	15,1	15,8	12,5	17,6
Traction power [kWh]	19,6	21,0	20,3	27,9

Tab. 3: Line analysis for line 4

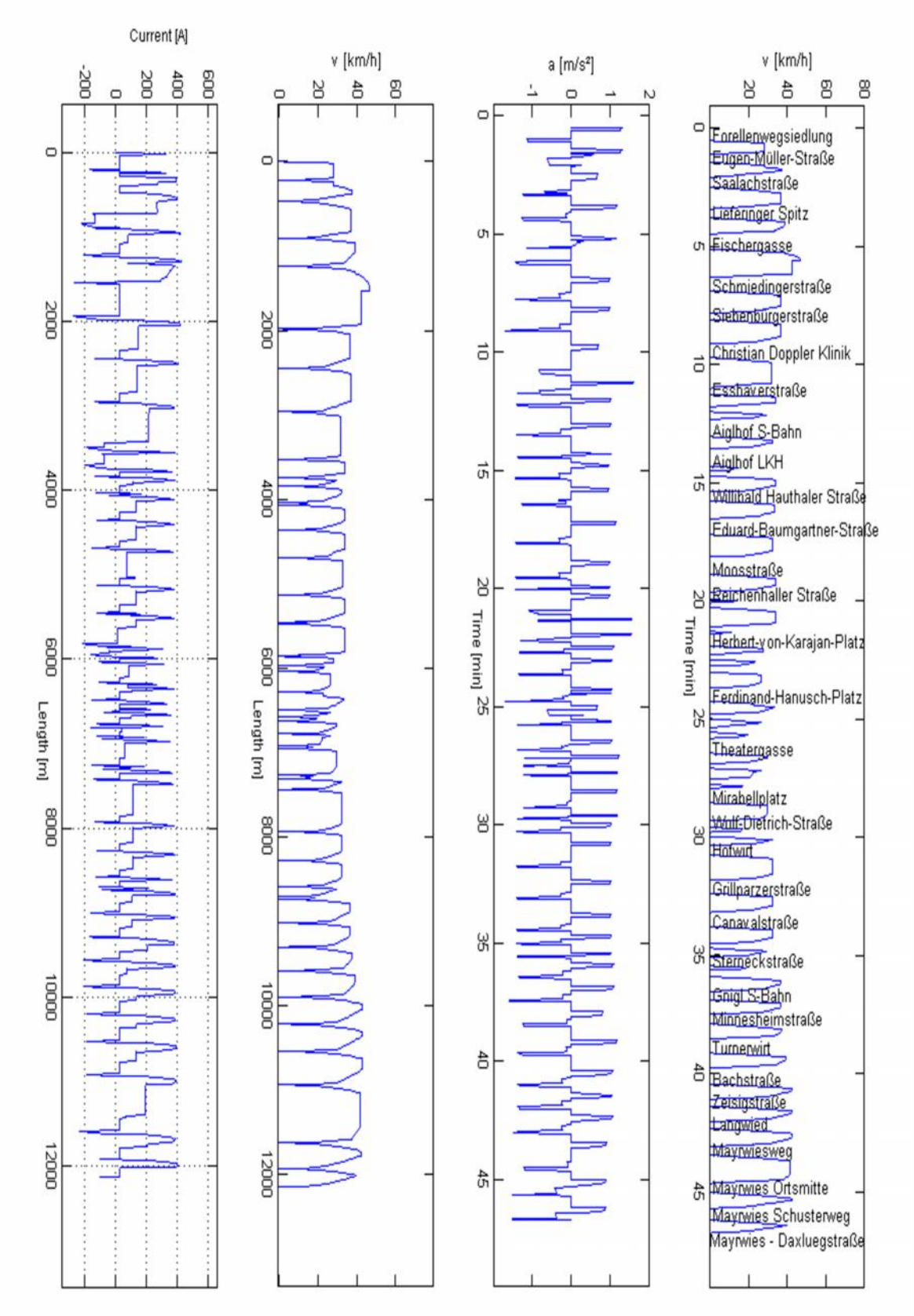

Fig. 13: Example of a simulated journey

VI. Planning and optimization of a track extension

Die Salzburg AG is planning a track extension from Mayrwies (current turning point of line 4) to Esch. Fig. 14 shows the Trolley bus network; here, line 4 is highlighted in red and the extension track sections are highlighted in green.

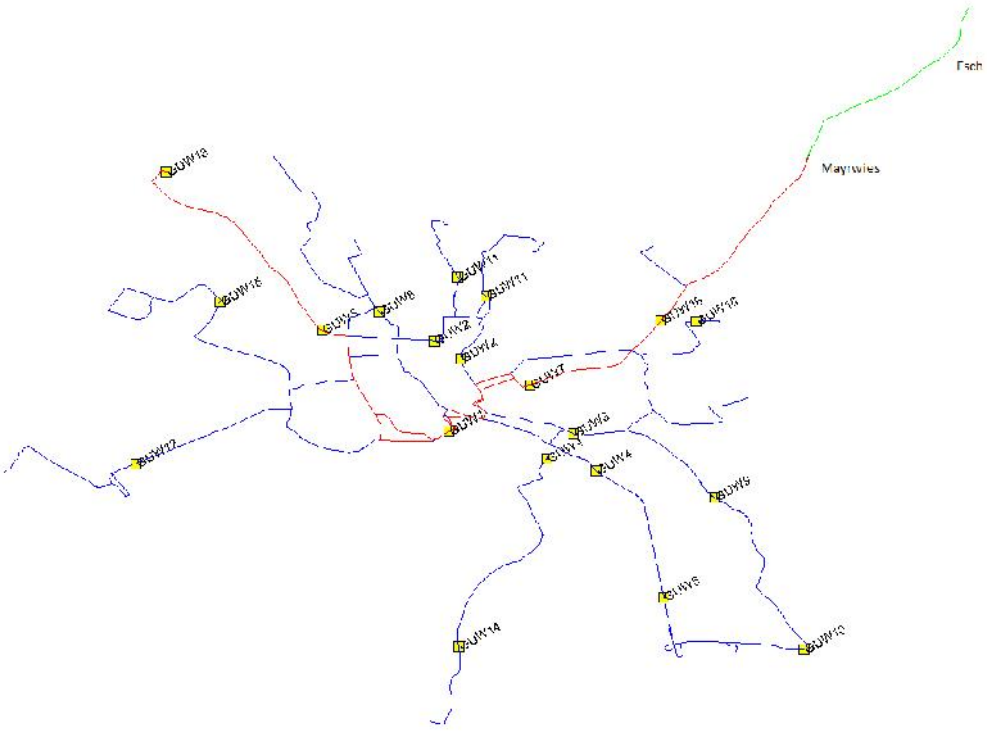

Fig. 14: Salzburg's trolleybus network with planned extension sections

The extension section has special requirements. It concerns an overland route(between the stop Schmiedbauer and the stop Rechl) with gradients of up to 9%. The track section length amounts to 3 km and is graphically illustrated on Fig. 15, including the planned

stops.

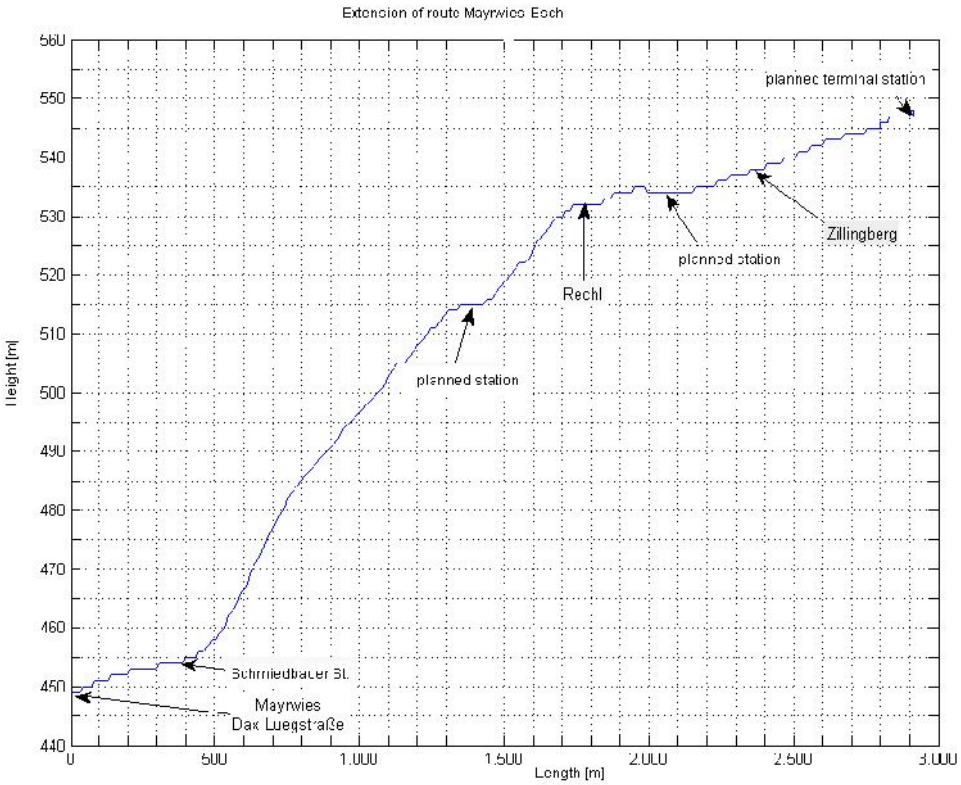

Fig. 15: Height profile of the extension section

It is now a matter of obtaining an energy consumption evaluation as well as an appraisal of the network stability for various versions with the help of the simulation. Here, the positioning of new GUW, possible energy stores and the contact wire cross section to be used is by choice. Attention is paid primarily to a stable power supply (particularly in regard of further extensions) and to the height of the regularly appearing power peaks in the planned GUW in order to determine the necessary transformer output.

Fig. shows the speed profile to be expected on the extension track sections from Mayrwies to Esch and vice versa (for the bus type Solaris Trollino 18).

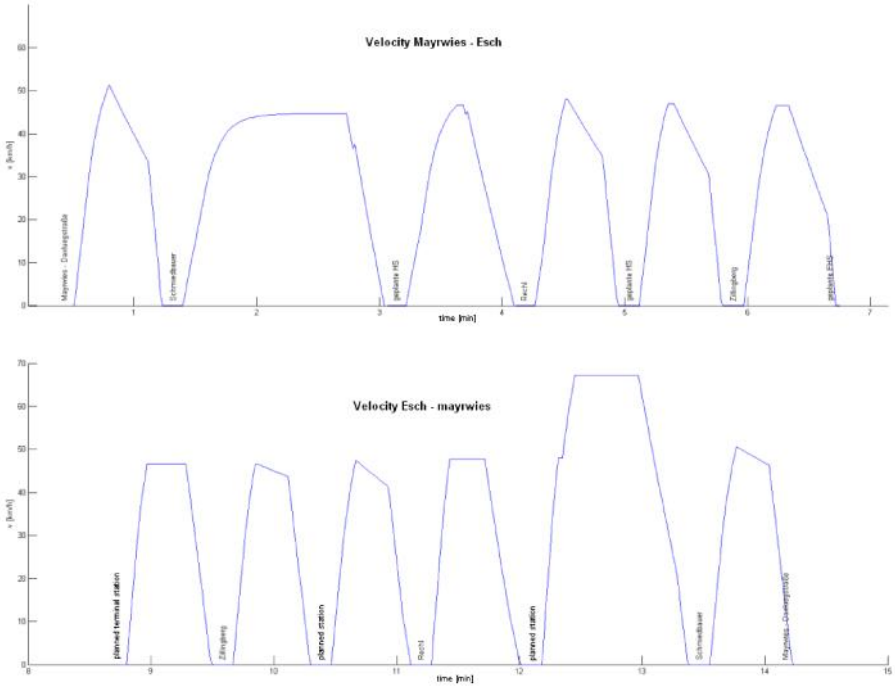

Fig. 16: Speed profile on the extension track sections

On the gradient from the stop Schmiedbauer onwards, only a maximum speed of 55 km/h is achieved. It is to be noted that in the simulation (and in all the following ones), there is a relatively high extent of utilization of 50% as well as a heating output of 40% (corresponds to 16 kW) that was being assumed. The actually feasible top speed is, perhaps, slightly higher.

By means of comparison, the simulation was also carried out for other bus types (van Hool, low-floor) (Fig. 17). Here, it is well evident that the respective power on the gradient, limited by the buses, leads to different maximum speeds. Also, the Solaris has a substantially better acceleration and coasting process.

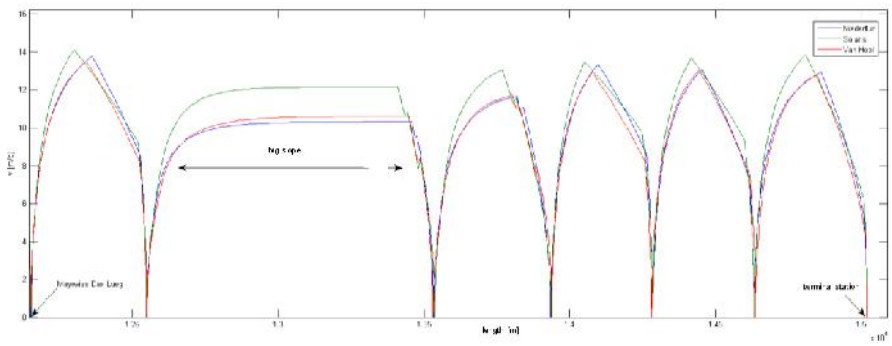

Fig. 17: Speed profile for various bus types

On the sections downhill from Esch to Mayrwies, large outputs rekuperiert can be recuperated. Hence, attention will be paid on the pages to follow also to the energy lost in brake resistors and to options for the reduction of these losses. For the simulation, there is the assumption that braking only takes place electrically.

Three versions will now be presented and the most important simulation results will be briefly looked at. Emphasis is placed on network losses and grid stability. Now and then the term of (network) efficiency is also used. This determines the proportion of the in-fed energy which is also absorbed and consumed by the buses. Whatever is missing from the efficiency to 100% corresponds to the network losses.

An installation of connectors in regular 400 m intervals is being assumed. These switch the overhead contact system (OCS) cables in parallel and the overhead contact system (OCS) resistance can be thereby nearly halved.

In order to estimate the required transformer performance, the load histograms from the simulation are used. These allow illustration of the outputs or currents provided by the GUW as relative frequency distribution.

Analysis of Variants

The analysis of variants has been carried out for Fahrdrahtquerschnitte 80mm², 100mm² and 120mm²,

Variant 1

In Variant 1 the existing mobile infeed station is replaced by a stationary substation. This corresponds to the conventional intuitive approach for network expansion. It is predictable that the voltage drop towards the planned terminus in Esch is problematic owing to the special requirements. This is confirmed by the results of the simulation.

Variant 2

In order to reduce voltage drops in variant 2 towards the track section end, the planned GUW is moved to the gradient-intensive part of the new section. By the positioning of the GUW in the power-requiring area of the track section, overhead contact system (OCS) losses are meant to be reduced.

Variant 3

Variant 3 is now a combination of the two preceding variants. There are two GUW's that are newly erected. One of them (GUW Mayrwies) replaces the existing mobile GUW as in variant 1, while the other one (GUW Esch) in turn is positioned midway on the slope of the upgraded line, as in Variant 2.

It strikes immediately that the voltage drops are very low between the two newly positioned GUW and also towards the end of the extension to Esch, the voltage on the bus is always more than 540V.

Because of the additional GUW, the voltage drops are more favorable in the track section course all together than in Variant 2, and there is no especially high drop between GUW 16 and GUW Mayrwies. This affects the network losses. Also, the peak loads are distributed better; now between three GUW instead of two. In particular, the subnetwork is better decoupled from the power feed of the GUW 16 which is thereby subjected to a lower additional load

by the planned new stretch. This becomes clear from the independence of the overhead contact system (OCS) cross section from the peak loads in the GUW 16.

Comparison of the Variants

The results of the three variants presented above will be briefly compared. Fig. 18 graphically illustrates the daily infeed requirements of the planned extension sections for the variants 2 & 3 as well as for all contact wire cross sections.

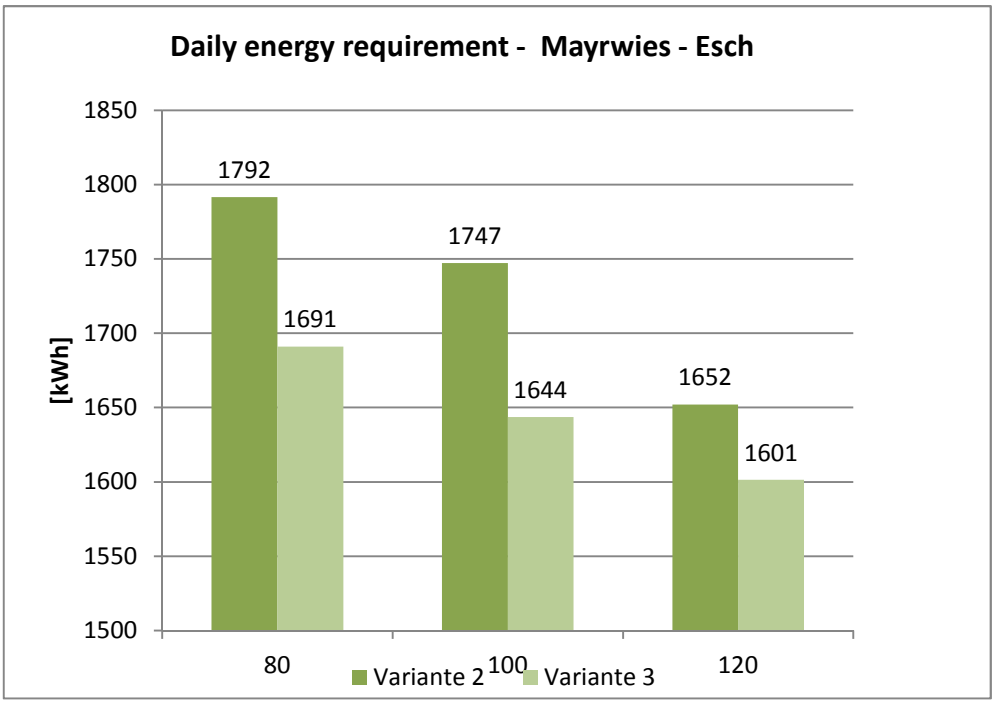

Fig. 18: Infeed requirements for the extension section

The difference between the worst values amounts to 200 kWh after all and/or about 11%. The difference between variants 2 & 3 is clearly recognizable.

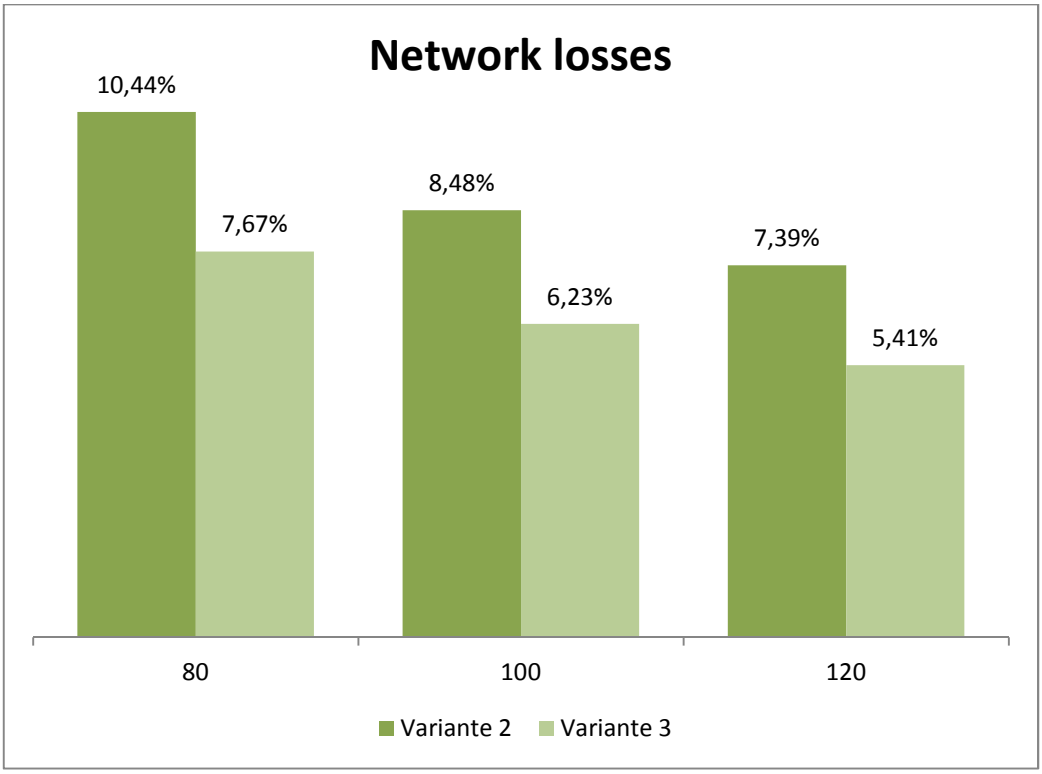

Fig. 19: Network losses of the variants 2&3 for individual bus

According to the criteria set out, variant 2 can be recommended in the cross sections 100mm² and/or 120mm² and variant 3 for all cross sections. For variant 2, a 1000kVA GUW is necessary and for variant 3, one 600kVA and one 800kVA GUW are respectively necessary. Variant 3 is certainly the most expensive option, but it also contributes an additional redundancy. I.e. if the two GUW's for variant 3 would be rated a little bit higher, network operation can also be ensured in case of failure of one of the two GUW's (then corresponds to variant 1 or 2).

A final choice is dependent on economic criteria, any future additional track section extensions, local condition etc.

Comparison Energy store and substation

There is the option of the positioning close to track section of energy stores. An energy store may be useful in various ways. There is the option of utilization for the "saving" of energy by the accumulator deevice sapping from the network any excessive electrical power (i.e. the voltage in the energy store exceeds a certain value; in case of the Salzburg grid, the open-circuit voltage is about 670 V and the threshold value could be, e.g., 700 V) and

when required feeds it in again (i.e. applied voltage falls short of a certain value).

An Trolley bus decelerating at a stop can serve as a simple example, where current fed into the network by recuperation entails a load increase in the bus and this flows into an energy store located nearby. With the departure of the Trolley bus from the station, there is a local voltage drop and the energy store feeds back the stored power. Without energy store, the brake energy in the brake resistors of the bus would not have been converted into useful thermal energy. Such a possibility of regeneration of the busbars in substations to medium voltage connections exist; it is however poorly compensated for by the power companies.

In the simulation, so-called flywheel energy stores were considered. These energy stores are well suited for the absorption of large currents, as arise during the braking process of Trolley buses. Another benefit is the contribution of an energy store to network stability. When positioned between two GUW, an energy store can lessen the voltage drop en route and therefore reduce the network losses.

The evaluation of the quantitative benefit of an energy store without aids is difficult, because the energy lost in the brake resistances depends on many parameters, like overhead contact system (OCS) cross section, set brake chopper voltage, mains voltage, number of active buses in the network, position of the GUW's etc. because their interaction is manifold. Hence, an analysis by simulation is very suitable.

With the cost comparison, attention is to be paid to the fact that a GUW requires MV connection and in particular, the power supply cables(connection of the GUW to the electric Trolley bus network) are costly.

As the last item, the option of the application of energy stores directly installed in the Trolley buses should also be pointed out.

<u>Summary</u>

According to customary planning, one would break down the network into about 3 km feeder segments and have it supplied by the GUW without nevertheless finding a concrete estimate for the necessary performance capacity of the transformer installed in the

GUW. In this manner, trolley networks grow in a natural manner. Variant 1 complies with this intutive approach.

Expected voltage drops were able to be determined by specific simulations (particularly on the critical points), as were power consumptions, network losses (overhead contact system (OCS) losses, brake resistors) and transformer variables. Also, the effect of energy stores can be estimated. On this occasion, beside the reduction of the losses in brake resistors, the contribution of energy stores is to be emphasised particularly to the network stability between feed-in points and to the reduction of the load peaks in the GUW. The comparison of the influence of GUW and energy stores on the electric grid has shown that it is most sensible to refrains from operating these in a mutually exclusive manner but rather top operate them side by side.