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STADTFahrzeug REVA

REVA EURO, CITY CAR FOR EUROPE

Final Report

Ausgearbeitet durch

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Abstract

REVA is a light-weight electric vehicle, which is in production in Bangalore, India, since June 2001. In the last few years, European market has gained importance, especially cities like London, where driving EVs is attractive due to saving congestion tax and other incentives. The sales price is attractive, compared to other electric vehicles.

REVA EURO was developed to match the following criteria:

- Top speed of 85 kph compared to 65 kph of the existing REVA
- Driving range of 100 km to 150 km compared to 50 to 80 km of existing REVA
- Acceleration 0 to 50 kph in less than 10 seconds
- Maintenance free drive train and batteries

During the project 3 prototypes were built to test the new drive train system and the ZEBRA batteries, which had been specifically designed for this project. Most of the testing was done in India on city and rough country roads. Most of the targets could be fulfilled and the prospects to introduce the concept into production was very good until MES-DEA announced, that our specific battery would not be produced in series.

The car also received a lot of media attention, when it was presented at the Geneva Auto Show in March 2007.

Zusammenfassung

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Resumée

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1. Introduction

REVA is an Electric Car, since June 2001 produced in India for the Global Market. More than 1800 cars have been built since then and are successfully driven in cities of India and other 12 countries. This car, produced at low cost (current price in India: US\$ 8000 –10000 depending on whether it is a base model or deluxe model), is an ideal, non-polluting, energy efficient city car for Europe, if adapted to European / Swiss market requirements. The objectives of the project are to build REVA EURO with the features:(i) Top speed 85km/h (Compared to 65 km/h of the present REVA),(ii)Range of 100 to 150 km (compared to 80 km of the present REVA),(iii)Acceleration 0 to 50 km/h of less than 10 seconds,(iv)Maintenance free drive train (v) Low purchase price. The Upgradation for the European market required Left Hand Drive, modifications for the Body, Seats and Suspension, Brakes, Drive Train, Battery, Energy Management System and Space Frame.

The project partners are PASOL AG, Switzerland, REVA Electric Car Company (P) Ltd. Bangalore India, MES-DES S. A. Switzerland. The project proposal was submitted on 02.07.2002 and 30.04.2003 by Mr. Paul Schweizer, CEO and MD of PASOL AG, a Swiss consulting firm in the field of Electric Vehicles, who was Executive Advisor to the REVA Electric Car Company (P) Ltd. MES-DEA

consented to supply the battery system and drive train components for the prototype vehicle. The project was sanctioned on 14.09.2005.

As soon as the sanction was received, the Project partners started working on the Project. Based on the overall vehicle specifications of an advanced version of a REVA type vehicle capable of transporting 2 adults and 2 children up to a speed of 85 kmph and 100 to 120 km range was drawn up. This included detailed vehicle simulation to determine speed-torque curves efficiency, continuous and peak power and torque requirements, transmission ratio, environmental specifications, system features etc.

This was followed by system design which included the overall layout and packaging of the motor, transmission, controller and battery and defined all the space requirements and mechanical and electrical interactions with the rest of the vehicle. MES-DEA did the costing of an optimized battery design, to fit the required specifications. Interactions between REVA's EMS and battery management of ZEBRA were studied and optimized to reduce cost. Adaptation of REVA's charger to ZEBRA's requirement was studied, interfaces built and tested.

The prototype was fabricated at RECC, based on actual REVA. Emphasis was laid to a production close to the actual REVA, so that the final production cost could be clearly evaluated. The car was based on REVA AC-drive train technology.

The prototype testing was carried out in 3 stages at RECC.

- (i) Bench testing,
- (ii) DYNO testing
- (iii) On Road testing.

Test report includes comparison of efficiency, performance, failures of the new system in on-road testing. Efficiency includes efficiency of the charger also. A separate analysis is done to compare ZEBRA battery efficiency with the lead acid battery currently used by REVA cars.

To keep initial purchase price low, it is suggested to go in for a leasing/rental scheme for the battery and just include in the purchase price the product cost without battery. Negotiations with leasing companies would be done to establish realistic cost estimates for ZEBRA batteries in REVA on a monthly basis. Kilometer based battery leasing/renting cost plus energy cost are anticipated to be considerably lower than equivalent running cost of a regular car.

The test results comprising range / endurance test with modified test car are furnished. Cost Comparison Report includes a complete analysis of the ZEBRA Battery Operated AC drive-train system. The effects to all system components, like AC motor, inverter, energy management system, charger, DC/DC converter were studied and compared with the lead acid batteries driven DC driven train system. Finally Business Case for REVA EURO car is presented.

2. Objectives

REVA is an Electric Car, since June 2001 produced in India for the Global Market. More than 1800 cars have been built since then and are successfully driven in cities of India and other 12 countries. This car, produced at low cost (current price in India: US\$ 8000 –10000 depending on whether it is a base model or deluxe model), is an ideal, non-polluting, energy efficient city car for Europe, if adapted to European / Swiss market requirements.

The objectives of the project are to build REVA EURO with the following features:

- Top speed 85km/h (Compared to 65 km/h of the present REVA)
 - Range of 100 to 150 km (compared to 80 km of the present REVA)
 - Acceleration 0 to 50 km/h of less than 10 seconds
 - Maintenance free drive train
 - Low purchase price
 - Upgradation for the European market
-
- Left Hand Drive
 - Body, Seats and Suspension
 - Brakes
 - Drive Train
 - Battery, Energy Management System
 - Modified Space Frame

3. Project Implementation

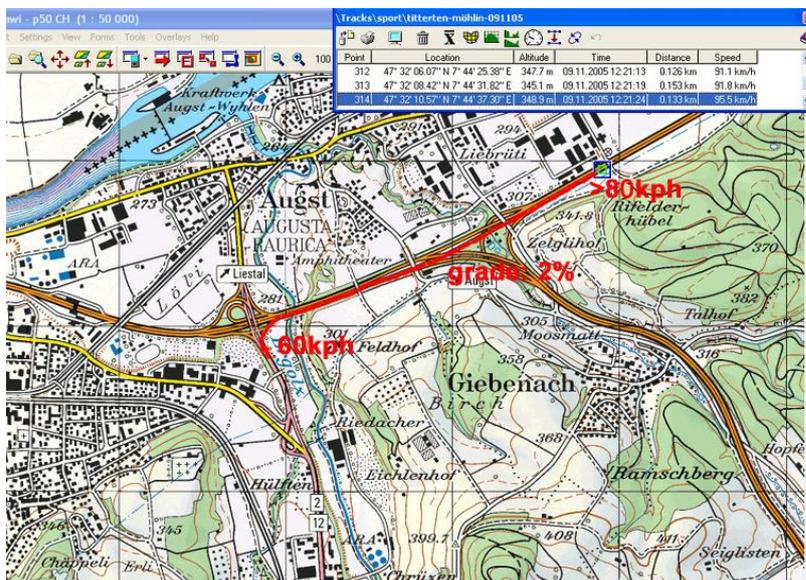
3.1 DEVELOPMENT OF SPECIFICATIONS

Based on the overall vehicle specifications of an advanced version of a REVA type vehicle capable of transporting two adults and two children up to a speed of 85 kmph and 100 to 120 km range was drawn up. This included detailed vehicle simulation to determine speed-torque curves efficiency, continuous and peak power and torque requirements, transmission ratio, environmental specifications, system features etc.

3.1.1 SIMULATION OF SPECIFIC DRIVE SITUATIONS

Simulation was done for 2 typical situations on European (Swiss) roads:

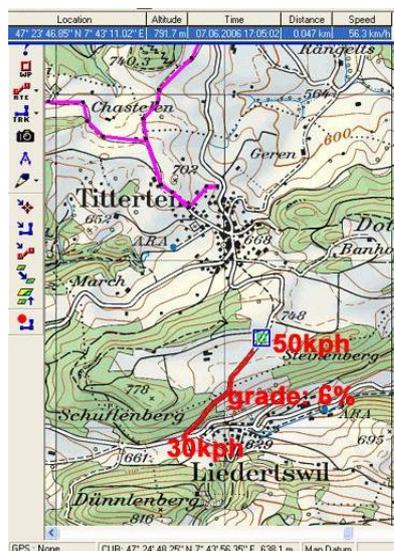
1. acceleration at the entry of a freeway with a slight incline (2% grade)
2. speed on a hilly mountain road in the Swiss Jura



Acceleration at freeway-entry with a 2% gradient from 60 kph to > 80 kph

A critical situation for a rather low powered vehicle is, when entering a freeway. It feels very unsafe, unless we can get upto 80kph in the entry lane.

Fig 1- Acceleration on freeway-entry with a 2% gradient



Minimum speed at 8% gradient: 50kph

At a gradient of 8%, we should get at least a speed of 50kph to avoid obstructing of other traffic. This is slightly faster than public buses and (unloaded) trucks.

Fig 2 Acceleration on Road with 8% gradient

Simulations were done for REVA with actual lead/acid batteries with a load of 2 persons. This is shown in Table 1.

The effect of the ZEBRA battery, replacing lead/acid battery pack, is shown in Table 2.

power [kW]	20 kph	40 kph	50 kph	60 kph	70 kph	80 kph	85 kph
0%	1.4	3.5	5.1	7.0	9.5	12.6	14.5
2%	2.6	5.9	8.0	10.6	13.7	17.3	19.5
8%	6.2	13.0	16.9	21.2	26.0	31.4	34.5

Table – 1 POWER REVA lead/acid, 830kg

power [kW]	20 kph	40 kph	50 kph	60 kph	70 kph	80 kph	85 kph
0%	1.1	3.0	4.4	6.3	8.7	11.8	13.6
2%	2.2	4.9	6.8	9.1	12.0	15.4	17.6
8%	4.8	10.4	13.7	17.4	21.7	26.6	29.4

Table – 2 POWER REVA ZEBRA, 680kg

LEGEND:	max power of drive train: 13.1 kW
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These situations have been verified with our Horlacher sport EV (to some extent with similar characteristics like REVA. Power has been limited to 13.5 kW to simulate actual REVA power capability). Table 3 shows the simulation results for this specific car.

power [kW]	20 kph	40 kph	50 kph	60 kph	70 kph	80 kph	85 kph
0% gradient	0.8	1.9	2.8	3.8	5.3	7.0	8.0
2% gradient	2.0	4.4	5.9	7.6	9.6	11.7	13.1
8% gradient	5.5	11.4	14.6	18.0	21.8	25.9	28.1

Table – 3 POWER Horlacher Sport lead/acid, 690kg

3.1.2 SPECIFICATION ZEBRA BATTERY

Battery voltage selection was mainly governed by cost considerations. Based on the range requirement of 100 to 150 km, together with MES-DEA we agreed to the following specifications:

REVA Z52-54- ML3P-126 Parameters

	unit	
Capacity	Ah	228
Rated Energy	kWh	12.4
OCV	V	54.2
Max. discharge Current 1 min	A	350
Weight with BMI	ca. kg	110
Energy 2h discharge	kWh	11.1
Peak power	kW	14.2
Thermal loss	W	67
Cooling		air
Dimensions	length	mm
	width	mm
	height	mm
No of strings		6
No of cells per string		21

Table – 4 ZEBRA battery specifications

3.1.3 SPECIFICATION OF DRIVE TRAIN

For the drive train evaluation we considered different options. Cost considerations made us adapt the specifications to a readily available inverter which limited the power to 13.1 kW.

Selection was for Curtis 1236-53XX¹

Together with a local manufacturer (Kirloskar Motors) specifications to meet our requirements were worked out. To keep cost low, a standard size housing was selected.

The specifications of the transmission of the previous DC motor were upgraded for higher RPM and for a fixed gear ratio of 9.4:1.

3.2 SYSTEM DESIGN

3.2.1 BATTERY – DRIVE TRAIN

The ZEBRA Z52 does not fit directly in to the same chassis location, as is standard for lead/acid batteries. The location of one chassis beam had to be modified, which was done, using a regular chassis, cutting the existing beam and welding a new beam at the new position. This modified structure was analysed applying FEA to project structural properties.

The battery bottom had to be lowered by 25mm to not elevate the seating position. Ground clearance has reduced from 165mm to 140mm, which is still adequate.

To adapt the AC motor with a different size than the former DC motor, the trailing arm is redesigned completely. Again the trailing arm is analysed with FEA to find the weak spots. The dimensions of the steel parts, forming the trailing arm as well as the supporting joints for motor and shock absorbers were optimised (weight reduction) during this process (see Fig-3).

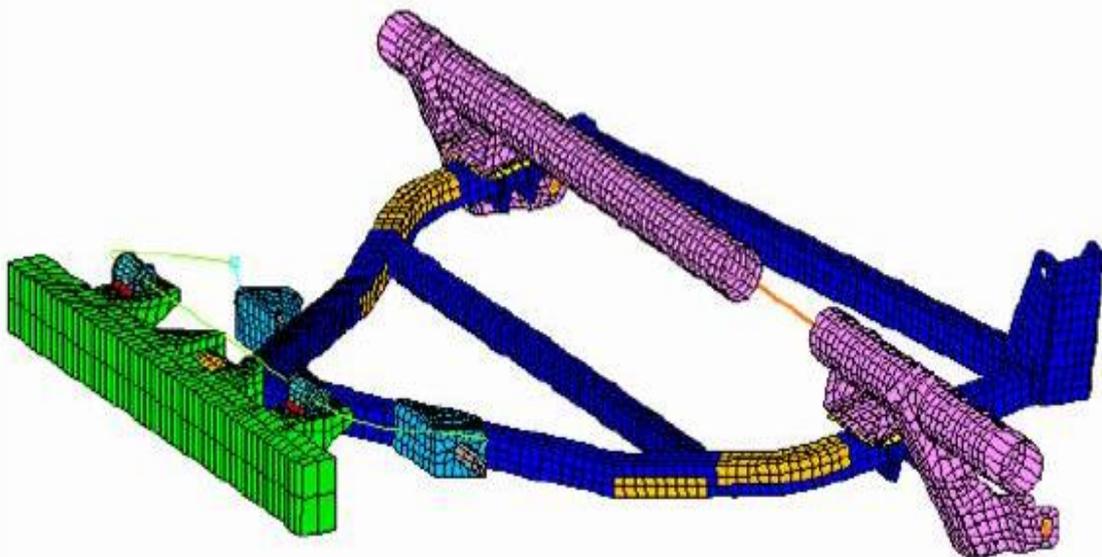


Fig-3 Stress Analysis of trailing arm

The transmission is modified according to the higher RPM requirements. New bearings were selected and new gears were designed. Because of the higher RPMs a new coupling between AC motor and transmission had to be developed. However, overall dimensions of the transmission were kept the same as for the actual transmission for DC motors. Fig-4 shows the entire trailing arm assembly.

Coordination of REVAs R&D, motor and transmission manufacturer was very challenging. The design underwent many iterations to meet the stringent space requirements but also the specific needs of this application. For the first time, the involved partners had to change their designs to meet the higher RPM and torque requirements. Details, like reliable internal connections between windings and motor cables had to be proven.

For the motor production process new processes had to be put in place to guarantee the reliable functioning of the new components like sensor bearing and temperature sensor. Routing of signal cables of these sensitive components had to be studied carefully. Servicing aspects were considered right at the design phase.

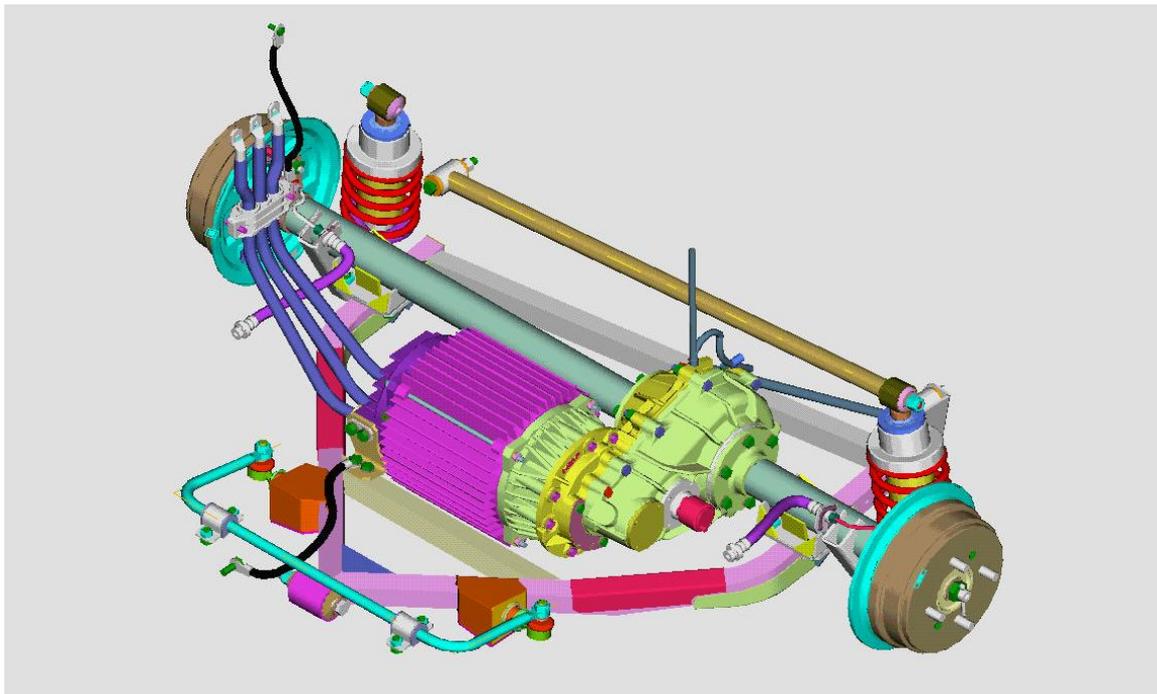


Fig-4 Trailing arm with integrated AC motor and transmission

3.2.2 PACKAGING OF ELECTRICAL COMPONENTS IN REAR HUB

Rear tub had to be completely redesigned compared to the original rear tub for DC motor drive train. The bigger area of the motor controller with its filters needed special attention. Charger and motor controller share the same heatsink, which enhances the cooling properties, such as increasing the life of the charger and motor controller. ZEBRA battery needs an isolated power bus. For that an isolated DCDC converter was installed.

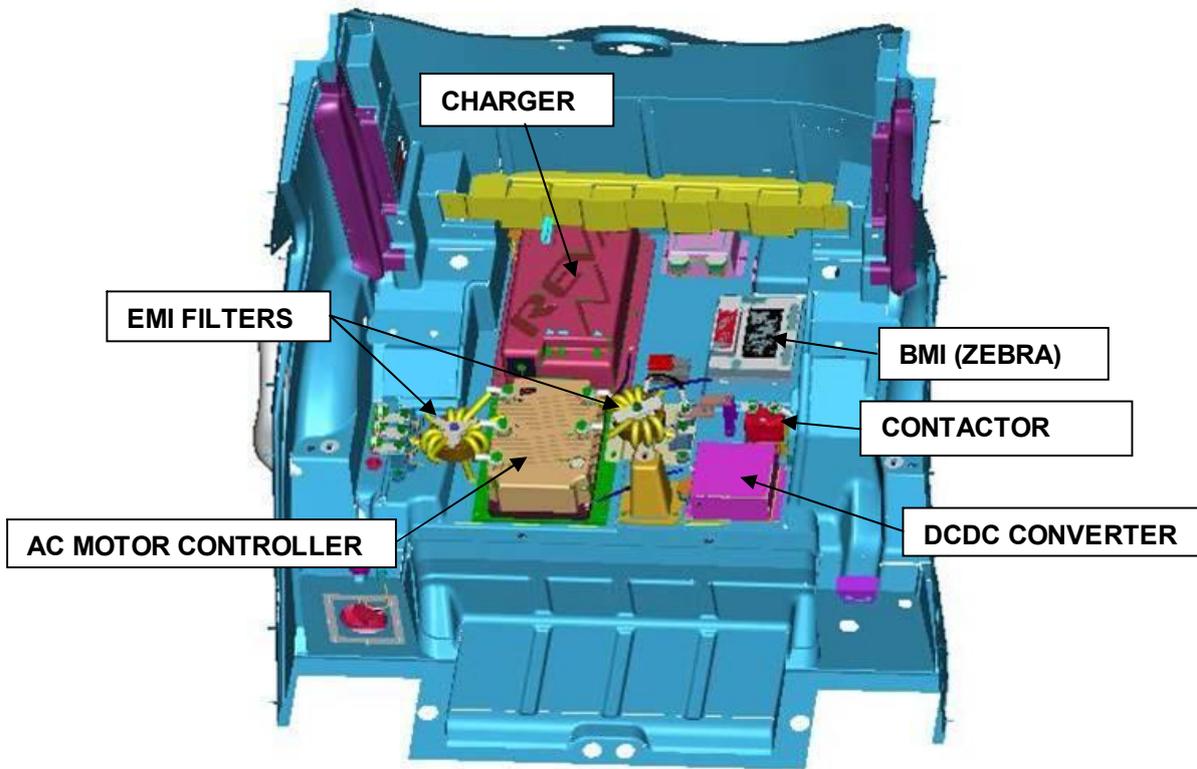


Fig-5 Rear Tub with electrical/electronic Components

Air ducts were integrated into the bottom to cool the motor controller during drive and the charger during standstill. For stationary cooling, two fans, which are operated by the motor controller, are integrated into the duct.

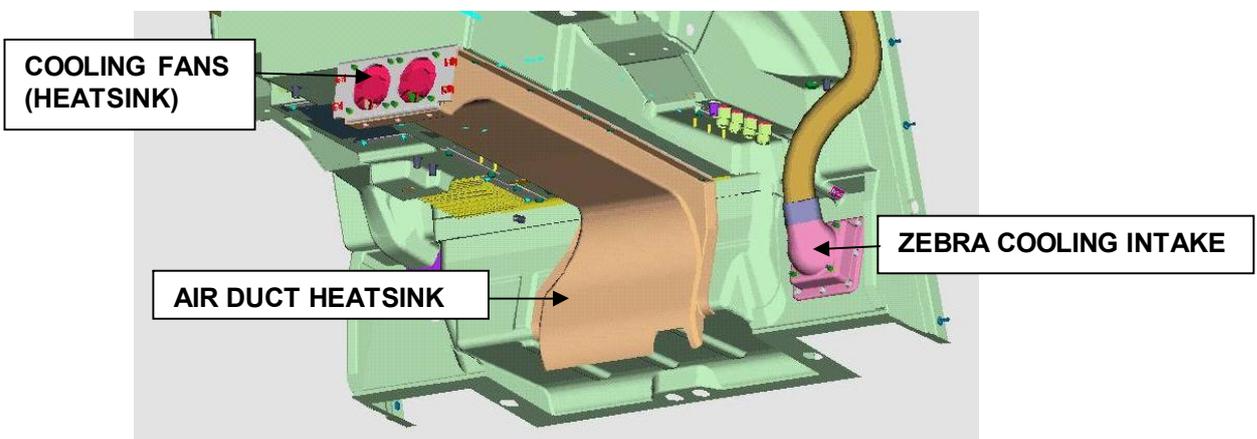


Fig-6 Rear Tub bottom with Airducts for ZEBRA cooling and Heatsinks

3.2.3 EMC DESIGN

A big challenge was to make the new drive train compatible to the very stringent EMC standard of the European Union. Fortunately, recently a very well equipped EMC has come up in Chennai (Sameer Lab), so the effect of EMI filters could be verified. Electrical design of the filters was done together with specialists from CEDT (Center for Electronics Design Technology) of Indian Institute of Science. Mechanical realisation was done by RECC with inputs of the magnetic core supplier.



Fig-7 EMC car transport to Sameer Lab, Chennai



Fig-8 EMI test in Sameer Lab

Several iterations had to be done, till we had a save margin for emissions, but also for immunity. For immunity we had to integrate some shielding in the area of the rear tub to prevent any influence of strong electromagnetic fields to the motor controller.

3.2.4 ELECTRONIC INTERFACES

ZEBRA battery (BMI) needs an isolated traction net to the 12V auxiliary supply (see Fig X). This is needed for regular isolation measurements of the BMI, which is an important feature for the save operation of ZEBRA batteries.

For that reason an isolated DCDC converter was installed and all 48V loads (air conditioner, heater) were isolated from the chassis.

All interfaces to charger or controller had to have opto coupler in/output stages, as at this low voltage power (traction) net and auxiliary (12V) bus have a common ground.

A master relay was introduced, which cut off all the loads during idle mode, that is during the time the BMI would switch off the traction net. Only BMI, remote control and hazard light is permanently supplied by the auxiliary 12V net to reduce discharge of the 12V auxiliary battery.

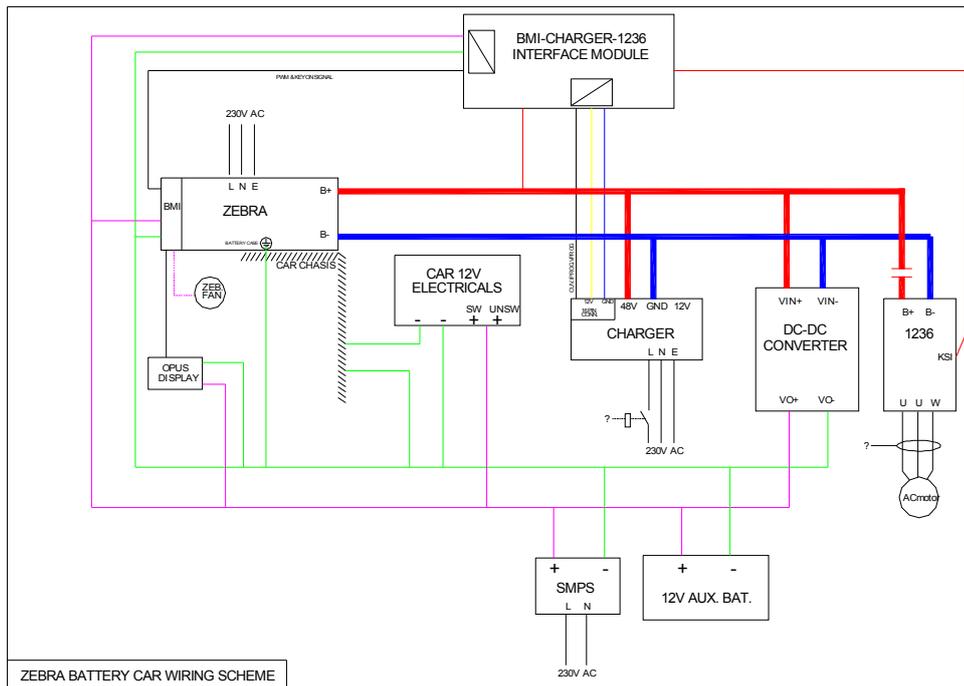


Fig 9 – Block diagram of ZEBRA interfaces

BMI-CHARGER-1236 INTERFACE MODULE:

This module has to transform the signal of the BMI to a control input signal of the charger (original REVA charger). Since we did not want to modify the standard charger to make easy replacements possible in the future, the interface had to control all the different features of the charger.

During a regular charge, the BMI controls several phases, where charge current has to be less than 0.5 Amps. As this feature was not foreseen the standard REVA charger, special circuits had to be designed and built into the interface.

In the standard application (with lead/acid batteries), the charger is permanently connected to the battery pack. The ZEBRA battery however, has to control the main contactors by the BMI to prevent any load at battery conditions outside the operating range, for example at low internal temperature. As neither charger nor AC motor controller (type 1236) are designed for this condition, additional relays and contactors had to be installed to enable a “one key on”-operation, when turning on the vehicle or putting the car on charge. The BMI would control the sequence and the interface had to introduce delays to not create error conditions of BMI, motor controller and charger: for instance “precharge fault”.

Some of the interface circuits could have been avoided, if we had got a special software for the ZEBRA BMI by MES-DEA or had made a modified charger for ZEBRA batteries, but we wanted to stick to standard components, also in production, to keep spare part variants low.

3.2.5 PROGRAMMING OF AC MOTOR CONTROLLER CURTIS 1236

The possibilities of the Curtis 1236 controller were used to replace functions, which in the regular REVA were realized in the EMS (Energy Management System for lead/acid battery pack). For that reason, the controller had to be powered not only during drives but also during charge. The auxiliary functions were programmed in VCL (Vehicle Control Language), a programming language, developed by Curtis to enable vehicle manufacturers to enhance the functionality of their vehicles².

The following functions were implemented by RECC for REVA ZEBRA:

GENERAL				
Drive SOC gauge in dashboard according to the CAN messages for SOC of the BMI (ZEBRA)	BMI	1236		IP
Control TEMPERATURE LIGHT in instrument panel for ZEBRA temperature problems (low or high)	BMI			IP
DRIVE MODE				
Dynamic limit regenerative and load current according to CAN messages from BMI	BMI	1236		
Indicate power status at instrument panel		1236		IP
“soft” switching of motor controller contactor (safety drop off and interlock with charge port)		1236	car electr.	
Control temperature light for motor and controller temperature		1236		IP
Control power profile for FORWARD and BOOST mode		1236	car electr.	
Control motor speed sensor light in instrument panel		1236		IP
Control NEUTRAL LIGHT in instrument panel		1236		IP
CHARGE				
Sensing charger temperature		1236	car electr.	
Activate CHARGE LIGHT in instrument panel during charge		1236		IP
Control temperature light for charger temperature		1236		IP

Table 5: Instrument Panel Functions, realised in VCL (Motor Controller 1236)

3.3 PROTOTYPE FABRICATION

Prototype fabrication was done in several phases:

1. The major new subsystems were installed in a modified test car (REVA 36).
2. EMC issues were studied in different cars (one to be tested by TÜV Süddeutschland)
3. Prototype II REVA 6A090700 (purple colour) was built ground up for enhanced testing and presentations

3.3.1 PROTOTYPE I, REVA 36 MODIFIED

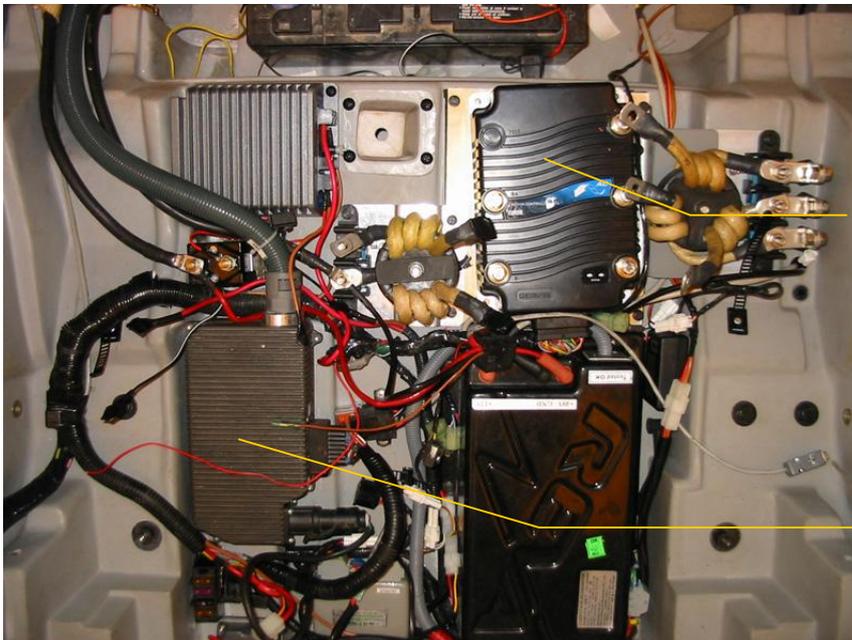
The car REVA 36 was completely dismantled. The chassis had to be modified to make space for the larger middle section, where the ZEBRA Z52 had to be placed.

The trailing arm with DC motor was replaced by the new trailing arm with AC motor and new transmission box (see Fig 10).



Fig 10: Trailing Arm with AC Motor and Transmission

The space below the rear seat (rear tub) was modified to make space for the new components, especially BMI and motor controller 1236 (Fig 11).



Motor Controller 1236

BMI (ZEBRA)

Fig 11: Rear tub, which holds all electronic and electrical components



Fig 12 Installing of ZEBRA Z52 in car REVA-36

3.3.2 PROTOTYPE II REVA 6A090700 (PURPLE)

The prototype was fabricated at RECC in the regular assembly line. Emphasis was laid to a production close to the actual REVA, so that the final production cost could be clearly evaluated.

Ground-up built car, based on redesigned chassis, trailing arm and wire harnesses.



The asymmetrical cut-out in the chassis can be clearly seen

Fig 13: First day of assembly: windshield, trailing arm and front wheels already assembled



Next day in assembly line: car seems to be ready to drive!

Fig 14: all Body Panels, wire Harnesses and rear Tub in place

Wiring under the dashboard is very cramped. This car has heater, airconditioner etc.

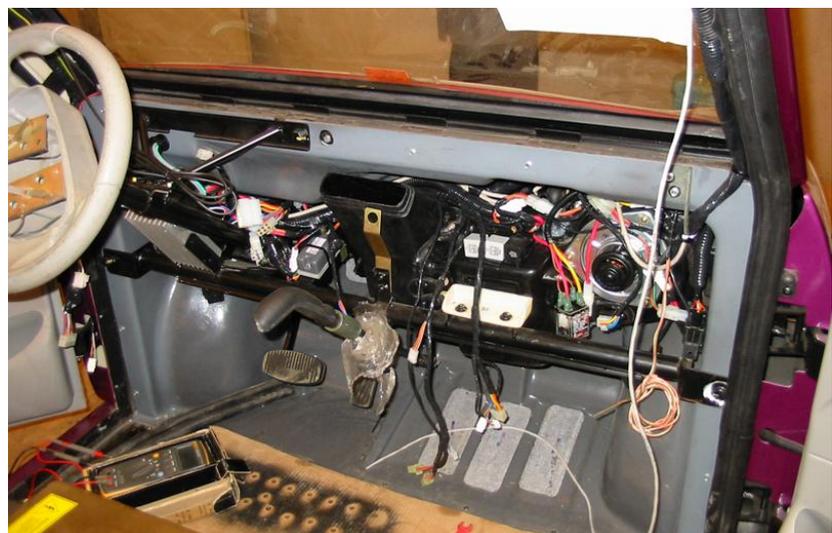


Fig 15: Dashboard Wiring

On the left side we can see the hose for the battery air-cooling, leading to the high pressure fan.

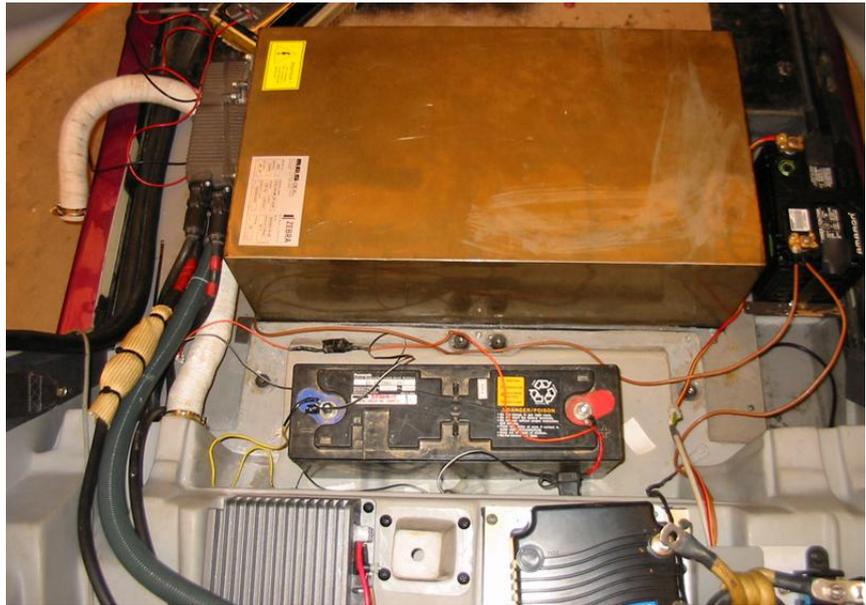


Fig 16: Installing zebra battery with cooling fan

The fan is mounted outside the rear tub to reduce noise inside the passenger compartment.



Fig 17: battery cooling fan outside the rear tub

A second prototype was built end of 2006, because the UK importer of REVA (goinggreen, brandname of car in UK is G-Wiz) wanted to demonstrate a G-Wiz with long range, which should be available for customers in autumn 2007.



Fig 18: Prototype with ZEBRA battery for UK

3.4 PROTOTYPE TESTING

At RECC the prototype testing was carried out in 3 stages.

- (i) Bench testing: The ZEBRA Battery along with the AC power train to ascertain the torque speed characteristics of the motor.
- (ii) DYNO testing: The car was subjected to intensive DYNO test to Benchmark the new technologies. This included speed torque capabilities drive train, but also top speed, max torque (gradeability) and efficiency tests. The torque speed characteristics are depicted in Fig – 8. Charger efficiencies were tested with a suitable charge algorithm according to ZEBRA's requirements.
- (iii) On Road testing: After completion of all the system tests, RECC conducted extensive on road tests. This was carried out using a functional test vehicle in the beginning to benchmark the endurance levels followed by extensive on road test of the actual prototype. This proved the day to day reliability of all the new systems in demanding real live traffic on Indian roads.

4. Results

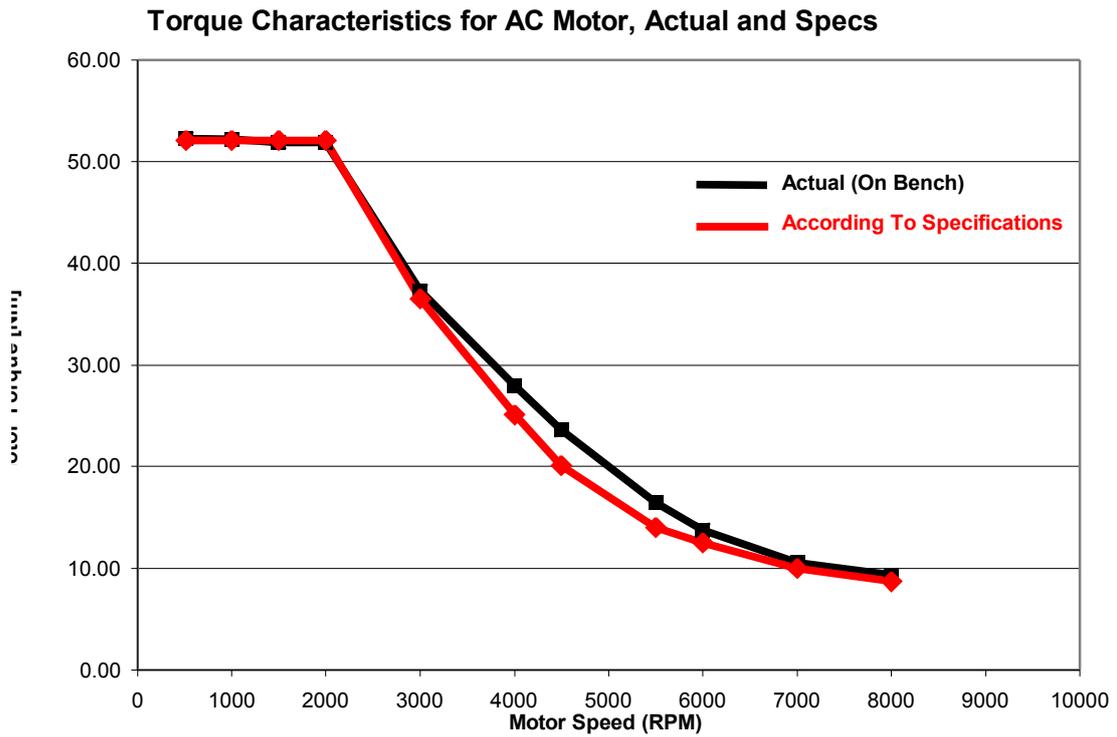
4.1 BENCH TEST OF AC-DRIVE TRAIN

Several Motors and controllers were tested on RECCs motor test benches (see Fig. 19)



Figur 19: motor test benches

After several iterations of fine tuning of motor characteristics and motor controller 1236, the final characteristic shown in Fig. 20 was selected.



Figur 20: Torque Characteristic for AC Motor

The results show a higher torque than specified at RPMs > 3500 < 6500. This corresponds to 35 kph to 65 kph, the speed range at which high acceleration is an advantage for safer overtaking.

4.2 DYN0 TESTS

RECC has a Dyno Test Stand on which all cars can be tested with respect to acceleration, top speed, gradeability (starting torque). Also range tests can be done, simulating actual road conditions. Fig X shows the Dyno Test facility.



Fig -21: Dyno test facility

Results of R36:

.....
.....

4.3 ROAD TEST RESULTS

Most of the road tests were done in India. As the main roads in and around Bangalore are always very congested, most drives were done on country roads. There are not maps on secondary roads available, so many drives were done, using the GPS and displaying the driven track on the screen of a notebook. So, after many drives, a quite complete map of secondary roads south of Bangalore was available for navigation (see Fig XX).

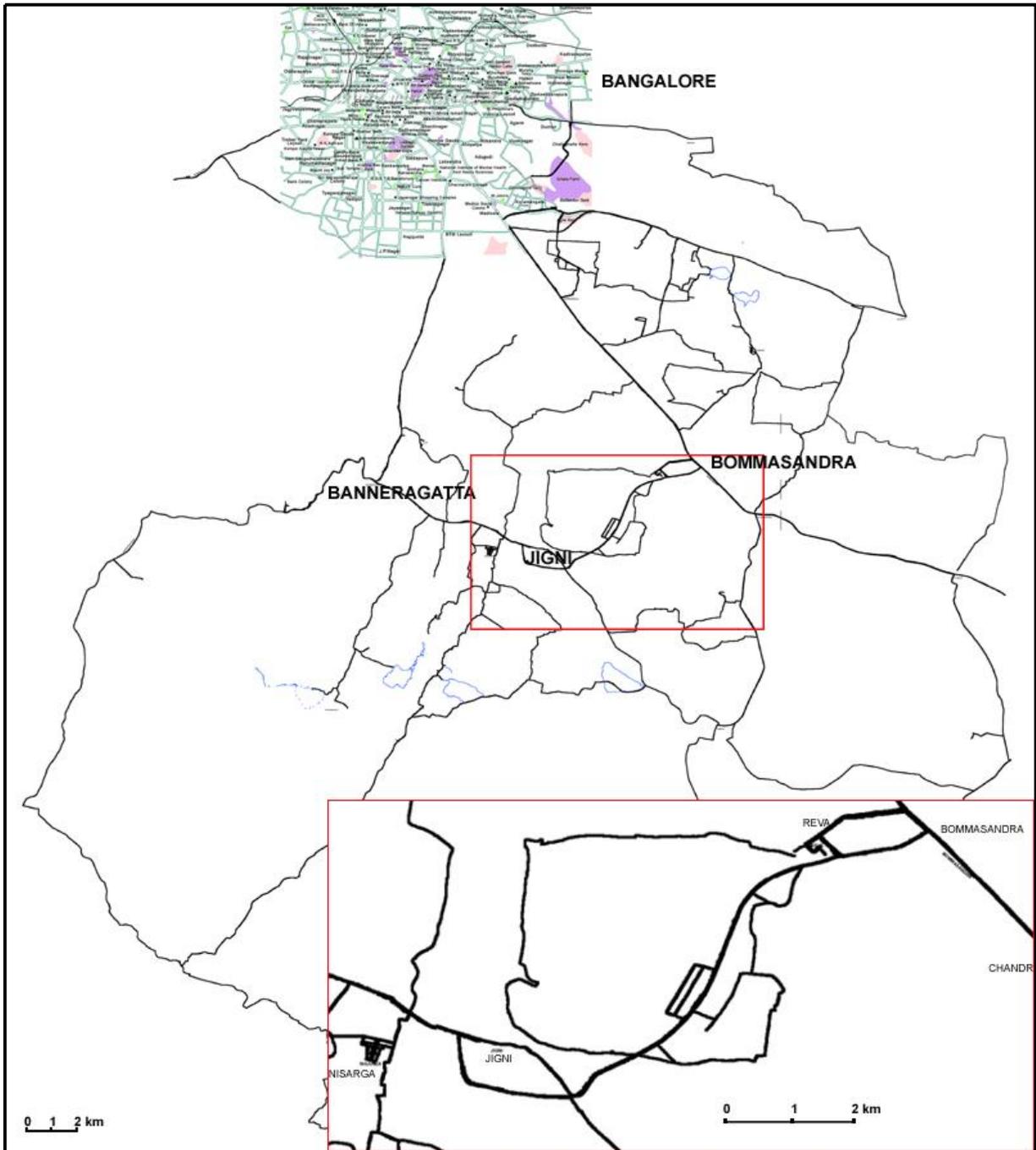


Fig 22: Map of secondary roads around Bangalore (tracks generated by REVA ZEBRA test drives)

4.3.1 REVA R36, ROAD TEST FROM 15.10.05 TILL 29.5.06

Am schluss 48Ah.... 150A max!!!

R36 in India: Z52 S/N #1

Z52 S/N #2

4.3.2 REVA 6A090700 (PURPLE) IN SWITZERLAND: Z52 S/N #1 REPAIRED

This report includes a complete analysis and comparison of efficiency, performance, failures of the new system in on-road testing. Efficiency includes efficiency of the charger also.

A separate analysis is done to compare ZEBRA battery efficiency/thermal losses with the lead acid battery efficiency, currently used by REVA cars. Test Report is furnished below:

4.4 EMC CERTIFICATION TEST FOR EU TYPE APPROVAL ("EU GESAMTGENEHMIGUNG")

5. Discussion of Results

5.1 PERFORMANCE

The reduced weight of the car has helped to get an acceleration ofseconds from 0 to 50 kph (acceleration test of 1.1.06).

Top speed was 82 kph.

These results are not completely satisfactory, but the system could not be optimized during the duration of the project.

5.2 RANGE

Range is very satisfactory.

5.3 BATTERY LIFE

Battery life of at least 100'000 km (or 6 years of operation) was expected. Unfortunately, there were too many quality problems with the ZEBRA batteries, which could not be solved during the duration of the project. Only with one battery (out of 3 samples) approximately 5'000 km could be completed, which is absolutely unacceptable.

6. Public Events – Press Coverage

7. Conclusion – Outlook

Glossar

References

¹ <http://www.curtisinst.com> PRODUCTS AC MOTOR CONTROLLERS → 50095REVEcolors.pdf

² VCL Common Functions 1-7.pdf, Curtis PMC, Livermore, CA