

Development of a globally competitive electric vehicle in India

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Abstract

REVA Electric Car Company visualized a market for a small environment-friendly car with low operating costs if designed to meet the local needs. This paper sketches the development of the small car from concept development, challenges faced in development and commercialization. The key design features, unique testing and trials, and innovations in REVA are highlighted. The market potential for REVA is tremendous, both domestic and international. The role played by governments and communities worldwide to promote EV industry and the support required from the governments to accelerate the EV program are outlined.

Keywords: EV, HEV, battery management.

1. Introduction

Though the first electric vehicle was developed in 1834, even today it is not a mainstream commercial proposition in developed markets also. Long distances, high speeds, low fuel costs and high carrying capacities combined with the conventional lobby make electric cars not competitive in those markets. Yet, in the Indian cities with dense traffic, scarce parking space, pollution problems and high fuel costs, REVA Electric Car Company (RECC) visualized a market for a small, environment-friendly car with low operating costs if designed to meet the local needs [1]. The success of EV technology will depend on the capabilities of organizations to integrate international standards at a low cost and capability to produce low volumes at low overheads. RECC, a joint venture company of Maini Group of Bangalore, India, and AEV LLC of California, USA, has just done that.

2. Development of REVA

The concept development of REVA, initial market survey to finalize product specifications and prototype design were done in 1994. The first prototype was ready in 1995 in California. It was brought to India for testing and trials in 1996. The prototype was extensively tested and tried during 1996–97 at the Automotive Research Association of India (ARAI), Pune, and certified for road worthiness and homologation*. However, the cost of manufac-

*Homologation of a car means getting it checked by a country's vehicle testing authority to see whether it meets all the relevant conditions set out in that country's vehicle laws. In India this task is carried out by Automotive Research Association of India (ARAI), Pune. The process takes anywhere between three and six months and costs a few million rupees.

turing the vehicle was found to be prohibitive and REVA team realized that a higher degree of indigenization would be required to make the car affordable to potential buyers in India.

Therefore, intensive indigenization efforts were made during 1998–2000. People were recruited and the organization started functioning like a typical start-up. Serious organizational challenges confronted the young company as the infrastructure and experience did not exist in India for the development of electric cars. Capital costs also had to be kept low.

A young team was recruited and their efforts were supplemented by executive consultants in various aspects. Special efforts were made to leverage the capabilities of different Maini group companies and their R&D centres.

During the years 2000–01, REVA was tested extensively under extreme Indian conditions of high summer heat, high humidity, monsoons and major fluctuations in supply voltage. Exhaustive tests have been conducted to prove its quality and reliability both for the domestic and international market. It was launched on May 11, 2001, the technology day, by the then Vice President of India Shri Krishan Kant, and was hailed as the most innovative product of the year.

3. Unique features

3.1. Key design features [2]

REVA was designed to be a cost-effective, efficient electric vehicle for urban commuting. The approximate ex-show room price of the vehicle for the standard model is Rs. 2.5 lakhs (US \$5,555) as on December 31, 2004 (Fig. 1), compares favourably with two-seater ‘Think’ manufactured by Ford which is priced at US\$ 22,000 (~Rs. 9.9 lakhs). A detailed description of the vehicle by subsystem is presented here:



FIG. 1. X-ray view.

3.2 Drive system

REVA uses a separately excited motor and controller that has been optimized for efficiency under the Indian driving cycle. The motor is directly linked to a transmission that drives the rear wheels. The single-speed transmission consists of a two-stage reduction gear set with ground gears to reduce noise. The drive system is rated at 13 kW peak.

Vehicle performance under congested traffic conditions has been improved by 20% through the use of an economy mode switch. This was achieved by controlling the acceleration parameters as a function of speed and optimizing field maps for efficiency. The controller is also equipped with regenerative braking that has been optimized with the hydraulic brakes and results in a range increase of 15%. To protect the power electronics from dust and humidity, they are housed under the rear seats with cut-outs for thermal management [3].

3.3 Power pack

REVA uses eight 6-volt tubular lead acid batteries with a single-point watering system. The battery pack is located under the front seats to lower the vehicle's center of gravity. Individual battery voltages are monitored along with battery pack temperature and water level. The vehicle is charged via plugging it into a 220 V-15 A plug point. The charger is a high-frequency onboard type that charges the vehicle to 80% in about 2.5 h. A 400W DC-DC converter is also integrated in the charger. The charger has been designed to operate over a voltage region of 160 V–260 V and handles frequent blackouts and brownouts (wild voltage fluctuations), typically encountered in India. As the vehicle is provided with an onboard charger, it has the capability to accept opportunity charging anytime, anywhere a 15 A, 220 V AC socket is available. Though the power pack gets 100% charged under 5 h, 80% in under 2.5 h, even 30 min charging will attain 25% state of charge. The key specifications of the power pack are given in Table I [3].

3.4 Energy management system (EMS)

The proprietary REVA Energy Management System (EMS) was developed to allow consumers to benefit from the cost, performance and environmental advantages of EVs for urban transport.

The most innovative feature of the EMS is its advanced state-of-charge (SOC) estimation capability, which is based upon seven years of research on five vehicle platforms. The SOC estimation routine utilizes advanced real-time modeling and analysis to detect changes in battery performance parameters, such as Ampere hour capacity and internal resistance for each individual three-cell battery in the pack [3].

Table I
Power pack specifications

Battery weight	: 258 kg
Battery capacity (C-5)	: 200 AH
Battery pack voltage	: 48 V nominal
Charger output	: 2.2 kW

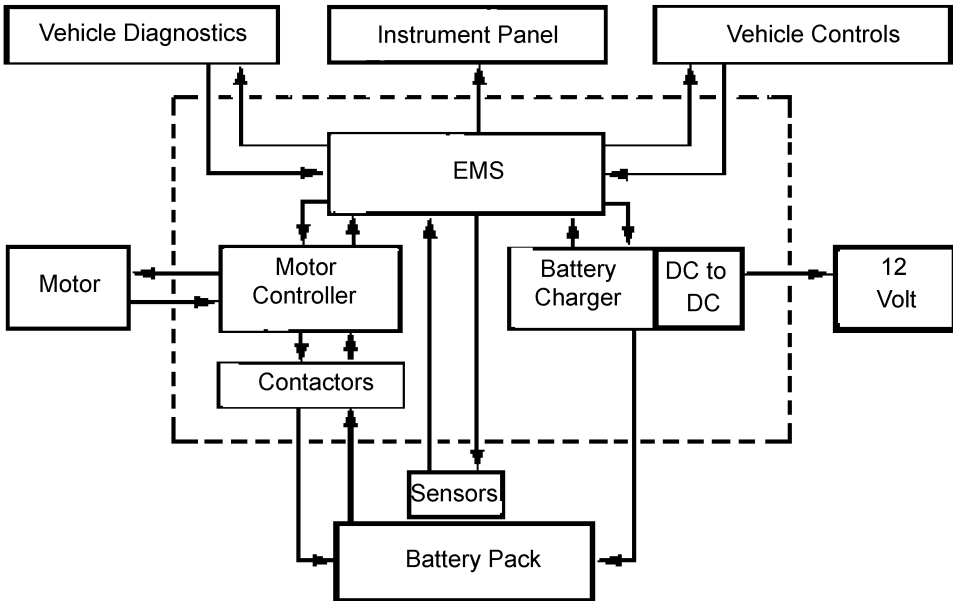


FIG. 2. Electrical system flow diagram.

This information, along with voltage, current and temperature is used individually to track the SOC of each battery. This feature allows the EMS to protect the weakest battery in pack from overcharge and over-discharge. Because packs typically fail as a result of small initial performance differences between batteries being amplified over time, this feature helps prevent the most common cause of premature pack failure.

By tracking changes in battery performance parameters, the EMS diagnostic functions are able to provide advanced warning of pack failure, *before* reductions in performance impact the driver. Similar real-time modeling is used to track other key vehicle systems, including motor, motor controller, charger, transmission, and system efficiency (tyres, transmission, bearings). Diagnostic warnings are indicated via a service warning light on the instrument cluster.

At the service station, the EMS diagnostics can provide a wealth of information to speed diagnosis and repair. By connecting a handheld diagnostic interface to the EMS, service personnel are able to determine why the service light was turned on, as well as review possible fixes suggested by the EMS.

The EMS collects data that can be used to verify that battery warranty conditions have been met, thereby reducing the cost of battery leasing to the end consumer. The EMS is able to record maintenance records, such as frequency of battery watering, average depth of discharge, maximum and minimum temperatures, etc. This information is used to pro-rate battery warranty coverage as a function of battery abuse, so conscientious drivers do not have to bear the costs of irresponsible drivers [4].

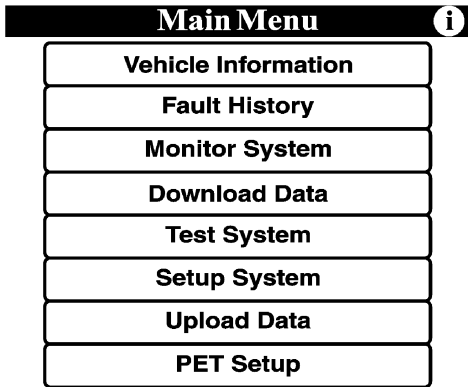


FIG. 3. PET–Main menu.

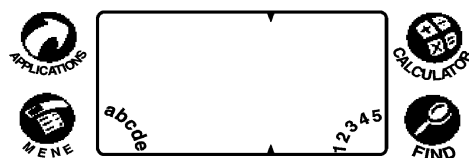
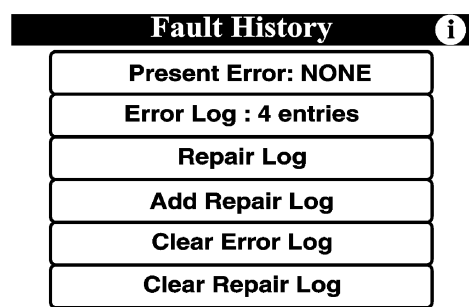


FIG. 4. PET–Fault history.

Data acquisition (DAQ) functions are provided for engineering and service. Recorded data includes Watt-h/km, total km, starting and stopping SOC, etc. available via the hand-held diagnostic unit. DAQ capabilities are intended primarily for the design and test phases of REVA development. In production, however, minimal DAQ capabilities will be retained to provide real-world usage data to support ongoing engineering improvements, as well as to help service personnel diagnose unusual problems.

3.5. Portable electronic tool (PET)

PET is a small light-weight self-powered LCD display, palm-based device. It is designed to have a serial interface to the EMS and to a PC for data storage and retrieval. Over 30 parameters can be acquired and communicated to Palm Pilot every two seconds. Fifty-six different error conditions can be detected and 100 occurrences of these errors can be stored in nonvolatile memory [4].

3.6. Climate control seats

Climate control seats (CCSTM) in REVA provide the first level of passenger comfort enhancement by allowing the occupant to adjust independently the temperature of the seats by a selector switch. The CCSTM uses semiconductor thermoelectric devices (TEDs) known as Peltier junctions. Small, light, reliable and requiring a little power, a CCSTM can deliver noticeably cool or warm air to the passengers in less than 30 s after activation. Unlike conventional heated seats, CCSTM can also cool the seat. An ‘in-seat’ air circulation system comprising a compact, efficient, low-resistant, high-capacity blower through a specialized fabric help achieve uniform temperature across the seat area. A ‘CCSTM electronic control-

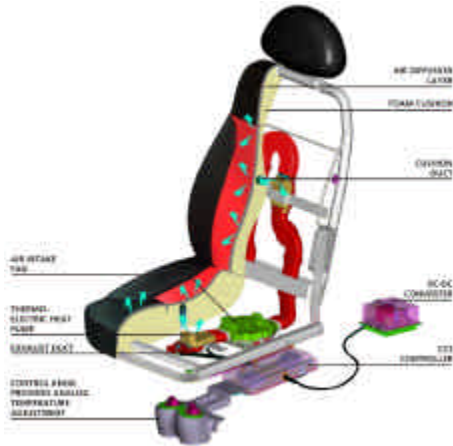


FIG. 5. Sectional view of climate control seat.

ler' is used to select and control the amount of ventilation, heating or cooling. The electronic controller is powered by a separate DC-DC converter of the vehicle's 48V system.

The CCSTM is extremely efficient and typically uses 50–70 watts per seat resulting in less than 3% decrease in range [5].

3.7 The REVA HVAC system

The airconditioning system in REVA is built around a mechanical vapour compression refrigerant system and a heater. The system is driven by an efficient permanent magnet DC motor which derives power from the 48V batteries through an 'electronic controller' which incorporates MOSFET-based 'softstart, current-limiting and protective tripping' mechanisms. The motor drives a compressor compatible for use with R-134a gas. The airconditioning system has been designed to work well even at 45°C ambient temperature. REVA also has an 800 W heater that is integrated with the evaporator housing.

The REVA airconditioning system incorporates special electronics to activate and deactivate it remotely and is integrated with the vehicle security system. This enables the user to 'precool' or 'preheat' the cabin before entering. This feature allows the airconditioning system to operate using the utility mains energy during charging, hence ensuring no drain from the batteries [6].

3.8 Chassis and suspension

REVA uses a lightweight tubular steel space frame that supports all the suspension and body components. The space frame encloses the passenger compartment completely and is designed with energy absorption sections.

The front suspension is conventional MacPherson type. The rear suspension consists of a single A-arm with a panhard rod to take the lateral loads. The motor and transaxle are directly mounted on the A-arm and act as a structural member.



FIG. 6. The shaker test.

4. Unique testing and trials of REVA

REVA has been tested extensively under extreme Indian conditions of high summer heat, high humidity, monsoons and major fluctuations in supply voltage. Exhaustive tests have been conducted to prove its quality and reliability both for domestic and international markets. In line with this, 40 pre-production batch of REVA cars were tested, with partial financial support from the Ministry of Nonconventional Energy Services (MNES), Government of India, for over 1 million km amounting to 25 times travel around the globe. Several specialized tests were conducted at national agencies. Pave test was done at the Vehicle Research and Development Establishment (VRDE), Ahmednagar. Hot test and Shaker test were conducted at ARAI, Pune. The NVH test for noise levels was conducted at the Facilities for Research in Technical Acoustics (FRITA), Indian Institute of Science, Bangalore. These noise levels are 10 dBA lesser than the accepted levels of 75 dBA for the IC engine vehicles. This implies that REVA is 50% quieter than the quietest IC engine vehicles.

Details of some of these important tests are briefly discussed here.

4.1. *Shaker test*

In the shaker test, the vehicle is subjected to simulated road inputs. Over 2,50,000 km on a four-post shaker testing rig was completed at ARAI, Pune, to understand better the effect of road conditions in India on structural integrity.

4.2. *Tether test*

As the battery has a range of 80 km between recharge, tether testing was resorted to. In this the vehicle was connected to a central pole by a tether and was powered by AC to run continuously in a circular path. The vehicle was regulated by a remote control, and was subjected to life test. It passed through numerous bumps and a water trough.



FIG. 7. The tether test.



FIG. 8. The hump test.



FIG. 9. The water test.

In addition, life tests were conducted on various components such as the motor, batteries, transmission, etc. to ensure a very high degree of quality and reliability [1].

5. Innovations in REVA

REVA as an electric vehicle is required to be light, efficient and cost-effective, and the materials and manufacturing processes used reflect this [2].

5.1. Tubular steel space frame

REVA has been uniquely developed to use a lightweight tubular steel space frame that supports suspension and all the body components. The tooling cost for manufacturing it is just 1/10th that of a conventional monocoque steel structure and 25% lighter in comparison to it.

5.2. Thermoformed body panels

The body is made of lightweight dent-proof ABS plastic panels. The extruded sheets are thermoformed to the desired shape and have a high impact resistance.

Their tooling cost is significantly lower and 50% lighter than that of stamped sheet metal body parts.



FIG. 10. The shower test.



FIG. 11. The Dyno test for higher degree of reliability.



FIG. 12. Three levels of safety–dent-proof body panels, side impact beams and a steel space frame.



FIG. 13. Bumpers: designed with energy-absorbent crush cones.

5.3. Rotationally moulded bumpers

The bumpers are one piece hollow, rotationally molded with integrated energy absorption cones and all light attachments. This one piece construction replaces 8–10 items normally found in bumpers and is also much lighter and 100% recyclable.

5.4. Sandwich doors

The doors incorporate a steel frame with side impact protection beams, sandwiched between two plastic panels. The use of this technology gives best-in-class safety at 15% lower weight, and will improve the range and performance of REVA.

5.5. Assembly line

The unique design of REVA allows low-capital manufacturing system by making use of self-supporting space frame and pre-painted plastic panels to allow the car to move from station to station on its own wheels in the final assembly.

5.6. Two onboard computers

These are provided for energy management and data acquisition for quick diagnostics. The EMS extends range by 15% and battery life by 25%.

5.7. Cost leadership

The company incorporated the latest electric vehicle technology and cost-effective manufacturing processes and materials used, making the car commercially viable at significantly lower price than that of other EVs of its class globally.

5.8. Low maintenance cost

It requires extremely low maintenance because of the absence of clutch, gear shift lever, spark plugs, radiator, etc. and minimum number of moving parts leading to less than 40%

cost of maintenance and the latest onboard diagnostic tools that store three years of data and enable prompt service, enhancing efficiency, performance and high degree of reliability.

5.9. *Savings in running cost*

The REVA has the lowest running cost of only 40 paise/km. From the viewpoint of operating costs, there will be a saving of over Rs. 1.65 lakh (\$3667) over a period of 5 years at an average running of 1,200 km per month.

6. **Main users of REVA**

REVA is an ideal city mobility vehicle for the urban commuter. Some of the target customers of REVA car are.

6.1. *Individuals*

- Single/working ladies
- Professionals (doctors, lawyers, etc.)
- Youngsters who commute to college
- Retired persons

6.2. *Fleet buyers/government organizations*

- Large/medium size organizations for their staff for various activities (sales, service, testing, materials, purchase, etc.)
- Rent-a-car outfits – they can provide an environment-friendly, safe, reliable, low-cost option for visitors to move around a city.
- Large complexes—(e.g. factories, hospitals, educational institutions, resorts, IT complexes, etc.) for safe and quiet transportation of senior management/visitors within the complex [6].

7. **Other features of REVA**

7.1. *Safety and reliability*

REVA ranks high in terms of safety features:

- The car is provided with dent-proof ABS body panels.
- The steel space frame and side impact beam provide additional safety.
- Low center of gravity makes the car highly stable.
- The regenerative braking adds to safety.
- Two onboard computers
- Three-year unmatched warranty

7.2. *Ease of use*

- Automatic: No clutch and no gear shifting lever.

- Ideal for stop-and-start city-driving condition. City driving necessitates stopping and starting the vehicle at traffic signals.
- Compact size makes it easy to park and maneuver
- Elevated seats and a wide door provide excellent ingress/egress especially for ladies in saree.
- REVA has a unique climate control seat option, adding to the comfort of the user.
- Onboard charger facilitates easy charging anywhere, at home or at work; one needs only a 15-Amp plug socket.

7.3. *Aesthetic appeal*

- Available in over 2000 shades

8. Market potential

Electrical vehicles have huge potential. Worldwide there is an increasing demand and awareness for low-cost EVs. Governments and communities are coming forward in support of EVs in a big way. The worldwide electric vehicle industry is projected to grow to over Rs. 45,000 crore (US\$ 10 billion) in the next 10 years.

REVA has already received tremendous response in various markets. With over 100 cars in the export market for testing and demonstration in countries like UK, Japan, USA, Malta, Ireland, etc., it has made a big impact in the international market. Commercial sales/lease of the cars has already commenced in UK, Malta and Ireland.

The scope for EV manufacture in the country is tremendous. It is expected that the volume would be about 1 million by 2010 and as much as 8 million by 2020. With government support in accelerating the electric vehicle programme, the volume could be as much as four times!

9. Role played by governments and communities worldwide to promote EV industry

A large number of concessions have been offered by government and communities for promoting EVs.

9.1. *Direct subsidy*

- There is a subsidy of up to £2,000 in UK, of FF 5,000 in France and of \$4,250–42,500 in the US depending upon the size of the EVs bought. These concessions are available up to the year 2007.
- In Japan and Italy, the governments give a subsidy equivalent to 50% of the incremental cost of buying the EV.

9.2. *Other support*

- Free parking and charging facilities in UK, USA, Italy, etc.
- Exemption from road tax and other concessions have been given in Austria, Switzerland, France, etc.

- A fixed percentage of all government fleet vehicles will be electric in USA and Italy.

10. Support required from Government of India to accelerate the EV programme in India

For the EV and HEV industry to realize its maximum potential, it is necessary for the governments at all levels to review and modify, where needed, policies that support the industry's development. These could come by way of:

- Encouraging EVs through purchase and usage by government departments and other undertakings of the government.
- Concessional duties on all EV components imported.
- Tax subsidies—road tax, sales tax, etc.
- Supportive legislation making EVs compulsory in certain zones and cities.
- Favorable R&D policy to promote research and developmental activity in the industry.
- Extending the present subsidy scheme available to institutions, government departments and undertakings, hospitals, educational institutions, tourism, etc. to individual buyers. The scheme be made consumer friendly by giving the subsidy to EV manufacturers.
- The role of government can be consistent with broader societal objectives while fostering needed changes. Appropriate government policies during the next five years will help to achieve the economic production levels for self-sustaining growth in the shortest possible period, resulting in India becoming a leader and dominant global player in the field of EV technology.

As already stated, the worldwide EV industry is projected to grow to over Rs 45,000 crores (USD 10 billion) the next ten years. Also, as future battery technology gets more inexpensive (such as lithium iron and nickel metal hydride), EV's acceptability and usability will further increase in the next 3–4 years. In the next 10 years, electric vehicles will certainly be the mainstay in technology—EVs powered with fuel cells for inter-city driving and with batteries for intra-city mobility [7].

11. Conclusions

For REVA to succeed, its price has to be very competitive. The design methods and manufacturing philosophy used in REVA allow it to be manufactured cost effectively at low volumes. Key systems such as EMS and climate control seat improve vehicle performance and passenger comfort at an affordable price. To ensure reliability, the vehicle has been successfully tested for over three years and many design changes made as a result of harsh road and environment conditions prevalent in India. REVA was launched in 2001 as the first mass-produced consumer electric vehicle in India and test-marketed overseas and the customer feedback is very positive.

EVs are a reality today. These are currently the best solution to reduce vehicular pollution in cities. Government of India can play the role of a catalyst, integrating the efforts of the EV industry for effective utilization of our resources. Industry and government can act

together to create a leading, globally competitive India-based EV and HEV industry. Important societal and economic benefits would result, including increased export sales, substitution of domestic energy sources for imported fossil fuels, foreign exchange earnings and pollution reduction.

Technical specifications

Type	: Two-door hatchback
Payload	: 4 persons (227 kg)
Top speed	: 65 km/h
Charge time	: 80% charge in 2.5 h; 100% in 6 h

Integrated power system

Motor	: High torque (70 Nm), separately excited DC motor, 13 kW peak
Controller	: 400 Amp microprocessor-based with regenerative braking
Charger	: 220 V, 2.2 kW, high-frequency switch mode type
EMS	: Microprocessor-based battery management system
Power pack	: 48 V, 200 Amp-h, EV tubular lead acid batteries

Dimensions

Length	: 2638 mm
Width	: 1324 mm
Height	: 1510 mm
Ground clearance	: 150 mm
Wheel base	: 1710 mm
Turning radius	: 3505 mm
Curb weight	: 670 kg

References

1. Chetan Maini, Challenges faced to develop small electric passenger car in India, *SIAT* 2003, ARAI, Pune, India, 15–18 January 2003.
2. Technology Development Board, Government of India, National Award for successful commercialization of indigenous technology (2003).
3. Development and production start-up of an urban electric vehicle for India, Paper presented at EVS-16, *16th Int. Electric Vehicle Symp.*, Beijing, China, Oct. 1999.
4. Chetan Maini and Paul Schweizer, *Benefits of energy management system and advanced diagnostics system of the REVA*, October 2000.
5. Chetan Maini, Why electric vehicles like REVA make perfect sense for developing countries?, *EVS 18*, Berlin, Germany, October 2001.
6. Chetan Maini, REVA heralds a new era in successful commercialization of EVs, *EVS 19*, Busan, Korea, October 19–23 2002.
7. Chetan Maini, Electric vehicles—a great alternative for India, *Automonitor*, January 2003.