t Z e r o

History & Technical Data

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history of the tZero

Over three decades ago, a dream was born – that electric vehicles could provide a driving experience that would ultimately surpass the best of gasoline-powered vehicles. It was envisioned that this technology could ultimately replace combustion-powered vehicles leading to a carbon-free future where all transport-related emissions were completely eliminated. It is upon this ethos that Alan Cocconi (Caltech BS '80) and Wally Rippel (Caltech BS '68) founded AC Propulsion (ACP) in March of 1992; Cocconi was chief engineer and Rippel was president. ACP's first product, designed that year, was a 100 kW drive and recharge system – the AC100. It consisted of an insulated-gate bipolar transistor (IGBT)-based power electronics unit (PEU) and a custom-designed induction motor.

One of the AC100's key features was an integrated recharge system where the inverter and motor, in addition to providing up to 100 kW of drive power, provided up to 19 kW recharge power using standard AC utility power as the input. This technology derived from work originally carried out by Rippel at JPL and later improved by Cocconi in connection with the GM Impact. The effective cost of the integrated recharge was about a tenth that of conventional. The new recharge technology, termed "Reductive Charging" provides "V2G" and "V2X" – where battery energy is controllably returned to the electric utility for grid stability or is available as AC power for external use. EVs equipped with V2G can provide critical support to the power grid at times of peak demand or limited supply. As such, the V2G technology can transform EVs from a "utility liability" to a "utility asset."

By 1994, a new generation of IGBTs was in production. This enabled ACP to upgrade performance of the AC100 without having to increase the physical size of either the Power Electronics Unit (PEU) or the induction motor. By year's end, ACP had designed and fabricated a prototype AC150 – where peak shaft power was now 150 kW (200 hp). ACP's business model was to work with major car companies – to sell EV drive systems, and to pioneer in creating improved EV technology. Car companies showed limited interest, especially after 1999 when GM and others backed away from EVs. Cocconi and ACP's second president, Tom Gage, realized that something dramatic would be needed to rekindle the post-Impact enthusiasm.

In 1995, ACP became aware of a light-weight, aerodynamic, hand-built sports car – the Piontek Sportech. Concluding that it would be a good platform for an electrified sports car which could showcase the AC150 drive system, a Sportech was purchased along with rights for EV use. By year's end, a prototype conversion was complete. The car was aptly named the "tZero" which derives from t_0, the mathematical symbol for a starting point in time. Three "production" vehicles were subsequently built between 1996 and 2003 using AC165 drive systems (AC150 upgrades) and a Kevlar and carbon fiber-reinforced body built over a custom reinforced stainless steel space frame. Each had numerous improvements beyond the original prototype, including an anti-skid feature where sensed lateral acceleration was used to limit regenerative braking. Acceleration was zero to sixty in 4.17 seconds and range was approximately 100 miles. The car pointed to a future where high-performance and clean air could join forces. Ironically, while motivating considerable interest among engineers, scientists and celebrities, there was little traction within auto companies. Two tZeros remain in existence; a third was destroyed by a fire not caused by the vehicle itself.

In 1999, Alec Brooks (Caltech PhD ’81) joined ACP to lead an effort in commercializing the tZero. It was determined that extensive vehicle modifications would be required in order to meet federal safety standards and that associated costs were well beyond ACP’s financial capabilities. As a result, the tZero remained a “showcase” for ACP technology.

In early 2003, ACP tested 18650 lithium-ion cells in connection with development of solar-powered UAVs. (This led to the “Solong” UAV which demonstrated multi-day solar-powered light – and the possibility of “perpetual flight.”) Based on this success, ACP realized that these same cells could be combined into modules which could replace the tZero lead-acid batteries.

ACP also realized that the cost of implementation would exceed available resources. Around this time, Cocconi and Gage were contacted by Martin Eberhard. After a test drive, Eberhard was enthused and wanted ACP to produce a fourth car which he would then purchase. When ACP declined, Eberhard offered to finance the conversion of a tZero to lithium – with the understanding that he would be able to use the car for attracting investment for an EV startup. ACP agreed and subsequently developed a 6,800 cell lithium ion battery pack for the tZero. In September of 2003, this work was completed and range was now greater than 300 miles and zero to 60 time was reduced from 4.17 sec to 3.6 sec.

In July of 2003, Martin Eberhard and Marc Tarpenning incorporated Tesla Motors (which later became Tesla, Inc.) with the intent of manufacturing EVs based on the tZero technology. After the tZero was converted to lithium power, J. B. Straubel and Elon Musk test-drove the car. Both were impressed and Musk decided that he too wanted to start an EV company based on the tZero technology. Gage suggested that the two groups join forces – which they did. A license agreement was effected between ACP and Tesla Motors. In early 2004, Musk joined Tesla Motors as the largest shareholder and Chairman of the Board. Fourteen years later, Musk recognized in a tweet what AC Propulsion had accomplished: “Major credit to AC Propulsion for the tZero electric sports car 1997-2003 that inspired Tesla Roadster. Without that, Tesla wouldn’t exist or would have started much later.” One creation, the tZero, had accomplished what governments and industry could not – to change the course of automotive history.

technical data:

Battery	Lead Acid	Lithium Ion
Type	Optima Yellow Top	18650, custom ACP packaging
Number of cells per module	6	68
Number of modules	28 (336 V nominal)	100 (375 V nominal)
Total number of cells	168	6,800
Cell capacity (2 hr rate)	51 Ah	2.0 Ah
Battery energy	17 kWh	51 kWh
Battery weight	550 kg (1210 lb)	306 kg (673 lb)
Cooling	Forced air	Forced air
Heating	36 W/module, controlled	not used
Active module balancing	5 A computer-controlled supply	100 mA controlled discharge
Weight	576 kg (1268 lb)	326 kg (717 lb)

Configuration — AC165 rear drive with modified Honda Civic manual transmission

Power Electronics Unit (modified AC150) — Includes motor inverter, charger, and 12 V auxiliary power

Inverter	
Topology and switching devices	Three-phase, voltage-fed, IGBT
Number of switches in parallel	12
Bus capacitors	Electrolytic
Switching frequency	10 kHz
Control	Scalar, mixed signal (inner loop: current mode, outer loop: slip frequency is determined by look-up table such that efficiency is maximized for each torque-speed point; regenerative braking is controlled by initial depression of accelerator pedal; test control mode: fixed slip frequency
Phase current sense	IR sense followed by delta-sigma isolator; 50 kHz BW
Peak phase current	700 A
Rated max. kVA	200
Cooling	Forced air with variable speed blower, serpentine fins
Weight	30 kg (entire PEU)

Motor	
4-pole	4-pole, cage induction
Bore diameter	5.00”
Stator design	48 slots, custom winding, custom teeth, non-skewed
Stator outer diameter	8.00”
Stator length	6.0”
Rotor design	68 slots, copper bars (non-skewed), copper end rings, stamped, laminated, brazed to bars, beryllium-copper capture rings
Speed sensor	64 pole, magnetic
Base speed	6670 rpm
Max. torque	246 Nm
Max. rpm	13,000
Max. power (shaft)	165 kW
Peak off. (motor + inverter)	91%
Weight	50 kg (110 lb)
Bearings	Grease packed, sealed
Cooling	Forced air with variable speed blower, double row serpentine fins

Reduction Gear	
Type	Two-stage, offset helical (Modified Honda Manual), insulated input shaft
Ratio	9:1

Charger	
Type	On-board, integrated, bidirectional capability
Power input	Singe phase 115 to 240 V, 50 Hz or 60 Hz
Power rating	19 kW with 240 V input
Power factor	>99%
Control	Temperature compensated battery voltage

Auxiliary Power Converter	
Topology	Forward converter, half-wave
Switching device	MOSFET
Switching frequency	100 kHz
Output voltage	13.5 V nominal, adjustable, current limited
Output current rating	100 A

Driver Display — Analog speedometer, analog volt/ammeter, LED display for battery module voltage beyond limits (lead acid), temp. (motor, PEU), Ah, Wh, Wh/mi, selectable, battery status

Cabin Heating and Cooling — Heating: motor waste heat + 2 PTC heaters
Cooling: ducted air, no air conditioning system

Vehicle		
Outline dimensions	3810 mm (L) x 1625 mm (W) x 1040 mm (H)	
Drag coefficient	0.35 (est.)	
Wheelbase	2235 mm	
Track	1384 mm (F), 1372 mm (R)	
Structure	Nitronic 30 stainless steel frame, Kevlar and carbon fiber body panels	
Suspension	Double wishbone, front and rear	
Steering	Rack and pinion	
Weight	1118 kg (lead acid)	891 kg (lithium ion)
Range	160 km (100 mi.)	515 km (lithium ion)
Zero to 60 mph time	4.07 sec (lead acid)	3.60 sec (lithium ion)
Max. speed	165 km/hr (103 mph), electronically limited	
Energy efficiency	93 Wh/km (lead acid)	86 Wh/km