# Development Trends in Electric Drive Trains and Power Storage in Electric Vehicles

**George Holling**
*Technical Director, Rocky Mountain Technologies, Inc.*

Ten years ago, the typical electric vehicle was a golf cart or forklift truck that featured a series wound DC motor, and more recently, AC induction motors with lead acid batteries as the main power storage. While these vehicles still dominate the market for electric vehicles, the automotive transportation sector has made some serious inroads in recent years with the introduction of General Motor's short lived EV-1 and most importantly Toyota's Prius Electric Hybrid vehicles.

The two main drive train technologies that are in production today are the All Electric Vehicle (AEV) ( also known as Battery Electric Vehicles - BEV), which is powered solely by its stored electric energy and the Hybrid Electric Vehicle (HEV) which uses a conventional combustion engine to assist the electric drive train and to recharge the main storage battery as necessary. Since the HEV can recharge its batteries, they typically have smaller storage batteries. The Plug-In Hybrid Electric Vehicle (PHEV) is a combination of these two technologies, where the main storage battery can power the vehicle for the first 15 to 30 miles of driving before the combustion engine will start to become active. Electric energy from the power company is typically less expensive than fossil or alternative fuels. Proponents claim that this technology offers the lower cost/mile for most drivers.

General Motors' EV-1 is an all electric vehicle that featured a high performance AC induction motor, which is still considered by many the standard for electric vehicle drive trains, and the batteries were lead-acid batteries with a relatively short battery life. Tesla Motors currently offers a high performance sports, the Roadster, which features an AC motor and a stack of Lithium-ion batteries similar to those used in laptops.

The Toyota Prius on the other hand is a hybrid electric vehicle that features an internal permanent magnet (IPM) motor and a NiMH intermediate storage battery. Toyota has more than 2,000 patents on its hybrid electric vehicle and it has established its hybrid drive train technology as the state-of-art standard, which has been licensed by Ford for its Escape hybrid and by Nissan for the Altima hybrid.

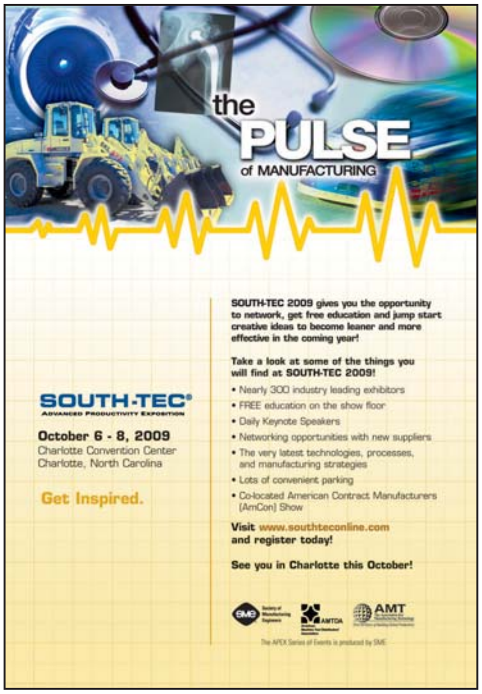
General Motors has announced the Chevy Volt for the 2010 model year, which is its first commercial PHEV entry. The Volt is a series powered HEV with a large Lithium-ion battery made by LG Chemical and also Hitachi that will power the Volt for the first 40 miles before its combustion engine and generator are needed to supply additional power.

The main distinction between all of these drive trains topologies is the AEV versus HEV with the PHEV sharing aspects of both of these. Foremost, the efficiency of the electric drive train is a primary concern in either application but it takes on more importance for AEVs than for HEVs. In an AEV, efficiency of the electric drive train determines battery size, overall weight and range and thus is the single major design consideration that impacts the overall AEV. Therefore it is important to optimize the overall drive train efficiency. Designers chose gears, multiple speed transmissions and continuously variable transmissions (CVT) to allow the motor to run at or close to its maximum efficiency range at all times.

While one of the goals of electric drive trains is to eliminate the gears/transmissions and the associated weight, cost and inefficiencies physical, principles dictate the use of these components when operating at low wheel speed as power is a function of Torque RPM. At low RPM little or no power is generated by the electric motor even though battery power is still consumed to overcome i2R and other losses, thus the need for gears.

A fixed gear ratio requires a motor with a high base speed (high motor current) and a very wide and efficient constant power range. Fixed gears are preferable in EVs as they may offer higher efficiency and less weight and complexity than transmissions. AC induction motors such as those made specifically for traction applications by Brusa and AC Propulsion do offer a wide constant power range versus conventional permanent magnet motors (AC PM, AC Synchronous etc.), such as those made by UQM. Conventional PM motors generally are limited to a useful constant power range of 2:1 versus base speed although some companies claim higher ratios, which often come at the expense of reduced efficiency. Reluctance machines also offer a wide constant power range and companies such as Satcon, LeTourneau and Rocky Mountain Technologies offer SR motors for traction applications, which can offer in excess of 95 percent motor efficiency.

The IPM was introduced as a traction motor by Toyota in the Prius. The IPM combines elements of both the reluctance and the PM machines. The IPM can operate with motor efficiencies of in excess of 97 percent over a wide speed and torque range. Since it uses both the PM magnet and reluctance to generate torque it has the higher power density compared to the SR or PM machine alone.



Due to the high efficiency of this motor (forced) air-cooled IPM traction drive systems have a viable alternative to the conventional liquid (water-glycol mix) especially in AEVs where no water-cooled combustion engine is present and a special cooler must otherwise be installed.

Conventional PM machines have failure modes that can pose a significant risk to the vehicle and its occupants such as high stalling torque or even catastrophic failure when a winding fails to a short. While many IPM designs try to maximize the power density of these machines through a technique known as 'flux channeling' (i.e. the Toyota Prius design), IPM machines can be designed to have limited torque in the failure modes while maintaining high power density and excellent motor efficiency. American Electric Vehicles has announced a battery and drive train for its MPV vehicle that utilizes such an IPM motor designed in partnership with Orchid International and Rocky Mountain Technologies that can achieve more than 95 percent total system (motor and drive) efficiency for the electric drive motor and controller.

Recently, much attention has focused on placing motors directly into hub of the driving wheels (wheel hub motor). Companies such as TM4 have demonstrated designs that can deliver sufficient torque in a light weight package. While much of the discussion associated with wheel-hub motor focuses on the concept of 'unsprung weight' (the weight located outside the sprung frame) many experts agree that this would be less of an issue for utility or city vehicles that do not need all the high performance features of a sports car.

A relatively new motor technology, the transverse flux motor (TFM), appears to have potential as a wheel hub motor as its airgap can be either radial or axial or a combination thereof, which makes it very suited for larger gap motors that can utilize the full extent of the magnetic surface available at the wheel's hub.

An interesting development trend that could affect electric traction motor is the use of amorphous metal motor for better performing motors with high power density especially for high speed and hub motors. Hitachi recently acquired Honeywell's Amorphous Material business and it has published data on amorphous metal motors and according to some publications its use could be expanded for larger traction motors. The main advantage of these amorphous metal motors is that the internal losses are much lower than that of comparable lamination based designs and such motor could be suited for much higher RPM, thus its high speed efficiency could offset any gear related losses. While these materials are not new, their use was considered prohibitively expensive in the past but recent publication indicates that this may be about to change.

Another interesting concept was published at e-Drive's Motor, Drive & Automation Systems 2009 conference in Orlando, where a switched reluctance-motor with an integral harmonic gear was introduced. This concept appears well suited for a hub motor. Due to the high inherent gear ratio of a typical harmonic gear this motor will operate at high motor RPM, which results in a high motor efficiency, high torque output and potentially a very good overall system efficiency at low weight which is of great importance for hub motors.

The above trends of using advanced Lithium-ion batteries in conjunction with IPM motors and the trend to implement wheel-hub drives can be expected to continue and to make AEVs and HEVs more commonplace and expand their inroads into the vehicle market based solely on their economic merits.

*Dr. Georgo Holling has more than 25 years progressive experience in the motor and drive industry as designer, manager and CEO with companies such as Honeywell, Pacific Scientific and General Electric. He has written more than 70 technical articles and papers and presented papers, invited sessions and tutorials at most major US motor and drive conferences and publications. Currently he serves as technical director for Rocky Mountain Technologies where his team develops high performance motors and drives for traction, oil and gas exploration, low cost high efficiency generator for wind turbines and inverters for wind and solar and provides consulting services.*

*Contact Rocky Mountain Technologies at www.rockymountaintechnologies.com.*

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