Smart Grid and E-Mobility

Peter Tschulik

(Dipl.-Ing. Dr. Peter Tschulik, Siemens A.G. Austria, Ruthnergasse 3, 120 Vienna, peter.tschulik@siemens.com)

1 ABSTRACT

Industrial companies and energy suppliers are working closely together with automotive engineering to make the vision of electric mobility in individual traffic a reality. An electric car is simultaneously both a means of transport and a mobile energy-storage device that can also be used as a source of energy in public networks in the medium term. Such cars could also be used as controllable loads for the fluctuating feed of wind or solar energy into a power grid - provided that the layout of the network permits such a scenario.

As an integrated technology company Siemens is heavily involved in electric mobility in its Corporate Technology department and in the Energy and Industry Sectors. The work focuses not only on the requirements made on the electric vehicle itself but also on the design of the infrastructure of the power grids. Areas under investigation include power generation and distribution, traffic and energy management, charging infrastructure, intelligent electricity meters, power electronics, software and sensors, and of course also the electric drives, and energy recovery and storage.

2 BACK TO THE FUTURE

On April 29, 1882, Werner Siemens drove the Elektromote - an electrically powered carriage - along a 540-meter test track in Halensee near Berlin.

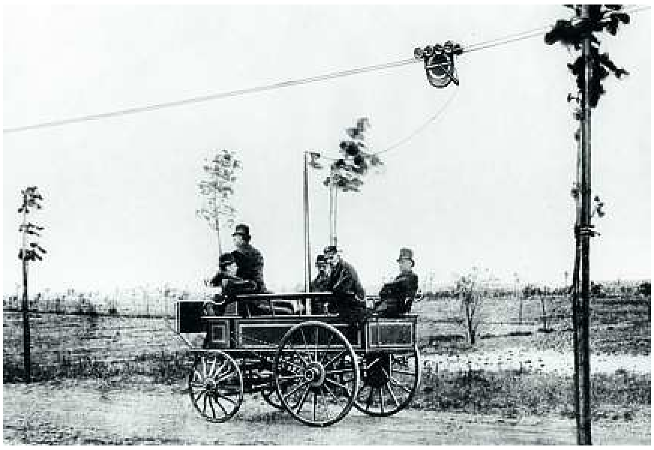

Fig. 1: Elektomote of Werner Siemens

Siemens' invention was not only the first electric vehicle, but also the world's first trolley bus. The Elektromote was followed in 1905 by the Electric Victoria, which rolled through Berlin as a taxi and delivery vehicle at a top speed of 24 kilometres per hour. Although these vehicles were well ahead of their time, their low battery capacities, speeds, and range couldn't compete with internal combustion engines. This state of affairs has lasted more than 100 years, and the rule of thumb even today remains that one liter of gasoline equates to nine kilowatt-hours. A lithium-ion battery with that sort of content weighs around 100 kilograms. Still, an electric car can travel around 60 kilometres on that energy, while a gasoline-powered vehicle will only manage 10 to 20 kilometres. This range superiority is due to the fact that electric motors are roughly four times as efficient as combustion engines. Lithium-ion batteries are familiar as high-performance energy storage devices in cell phones, PDAs, and laptops. They can store two to three times as much energy as conventional nickel-cadmium batteries of the same weight. However, a €10,000 Li-ion battery would be required to power a passenger car that uses approx.15 kilowatt-hours per 100 kilometres. Mass production will thus be required to bring prices down to affordable levels.

3 ELECTRIC ECOSYSTEM

A vision of mobility is emerging in which vehicles not only deliver clean transportation, but also store excess energy from renewable sources. New drive systems, battery, billing, and smart grid technologies are setting the stage for tomorrow's energy and transportation ecosystem.

Imagine millions of electric vehicles in parking lots and garages, each drawing power from the grid. Now take the thought one step further and imagine each vehicle returning some of its stored energy to the grid during periods of peak power demand. That's the vision that is set to transform the automotive industry over the next few years. It's a vision that is not possible with the internal combustion engine. However, it can be achieved with a bidirectional battery that can be charged up or used as an energy source.

Fig. 2: Tomorrow's electric vehicles will redefine mobility. Not only will they recharge in only minutes at fast charge stations.

They will also function as mobile power storage units for the smart grid.

This vision of electric mobility has come about as the result of the convergence of a number of factors. An increasing number of people want to be mobile, while energy consumption is rising dramatically, especially in emerging markets such as India and China. In the past, these demands were met mainly by using fossil fuels. And indeed, for over 100 years cars have been powered by combustion engines while electrical power has essentially been produced by burning coal or natural gas. Only railway traffic was mainly based on electric engines.

Time is running out, however, because fossil resources are being depleted, and the CO2 emissions they produce are accelerating climate change. More and more energy suppliers are therefore utilizing renewable and CO2-free energy sources, such as wind and solar power. The problem here, however, is that their yield depends on the weather. As the share of electricity from such sources increases, so too does the need to develop interim storage facilities whose energy can be tapped at a moment's notice. One idea is to use batteries in electric cars, which, depending on demand for electricity and price, can either be recharged from any power outlet or return electricity to the grid. If, for example, a surplus of electricity is available, as is often the case at night or during periods of windy weather, prices could be lowered, making it attractive to "fill up" at such times. Conversely, if winds were calm, or a lot of electricity was being used during the day, the price might rise accordingly, which would lead many vehicle owners to sell their electricity back to the grid at a profit.

In fact, an intelligent management system installed in each car could even make the decision itself, provided it knew how far its driver planned to travel that day, and how much electricity the battery would require for that distance. In any case, most cars sit idly for most of the day, which means they could be continually connected to the grid from their office parking spaces, parking lots or home garages. Flexibly determining electricity prices in accordance with supply and demand would also eliminate any problem associated with many vehicles trying to recharge at once, which of course would cause prices to skyrocket.

4 CARS THAT GENERATE INCOME

By storing energy that can be returned to the grid, electric cars can act as buffers for wind and solar power. The rule of thumb is that there should be some 300 electric vehicles as potential energy storage units for every wind turbine with a peak output of three megawatts. The existence of cars as mobile storage units would kill two birds with one stone. Assuming vehicle batteries could handle numerous charging and discharging cycles, energy supply companies would be provided with a buffer against surplus energy from renewable sources, while vehicle owners would have a source of income to help them finance their relatively expensive batteries. In the foreseeable future, batteries will remain one of the most expensive components electric cars. Achieving a range of 100 kilometres for a mid-sized vehicle today requires a battery with approximately 15 kilowatt-hours of energy content. Such a battery currently costs more than €10,000. However, there are other options for such mobile power plants besides having them financed through income from electricity. For one thing, vehicle owners wouldn't necessarily have to buy the battery. Instead, it could be leased from an energy supplier. In other words, an energy company would decentralize its energy storage capacity and finance the battery through the latter's "secondary use."

Regardless of what form electric cars may take, and what role they will play in the electricity mix, any future concept will need to incorporate the most important stakeholders: electricity producers, automakers, suppliers, and governments, whose policies should pave the way for the necessary paradigm change. Extensive R&D investment will be required - particularly in the fields of energy storage, vehicle engineering, and power-grid integration. In fact, such alliances are already in place. For instance, BMW, Daimler and Volkswagen are working with major German power suppliers such as Vattenfall, RWE, and Evonik. VW also recently began working with Toshiba on the development of battery technology. Powerful batteries are indeed the key to the entire vision. The Siemens R&D focus is on electric vehicle system requirements and the design of a mobility power grid infrastructure. Among other things, Siemens engineers are examining power generation and distribution options, transport and energy management systems, smart metering, power electronics, software, sensors and, of course, electric drives and the recovery and storage of energy.

As electric vehicles enter the market, the power grid will have to be updated. It will, for example, be necessary to install systems that can accommodate the total electricity requirements of the individual vehicles in public areas such as inner-city parking garages and sports stadiums. Here, one distribution transformer complete with switchgear will be needed for every 50 vehicles. This means several dozen such transformers will have to be linked via medium-voltage switchgear. Having several thousand vehicles parked in one place will require major facilities, and these will have to be installed in basements or separate buildings. After all, if 10,000 vehicles simultaneously tap the grid for 20 kW each, the resulting required output will be 200 megawatts - which is what a medium power plant produces.

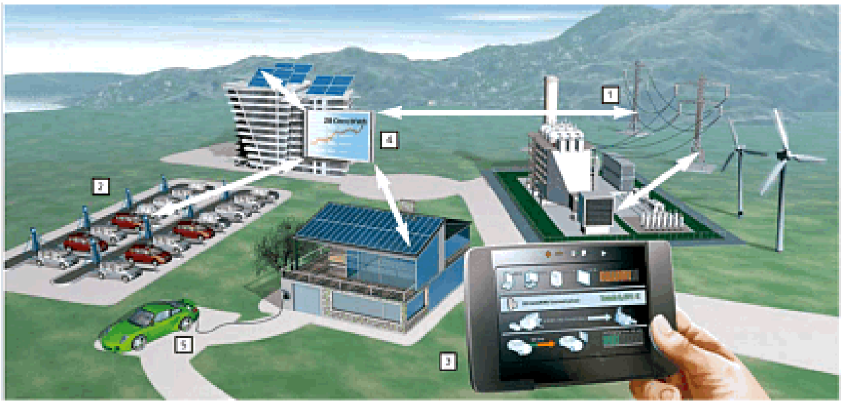

Fig. 3: Integration of electric vehicles into smart grids.

Experts believe that in Germany alone, there is potential for 4.5 million electric vehicles on the road by 2020. All of these vehicles could get their power from the existing grid. And that's just a conservative estimate, because these vehicles would only add up to about half of the second cars owned by families, most of which never travel over 70 kilometres a day. However using batteries as storage is today 100 times more expensive than storing energy in pump storage power plants.

5 SELLING MILES INSTEAD OF CARS

Germany is not the only country pursuing new electric mobility concepts; ideas are also being generated and implemented in the U.S., Australia, Israel, and Denmark, as well as in other nations. In California, a start-up called Better Place is addressing the entire value chain for a modern mobility system based on renewable energy sources. Launched two years ago, Better Place is working on the creation of a comprehensive infrastructure for the operation of electric vehicles. Following the concept used to attract mobile phone customers, Better Place plans to provide its customers with cars at discount prices - or even for free. Customers would then pay for the distances travelled, with their invoices based solely on the actual number of kilometres driven. Better Place believes it can provide customers with a better kilometre-based leasing deal for electric vehicles than can be obtained for a vehicle with a combustion engine. Here, battery stations designed like gas stations would enable batteries low on energy to be quickly exchanged for fully-charged ones. Better Place has entered a partnership with Renault-Nissan and plans to work with local energy utilities to establish energy infrastructures in various countries. The first electric car-based systems are expected to be up and running by 2011.

German companies have also recognized the market potential offered by electric vehicles and are working hard to develop appropriate solutions. Daimler, for example, is looking to establish an alliance with energy provider RWE that would standardize battery charging stations. The fact that Abu Dhabi recently decided to become a major Daimler shareholder appears to confirm that the automaker is on the right track. Through Daimler, Abu Dhabi is banking on an accelerated transition from combustion engines to alternative drive systems, thus preparing itself for the “post-oil era.” Similarly, BMW and Volkswagen are working with energy companies - among other things in order to determine which types of infrastructure are necessary for different mobility requirements. Their ultimate goal is to establish a foundation for the widespread introduction of electric vehicles.

The electric automobile revolution could end up taking place in Asia, however, as completely new players are now joining traditional automotive companies there. At the 2008 Geneva Motor Show, for example, a Chinese plug-in hybrid electric vehicle known as the “F3DM” was unveiled by a company called Build Your Dream (BYD). The car is equipped with a small-volume combustion engine (1.0 liters displacement), a complete electric drive system, and a battery/storage unit that can be charged internally via a generator and/or by exploiting braking energy recovery, or externally at a conventional 230-volt outlet. The vehicle’s range in the pure electric mode is 110 kilometres, which is more than the average one-day requirement of most commuters. BYD, which is headquartered in Shenzhen in the Chinese province of Guangdong, was established in 1995. It now has 120,000 employees and is one of the top 20 companies in China. For six years now, its 6,000 engineers have been intensively studying and developing hybrid and electric vehicles. Thanks to Chinese expertise in the field of Li-ion batteries, which comes from decades of experience with cell phones and PCs, BYD is one of the few automakers anywhere that can independently develop and produce the battery technology required for modern electric vehicles. If these vehicles manage to fulfil the safety regulations in Europe, they would become serious competitors to European car manufactures.

6 MOBILE POWER PLANTS.

Connecting electric vehicles to the power grid poses a particular challenge, as large amounts of energy will need to flow quickly and in both directions if the electrical energy from batteries is to be used as so-called “regulating energy” during peak times. Regulating energy refers to the energy a power network operator must provide in order to offset frequency fluctuations in the network, which arise when more energy is being used than the base-load power plants are capable of supplying. Regulating energy then has to be supplied at short notice from natural gas plants, pumped storage hydropower stations, thermal plants, or energy storage units. Already most of the components, systems, and solutions needed to establish an infrastructure to connect electric vehicles to the power grid are available: Switchgears, inverters, and control technology, network coupling, and local grid transformers.

7 REFERENCE PROJECTS

Siemens’ Energy Sector established a research alliance in February 2009, when it signed an agreement to join an international consortium in Denmark known as the EDISON project. EDISON stands for “Electric vehicles in a Distributed and Integrated market using Sustainable energy and Open Networks.” The goal of the project is to standardize electrical energy-storage equipment and charging/discharging technologies for electric and plug-in electric hybrid vehicles. Innovative ways of linking electric vehicles to the power supply grid in Denmark are studied.

Today, 20 percent of Denmark’s electricity is produced by wind power, making it the world leader in this area and this figure is set to rise to 50 percent by 2025. Still, the good feeling about so much renewable energy is dampened by the fact that when the wind blows too strongly, the wind-turbine rotors generate more electricity than Denmark’s grid can handle. Up until now, Danish power utilities have had to send this surplus electricity to neighbouring countries - and pay for doing so. It is therefore not surprising that Denmark is a pioneer in the development of storage technologies to accommodate excess electricity, with researchers focusing mainly on the batteries used in electric vehicles. Current plans call for one out of ten cars in Denmark to run on electricity from wind power in ten years. Although this goal may seem ambitious, given that there are hardly any electric vehicles on European roads today, Denmark is moving ahead rapidly with electric mobility through a broad range of projects. Practical testing will begin in 2011 on the Danish island of Bornholm in the Baltic Sea.

As a partner in the EDISON project, Siemens is responsible for coordinating and delivering key technologies, such as those needed for charging stations and associated control systems that ensure optimal utilization of battery capacities. At the heart of the overall setup are the power electronics and communication systems for managing battery charging and feeding to the grid. The power grid connection constitutes a special challenge because large amounts of energy have to flow quickly and bidirectionally to be able to use the electrical energy in the batteries also as balancing power.

Siemens' testing activities are not limited to Denmark, of course. The company's researchers are also active in Germany, where, for example, they are working with Harz.EE.mobility in a project designed to determine how distributed wind, solar, and biogas power systems can be better aligned with the grid. Three participating districts in Germany's Harz region are looking at how to incorporate electric vehicles into such a system. Siemens will deliver charging posts, an energy management system for the integration of electric cars into the smart grid, and associated communications.

The Austrian Mobile Power Platform was founded with the goal of rapidly implementing electro mobility in Austria. Amongst them is Verbund as electricity producer, Magna as producer of car components and Siemens as supplies of smart grid infrastructure. The platform comprises of a growing number of top representatives from the sectors of vehicle-, system- and infrastructure development.

Against the background of the economic goals of energy efficiency, reduction of emissions - especially those of CO2, but also particulate matter or noise - as well as supply security, the partners want to establish a valid superordinate overall system that works not only in Austria but also transnationally.

Fig. 4: Logo of the Austrian Mobile Power initiative

The Austrian Mobile Power initiative follows a clear vision for the future of automobility: cars and light-duty commercial vehicles will in future be powered by electricity from renewable energies. As the country of renewable energy sources, Austria offers the best prerequisites for an environmentally friendly, sustainable transport system based upon renewable energy sources. Austrian Mobile Power wants to use this unique opportunity and promote developments in this area.

In 2020 there will be at least 100,000 electric vehicles on the roads in at least one conurbation. Throughout Austria, there could indeed already be 500,000 electric vehicles in operation at this time. In 2050, there will then only be purely electrically powered vehicles in Austria. AMP is making an important contribution to achieving the platform members' ambitious goal by investing 50 million Euro for the introduction of electro mobility in Austria by 2020. The funds will be used to promote the market launch of production-ready electric vehicles, to make an ample charging infrastructure available for electricity generated from renewable energies, as well as developing customer-oriented mobility services. A central task of the platform is the integration of model regions for electro mobility in Austria.

8 OUTLOOK AND CONCLUSION

Climate change, gas prices, the increasing demand for mobility, new technological developments for engines and batteries - all these factors contribute to the fact that an old idea is coming back to life: electric automobiles. Electric vehicles are creating a surge of development and are the cause of exciting new alliances. Cars are turning into mobile energy storage units with the ability to re-feed energy back to Smart Grids. Electric vehicles, therefore, become much more than environmentally compatible vehicles: they are an important element of an intelligent energy infrastructure and contribute to the grid's ability to compensate for fluctuating infeed from renewables and distributed generation units.

The increasing share of decentralised and renewable energy and electric cars are a growing challenge for the electrical grid. In order to master these challenges, the grid and its consumers must become more flexible and interactive. Therefore today's grid have to be transform into an intelligent network that allows bi-directional communication between electricity suppliers and consumers and fosters sustainability by providing incentives for the efficient use of green energy. What is needed is an end-to-end infrastructure starting with generation over transmission and distribution to smart consumption.

Much still needs to be done here. For instance:

- Power grids have to be able to react correctly and quickly to fluctuations in the supply of electricity from renewable energy sources such as wind and solar facilities.
- Standards must be defined regarding the charging voltage of the power electronics, and a decision needs to be made as to whether the recharging processes should be controlled by a system within the vehicle or one installed at the charging station.
- Components for bidirectional operations and flexible billing for electricity still need to be developed if passenger cars are to be used as electricity storage media. And all these things must be part of the smart grid of the future.

Siemens has years of experience and tremendous expertise in all aspects of the energy supply chain. The company is thus ideally suited to help design tomorrow's electric mobility system - from vehicle parts to power grid components.

9 ACKNOWLEDGMENT

Siemens is carrying out intensive research into the subject of electro mobility. The Corporate Technology department and the sectors Energy and Industry of the integrated technology company are investigating both the requirements that must be met by the electric car itself and the design of the infrastructure of associated electrical networks. In particular, Siemens is concerned with energy generation and distribution, the management of traffic and energy, smart metering, power electronics, charging infrastructure, software, sensors and, of course, the electrical drives and the recovery and storage of energy.

10 REFERENCES

KUNZE Klaudia: Electric Ecosystem, Pictures of the Future | Spring 2009
SCHRÖDER Tim: From Wind to Wheels, Pictures of the Future | Fall 2009.
Austrian Mobile Power: http://www.austrian-mobile-power.at