Gaining traction
Six technologies that are driving efficiency, reliability and cost reduction in the passenger rail transport industry

Passenger rail travel is growing in many parts of the world, and while more and more regions are building new networks, there is a substantial upgrade and retrofit market in locations with established systems. The trends driving the rail industry are undeniable. In 2008, for the first time half the world's population lived in urban areas and that figure is projected to climb to 60 percent by 2030. By 2015, there will be more than 550 cities with a population greater than one million. In the US, population is expected to rise by 30 percent between 2000 and 2030 with an influx of 120 million into the nation's mega-regions.

Public transit plays a major role in the development of livable, sustainable urban environments, and the rail industry is already experiencing a level of investment that far outpaces the overall economy. According to a 2009 report by industry analyst Lucintel, the global market for new passenger rail vehicles grew at a rate of 9.1% between 2004 and 2009. The same study projects an even higher 10.5% growth rate from 2009 to 2015, reaching a total of just under $40 billion per year.

While much of this spending on new equipment is taking place in Europe and Asia, it is also true that in the US Amtrak has seen its ridership increase by 3.7% between October and March 2012. The company's Northeast regional service posted an 8.2% gain over the same period one year earlier. The challenge faced by passenger rail system operators in North America is similar to that faced by other basic infrastructure industries: how to increase efficiency and reliability while minimizing cost and environmental impact and delivering safety comfort and punctuality to the train traveler.

For the electric rail systems that make up much of the metro and commuter rail market, advances in materials, power electronics and component design have ushered in a new generation of equipment that offers improvements across all of these areas. These technologies appear in both rolling stock and wayside applications. Some represent a step change in how electric rail systems will work in the future while others are more humble in their innovation.

1. Vacuum circuit breakers

The common vacuum circuit breaker has a simple but essential function. It interrupts the flow of electricity to protect other equipment from dangerous currents, a vital role in any electrical supply. Traditionally, circuit breakers have operated on a spring mechanism with numerous moving parts. However, magnetically actuated circuit breakers are making inroads not only in the electric utility industry but also in the rail sector as well. These devices have only a single moving part and can operate essentially maintenance-free for years.

Vacuum outdoor circuit breaker for rail infrastructure

More recent designs also incorporate electronic rather than mechanical ground-level controls, and are designed to be installed quickly with no mechanical adjustments required on site. Some even fit into legacy equipment fixtures. This becomes important if the installation process requires the railway substation to be taken out of service. Together these attributes add up to greater reliability, lower maintenance costs and less downtime.

2. FACTS

Flexible AC Transmission Systems (FACTS) are actually a family of power electronics devices that perform a variety of functions. In rail applications, they are used to maintain voltage levels and power quality on the rail system's power supply, but also to ensure the stability of the interface between that system and the surrounding grid.

Modern passenger rail systems draw a lot of power. Individual trains use in the range of 10MW and traction loads as a whole can represent between 50MW and 100MW of demand on the feeder lines that supply power from the local grid. That is equivalent to the output of a small power plant, and the frequent variations in demand caused by the cycle of acceleration and deceleration can present operational challenges for both the rail operator and the utility.

Limited space, restrictions on noise and proximity to people all place constraints on any solution, but FACTS devices make the power systems serving rail networks more resilient and more efficient while observing all of these constraints. In some cases they can even reduce the number of feeder lines needed to supply power to the system, or reduce the voltage level required for the feeder network to operate effectively.

3. Traction motors

Traction motors must meet very challenging operating conditions. First they are assembled inside the bogie frame and are exposed to the very harsh environmental conditions under a train: wind, dust, foul, sand, ballast stones, ice, snow and of course water (rain as well as flooding). Traction motors are also installed perpendicular to the track and within the wheel flanges which limit considerably the available space for the motor.

Manufacturers are currently developing advanced traction motors using permanent magnets. These lightweight space saving traction motors are mainly focused on meeting the ever smaller space available in LRVs (i.e., tramways). These vehicles must be low-floor, which rules out the use of conventional axles. Instead, wheels are powered on one side by one traction motor mounted between two wheels

4. Static converters

Static Power converters are needed to shift between alternating and direct current to control the voltage delivered to the traction motors. Converters also ensure the continuity of the power supply by switching to islanded operation if there is a short disturbance on the power grid and in normal operation by smoothing the power flow from the catenary.

Historically, converters were mechanical in nature, but they have gradually been replaced by static converters based on power electronics (i.e., advanced semi-conductors). Since the 1990s, advances in converter technology have allowed trains to operate more efficiently due to new power electronics switching devices that dissipate less heat and also due to electronic microprocessor control which has enabled more advanced traction control algorithms such as for wheel slip control.

Modern static converters are also designed to make them easier to install and maintain, and they provide rolling stock manufacturers greater flexibility in their designs. One example of this is liquid cooling, which reduces the size and the weight of the converter. This has several implications. It reduces the weight of the train, allows the converter to be placed on the roof or under the floor in confined spaces, and opens up more interior space for passenger amenities. Liquid cooling also allows the converter's controls and electronics to be sealed from dirt and humidity and maintains even temperatures across all parts of the

Modular induction traction motor

equipment—important factors in extending the life of the power semiconductors at the heart of all static converters.

5. Traction transformers

Transformers play a vital role in the propulsion system of electric drive trains, and they face a variety of challenges. They operate in harsh outdoor environments exposed to extreme temperatures, vibration and humidity, and they are subject to grueling performance requirements. Rapid temperature rises during acceleration, which are exacerbated in cold weather, subject components to great stress.

In designing traction transformers, weight and space are the enemies. Every pound means additional power and operating costs for the system owner, and as with static converters, smaller transformer designs leave more space for seats as well as access for disabled passengers in low floor trains. Environmental concerns are also coming to the fore as rail operators look for ways to green their operations. Fortunately, traction transformers have witnessed innovations in several areas that speak to these challenges.

First, as we just described, the reduced weight of modern traction transformers saves fuel (in diesel-electric trains) and/or reduces the amount of electricity required to move the train. In either case, one benefit is a reduction in CO2 emission associated with train propulsion.

Second, some traction transformers now use ester oil instead of the conventional mineral oil typically used as an insulator and heat exchange medium in transformers. The difference is twofold: ester oil performs better, and is biodegradable. Its high flash point is particularly important for trains operating in tunnels as well in growing urban underground networks because of strict regulations on flammable materials.

The next generation in traction transformers being developed today represents a major improvement in all of the aspects we've covered. They are smaller, lighter, quieter and more efficient (95% vs. the current industry norm of 92%) than today's traction transformers and will use little oil. And, they can handle twice the power of comparable transformers of the same size currently in use.

This quantum improvement is due to a radical departure from transformers based on a magnetic core to a design that relies entirely on power electronics to shift voltage levels up or down. A prototype of the power electronic traction transformer (PETT) is currently being tested by SBB, the Swiss national rail carrier.

6. Wayside energy storage

The term "regenerative braking" has been popularized in recent years by the spread of hybrid and electric cars that capture the energy traditionally released as heat in conventional braking systems. But in reality the technology has been around for years. Rail systems have had difficulty, though, in realizing its full potential. The energy captured from a decelerating train could be used if another was accelerating nearby, but otherwise it would be directed to resistors on the train's roof or on the wayside and lost as heat.

Historically, the main problem was storage—there was simply no easy way to capture and hold the energy from a braking train so that it could be used when needed. With the advent of mature super capacitor products and the development of new battery chemistries such as Li-ion, that is beginning to change. A recent pilot project at the Southeastern Pennsylvania Transit Authority (SEPTA) provides an interesting example of how energy storage may one day revolutionize rail system operations.

SEPTA is the third-largest power consumer in the local utility's service territory, and of that, 80 percent is used in propulsion. SEPTA uses electric multiple units (EMUs) where propulsion is handled by many motors in the passenger cars themselves rather than a single locomotive. One "married pair" of EMUs produces 4.6 kWh of energy in one stop.

Traction transformer

SEPTA's intent was not only to capture this energy and re-use it within the SEPTA network, but to return power to the grid. In fact, the project envisioned three applications for the energy captured via regenerative braking:

- Providing frequency regulation services to grid operator PJM
- Participating in the wholesale energy market via PJM's load response program
- Optimizing voltage and power quality on SEPTA's own system

The solution SEPTA implemented involved an array of high capacity Li-ion batteries and capacitors combined with software and controls to interface with PJM, the grid operator, and the rest of the SEPTA power network. The control system is designed to optimize operations across all of the above objectives in order to maximize both battery life and total economic value.

Results from the initial system tests were very promising. Round-trip efficiency (i.e., the amount of energy returned to the system from what is captured from braking trains) was an impressive 93.5 percent. SEPTA estimated their energy storage system would yield combined cost savings and revenues in the range of $170,000 to $440,000 per year. The wide range of possible results can be attributed in large part to how and when SEPTA participates in PJM's frequency regulation and energy markets. Delivering power at highly lucrative times, obviously, produces more revenue.

SEPTA's wayside energy storage facility was put into service in April 2012 and has been fully operational since.

Other projects for recycling surplus braking energy based on the same Envistore™ system with either super capacitors or other advanced battery chemistries are also under way. In general, such projects are expected to reduce the energy consumption of train operation by 10 to 20 percent, and to provide a payback period under 5 years.

Conclusion

Advances in design and technology, particularly in power electronics, are not only improving on existing rail applications, but are inventing new ones. The result is a more efficient, more reliable passenger rail infrastructure that is also far more cost-effective. As these products and systems are propagated across the rail sector, they could usher in a new era in rail travel not only within newly build networks but in established ones as well.

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