HYBRID TRACTION SYSTEM

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ABSTRACT

The East Japan Railway Company (JR EAST), and Hitachi Ltd. have developed the world's first prototype hybrid rail car, the New Energy Train, responding to the need for higher energy efficiency and greater environmental performance in the railways.

THE CHALLENGE
The Hitachi Hybrid Traction System tackles head-on the challenges of internationally increasing fuel costs, the world focus on global warming and the challenges faced in meeting increasing emissions targets.

With modern DMUs struggling with ever increasing weight, noise pollution and poor emissions, the need for an answer to provide the 'go anywhere' train of the future has never been greater. The Hybrid Traction System has been developed with the focus of improving energy consumption and environmental performance, realized through the development of Hitachi's latest battery technology that underpins the Hybrid System.

THE INNOVATION
The Hitachi Hybrid Traction System, is based on power supplied by a combination of a high efficiency diesel engine generator and the new, high energy, high density lithium-ion battery from Hitachi Vehicle Energy Ltd. Battery technology is developing rapidly with significant reductions in weight and enhanced storage capacity, driven hard by the demands of the automotive industry.

Hitachi's Energy Management System operates at the heart of the traction converter and inverter, interfacing between the engine generator, battery and traction motors to optimise energy consumption. The system works by using the battery to either supply extra power on top of the engine generation when required during high acceleration, or absorbing the surplus power from the engine when coasting. Regenerative braking is employed, with the battery capable of absorbing the high density energy generation. The technology also means that the engine can be switched off at stations reducing noise and pollution experienced by travelling passengers and station staff.

THE REALISATION
With 28,000km testing under its belt, the Hitachi Hybrid Traction system has shown excellent results. Fuel savings of 20% have been achieved and the harmful emissions were approximately 50% of that of a conventional diesel rail car.

Hitachi is confident of the success of this technology. The current series hybrid configuration will allows for the diesel engine to be replaced in the future by emerging power plant technologies and coupled with giant leaps forward in battery technology Hitachi would like to welcome you to the world of Hybrid Rail.

1. INTRODUCTION

Modern EMU's far outstrip the performance of DMUs, as they are more environmentally friendly, and energy efficient. However, due to the high capital cost and maintenance implications brought about by the process of electrification, the DMU is still the preferred option for rural and unelectrified lines.

With environmental performance and energy efficiency of modern transport at the top of the transport development agenda, work needs to be done to improve the environmental friendliness and performance of the DMU. Hitachi, true to character, is leading the way in creating the technology to provide this long sought-after solution: The Hitachi Hybrid Traction System.

1.1 DMUs – The Current Technology

The use of DMUs on the rail network is crucial for the continued effective use of simple unelectrified infrastructure. Where there is no electrification, maintenance costs of the infrastructure are low and with the only current alternative being the huge cost of electrification, seen by some as ultimately prohibitive, DMUs are therefore a preferred choice for the future operation of unelectrified lines.

However, the industry recognises there are key disadvantages associated with DMUs when compared to EMUs. Diesel railcar operations are currently 30% less energy efficient than electric railcars. This is in part due to their extra weight, but also the fact that they cannot use regenerative braking. The DMU is also compromised by noisy engines and the associated pollutants generated by the diesel power train. Harmful emissions of Nitrogen Oxide, (NOx), Hydrocarbons, (HCs), and Particulate matter, (PM) are a key target of future 'green' taxes and emission control regulations.

Future DMUs will have to look at a step change in technology for their power trains, as it is widely agreed that diesel engine performance improvement alone is not satisfactory for achieving the future required reductions expected for emissions.

The next generation of DMUs need to achieve a much higher level of environmental friendliness, based on reducing both noise and emissions, and, in order to increase energy efficiency, developments in weight reduction, and the use of electric based traction equipment. Facilitating regenerative braking would be required to match the energy performance of today's EMUs. Let's look at the Hitachi solution.

1.2 The Hitachi Hybrid Traction System

In response to the needs of greater environmental friendliness, and higher energy efficiencies, the New Energy Train prototype, has been developed.

East Japan Railway Company and Hitachi Ltd. have worked together to create this breakthrough in rail power system technology. Hitachi Ltd. provided the Hybrid power technology and energy control management system which makes the operation of the New Energy Train possible.

In order to maintain reliability and performance, so that testing would show the true effect of using the hybrid traction technology, the NE Train was built using as many like-for-like components from one of JR East's current electric commuter rail cars, the class E231. This included the bodyshell, bogies, motors, inverter, converter and controller, and air conditioning system, such that test performance would be directly comparable to current EMU rolling stock performance in Japan.

The New Energy Train is driven by two 95 kW motors on one bogie, which are fed by the energy management system using a regulated balance of engine-generated and battery storage power. The NE Train has a maximum speed of 100 km/h and its acceleration and deceleration are equal to the latest electric commuter trains in Japan.

2. HITACHI HYBRID TRACTION SYSTEM

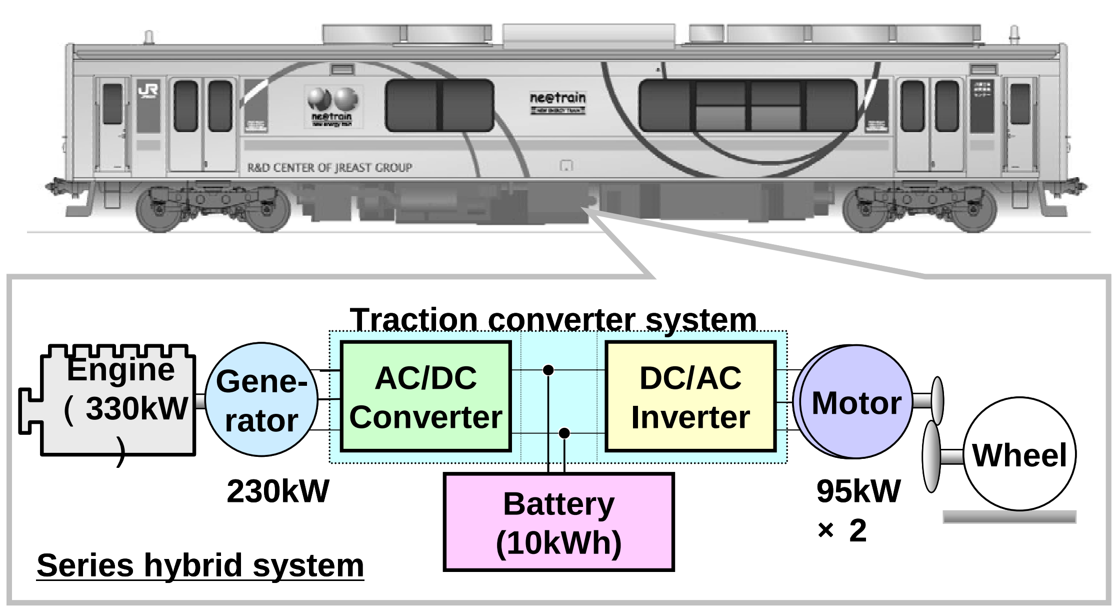

Figure 2: Series Hybrid System Layout

The NE Train, a diesel electric hybrid, uses a high power 330kW diesel engine to power an induction generator. As seen in Figure 2 above, the wheels are always driven by the 95kW traction motor and not directly by the engine, hence a series hybrid configuration.

Power generated by the engine can be channelled directly to the traction motors, or can be used to charge the battery. The battery can receive power from the generator at the same time as powering the motors. It also has the capacity to absorb power from regenerative braking of the wheels. This system flexibility allows a complex energy management system to be operated in order to maximize the energy efficiency.

Each of the main traction components are from the JR East class E231 commuter EMU and are well proven components. The engine generator is a diesel engine, with a maximum power of 330kW available at 2100rpm. The generator is asynchronous with an average power output of 230kW. The traction motor is the same as that from the E231 Commuter railcar with an average power of 95kW. The traction converter is from the E231, and includes the converter/inverter, but more importantly also the newly developed energy management system.

The storage battery is a high output density type lithium-ion battery. The battery operates in the DC interface between the converter and inverter, which facilitates the use of the battery to store power from the engine generator, from the traction motor during regeneration, and also to drive the traction motor.

The battery has been developed in-house by Hitachi Automotive Systems. The Energy density and capacity of the battery are steadily increasing while the size and weight is decreasing, pushed rapidly by developments in the automotive industry. This has allowed for the development of its use in rail cars, where a high power density is required alongside high energy density performance. This is in order to accelerate the train from standstill comparable to EMU’s and then also to absorb a large amount of energy rapidly under regeneration.

The lithium-ion battery was chosen due to its high performance for both power and energy density, and also due to its potential for cost reduction, due to increased use in automobiles based on mass production. The NE Train battery has a capacity of 10kWh and an output power of 250kW.

3. HITACHI ENERGY MANAGEMENT SYSTEM

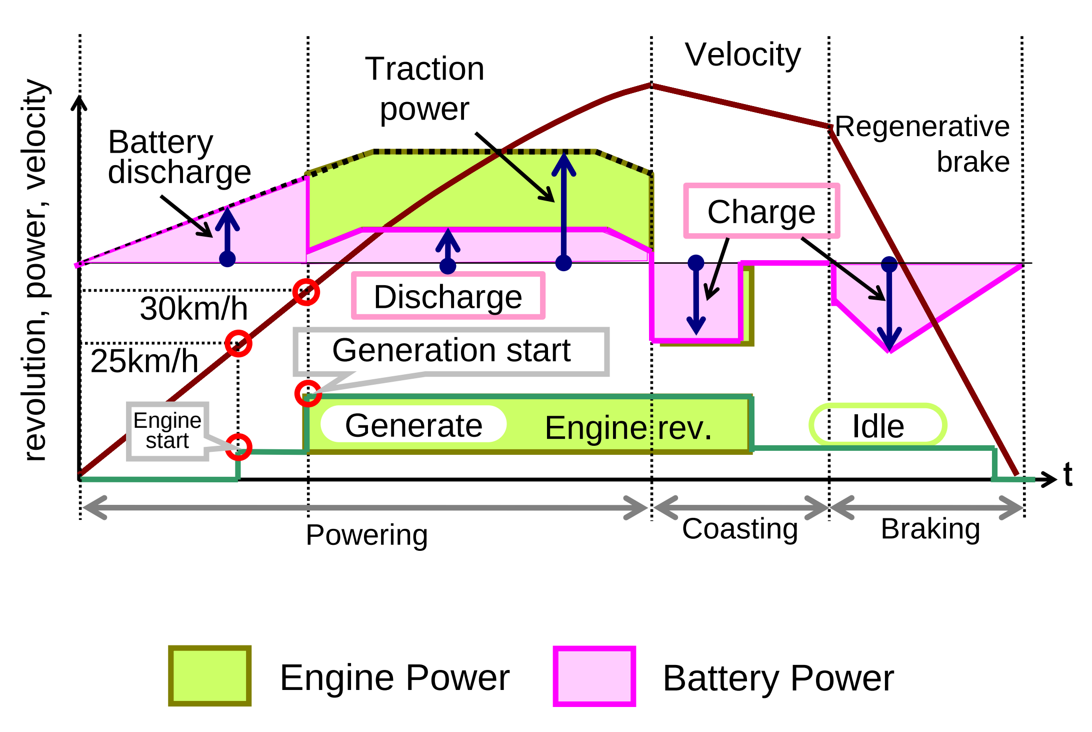

Figure 3: Energy Management Regime

The aim of the energy management system is to allow the diesel engine to run as long as possible during operation at its most efficient power rating. On top of this, in order to combat noise and pollution in stations, the train will operate on battery power up to 30km/h.

These strategies are controlled by the energy management system using the battery to either supply extra power on top of the engine generation when required during operation, or absorbing the surplus power from the engine when coasting. The battery is also required to absorb high density energy generation from the regenerative braking.

Figure 3 above shows the four zones of operation making up the energy management strategy for the NE Train Hybrid Propulsion System. These are described below:

a) Departure
The vehicle begins using only the battery to accelerate on departure from a station. When it reaches the output limit of the battery's capability to accelerate the train further, the output will be supplemented by power from the engine generator.

b) Powering
The constant power is generated by the engine, at its most efficient rotational speed of operation. If the engine generator provides more than enough power, the battery will absorb the surplus. On the other hand, if the engine cannot provide enough power for acceleration or inclines, the power shortage will be made up by the battery.

c) Coasting
The loss of energy is made up by the power generation of the engine. As railway vehicles have about 1/5 the rolling resistance of automobiles, it is possible to run about 5km in the state of level if it accelerates up to 70km/h once. Typically it will take about 3kWh of storage energy to accelerate a 35-ton rail car up to 70km/h. Stopping at the end of a run will generate 1kWh of energy from the regenerative brake. This deficit of 2kWh per run will be made up by the engine power generation during coasting.

d) Braking

By stopping the engine power generation during braking, the charging or regenerative power to the battery has priority. Once stopped the engine is switched off for quiet operation in the stations.

4. TESTING AND RESULTS

The New Energy Train, experimental railway vehicle was designed as a single vehicle that could be run independently as the minimum experimental unit. By using current technology from the modern class E231 train the testing was able to focus solely on the new parts of the train, the hybrid energy management system and the battery performance.

The NE Train has achieved 28,000km in testing since 2003. During these runs, a basic driving performance was confirmed, and various strategies necessary to improve the energy saving results were clarified.

The measured parameters from testing included the emissions compared to a diesel only rail car, and overall fuel consumption.

The initial testing was completed without stopping the engine at stations because of engine response times at re-acceleration. However, later in the testing battery improvements allowed the train to accelerate away with enough time to start the engine before it was needed. This improvement with stopping the engine at stations led to the fuel consumption being cut by between 2-5%. This also provided the huge benefit of no noise or emissions pollution in the stations.

The above fuel savings, coupled with the use of regenerative braking on the hybrid vehicle led to a saving of up to 20% of the energy used by a regular diesel multiple unit.

Finally, the New Energy Train's exhaust emissions from the engine were staggering. The amount of toxic substances in the exhaust gases, for example, NOx, HC, CO and PM were cut by approximately 50% compared to a conventional diesel rail car.

5. CONCLUSION

The new energy train has successfully proved the operational feasibility of the hybrid Hitachi traction system. The Hybrid Traction System has demonstrated excellent results in terms of its reduced energy consumption and environmental impact considering both noise and emission pollution. The hybrid traction system has enabled diesel technology to remain as a prime energy source, but the addition of the energy management system coupled with the new battery technology means that the engine's operation can be maximised to produce the best fuel consumption and environmental performance.

Continued rapid developments in battery technology, as undertaken by Hitachi and in the automotive industry as a whole, are making the case for hybrid rail technology stronger by the day. The New Energy Train has had its first production order and further take up is expected in the near future promising a bright future for Hitachi hybrid rail.

5.1 Evolution v Revolution

In reference to the title of this paper it is proper to comment on how evolution and revolution in technology sit together in the hands of Japanese research and development.

Evolutionary, moment by moment, development of traction systems is the Japanese way, progressing technology from initial use on local line trains onto the infamous Shinkansen, (bullet train), when a set period of defect free running is achieved. This results in the amazing reliability performance of the Japanese trains, and excellent performance of traction packages, which, when considered in evolution have been being developed for nearly 100 years. But, this breakthrough in hybrid technology innovation has been conceived by the careful merging of the evolutionary developments of the traction systems with the revolution underway in battery technology developments.

Revolution without evolution in the railway industry is destined to not get off the ground, as the factors of risk and cost are too important at all levels. Therefore this clever approach has opened the way towards the future paths of possibility, for example, battery only powered trains, and replacements of the prime mover with fuel cells, or other hydrogen or biomass fuelled engines. Now the battery technology and energy management system for the series hybrid is proven it is possible to look at new developments for the prime mover. Hitachi has built the bridge to the rail power trains of the future.

5.2 A provoking question

Network Rail have warned that EC4T charges could be set to rise by 65% in the near future (1). Is it possible that will there be a business case for running a diesel-electric hybrid with internal regenerative braking on electrified infrastructure which does not allow the operation of conventional regeneration back into the National Grid? For the diesel-electric hybrid train savings in energy consumption, (fuel costs) by use regenerative braking are pocketed directly by the operator.

6. REFERENCES

(1) Rail Business Intelligence No 272 June 29 2006