

## HYBRID LOCOMOTIVES OVERVIEW OF CONSTRUCTION SOLUTIONS

**Marcin Konarzewski, Tadeusz Niezgoda, Michał Stankiewicz, Piotr Szurgott**

*Military University of Technology  
Department of Mechanics and Applied Computer Science  
Gen. Sylwestra Kaliskiego Street 2, 00-908 Warsaw, Poland  
tel.: +48 22 6837467, +48 22 6839461, +48 22 6837272, fax: +48 22 6839355  
e-mail: mkonarzewski@wat.edu.pl, tniezgoda@wat.edu.pl  
mstankiewicz@wat.edu.pl, pszurgott@wat.edu.pl*

### **Abstract**

*Nowadays, transportation becomes a significant source, apart from factories and power plants, of air pollution. Therefore, due to legal restrictions on the emission of noxious gases, other power sources for vehicles are necessary. Some of these power sources allow replacement of the internal combustion engine completely, whereas the other ones only support the engine operation. Hence, a hybrid powertrain – alternative to the drivetrain equipped with an internal combustion engine only – is increasingly being used. The hybrid powertrain was mostly applied in cars and buses but recently it has been also used in railway vehicles such as locomotives and multiple units. The paper presents a shortened and brief overview of construction solutions of selected hybrid locomotives. A list of the applied hybrid drive systems as well as the basic data and properties are provided. The most important variants of vehicles are compared. The presented material allows identification of the development trends in the considered area. The hybrid locomotive usually uses an onboard rechargeable energy storage system, placed between the power source and the traction transmission system connected to the wheelsets. Modification of a classic diesel-electric locomotives is a relatively simple procedure since they have all the components of a series hybrid transmission except the storage battery. Therefore, the existing and operated diesel-electric locomotives can be modified to increase their efficiency and reduce operating costs and emissions.*

**Keywords:** *hybrid powertrain, hybrid locomotive, diesel-electric locomotive, railway vehicles*

### **1. Introduction**

The increasing environmental pollution and the depletion of energy sources are the main problems faced by the entire world. Nowadays, transportation becomes a significant source, apart from factories and power plants, of air pollution. There is a huge number of vehicles (e.g. cars, trucks, locomotives) with an internal combustion engine, which produces pollutants into the environment. Therefore, vehicles with the internal combustion engines are considered to be one of the major air polluters due to the emission of unburned hydrocarbons (HC), carbon monoxide (CO), carbon dioxides (CO<sub>2</sub>) and nitrogen oxides (NO<sub>x</sub>). Hence, other power sources for vehicles are necessary due to legal restrictions on the emission of noxious gases. Some of these power sources allow replacement of the internal combustion engine completely, whereas the other ones only support the engine operation.

A hybrid powertrain – alternative to the drivetrain equipped with an internal combustion engine only – is increasingly being used. The hybrid powertrain was mostly applied in cars and buses but recently it has been also used in railway vehicles such as locomotives, multiple units and trams. The most common hybrid powertrain in vehicles is a combination of the internal combustion engine with an electric motor. The general characteristics of such system can be summarized as follows: the internal combustion engine is connected to a power generator; the electric motor is not only the engine but also acts as a generator used to charge the batteries that power it during operation.

Both motors can work together during the high demand for torque (e.g. acceleration or driving uphill) or separately. The internal combustion engine usually does not work during stops. It works and charges the batteries mostly while the vehicle drives at the constant speed.

## 2. Hybrid locomotives

At present, many railway companies – especially those, which operate at the railway sidings – deliberate whether, still bear significant costs related with locomotives with old internal combustion engine or purchase modern locomotives. Modernization of existing locomotives can be also one of the possible solutions. More and more often railway companies are interested in modernization of locomotives to meet the latest environmental requirements and to eliminate the exhaust gases from human environment. It is mostly related with shunting locomotives, which are usually equipped with the internal combustion engines.

The hybrid locomotives usually use an onboard rechargeable energy storage system placed between the power source and the traction transmission system connected to the wheelsets. Modification of classic diesel-electric locomotives is a relatively simple procedure since they have all the components of a series hybrid transmission except the storage battery. Therefore, the existing and operated diesel-electric locomotives can be modified to increase their efficiency and reduce operating costs and emissions.

The paper presents a shortened and brief overview of construction solutions of selected hybrid shunting locomotives. The presented material gives the opportunity to identify the development trends in the considered area.

### 2.1. Toshiba HD300 Series (Japan)

The HD300 series locomotive depicted in Fig. 1 is a type of hybrid diesel – battery Bo-Bo wheel arrangement shunting locomotive operated by Japan Freight Railway Co. Ltd. A prototype was built by Toshiba Logistics and delivered in March 2010. The main aims in development of this locomotive were to reduce toxic exhaust gases, lower the exterior noise level, and reduce CO<sub>2</sub> emissions, based on the concept of an *ECO-friendly, clean locomotive* [1].



Fig. 1. Prototype of the Toshiba HD300 shunting locomotive [2]

A modular concept was adopted in the Toshiba locomotive. It means that each device was modularized to make it easier to introduce future new technologies, e.g. replacing the internal combustion engine with a fuel cell without considerable changes in vehicle body. The general structure of the locomotive is shown in Fig. 2.

A series hybrid system was applied in the HD300 series. Energy flows at powering and the breaking modes are presented in Fig. 2a and 2b, respectively. The internal combustion engine works as the power source only and it is used for generating the electric power. Therefore, it is quite easy to take preventive action against the exhaust and noise [1]. NO<sub>x</sub> emission is about 62% lower whereas the fuel consumption is reduced of 36% in comparison to the conventional diesel locomotive. The noise reduction is about 22 dB for the engine running with high speed rotation [2].

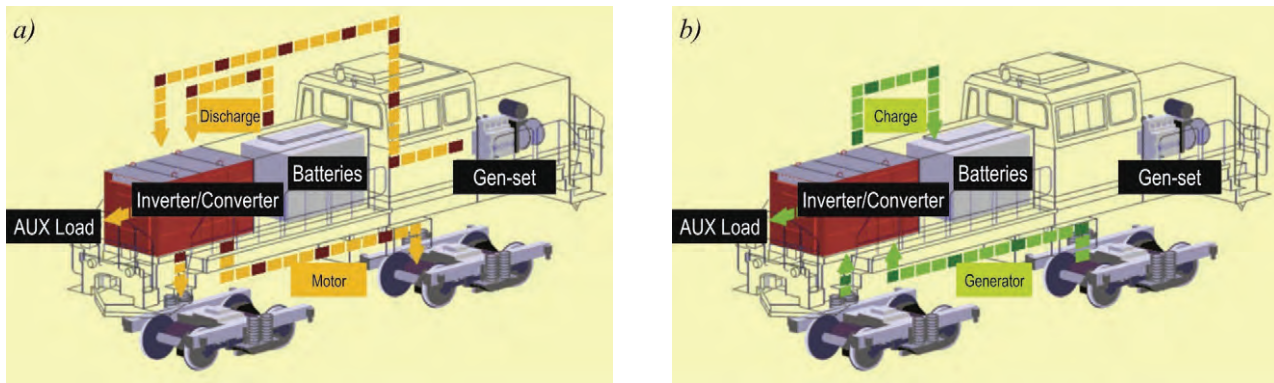


Fig. 2. Energy flows at powering (a) and breaking (b) mode for the HD300 hybrid locomotive [3]

The HD300 locomotive is equipped with high-performance and high-capacity lithium-ion LIM30H-8A batteries manufactured by GS Yuasa. The main battery output capacity is high enough to start driving even in cold regions and regardless of deterioration of the modules over time. Moreover, the main battery is endowed with some redundancy by forming multiple banks, so that operation can be continued by cutting out the defective bank in the event of a fault [1].

Technical parameters of the HD300 hybrid locomotive are provided in Tab. 1 in chapter 3.

## 2.2. TEM9H Sinara Hybrid (Russian Federation)

TEM9H Sinara Hybrid (Fig. 3) is the first Russian hybrid locomotive developed on the basis of the TEM9 diesel locomotive. It is built by Ludinovsky locomotive plant (LudTZ) [3]. The locomotive is Bo-Bo wheel arrangement shunting locomotive. It has an electric transmission with a variable alternating current individual drive to each wheelset and a total output power of 1,200 KM. It will be equipped with lithium-ion batteries and super condensers. Technical specifications of this locomotive are enigmatic but the manufacturer ensures that diesel fuel consumption will fall by 40% and exhaust emissions reduced to 55%, which corresponds to European rolling stock standards. The TEM9H Sinara Hybrid is able to work 4 hours using battery only [4].

Technical parameters of the locomotive are provided in Tab. 1 in chapter 3.



Fig. 3. The TEM9H Sinara Hybrid shunting locomotive [5]

## 2.3. Railpower GG20B Green Goat (Canada)

The Railpower GG20B Green Goat is a diesel hybrid shunting locomotive built by Railpower Technologies Co. The prototype numbered RPRX 2001 was built in 2001 and it was identified as GGS2000D (Fig. 4). Consecutive versions of locomotives were slightly different in outward appearance – hoods sizes, louvers, number of air vents, exhaust stack, etc. – and equipment – e.g. 90 KM diesel generator mounted in the prototype was successively replaced by 130 KM, and even 670 KM gen-set in Canadian Pacific version (Fig. 5) in 2006 [6].



Fig. 4. The Railpower GGS2000D – a prototype of the GG20B Green Goat locomotive [6]



Fig. 5. The Railpower GG20B Green Goat shunting locomotive operated by Canadian Pacific [6]

A scheme of the hybrid technology applied in this locomotive is depicted in Fig. 6. The internal combustion engine is used only to charge the batteries. It allows avoiding major losses in fuel consumption when running at idle [7]. Large savings in fuel consumption (40–70%) and significant reduced emissions (80–90%) are possible due to reduction of the idling time. The internal combustion engine is turned off during the operating stops and the restart is done from the batteries [7]. *Green Goats* are usually equipped with Caterpillar C9 four-stroke diesel turbocharged engines.

In 2007, it was attempted to converse one locomotive to hydrogen fuel cell hybrid. It was planned to place the hydrogen storage tanks on top of the long hood, whereas the fuel cell were located where the gen-set was normally found. To date, 55 locomotives of this type have been produced. They are used by both private railroad companies and the US Army as well.

Technical parameters of the Railpower GG20B locomotive are provided in Tab. 1 in chapter 3.

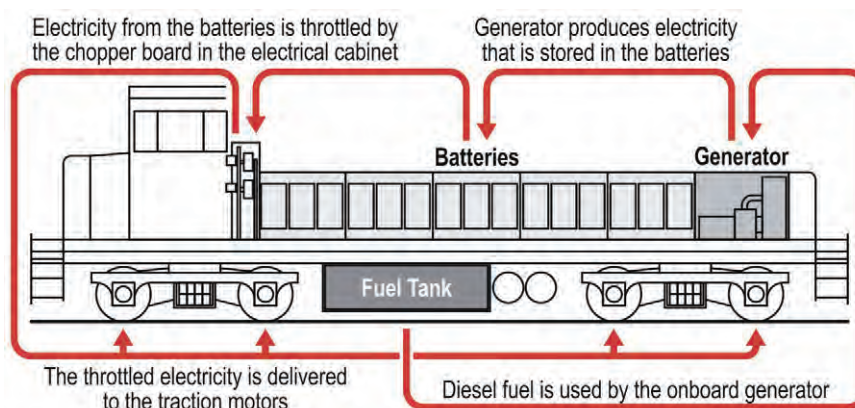


Fig. 6. A scheme of the hybrid technology applied in the Railpower GG20B Green Goat shunting locomotive [8]

## 2.4. GE Evolution Hybrid (United States)

The GE Evolution Hybrid locomotive was presented in 2007 under ecomagination strategy. It was built by GE Transportation and designed to reduce fuel consumption and emissions over its extended lifetime [9]. The GE Evolution Hybrid is Co-Co wheel arrangement locomotive. It is equipped with the GEVO four-stroke diesel engine. The energy dissipated during braking is captured and stored in a series of sophisticated batteries. The sodium metal-chloride (lead-free) rechargeable batteries are able to provide superior performance by allowing operators to draw an additional 2000 KM when needed [10]. Therefore the total power output is about 4,400 KM. The GE Evolution Hybrid was being developed with the goal of creating the cleanest, most fuel-efficient high-horsepower diesel locomotive ever built. It is assumed that fuel consumption can be reduced by as much as 15% and emissions by as much as 50% compared to most of the freight locomotives in use today [11].

The GE Evolution Hybrid locomotive shown in Fig. 7 whereas its technical parameters are provided in Tab. 1 in chapter 3.



Fig. 7. The GE Evolution Hybrid locomotive [10]

## 2.7. Alstom BR 203H (Germany)

Alstom launched its prototype hybrid shunting locomotive (Fig. 8) at InnoTrans 2006. The Alstom BR203H is based on the German shunting locomotive BR203. The prototype was equipped with 200 kW gen-set and 350 kW battery module. The hybrid system is parallel, hence the locomotive can be powered either by the generator or by the energy stored in the batteries, or the use of both power sources simultaneously. Energy flows in different modes of hybrid system working are presented in Fig. 9.



Fig. 8. The prototype of the Alstom BR203H shunting locomotive [12]

According to Alstom [13], advantages of the hybrid concept in this locomotive are as follows: approximate 40% fuel saving, approximate 50% reduction of emission, 10dB decrease of noise while the generator runs.

The Alstom BR203H technical parameters are provided in Tab. 1 in chapter 3.

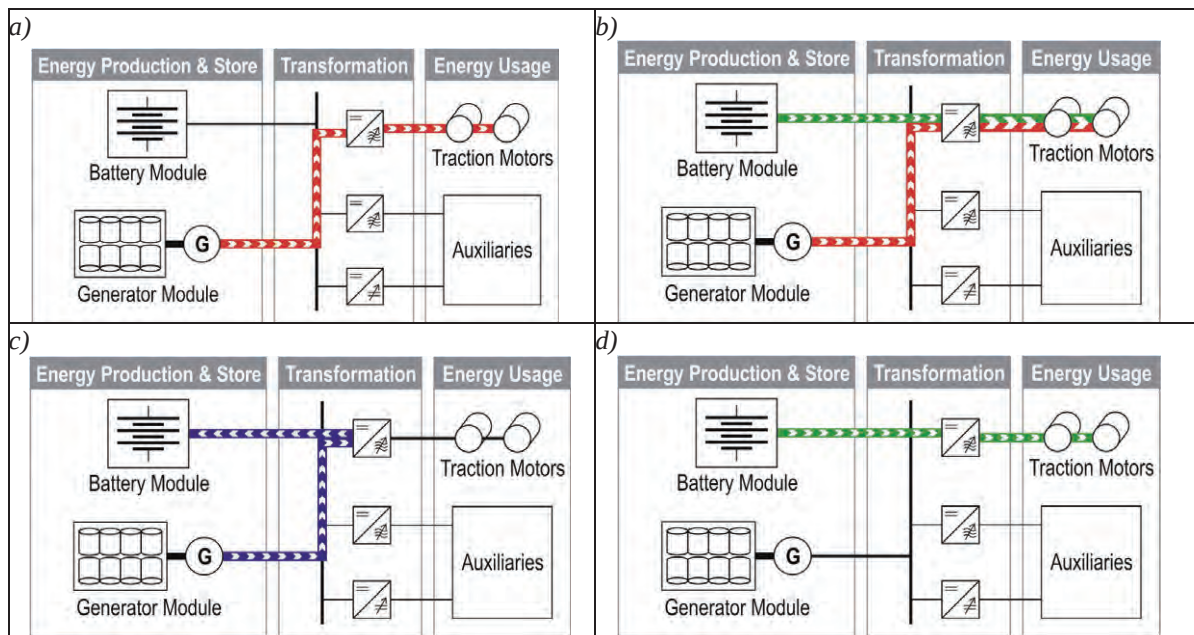


Fig. 9. Energy flows in different modes of hybrid system working: basic mode as diesel-electric shunter (a), hybrid mode for power peak (b), battery refilled during traction off (c), battery mode while generator module is off (d) [13]

## 2.6. Řada 718 (Czechoslovakia)

The Řada 718 hybrid shunting locomotive was built by ČKD Praha in 1986 [14]. It was equipped with 189 kW LIAZ M 637 diesel engine. Additional energy of 360 kW was received from the Ni-Cd batteries. Energy dissipated during braking was captured and stored in batteries. It was also possible to recharge batteries during stops using diesel generator or from the 3 x 380 V network.

The locomotive was tested in ČKD sidings and later in the test circuit in Cerhenice. Finally, it was operated in Olomouc since October 1986. The circuit test results revealed about 20–30% lower fuel consumption in comparison to the standard diesel-electric shunters [14].

The Řada 718 locomotive presented in Fig. 10 whereas its technical parameters are provided in Tab. 1 in chapter 3.



Fig. 10. The Řada 718 locomotive hybrid locomotive [15]

## 2.7. Rába Mk 48 Hybrid (Hungary)

A Rába Mk 48 Hybrid is a rebuilt diesel-hydraulic narrow-gauge locomotive Rába Mk 48. Modification was carried out to reduce emission since the Mk 48 Hybrid was planned to operate for Szilvásvárad Forest Railway and carried tourist traffic mostly [15]. The loco was rebuilt by MÁV

Vasjárom. It is equipped with Cummins QSB6.7 diesel engine and Lithium-Iron-Phosphate batteries. The batteries are charged when the locomotive is running down the line's steep gradients. The stored energy is used to power the locomotive in electric mode for shunting at stations. In hybrid mode, the locomotive can operate parallel using diesel gen-set and the batteries [16].

The Rába Mk 48 Hybrid locomotive presented in Fig. 11 whereas its technical parameters are provided in Tab. 1 in chapter 3.



Fig. 11. Szilvássvár Forest Railway Rába Mk 48 battery-hybrid locomotive [16]

### 3. Summary

Selected technical parameter, e.g. locomotive weight, axle arrangement, hybrid system, maximum power of the diesel engine, the total output power, and types of batteries for considered hybrid locomotives are provided in Tab. 1.

Tab. 1. Summary of the technical parameters of considered hybrid locomotives

| Locomotive             | Weight | Axle arr. | Hybrid system | Diesel engine power | Total power output  | Battery types          |
|------------------------|--------|-----------|---------------|---------------------|---------------------|------------------------|
| Toshiba HD300          | 60 t   | Bo-Bo     | series        | 275 KM (205 kW)     | 670 KM (500 kW)     | lithium-ion            |
| TEM9H Sinara Hybrid    | 90 t   | Bo-Bo     | not specified | 857 KM (639 kW)     | 1,200 KM (895 kW)   | lithium-ion            |
| Railpower GG20B        | 130 t  | Bo-Bo     | series        | 290 KM (216 kW)     | 2,000 KM (1,490 kW) | lithium-ion            |
| GE Evolution Hybrid    | 207 t  | Co-Co     | parallel      | 4,400 KM (3,280 kW) |                     | sodium metal-chloride  |
| Alstom BR 203H         | 80 t   | Bo-Bo     | parallel      | 268 KM (200 kW)     | 737 KM (550 kW)     | nickel-cadmium         |
| Řada 718.5             | 64 t   | Bo-Bo     | parallel      | 253 KM (189 kW)     | 684 KM (510 kW)     | nickel-cadmium         |
| Rába Mk 48 Hybrid [17] | 17.6 t | Bo-Bo     | parallel      | 273 KM (204 kW)     | 488 KM (364 kW)     | lithium-iron-phosphate |

### Acknowledgement

The study has been supported by the National Centre for Research and Development (Poland) under the Applied Research Programme as a part of the project PBS1/B6/5/2012, realized in the period of 2012–2014. This support is gratefully acknowledged.

## References

- [1] <http://www.toshiba.co.jp/sis/railwaysystem/en/products/locomotive/hybrid.htm>, retrieved 29.06.2013.
- [2] Soeda, T., Lin, M., Hasebe, T., Ujiie, A., *Electrical Equipments Used in Diesel Hybrid Shunting Locomotive HD300*, Proceedings of the 9th World Congress on Railway Research, Lille, France 2011.
- [3] <http://www.railway-technology.com/news/newsrussian-railways-to-develop-first-hybrid-locomotive>, retrieved 29.06.2013.
- [4] <http://www.railwayinsider.eu/wp/archives/26603>, retrieved 29.06.2013.
- [5] <http://www.drehscheibe-foren.de/foren/read.php?2,5950849>, retrieved 29.06.2013.
- [6] Moore, J., *Low Emissions Locomotive Spotter's Guide*, 2007.
- [7] Michnej, M., Szkoda, M., *Współczesne rozwiązania hybrydowych układów napędowych spalinowych pojazdów trakcyjnych*, TTS Technika Transportu Szynowego, Vol. 13, No. 10, 2007 [in Polish].
- [8] Dzienkowski, K., *Hybrid Locomotives: Better Economics, Better Environment*, ARB's Rail Symposium, El Monte, CA, United States 2006.
- [9] [gas2.org/2012/03/28/ges-hybrid-locomotive-cuts-fuel-consumption-and-emissions](http://gas2.org/2012/03/28/ges-hybrid-locomotive-cuts-fuel-consumption-and-emissions), retrieved 29.06.2013.
- [10] [http://www.comsol.com/stories/general\\_electric\\_modeling\\_train\\_batteries/full/](http://www.comsol.com/stories/general_electric_modeling_train_batteries/full/), retrieved 29.06.2013.
- [11] [http://www.gettransportation.com/resources/doc\\_details/9-hybrid-locomotive-ecomagination-fact-sheet.html?tmpl=component](http://www.gettransportation.com/resources/doc_details/9-hybrid-locomotive-ecomagination-fact-sheet.html?tmpl=component), retrieved 29.06.2013.
- [12] Girard, H., Oostra, J., Neubauer, J., *Hybrid shunter locomotive*, Proceedings of the 8th World Congress on Railway Research, Seoul, Korea 2008.
- [13] Hiller, K., *Technics and Economics in Rail Bound Freight Business*, [http://www.bahnindustrie.info/uploads/media/Hiller\\_Alstom.pdf](http://www.bahnindustrie.info/uploads/media/Hiller_Alstom.pdf), retrieved 29.06.2013.
- [14] <http://www.zelpage.cz/atlasloko.php?id=718&lang=pl>, retrieved 29.06.2013.
- [15] <http://www.atlaslokomotiv.net/katalog/718/718-501.jpg>, retrieved 29.06.2013.
- [16] *Battery-diesel hybrid locomotive cuts emissions in the forest*, <http://www.railwaygazette.com/news/business/single-view/view/battery-diesel-hybrid-locomotive-cuts-emissions-in-the-forest.html>, retrieved 29.06.2013.
- [17] Poór, I., Varga, M., Németh, G., Rónai, A., Nemes, P., *Az Mk48 403 Mozdony Hibridhajtású Fejlesztése*, Vasútgépészet, No. 4, 2012.