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Lithium batteries from electric buses for stationary storage applications

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Abstract

Two companies, namely Solaris Bus & Coach S.A. and PGE Polska Grupa Energetyczna S.A. (PGE S.A.), representing different industries, intend to work together in order to use common battery packs both in automotive and stationary applications.

Solaris is a leading European manufacturer of innovative buses as well as urban rail vehicles and has supplied over 15 000 buses to customers in 32 countries. In 2011, Urbino electric – the first Polish battery bus was officially presented. Since that time, Solaris has produced over 100 battery electric buses (in total over 1600 buses, including hybrids and trolleybuses) and carried out standardization of batteries used in buses.

PGE Polska Grupa Energetyczna S.A. is a parent company of PGE Capital Group, and it is the largest vertically integrated company in energy sector in Poland in terms of revenues, installed capacity and electricity produced. Thanks to the combination of its own fuel resources, power generation and distribution networks, PGE guarantees safe and reliable electricity supplies to over 5 million households, businesses and institutions.

The strategy objectives of Solaris and PGE S.A. include maintaining a position of a reliable and active supplier of goods and services, as well as development in the area of new technologies, new business models and new business segments.

This paper will present an overview on possible usage of the same lithium ion batteries both in automotive and stationary storage applications, which may have an impact on reducing component price and emissions in our country.

Keywords: stationary energy storage system, automotive energy storage systems, lithium-ion batteries

1 Electric buses sector development in Poland

Currently approximately 12 000 city buses are registered in Poland [1]. Since 2012 one can observe a growing number of electric buses. This chapter contains a comparison between the city bus fleets in Poland and

Europe. Authors of the article also present different customers' requirements. Additionally, development of the Polish bus market is discussed from the perspective of Solaris.

The bus market in Poland is changing dynamically. The share of buses with alternative propulsion has been increasing. Last year showed a significant increase in the number of sold electric buses. Customers who bought or tested one electric bus in previous years, have already started procurement processes on a larger scale. There are individual tender inquiries for 20-40 electric buses. The percentage share of the manufacturer in the market is shown in Figure 1. Solaris Bus & Coach S.A. is the largest producer of buses in Poland, with a market share of over 50% in the last years.

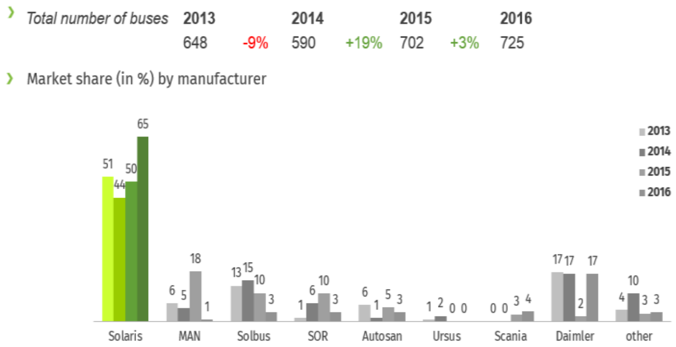

Figure 1. Poland city buses (including trolleybuses), first registrations >8t GVW [source: Solaris Bus & Coach S.A]

The diagram presented in Figure 2 shows the number of vehicles and shares in the electric bus market by orders placed in the continental part of Europe. Taking into consideration only electric battery buses in 2016 in Europe, Solaris is the second largest bus producer.

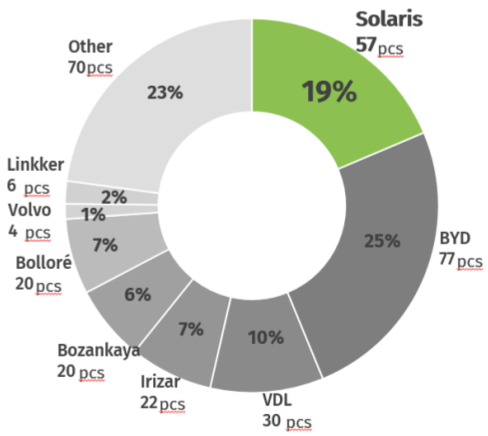

Figure 2. Manufacturers' shares in the battery bus market in 2016 (orders placed in Continental Europe) [source: Solaris Bus & Coach S.A]

Based on research and prognosis by UITP [3], VDV [4], SCI Verkehr [2] and the Solaris market expertise, Solaris has created a map of development in the electric bus market in Europe, which presents the planned share of Solaris buses.

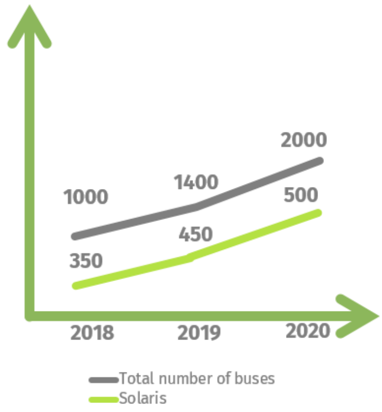

Figure 3. Expected electric bus production volume and the Solaris market share in the years 2018 – 2020 [source: Solaris Bus & Coach S.A]

A significant increase of interest in battery buses is expected among European customers . European cities such as Hamburg, intend to purchase only alternative drivetrain buses after 2020.

In Europe, there are two main trends in charging electric buses. They also affect the size and the type of batteries used in electric buses. In some cities, electric bus market leans towards overnight charging. Below are presented some selected cities, in which the strategy of the e-mobility development shows tendencies for depot charging buses with big batteries, i.e. Essen, Munich, Bonn, Hamburg, Stuttgart, Bergamo, Milan, Copenhagen, Madrid, Istanbul. However there are also cities, which prefer fast battery recharging during bus operation on the line, e.g. Hannover, Dresden, Barcelona, Warsaw, Jaworzno, Cracow, Inowrocław, Zielona Góra, Eindhoven, Oslo, Pizen, Helsinki, Tampere, Oberhausen, Paris, Utrecht, Stockholm, Umea, Geneva, Belgrade and others.

In such solution, Diesel bus can be fully replaced by electric one, which does not require to carry additional several tons of the traction batteries in order to be able to operate all day long.

Figure 4. Examples of European cities interested in pantograph charging solutions [source: Solaris Bus & Coach S.A]

Figure 5. Examples of European cities interested in overnight charging solutions [source: Solaris Bus & Coach S.A]

Because of different city charging systems, tailor-made traction batteries shall be taken into consideration. Such batteries are much smaller and lighter than in the overnight-charging version, though require different battery chemistry to last for a particular duration of time, required by customers. Unfortunately, this solution requires an investment in charging infrastructure and building it usually in the city centre. Poland, in comparison with Europe, has a bigger share of cities, which plan to invest in charging infrastructure. Those cities plan to electrify existing bus lines (currently operating on diesel) without compromise.

The Polish Government plan to develop electromobility in public transport. A new program "e-BUS" was created to support it. The e-BUS program is one of the flagship projects included in the Polish Government's Strategy for Sustainable Development. By signing letters of intent on cooperation on 20 February 2017, local governments involved in the venture, too. Moreover, stakeholders have organised a conference dedicated to the issue, titled "E-bus - practical aspects of electrification of public transport". Moreover, pilot programs on market research have been launched by PARP and the Polish Agency for Enterprise Development.

Further selected initiatives, scheduled for this and the next year, are listed below:

- Regulation of the Minister of Energy regarding electromobility and alternative fuels ,
- the launch by PARP of the program "Accelerator of Electromobility",
- the launch by NCBiR (National Centre for Research and Development) of the program "Zero-Emission Public Transport" regarding the development and market launch of a new generation of emission-free buses,
- the launch by NCBiR of the program on charging infrastructure,
- financial support from NFOŚiGW (the National Fund for Environmental Protection and Water Management) for electric buses, electric cars, charging infrastructure and for pilot programs,
- the launch by NFOŚiGW of the program GEPARD (Gazela Bis), dedicated to electromobility,
- a reallocation of EU funds to support municipal transport that uses alternative fuels
- drafting a compendium titled „Practical guide on electromobility for local governments",
- standardization of charging infrastructure, as well as the release of venture capital funds for start-ups, including those working in the field of electromobility." (replay of the Ministry).

The program E-Bus program consists of three stages. "The first one assumes the adoption of Electromobility Act by 2018 and concentration of public funding. The act has already passed the phase of public consultation.

The second stage of the program, scheduled for 2019-2020, involves the construction of the proper infrastructure and commercialization of research results in this area. In the third stage, 2020-2025, it is assumed that as the electromobility market gradually matures , elements of support would be gradually withdrawn.” [8]

The Responsible Development Strategy (*Strategia na Rzecz Odpowiedzialnego Rozwoju*) assumes that there will be one million electric vehicles on Polish roads by 2025. The development of electromobility will lead to the development of the whole power industry, including the development of power grids.

Investments in electromobility in Poland have already begun. Among others, the investment has been made by the Korean company, LG Chem to increase production capacity at the lithium-ion batteries production plant in Biskupice (near Wroclaw). The factory is expected to cover 3% [9] of world market demand for lithium-ion batteries in the future (5 GWh/year).

Solaris, as a leader in the field of innovative urban transport solutions, has established and has been managing a new e-mobility research cluster. “Solaris and a group of Polish companies and technical universities have signed a letter of intent on the creation of a cluster for development of e-mobility. The signatories have declared to work together in order to, among other things, devise electric bus constructions, batteries and charging modes. The total value of research and development projects - the cluster members want to implement - exceeds EUR 23.5 million. Following the concept of “Polish Electric Bus – supply chain for e-mobility”, the cluster has united companies not only involved in production of drives, batteries and other electric bus components, but also companies involved in power industry and several universities. The goal of the cluster is to develop e-mobility, in particular in the field of electric buses and components used for their manufacturing, based on technical solutions devised in Poland. Research and development will especially cover as follows:

- the creation of a city bus construction applicable to electric vehicles,
- energy management in order to improve the operability of electric vehicles,
- the enhancement of technical parameters of electric drives and energy storage facilities,
- development of innovative battery charging methods,
- development of new standards for training for engineering staff in the field of e-mobility.

Value of around a dozen projects the cluster members would like to implement has been estimated so far. The ventures are to be financed by both the company funds and means secured from other sources.”

The cluster members do not exclude possibility that other companies experienced in e-mobility technology can join the initiative. The cluster grows, accepting new members, for example Polish power utility companies.

Electrification of public transport responds to the customers’ expectations. Usually the Public Transport Operator (PTO) is a public or private transport company providing services related to transport for cities. A key issue for customers is to create a suitable vehicle for them. Customers buying buses have different requirements depending on city size, climate, or country-specific conditions in which these buses will be used A comparative analysis of Polish customers in relation to customers in Europe has been performed, and main differences are listed below.

- Most customers in Poland are looking for a universal vehicle capable of handling all or most of the lines in the city. They don’t intend to create dedicated electric bus lines.
- The longest of the operated lines need larger batteries, however having additional infrastructure in cities is not completely excluded. If it is necessary to install special infrastructure in the city, the choice must be justified.
- Quite often (though not always) delivery of buses is combined with a dedicated charging system, , and in that case, installation of the equipment is often required by the electric bus supplier. Every PTO bus owner needs plug-in charging from an external charger, and sometimes charging at the bus terminal using pantograph mounted on a bus. Induction charging has not been ordered yet due to high infrastructure costs.
- Delivery is always related with the whole city-specific passenger information system.

- Purchase and sale is carried out exclusively through tendering procedure for public customers.
- Most of investment in electromobility is supported by EU subsidies.
- The most frequent order is for 12-meter buses.

All vehicles are equipped with air-conditioning in passenger compartments. Additionally, interior heating is usually based on the hybrid system (electric heater + diesel heater, which provides heat while ambient temperature is very low) or only diesel heating system. The majority of customers in Poland prefer the simplest central motor. Up to now, most buses have been delivered with high energy batteries. Requirements of customers on the European market are very similar to requirements of Polish customers as regards basic issues. Additional requirements are connected with the geographical location and the specificity of the market. The main difference in requirements between Polish and, for example, Scandinavian customers relates to the heating system. The temperature range for the operation of vehicles and chargers starts at -35 degrees Celsius. Standard heating is based on biodiesel alternatively with electric heating. Scandinavian customers usually require short time opportunity charging and overnight charging via pantograph. Additional activities for drivers, like connecting electrical plugs to charge the bus, are not expected in that region. It is very important for customers to adapt to the standard charging system that is likely to be determined and financed by cities. Distinguishing features of that market are the requirements like low-entry buses, very short delivery time and motors integrated with an axle or hub-wheel motors (due to the number of seats and a large space for disabled persons) are and are. The buy back, which usually takes place after 7-10 years can gives components like traction batteries for second stationary life application. There are many buses operating in suburban areas in this part of Europe. Expectations for buses used at suburban lines are: range of 200-300 km on a single charge, as many seats as possible and plug-in charging systems. Customers often expect data loggers, which ensure online supervision over the bus fleet and chargers. The aim is to monitor power consumption (instantaneous / average), battery state, battery charging, average speed, number of passengers, etc. Customers are also interested in early warning systems to prevent a failure of the vehicle. In Central Europe, i.e. in Germany, there is demand for buses for a distance up to 200 km. This market is mainly interested in plug-in charging at the depot, electric heating, electric air-conditioning, which is always needed, 30 seats, traction battery life time of at least 8 years, short delivery time and the buy back after 12 years (usually free of charge). There are also customers who purchase buses equipped with on-board charger –in order to save space on the depot. Some of customers are interested in buses equipped with pantograph for opportunity charging, too. These customers, as well as customers in Poland, tested different pantograph charging systems, but with high capacity batteries to ensure continuity of operation on the line in case of damage or a problem with charging system, as well as Poland.

High range of a bus on each single charging is required also in countries such as France, Belgium or Spain. In these countries, 12m buses are equipped with plug-in, while 18m buses are equipped with pantographs and can charge in the city. Unlike in Scandinavian countries, French, Belgian or Spanish customers often equip their buses only with electric heating.

Diesel heating is only an option, it is rare and usually is not purchased. The market is dominated by LCC contracts for 15 years, and requires a remote vehicle monitoring system for key components. Tenders are organized for complex solutions: buses and infrastructure. In large urban areas, such as Paris, there is a constant supervision of over the conservation officers, which limits setting up the extra charging infrastructure. Local customer requirements with regard to the location and number of plug-in sockets are unique in Europe. A common requirement is to have two plug-in sockets in one bus. The first one behind the front and the second one rear under the engine flap.

Most tenders in Spain and France require the battery leasing. That kind of financing gives more possibilities for both customers and leasing companies. Customers pay a monthly fee, which usually includes service and maintenance for the agreed duration. Lessors are owners of batteries and they are responsible for keeping technical and commercial conditions and exchange of batteries in the appropriate time.

Italy is one of the warmest European countries, where there are possibilities to find cities/towns interested both in plug-in charging system, and solutions based on high power batteries with pantograph charging systems (e.g. Bolzano). In Italy, there is a significant problem to find the proper place for stationary chargers at the depots, so customers prefer on-board chargers built into the vehicles or external chargers with the ability to charge a few buses from one device at the same time. Vehicles in this part of Europe are always equipped with air-conditioning for the passenger area. Buses are bought with the full supplier service and only through public tenders.

As it can be seen from the above, despite different requirements of customers from different parts of Europe, two main trends are developing. The first one goes towards electric buses equipped with high energy batteries , as large battery capacity allows to cover a longer distance and can be charged through plug-in. The second possibility is to use high power batteries, allowing fast charging, however their energy density is lower, so availability of energy on the vehicle will decrease, comparing to high energy batteries.

2 A brief overview of energy sector and perspectives of energy storage development in Poland.

PGE Capital Group is the biggest producer of electricity in Poland, with a 37% share in power generation, delivering power to over 5 million clients. The annual output of electricity produced by the Group amounts to 53,67GWh, and about 80,6% (48,65 GWh) of this is produced of coal (2016).

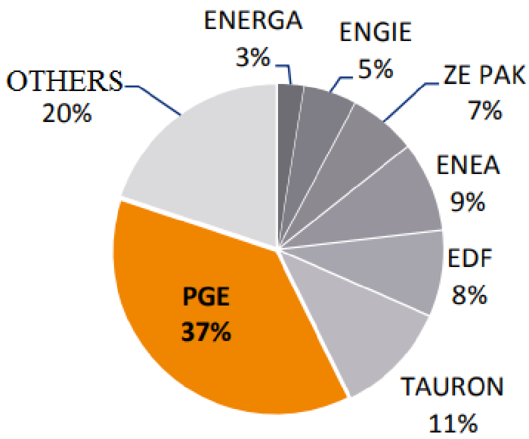

Figure 6. Net electricity generation in Poland by company (2015) [10]

The largest coal-fired plant in Poland is the Bełchatów Power Station, belonging to PGE Capital Group. The power station has installed capacity of 5,3 GW (data by PGE GiEK - 2017), and its production accounts for ~22% of electric energy generated in Poland. In spite of an increasing consumption of electric energy in subsequent years (the growth amounted to 1,7% in 2015, and 1,97% in 2016), we can observe a decrease in demand for electricity produced of coal. In 2016 the coal power plants ensured around 81 percent of the domestic demand for electric energy. According to the reports by Polskie Sieci Elektroenergetyczne S.A. (National Grid), electric energy produced of coal fuel in 2016 was 132,6 TWh, that is less than 2,1 percentage point in 2015. In Poland's energy mix, one can observe a gradually growing importance of renewable energy sources. This segment is dominated by wind power industry.

The installed capacity of wind turbines in Poland has increased from 1,6 GW in 2011 to 5,7 GW in 2016. Taking in account the peak power demand in winter (26,2 GW) and in summer (22,7 GW) [11], wind turbines are important in generation mix in Poland. In 2016, the growth of electricity produced by wind turbines in comparison with 2015 amounted to 16 percent., achieving 11 623 GWh. Wind power generation crowds out energy produced in conventional energy sources . In case of the big wind capacity occurrence, energy prices fall in spot deliveries. The growth of installed capacity in wind farms implies that the conventional energy sources produce less energy. Therefore, the price of energy falls in the wholesale market.

PGE invests in new, effective solutions for renewable energy sources. Over the last years, substantial investments in RES have been directed at the wind power generation has been . In December 2015 the Lotnisko wind farm with installed capacity of 90 MWe and the 12 MWe Kisielice II wind farm went into commercial operation. Both farms obtained concessions in January and February 2016. The total installed capacity in wind farms within PGE's assets increased from 0,31 GW in 2014 to 0,53 GW in 2016. Table 1 presents the PGE Capital Group's utility scale wind power assets.

Table 1. PGE Capital Group's utility scale wind power assets.[10]

Wind power plant	**Power Generation [GWh] - 2016**	**Installed Capacity [MW]**
	1.083,3	***529***
Lotnisko *	174,6	90
Resko II**	171,9	76
Żuromin	133,8	60
Pelplin	97,4	48
Karwice***	85,4	40
Jagniątkowo	70,1	30,6
Kisielice	70	40,5
Wojciechowo****	62,2	28
Karnice I	57,9	29,9
Kamieńsk	54,1	30
Malbork	36,8	18
Resko I	25,4	14
Galicja	23,8	12
Kisielice II*****	19,9	12

* data for the period March to December 2016
** data for December 2015
*** data for July to December 2015
**** data for March to December 2014
***** data for February to December 2016

In addition to the newly commissioned on-shore investments and the investments in the renewable energy segment, PGE plans to develop offshore wind farms with a total installed capacity of 1,000 MW. The development of new financing models, the success of the auction support system for Renewable Energy Sources and the development of new business models in the field of power distribution are the main factors determining success in this direction. The direction supports the PGE's strategic goal to achieve a leading position in the segment of Renewable Energy in Poland, reaching a 25% share in the sector by 2025 [10]

The introduction of unstable wind and solar generation into the power distribution network generates a number of issues relating to the stabilization of the network and balancing supply and demand for power and energy. Energy storage has been recognized as one of the solution to respond to these challenges and to ensure a continued security of continuous electricity supply. As a responsible supplier, PGE is looking for new technological solutions that will be able to deliver the highest quality products and services to its customers. For this reason, the group actively conducts activities in the field of electricity storage. The PGE Capital Group's carries out research and development projects in the field of battery energy storage and invests in the implementation of new energy storage solutions. Storage systems are tested within the PGE's low and medium voltage power distribution network, as well as in the area of renewable energy production. Current efforts are aimed at testing practical application of battery energy storage systems with a capacity of up to several MW mostly based on lithium-ion batteries, for the purpose of DSO operator, energy clusters, for utility wind farms and photovoltaic operators. PGE develops new business models for profitable energy storage systems.

Moreover, PGE conducts R&D activities to acquire its own solutions through cooperation with technology developers - in the areas of energy storage components such as power electronics, batteries, data transmission systems, system architecture - both in terms of large system resources, in the distributed energy consumer segment and the electric mobility segment. One of the projects is carried out by the Capital Group in cooperation with Solaris Bus & Coach S.A., the leading European manufacturer of electric buses. The scope of cooperation includes research and development of energy storage system using decommissioned bus lithium batteries in order to economically store energy generated in wind farms.

3 Electric bus lithium batteries for stationary storage applications – case study and R&D status

In this section the authors will analyse possible R&D, business strategies for application of batteries from electric buses in the stationary storage applications and will compare stationary and automotive standards. The authors will analyse the economic effectiveness of various applications of the batteries for today and the near future, confronting them also with the existing alternative solutions.

SBC produces a wide range of electric buses in different configurations: battery electric buses (for overnight and opportunity charging), as well as trolleybuses, with a length of 8.9 to 18.75 meters.

For such a wide portfolio of products that can be configured in different ways and equipped with batteries of different capacities, it was necessary to create a modular system that would allow to use the same blocks in different configurations.

During the development of modular battery packs, the immediate thought was to use them in a second life application. A modular solution has been designed for a potential using without modification, for example in stationary applications.

The battery and battery type in the electric bus is defined by a wide range of various parameters such as route conditions (land inclination, distance between charging points, passenger load, commercial speed, layovers) and climate conditions (mainly ambient temperature range). Basing on over 1000 performed simulations, we can observe that most of clients expect to cover daily long distances, even up to 300 km. It is currently almost impossible to fulfil their requirements regardless of weather conditions and without extra charging during a short layover at the terminus, due to the battery system weight.

While technical feasibility study is prepared, it is necessary to predict energy consumption for the worst conditions. Public transport operator has to guarantee covering the whole daily distance, regardless of weather conditions, if not – the operator must pay significant fines for failure to provide proper service. The scenario of 270 km route in the average city was taken into consideration in this paper.

Average commercial speed: 18 km/h (SORT-2 conditions)

Electrical heating + A/C for full passenger compartment

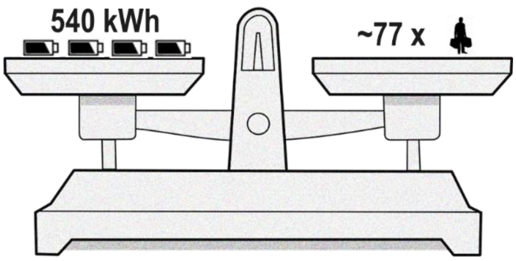

Figure 7. Battery system weight for 270 km route with average energy consumption of 2 kWh/km (regardless of the state of health of the battery) [source: Solaris Bus & Coach S.A]

The most complex challenge is to find the proper battery technology to fulfil customer’s requirements. To cover 270 km route, it is necessary to have 540 kWh of net energy in batteries, – which not include such things as battery ageing or recommended usage of SoC to extend battery lifespan. Each additional kilowatt-hour has some impact on the total weight of the battery system, which is presented in Figure 7.

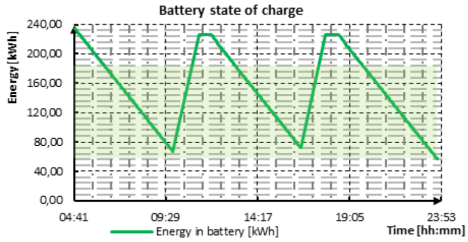

Figure 8. High Energy battery state of charge during one day [source: Solaris Bus & Coach S.A]

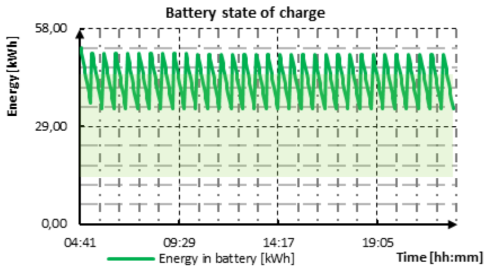

Figure 9. High Power battery state of charge during one day [source: Solaris Bus & Coach S.A]

Both figures present daily routes of buses, the difference between them lies in their charging time, type and usage of batteries. The first one, equipped with high energy battery (240 kWh) requires extra charging every 90 km in the worst weather conditions. Full charging can take up to 2 hours every time if charging power is approximately equal to 80 kW. The second one, equipped with high power battery (58 kWh) requires charging every single route (~8 km) for approx. 6 minutes in the worst weather conditions – charging power is approximately equal to 200 kW. The second bus will spend one hour less on the line due to shorter charging times. Another advantage of the second solution is the total weight of the battery system, which will allow to take more passengers on-board.

One of key factors is battery ageing. For public transport operators it is one of the most important features: at some point battery might not provide enough energy to cover completely daily route. Therefore, usually one of two parameters can be taken for "end of life" : minimum distance, which needs to be covered in the worst weather conditions or how much energy is available in the battery after defined number of years (i.e. 80% after 5 years).

Battery systems for buses need to be prepared for various load, except almost constant energy demand for some accessories. For most of the time, energy demand varies thanks to fluctuation of traction's power demand as well as air compressor, steering pump and HVAC system (HVAC – Heating, Ventilation and Air Conditioning). Due to the limited possible weight of battery system, minimum distance between charging points and required charge/discharge parameters, batteries shall be prepared for both variants: with minimum number of batteries as well as maximum number of them. In the compliance with market's expectations, Solaris can offer High Power batteries starting from 58 kWh up to 145 kWh (increase every 29 kWh).

Requirements of the batteries in stationary applications are different from those of the automotive industry. Energy density and weight of a battery are no longer the a key factor. In case of stationary applications the battery life as well as possibility of creating a MWh or even GWh installation are the most important challenge.

PGE Capital Group is leading research and development projects in the field of battery energy storage, investing in implementation of new energy storage solutions. Storage systems are implemented in the area of the PGE's low and medium voltage power distribution network, as well as in the area of renewable energy production. Current efforts are aimed at testing practical application of battery energy storage systems with a capacity of up to several MW mostly based on lithium-ion batteries, for the purpose of DSO operator, energy clusters and for utility wind farms and photovoltaic operators.

The basic technical requirements for energy storage for wind farms and photovoltaic plants include the parameters given below:

· Estimated battery power from 200 to 800 kW depending on farm size.

· Power / energy ratio: 1: (3-4).

· Minimum battery life: approx. 1000 cycles.

· Number of charge / discharge cycles per day: 1-2.

· Acceptable loss of battery capacity: approx. 20% within 10 years,

working in the temperature range from -25 to +40 degrees Celsius

Proper selection of energy storage system depends on a number of factors, but the main role is played by the power consumption profile of the relevant power distribution circuit and the available power supply profile. Nominal electrical parameters of the battery storage system are adjusted to the demand profile, so that discharge currents do not exceed certain values that are unfavorable to the type of battery used, shortening the battery life and the entire energy storage life.

Table 2. Comparison of the requirements of different types of application [source: Solaris Bus & Coach S.A]

Application type	Bus energy storage system	Stationary energy storage system
Nominal voltage	600 V DC ÷700 V DC	600 V DC ÷700 V DC
Operating voltage	520 V DC ÷750 V DC	520 V DC ÷750 V DC
Power supply voltage	600 V DC 750 V DC 3x400 V AC	depending on the system architecture, up to 15 kV
Required capacity	58 kWh ÷ 145 kWh	750 kWh ÷ 3 MWh
End of life	80% of nominal capacity	60% of nominal capacity
Required maximum charging power [kW]	200 kW ÷ 450 kW	250 kW ÷ 1 MW
Required maximum discharging power [kW]	200 kW ÷ 300 kW	250 kW ÷ 1 MW
C-rate	Charging: up to 4C Discharging: up to 4C	Charging: up to 0.33C Discharging: up to 0.33C

Table 2. shows the comparison between requirements for mobile and stationary applications. The main parameters, which shall be similar are nominal and operating voltages. If that feature is common, then designing a system based on multiple battery packs is less complicated. Stored energy in a battery system is also very important for both types of application, however stationary application allows to use a battery

significantly longer than the mobile one. That phenomenon is directly connected with the end of life conditions. Public transport operator usually wants to operate the bus as frequent as he can, with as many passengers as allowed and as far as possible, which means the reduced time for charging or longer distances between charging). The batteries with capacity of below 80 percent usually are not suitable to work properly in such hard operation conditions Therefore, it is recommended and required to change the batteries when their rated capacity drops below 80 percent of the nominal value . When considering the stationary application, batteries operate in less demanding conditions than in electric buses (lower charge/discharge currents, less frequent charging/discharging cycles). It is assumed that batteries in stationary applications may still be used, even if the rated capacity drops to around 60% of nominal value. and can fulfil client’s requirements This means that batteries that cannot be longer used in electric busses, can be still applied in many stationary applications (for example wind power generation).

For stationary application gravimetric and volumetric energy density is not as important as in mobile application. Bus application with opportunity charging requires usually high power for a short time (50% of available energy can be charged in less than 8 minutes). High power can be absorbed only by using high quality cells, which are designed to be charged and discharged with high currents. The best chemistry to provide those features is LTO – lithium titanite oxide cells, which have great power density. High Power batteries have been used by Solaris in some electric buses since 2015. Stationary application usually does not require such a quick charging as buses, so full charging in 3 hours shall be considered.

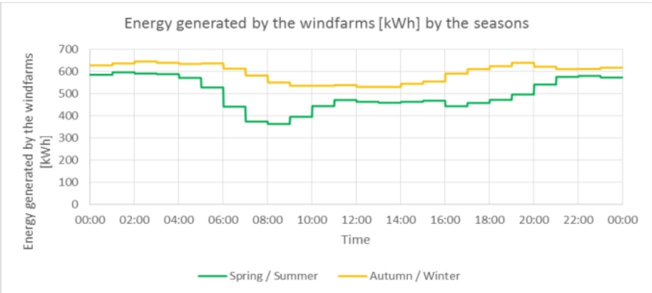

Figure 10. Average energy generated by windfarm in Świętokrzyskie region Poland by the seasons [source: Solaris Bus & Coach S.A]

As Figure 10 shows, average generated energy varies depending mostly on weather conditions and season. Significantly more energy is generated during the night hours, when the wind is stronger than during the day. When power demand is highest, and enough energy must be provided to the grid, it becomes necessary to install additional energy storage system (ESS). ESS can be based on a single container or the system can contain a required number of containers to provide demaned energy and discharge power.

Below are presented two solutions, both for a 20’’ container, however they have a different number of battery packs, which is explained in the figures.

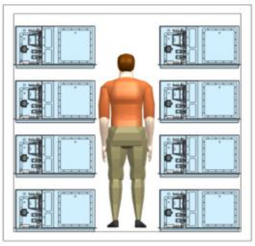

Figure 11. Option 1. 20" container [source: Solaris Bus & Coach S.A]

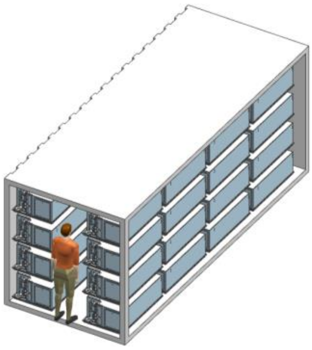

Figure 12. Option 1. 20" container [source: Solaris Bus & Coach S.A]

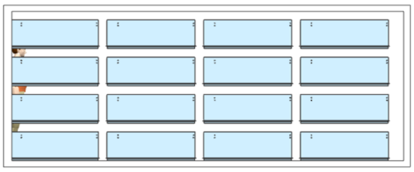

Figure 13. Option 1. 20" container [source: Solaris Bus & Coach S.A]

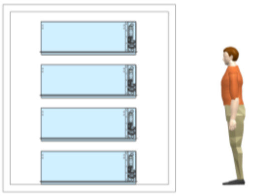

Figure 14. Option 2. 20" container [source: Solaris Bus & Coach S.A]

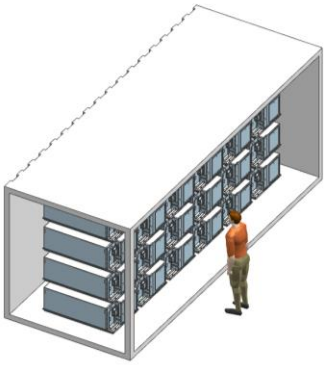

Figure 15. Option 2. 20" container [source: Solaris Bus & Coach S.A]

Figure 16. Option 2. 20" container [source: Solaris Bus & Coach S.A]

The only difference between option 1. and option 2. is the placement of battery packs. The first option allows for mounting up to 32 battery packs in one 20’’ container, while in the second option, due to better service access, the number of packs is reduced to 24. The stationary energy storage system should allow to store approximately 400 kWh of usable energy for 24-battery-pack-based-system up to approximately 600 kWh of usable energy for 32-battery-pack-based-system.

Energy storage systems can be installed both in stationary and mobile applications, however there are differences in standards that need to be met by the batteries for the two applications. These differences need to be considered during designing batteries to have their second life in stationary applications. Some of standards for stationary and mobile application should be considered during the designing phase and will be explained by the authors in details in another article, however analysis of base requirements can be found below.

Stationary batteries standards mainly focus on safety issues (protection from electrocution – EN 50272) and charging requirements of those batteries. Those standards describe transport, storage and recycling methods. Flow battery systems can be considered as one of energy storage systems (DIN EN 62932). This standard refers to batteries with nominal voltage lower than 1.5 kV DC. It specifies testing methods as well as protection from electrocution and protecting the natural environment. Most of the stationary batteries standards are IEEE (Institute of Electrical and Electronics Engineers) standards, which describe issues related to installation, maintenance and testing of different battery types. They also describe topics of ventilation and thermal management (1635-2012) and battery lifecycle (1561-2007).

Automotive batteries standards describe very similar issues. For example lifecycle of battery's module is described in SAE J 2288, battery's performance in SAE J 1798 and safety regulations in SAE J 2929 as well as in EN 50604. Lithium-ion battery packs' tests are described in ISO 12405 and lithium-ion energy storage systems combined with supercapacitors or lead batteries can be found in standard ISO 18300. Another important standard is SAE J 2380, where vibration issues are described. Structure, component's placement and design are detailed in DIN 91252. Crash tests of electric vehicles with traction batteries are described in SAE J 1766.

Some examples of energy storage systems standards are presented in the tables as follows:

Table 3. Standards for stationary application [7]

Standard	**Stationary application - standard name**
ANSI/IEEE 450-2002	IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications
ANSI/IEEE 1184-1994	IEEE Recommended Guide for Selection and Sizing of Batteries for Uninterruptible Power Supply, (UPS)
ANSI/IEEE 1188-1996	IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications
IEC 60896-1 1987	Stationary Battery Tests
BS 6290 1999	Stationary Battery Tests
IEC 62040-3	Specification for uninterruptible power systems (UPS). Performance requirements and test methods (V indicates a prestandard)
ENV 50091-3	
NFPA 111 1989	Standard for Stored Electrical Energy Emergency and Standby Power Systems
IEEE 1106-2015	IEEE Recommended Practice for Installation, Maintenance, Testing, and Replacement of Vented Nickel-Cadmium Batteries for Stationary Applications
484-1987	IEEE Recommended Practice for Installation Design and Installation of Large Lead Storage Batteries for Generating Stations and Substations
485-1983	IEEE Recommended Practice for Sizing Large Lead Storage Batteries for Generating Stations and Substations
937-2007	IEEE Recommended Practice for Installation and Maintenance of Lead-Acid Batteries for Photovoltaic (PV) Systems

1013-2007	IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stand-Alone Photovoltaic (PV) Systems
1115-2014	IEEE Recommended Practice for Sizing Nickel-Cadmium Batteries for Stationary Applications
1187-2013	IEEE Recommended Practice for Installation Design and Installation of Valve-Regulated Lead-Acid Batteries for Stationary Applications
1188a-2014	IEEE Recommended Practice for Maintenance, Testing, and Replacement of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications - Amendment 1: Updated VRLA Maintenance Considerations
1189-2007	IEEE Guide for Selection of Valve-Regulated Lead-Acid (VRLA) Batteries for Stationary Applications
1361-2014	IEEE Guide for Selecting, Charging, Testing and Evaluating Lead-Acid Batteries Used in Stand-Alone Photovoltaic (PV) Systems
1375-1998	IEEE Guide for the Protection of Stationary Battery Systems
1491-2012	IEEE Guide for Selection and Use of Battery Monitoring Equipment in Stationary Applications
1561-2007	IEEE Guide for Optimizing the Performance and Life of Lead-Acid Batteries in Remote Hybrid Power Systems
1562-2007	IEEE Guide for Array and Battery Sizing in Stand-Alone Photovoltaic (PV) Systems
1578-2007	IEEE Recommended Practice for Stationary Battery Electrolyte Spill Containment and Management
1635-2012	IEEE/ASHRAE Guide for the Ventilation and Thermal Management of Batteries for Stationary Applications
1661-2007	IEEE Guide for Test and Evaluation of Lead-Acid Batteries Used in Photovoltaic (PV) Hybrid Power Systems
1679-2010	IEEE Recommended Practice for the Characterization and Evaluation of Emerging Energy Storage Technologies in Stationary Applications
1881-2016	IEEE Standard Glossary of Stationary Battery Terminology
2030-2011	IEEE Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), End-Use Applications, and Loads
ABNT NBR 16404:2015-06-25	Lead acid battery-stationary vented - Installation and assembly requirements
EN 62932	Flow battery systems for stationary applications
EN 62485-5	Safety requirements for secondary batteries and battery installations. Part 5. Lithium-ion batteries for stationary applications
EN 50272-2:2002-03-26	Safety requirements for secondary batteries and battery installations - Part 2: Stationary batteries.
IEC 62485-2:2011	Secondary batteries and battery installations. Safety requirements. Part 2. Stationary batteries
ABNT NBR 15641:2008-11-17	Stationary valve regulated lead acid battery - Maintenance
EN 50272-2:2001-09-04	Safety requirements for secondary batteries and battery installations. Stationary batteries

DIN EN 62932-1:2016-06	Flow battery systems for stationary applications - Part 1: General Aspects, Terminology and Definitions
DIN EN 62932-2-2:2016-05	Flow battery systems for stationary applications - Part 2-2: Safety requirements

Table 4. Standards for mobile application [7]

Standard	**Mobile application - standard name**
ISO 12405-1:2011-08-31	Electrically propelled road vehicles. Test specification for lithium-ion traction battery packs and systems. High-power applications
ISO 18300:2016-11-30	Electrically propelled vehicles. Test specifications for lithium-ion battery systems combined with lead acid battery or capacitor
SAE J 1798:2008-07-08	Recommended Practice for Performance Rating of Electric Vehicle Battery Modules
SAE J 2288:2008-06-30	Life Cycle Testing of Electric Vehicle Battery Modules
SAE J 2929:2013-02-11	Safety Standard for Electric and Hybrid Vehicle Propulsion Battery Systems Utilizing Lithium-based Rechargeable Cells
SAE J 2380:2013-12-10	Vibration Testing of Electric Vehicle Batteries
JIS D 1303:2004-03-20	Electric vehicles - Batteries - Test method of charging efficiency
DIN EN 50604-1:2014-11; VDE 0510-12:2014-11 - Draft	Secondary lithium batteries for LEV (Light Electric Vehicle) applications - Part 1: General safety requirements and test methods; German version prEN 50604-1:2014
UL 2271:2013-12-11	Batteries for use in Light Electric Vehicle (LEV) applications
UL 2580:2013-12-16	Batteries for use in electric vehicles
UL 2089:2011-11-22	Vehicle battery adapters
DIN 91252:2016-11	Electrically propelled road vehicles - Battery systems - Design specifications for Lithium-Ion battery cells
UL 1973:2013-02-15	Batteries for Use in Light Electric Rail (LER) Applications and Stationary Applications

Summary

As a result of dynamic changes in e-mobility, Solaris (the leading European manufacturer of innovative buses and urban rail vehicles) and PGE S.A. (the largest vertically integrated company in energy sector in Poland) are looking for new common areas of cooperation. Pure energy from renewable energy sources makes electric vehicles even more eco-friendly, which results in significant increase of desirability of such by perspective final customers such as local authorities in case of electric buses. Presence of PGE S.A. in further steps of e-mobility concept development gives an opportunity to create new revenue, which leads to use currently owned renewable energy sources. Cooperation between companies from different industry sectors (Solaris as the public transportation OEM, PGE as a renewable energy supplier) gives an opportunity to create new solutions for the both clients – individual and commercial.

PGE and Solaris have undertaken joint efforts to verify the use of bus lithium batteries for stationary applications. Activities support the development of new technologies and business models the field of renewable energy sources and sustainable transportation. The scope of co-operation is based on the experimental development of new solutions for battery stationary storage, primarily for wind energy purposes. At present, work is underway on the identification of target locations within PGE's wind power assets, building a coherent business and technical model of the energy storage systems for target locations.

Studies based on the mathematical model carried out by Solaris R&D Department have concluded that it is likely to select a proper bus battery providing continuous charge and discharge cycles while considering the provided load and climate profiles found in wind farms in the Świętokrzyskie area. Initial profitability calculations performed by PGE S.A. have also confirmed the probability of a return on the investment in these energy storage systems. Both companies are looking forward to launch the pilot phase of this research project in 2018.

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