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Design of Hybrid Energy System for Railway Application (Case Study of People Mover System in Doha, Qatar)

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ABSTRACT

This paper presents the conceptual design of hybrid energy system used in railway application. The hybrid system with batteries and energy storage double-layer capacitor is a new technology that is used under extreme climatic conditions, especially in daytime temperature up to 50°C, high relative humidity, dust and heavy rain. It is a combination of double-layer capacitors and traction batteries. It draws power both externally and from braking energy. In order to reduce CO2 emissions to the environment, energy-saving drives and energy storage are used. Also, in public transportation, Sitras Hybrid Energy System (HES), hybrid energy storage system for trams, has been developed which combines a double-layer capacitor with a nickel-metal hydride battery. The storage not only allows driving without overhead lines, it also enables braking energy to be recovered. A reliable cooling system is required to ensure that the performance of the battery and the capacitor storage is maintained for as long as possible. The results of finite element model showed the robustness for railway application. The computational model refers to proof of static and dynamic strength in accordance with EN12663. A cooling system for a tram using this innovative technology was designed and qualified for the "Qatar Education City People Mover System (PMS)" project.

KEYWORDS

Hybrid energy system
Traction batteries
Double-layer capacitor
Cooling system
People mover system

INTRODUCTION

The People Mover System project for Qatar Education City (QEC) is a big project and big challenge. QEC is an expression of the future vision of Qatar and this is the first railway project in Qatar. The hybrid system with batteries and energy storage double-layer capacitor is a new technology that is used under extreme climatic conditions, such as daytime temperature up to 50°C, high relative humidity, dust and heavy rain. In addition, a high level of safety requirements must be met.

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The project, which is set to be the first PMS in Qatar, represents a precursor of the country's US$35 billion investment in rail infrastructure over the next 10 years, as part of the 2022 FIFA World Cup Infrastructure Program.

The energy-saving PMS, which utilizes battery-powered trams, is designed to reduce the flow of traffic within Qatar Education City. It will allow students to travel free of charge to their destination within the city. A fleet of 19 trams will operate on an 11 km-long route through 25 Stops, with a capacity of 3,300 passengers/hour in each direction as can be seen in Fig. 1.

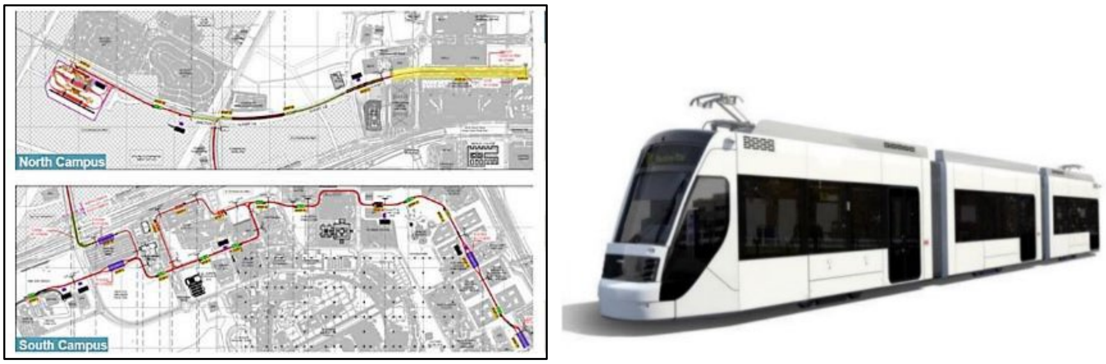

Figure 1. route within Qatar Education City (left) and the Avenio (right) [1]

The tram system for Doha is a completely catenary-free tram line. In addition, the trams are equipped with energy storage systems, which are charged at the stops via special ceiling busbars. This means that the energy consumption of a tram can be reduced by up to 30 percent and its CO2 emissions by up to 80 tonnes. A tram can also travel up to 2.5 kilometers with the storage before it has to recharge.

LITERATURE REVIEW

In recent transport system, especially in railway applications, emission is the most significant environment impact that need to be paid attention as part of international agreement [2]. Vehicle hybridization enables reduction in fuel consumption and particular emission [3]. Hybrid and plug-in hybrid propulsion system used in transport system are significantly being developed to get an efficient fuel consumption [4] and emission reduction [5].

Plug-in hybrid systems offered charging benefit with using external electric power sources during stabling periods. However, the implementation of this hybrid system into railway area is just only limited to shunting locomotives [6], meanwhile using fast charging facilities in specific stations is mainly considered for battery-electric multiple unit (BEMU) operation, as a supplement to electrical railway for regional lines [7,8] and tram networks [9].

In hybrid vehicles, strategies to manage energy systems are the main issue to overcome. The aim of these strategies is to minimize consumption of energy by controlling power flows from different sources of energy systems. A global optimization technique in form of dynamic programming (DP) is normally used in stochastic analysis [10,11,12], but in this case, the method was also used in hybrid railway vehicles to optimize the amount of its energy [13,14,15].

The present study contributes to the conceptual design of hybrid energy system (with batteries and energy storage double-layer capacitor) mostly used in railway technology under extreme temperature condition up to 50° C, high level of humidity, dust, and heavy rain. An innovative and reliable cooling system for a tram was also discussed based on Qatar Education City People Mover System (PMS) project.

RESEARCH METHOD

Hybrid energy system

The drive energy is transmitted via roof conductor rails in canopied stations and tunnels. In these sections the energy storage systems are charged to enable the vehicle to cross subsequent line sections that are without an overhead contact wire.

To store the necessary drive energy, a hybrid energy system (HES) is used. It is a combination of double-layer capacitors and traction batteries. It draws power both externally and from braking energy. The Avenio features four separate and independent brake systems and their design and brake performance conform to European Standard EN 13452 and German Standard BOStrab.

To meet an extreme climatic requirement in accordance with standard EN 60721-3-5 and to ensure operation and long lifetime of capacitors and batteries, the tram is equipped with

- more powerful air-conditioning system
- cooling systems for the capacitors and batteries

The Figure 2 shows the hybrid energy system with the cooling systems on the roof.

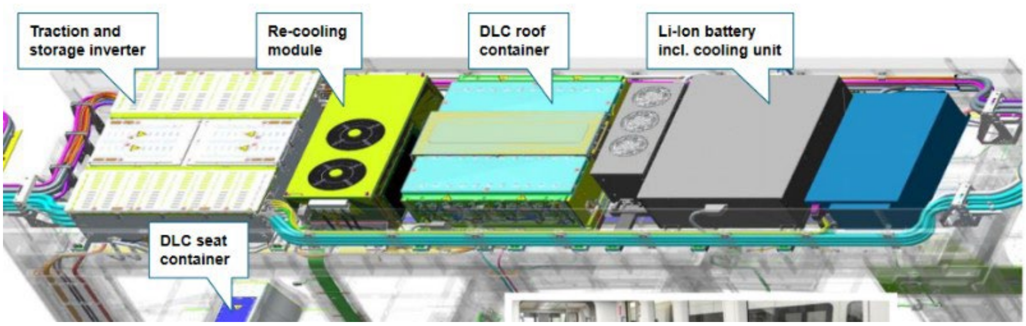

Figure 2. Siemens Hybrid Energy Storage System [1]

In order to operate the drive energy system with high efficiency, it is necessary to keep the temperature of the capacitors and the batteries within an efficiency-optimal temperature range. To ensure this, a sophisticated thermal management system is required.

The cooling system, which is described in this paper, is part of the energy storage (Double-Layer Capacitor DLC module). The version of these tram contains 24 DLC modules, which generate heat loss of maximum 15 kW at the end of lifetime of DSC module. The cooling system must ensure that all modules are cooled evenly.

For the intended use, the DLC modules should be cooled and thus the cooling medium must be cooled under outside temperature. Therefore, a dual-circuit cooling system (i.e. water circuit, chiller system) necessary. The evaporator of the chiller is connected directly with the water circuit of CapModul (cooled plate), which cools the DLC modules.

The following table shows some main requirements for design of the cooling system

Table 1. Main requirements of the cooling system

Item	Requirements
Ambient temperature / rel. Humidity	48 - 55 °C / 15 - 100%
Max. Cooling Capacity	15 kW
Cool Water temperature (glycol - water mix)	20 - 25°C
Power	460 V / 60Hz
Internal System Redundance	100%
Testing Standard Vibration & Shocking in Railway	IEC 61 373:1999-01

Design of cooling system

To meet the redundancy requirement the cool system is built in two same circuits, which can be switched between each circuit by system controls during the operation. Figure 3 shows the scheme of both circuits.

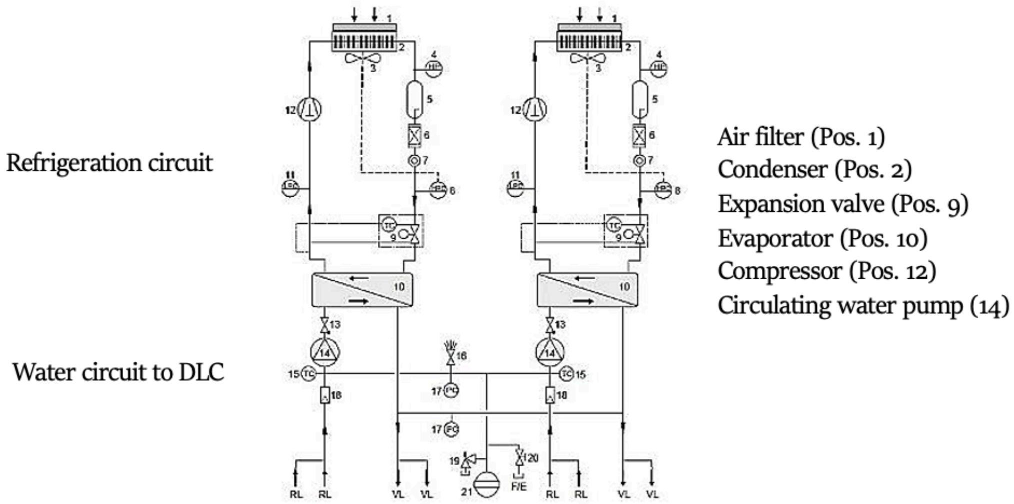

Figure 3. Circuit scheme of redundancy cooling system

The required volume flow of the pump can be determined by following equation:

$$\dot{V} = \frac{\dot{Q}}{\rho \cdot c \cdot \Delta\upsilon} \quad (1)$$

$\dot{Q}$: Cooling capacity in kW
ρ : Density of medium in kg/m³
c : heat capacity in $\frac{kJ}{kg \cdot K}$
$\Delta\upsilon$: temperature difference in K

DISCUSSION

After investigation of all pressure drops in all water circuit by calculating of the circuit and measuring of cold plate of DLC the type of pump can be chosen. Further components of the refrigeration unit, as compressor, condenser, evaporator, and expansion valve are chosen by using calculation program from each supplier. The rail applications require a special construction of housing and interior design to meet high Robustness and Reliability. The supplier of housing must also have a special certification for rail applications. Further requirements, as Fire resistance and conformity to environmental compatibility, must be also fulfilled. The design of the system is production- and service-friendly. Figure 4 shows the result of design and engineering of the cooling system.

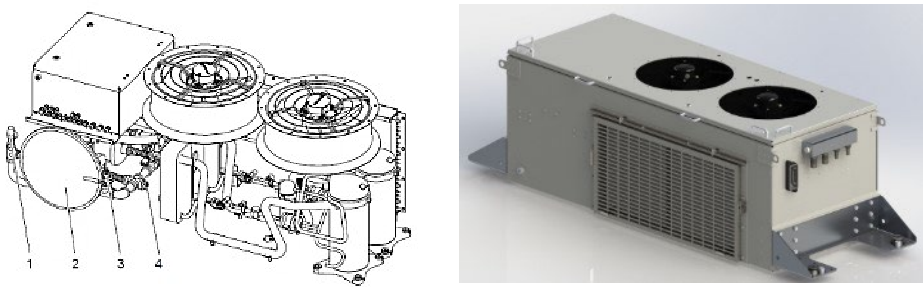

Figure 4. Structure of the system (left) and housing (right)

Finite element modeling is also used to optimize the housing to meet the high robustness for rail application. The computational dimensioning refers to proof of static and dynamic strength in accordance with EN12663.

The structural stresses of the housing and the clamps were investigated. The Screw calculation includes the connections of the housing to the pins and the Connections under the recording. Furthermore, the failure redundancy for a larger Number of screws as calculated examined. For this purpose, the connection of the highly loaded screw disconnected and the remaining connections after the dynamic Load cases investigated. Figure 5 shows some results of the structure stress investigation.

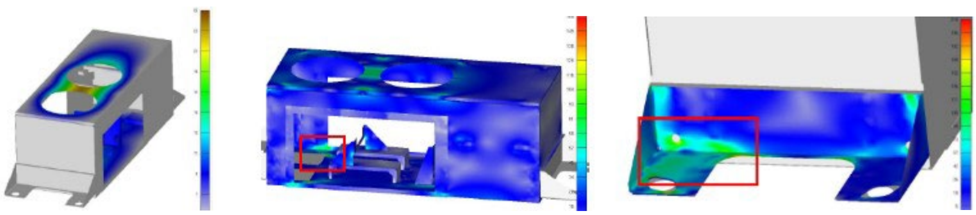

Figure 5. FEM Simulation of the housing

In order to validate the design, there are two types of validation which had been carried out, namely performance test and sound pressure test. The first validation was performance test, which was accomplished in the climate chamber. The cooling capacity, pressure drop, and volume flow were investigated. The function of system redundance and also the system robustness and reliability at different circumstance, as blocked condenser or air filter, high temperature and humidity, failed sensors, etc.

Further investigation of the system was measuring of noise level and force level. The sound pressure measurement was investigated according to the standard EN ISO 3744 in the frequency range 100 Hz and 10 kHz. The sound pressure was measured in the points according to the following figure 6. These sound pressure levels are the basis for determining the sound power level.

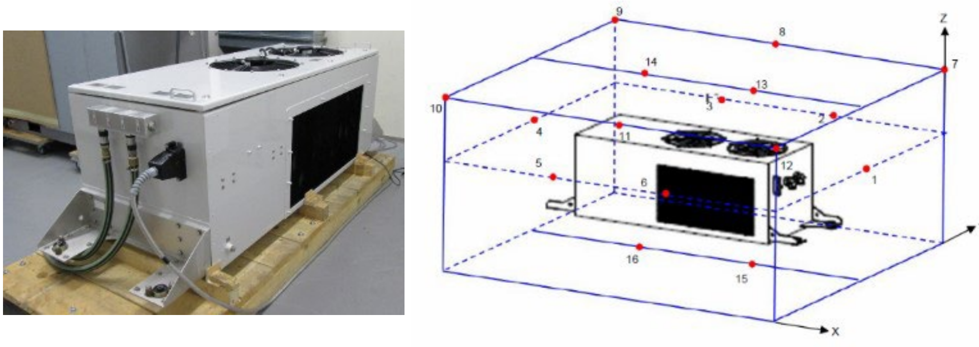

Figure 6. Performance test and measurement points of sound pressure

CONCLUSION

In this study, the design of hybrid energy system used in railway application is presented. The study case application of People Mover System (PMS) in Doha, Qatar was adopted. The hybrid system equipped with batteries and energy storage double-layer capacitor is reliable under extreme climatic conditions up to 50°C in daytime temperature. Furthermore, this hybrid system is able to withstand in high relative humidity, dust and heavy rain. The following conclusions can be drawn as follows:

1. The roof conductor rails transmit drive energy in canopied stations and tunnels. The energy storage systems are charged to enable vehicle crossing to subsequent line sections without an overhead contact wire.
2. In order to meet an extreme climate requirement and used side by side with hybrid energy system, the tram must be equipped both of more powerful air conditioning system and cooling system for capacitors and batteries.
3. The thermal management system is needed to ensure temperature of capacitors and batteries are ranging within an efficiency-optimal temperature.

The future work will focus on investigating the performance of this hybrid energy system under particular extreme climate conditions with different moving load cases.

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