Aktualne problemy pracy systemów elektroenergetycznych

pod red. Ryszarda Zajczyka

Wydawnictwo Politechniki Gdańskiej

PRZEWODNICZĄCY KOMITETU REDAKCYJNEGO
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Wydano za zgodą
Rektora Politechniki Gdańskiej

Oferta wydawnicza Politechniki Gdańskiej jest dostępna pod adresem
https://www.sklep.pg.edu.pl

ISBN 978-83-7348-900-4

WYDAWNICTWO POLITECHNIKI GDAŃSKIEJ

Wydanie I. Ark. wyd. 17,9, ark. druku 17,0, 281/1225

Druk i oprawa: Volumina.pl sp. z o. o.
ul. Księcia Witolda 7-9, 71-063 Szczecin, tel. 91 812 09 08

5. POST EV BATTERY ENERGY STORAGE FACILITIES IN THE ELECTRIC POWER SYSTEM OF A NON-RESIDENTIAL BUILDING ENHANCING THE RELIABILITY OF ELECTRICITY SUPPLY AND IMPROVING ENERGY EFFICIENCY

Mariusz Kłos[1], Krzysztof Zagrajek[1], Józef Paska[2]

[1] Politechnika Warszawska, Wydział Elektryczny, Instytut Elektroenergetyki

[2] Narodowe Centrum Badań Jądrowych, Interdyscyplinarny Zakład Analiz Energetycznych, Warszawa

Introduction

Nowadays, so-called smart grid solutions are growing in popularity [1–3]. The purpose of creating such developments is to make more efficient, both technically and economically, use of the resources available to us on a given segment of the power grid [4]. Smart grid elements may include remote metering, devices for controlling the operation of other electrical appliances, distributed generation from renewable energy resources such as PV installations [5], electricity storage [1], or electric vehicles [6–8]. All of these elements should be linked to each other by a dedicated ICT infrastructure that will enable communication between the various actors [9]. On the other hand, in the most European countries, where the generation subsector is based on fossil fuels, problems with available capacity in generation sources are forecasted, which may result to the introduction of power consumption constraints for end users in the future, but also power outages (including long ones – blackouts) [10, 11]. With this in mind, it is necessary to look for solutions that will allow efficient use of distributed generation resources. It is well known that photovoltaic (PV) installations are volatile, and their production depends on the climatic/weather conditions of the region and time. So, it is necessary to consider how to store the electricity produced in an efficient way, while taking into account sustainability. One such solution is the use of traction batteries from electric vehicles (EVs) – hereafter post EV batteries, the parameters of which after a certain period of time do not allow further operation in EVs, however, they can be the components of on-site energy storage [12, 13]. Taking into account also the development of passive building, it is possible to create energy management installations in buildings (especially non-residential – with higher energy consumption) based on solutions from the field of material's engineering (insulation materials), as well as electrical engineering – integration of post EV batteries with distributed generation resources and the building's electrical power system. Such a solution is being developed as part of the Horizon 2020 European research project POWERSKIN+ [14]. This article presents selected electrical engineering issues concerning this project.

Horizon 2020 POWERSKIN+ project

In order to apply the solution in the area of post EV battery integration with the electric grid in an energy and environmental efficient manner, it was decided to place them in the examples of non-residential buildings analyzed within the Horizon 2020 POWERSKIN+ project [14]. The aim of the project is to develop a façade solution based on the integration of highly energy efficient components, including super-insulative elements, solar energy harvesting and active energy storage features, all in one combined active/passive management system especially addressed for modern curtain wall facades in non-residential buildings [14]. Fig. IV.5.1 shows a schematic of the POWERSKIN+ module.

Fig. IV.5.1. POWERSKIN+ facade module [14]

In principle, the POWERSKIN+ project brings together research work from many areas such as material's engineering, passive construction and electrical engineering. Innovative vacuum insulation panels for walls (VIP) and glass (VIG) will be used in each module. In addition, photovoltaic cells based on perovskite technology will be installed on the surface of these panels. The rooms of the building that will be integrated with POWERSKIN+ modules are to have electricity storage consisting of lithium-ion cells retired from the electromobility sector, so-called post EV batteries [14]. This article will discuss only the electric power aspects of the POWERSKIN+ project.

Concepts for supplying power to loads in the POWERSKIN+ project

As can be seen from Fig. IV.5.1, from an electric power point of view, each of the POWERSKIN+ modules, i.e. transparent and opaque, will be equipped with photovoltaic panels based on perovskite technology and electric energy storage. The first problem that was defined was the selection of suitable post EV cells, so that it would be possible to store energy efficiently and, above all, safely. A selection of purchased post EV batteries was therefore made using chemical, physical and electrical tests. In this article, the detailed process of cell selection will not be described, because from the point of view of the process of their integration into the power grid, it is important that the electrical parameters are established before the construction of power electronics equipment. Researchers from the Department of Chemistry and the Department of Physics of the Warsaw University of Technology took an active part in the aforementioned process. The second problem that had to be faced was the development of a concept for the placement of POWERSKIN+ modules in the power grid of a non-residential building. Three concepts were proposed:

- the concept of the Central Power System;
- the Concept of Group Power Supply System;
- Distributed Power System concept.

Fig. IV.5.2 shows single line diagrams of the placement of the POWERSKIN+ module in the power grid of a non-residential building. It is worth noting that by POWERSKIN+ module in Fig. IV.5.2 is meant only the electrical part of the entire solution.

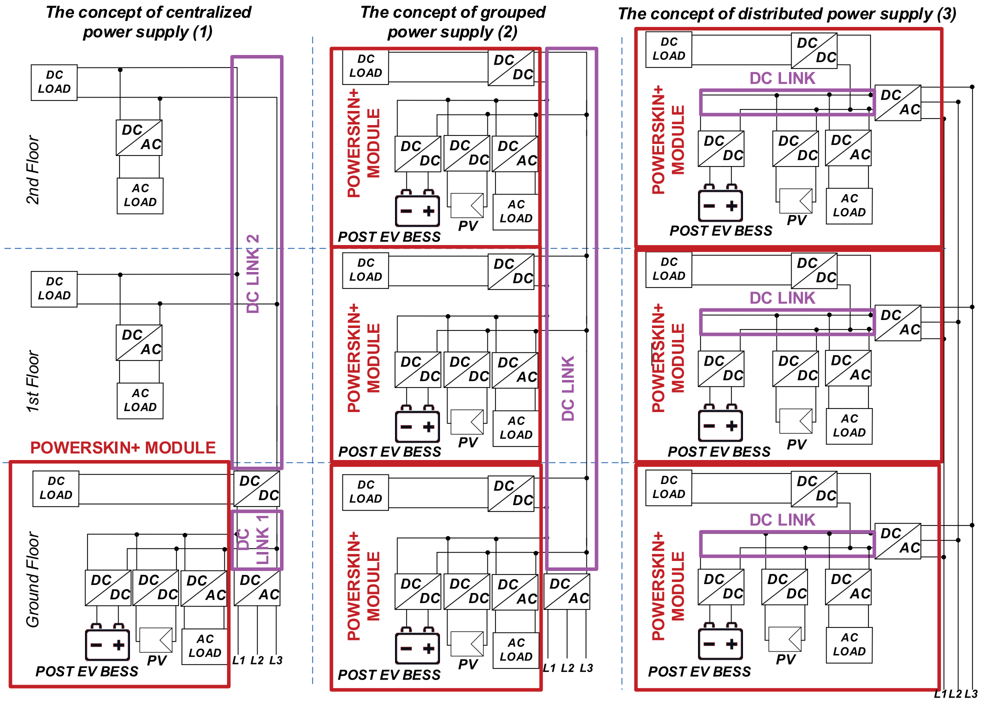

Fig. IV.5.2. Concepts for powering a non-residential building using POWERSKIN+ modules

The first concept shown in Fig. IV.5.2 is a central power supply system for loads in a non--residential building. In this case, the power output from the POWERSKIN+ modules, which are part of the building's façade (Fig. IV.5.1), would have to be brought to a single point from which further power distribution would take place around the facility. In this concept, it was also planned to separate the direct current (DC) network, to which the loads supplied by the POWERSKIN+ modules would be connected. However, this option was abandoned at the design stage due to the need for significant changes in the power installations of the POWERSKIN+ project's demonstration buildings. In concept 2, i.e. group power supply of loads from POWERSKIN+ modules, it was planned that each floor of the demonstration building would have its own power source (PV installations) and its own electricity storage built from post EV batteries. As in concept 1, it was planned to separate the DC grid for powering dedicated loads from the POWERSKIN+ module. In concept 3, i.e. a distributed power system, each floor of a non-residential building would have its own power source (PV installation) within the electrical part of the POWERSKIN+ module, its own electrical energy storage, and its own dedicated DC circuit to which DC loads can be connected, as well as AC loads via inverters. The advantage of this concept is that there is no conversion of the building's internal power lines to a DC system, which means a significant reduction in investment costs. The choice of concept should also be determined by the size of the electricity storage. It should be noted that in the case of the first concept, the capacity of the energy storage should be large enough to power the entire building, while in concepts 2 and 3 it can be limited to the size of the loads on a given floor of the building. Nevertheless, the power structure of concept 2 allows easy exchange of electricity between building floors, while in concept 3 it is limited by the maximum power of the inverter. One of the biggest advantages of concept 3 is the possibility to work in island mode. Taking into account all the advantages and disadvantages of the different concepts, it was decided to proceed with concept 3 – a distributed power system.

Electrical architecture of a single POWERSKIN+ module

General information

In the electrical part, a single POWERSKIN+ module consists of a PV plant, electricity storage, a DC switchgear, two DC/DC power electronic converters for grid integration of the POWERSKIN+ module with the electricity storage and PV plant, as well as two inverters that will enable the connection of AC loads directly to the POWERSKIN+ module switchgear and ensure cooperation with the AC building grid. Ultimately, the proposed solution is to be made available in the form of a modular design, i.e. the deployer should offer customers a series of designed power electronic converters to enable easier integration with the existing building AC infrastructure. Fig. IV.5.3 shows a block diagram of a single POWERSKIN+ module, in the electrical power part (a) and the communication part (b).

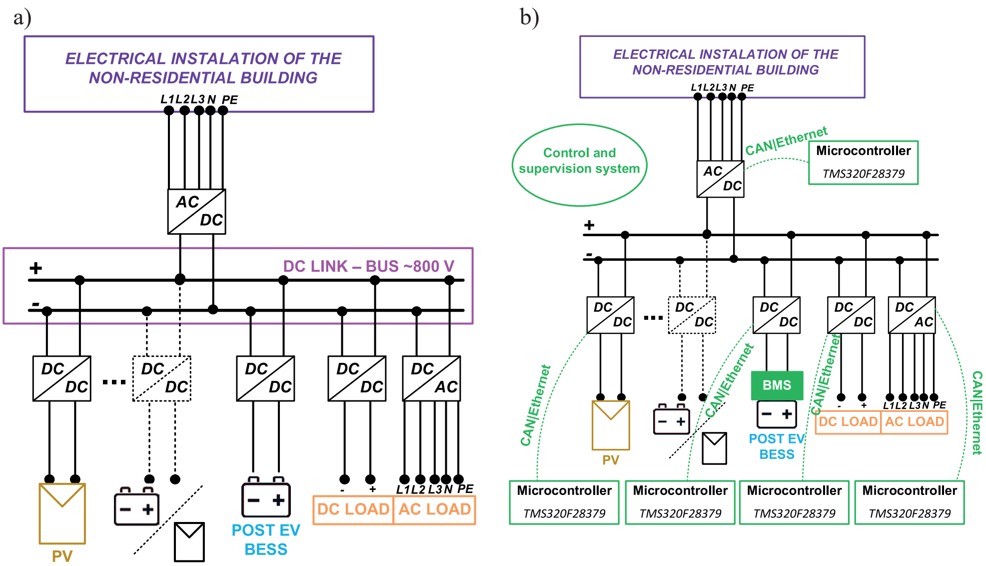

Fig. IV.5.3. Block diagram of the POWERSKIN+ module in the: a) electrical power part; b) communication part

The following subsections discuss the various components of the POWERSKIN+ module, excluding the photovoltaic installation due to the fact that virtually any type of photovoltaic technology can be used. However, it is worth noting that the POWERSKIN+ project will use perovskite cells, both opaque and semi-transparent, on window glass [15].

DC/DC and AC/DC converters

A classic Boost converter was used to integrate the PV system with the POWERSKIN+ module's DC power system. This converter consists of two semiconductor elements – a transistor and a diode, and two passive elements – an input capacitor and an inductor. The operation of the converter is based on cyclic short-circuiting the coil and transistor circuits to GND and then breaking the circuit by closing the transistor channel. Since the supply source is a set of photovoltaic modules, the converter control algorithm is MPPT (Maximum Power Point Tracker). By knowing the current-voltage characteristics of a given module panel, the power characteristics of the module can be determined, as a function of voltage. The MPPT's task is to observe the operating point of the photovoltaic module array adjusts the module voltages so that maximum output of the modules is delivered to the microgrid. However, to integrate electricity storage with a DC link, more sophisticated designs should be used to ensure galvanic isolation of the devices [16–18]. The converter that provides it is the double active bridge (DAB) type H. This circuit consists of two H transistor, a high voltage bridge and a low voltage bridge respectively, coupled together through a high frequency transformer. In Fig. IV.5.4 the topology of the DAB is depicted.

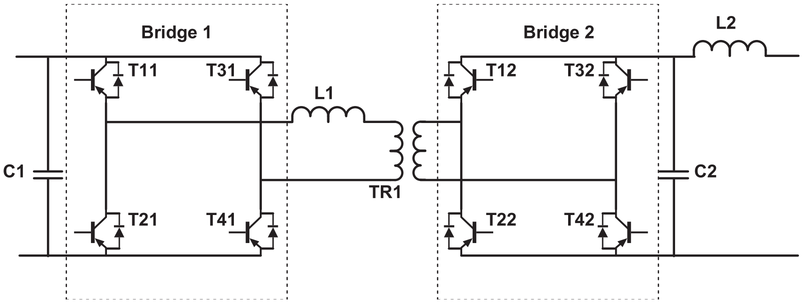

Figure IV.5.4. Topology of the dual active bridge (DAB) DC/DC converter – based on [16, 18]

The high voltage circuit (bridge 1) consists of power transistors (MOSFETs or IGBTs – based on silicon carbide (SiC) or gallium nitiride (GaN)), which operate complementarily and a DC voltage capacitor [19]. The low voltage circuit (bridge 2) consists of the same components as bridge 1 and also includes a reactor to ensure current integrity on the output side. In this circuit, more current flows on the low side than on the high side due to the reduced voltage on the transformer. The principle of the converter is based on the phase shift between transformer voltage waves of similar shape. There are two control methods [20]:

- phase shift control between individual bridges (single phase shift – SPS);
- phase shift between the individual branches of bridge 1 and 2 (dual phase shift – DPS).

During the design process of POWERSKIN+ project, it was decided to use control method, which is based on phase shift between the individual branches of bridges 1 and 2 (DPS).

In terms of inverters, a mature technology commonly used in the electric power industry, i.e. three-phase two-level AC/DC converters, was selected. It allows bi-directional energy flow in a wide power range (W–MW), with appropriate voltage levels. For higher powers, silicon carbide based IGBT transistors are used. To ensure proper operation of the converter, filters should be used. Their task is to shape the sine waves as well as reducing higher harmonics, especially keep the total harmonic distortion factor in limits [21]. A common solution is the use of an L-filter (reactor based), similarly an equally common solution is the use of an LCL-filter, which is smaller in comparison to the L-filter, however, requires a more complex control system.

Demonstrators of the POWERSKIN+ project

Mock-up of battery energy storage system – Politecnico di Torino

In order to test the feasibility of the design assumptions on the electrical side, there will be several demonstrators located in different places in Europe. However, the first demonstrator is an attempt to bring the POWERSKIN+ module to microscale in the form of a mock-up. It will be placed at the Politecnico di Torino in Turin [14]. Fig. IV.5.5 shows the structures that will serve as a representation of the facade of the building with the POWERSKIN+ module installed.

Fig. IV.5.5. Mock-up installation in Politecnico di Torino [14]

The Warsaw University of Technology was also assigned to develop an battery energy storage microdemonstrator that works with the installation shown in Fig. IV.5.5. The task of it was to power the load-heating foil, with a power of 40 W for 12 h. For this purpose, SK Innovation post EV batteries with a total capacity of 800 Wh were selected. Fig. IV.5.6 shows a single-line diagram of such a solution.

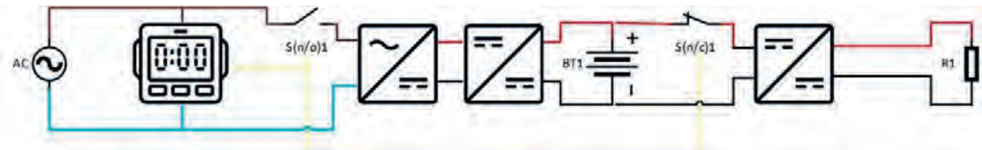

Fig. IV.5.6. Single line diagram of the battery energy storage microdemonstrator

The microdemonstrator consists of an AC/DC power supply (230 V/24 V), two DC/DC converters, and the control of the charging and discharging process was done with a timer and contactors, which are programmed for a 12 h discharge process. Fig. IV.5.7 shows the actual implementation of such a microdemonstrator (a) and the *U*(*t*) characteristics for the charging and discharging processes (b).

a) b)

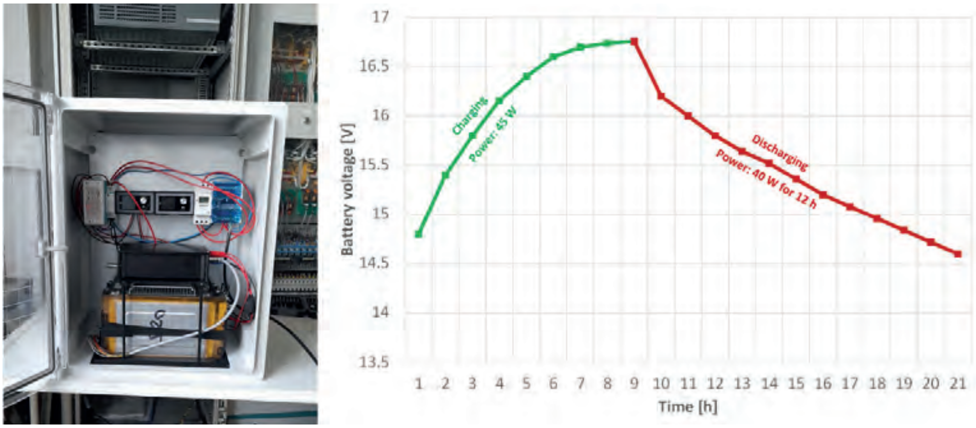

Fig. IV.5.7. Battery energy storage microdemonstrator for Politecnico di Torino: a) device; b) $U(t)$ characteristics for charging and discharging processes

Project of the demonstrator in Instituto Pedro Nunes

From the project's point of view, the target demonstrator for the POWERSKIN+ modules will be a full-scale facade model of POWERSKIN+ installed at Portugal's Instituto Pedro Nunes [14]. In principle, the demonstrator's functionality will allow the operation of the POWERSKIN+ module's for 500 W dedicated loads to be maintained in off-grid operation for 24 hours, increasing their reliability during possible power outages. This means that post EV battery energy storage system with a useful capacity of 12 kWh was selected. By useful capacity is meant such battery capacity that will allow the entire storage facility to operate between 20% and 80% depth of discharge (DOD). This means that the nominal capacity of the battery is 18 kWh. The target demonstrator, unlike the microdemonstrator, will also allow integration of the electricity storage into the PV plant or PV plant emulators. Fig. IV.5.8 shows a block diagram of the designed demonstrator of the POWERSKIN+ module from the point of view of the electric power installation.

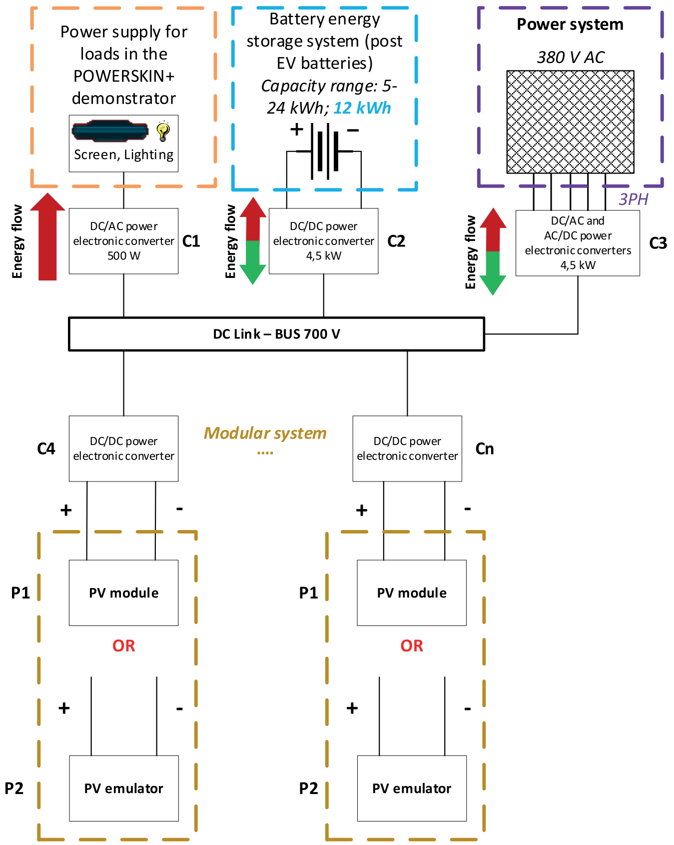

Fig. IV.5.8. POWERSKIN+ module demonstrator project at Instituto Pedro Nunes

Conclusion and disscusion

The issues of increasing the supply reliability of electricity loads in non-residential buildings, in particular their ability to operate in off-grid mode, and improving energy efficiency are the subject of research and development projects in the European Union. It should be noted that the developed solutions will be validated in a number of locations, and the analysis of performance results will be the subject of further research.

Acknowledgements

POWERSKIN+ Highly advanced modular integration of insulation, energising and storage systems for non-residential buildings. This paper was funded by the European Union's Horizon 2020 research and innovation program under grant agreement No. 869898

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