Peak shaving in microgrids using battery storage

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Abstract. In this contribution we focus on technical and economic aspects of using battery storage in microgrids for peak shaving. We perform feasibility analysis of large battery storage usage in microgrid systems under the current Slovak legislative windows. We use multiple real-life consumption profiles from various industry oriented microgrids. The primary usage of battery storage in our models is peak shaving and possible reduction of required reserved capacity. The main objective is to find the equilibrium between technical innovations, acquisition costs and energy cost savings.

Keywords: microgrid, peak shaving, energy storage

1 Introduction

For most customers, energy consumption varies throughout the workday, with tell-tale peaks and valleys. To accommodate this fluctuating demand at the macro level, utility providers may also vary their pricing throughout the day (7,8).

Peak shaving generally refers to levelling out peak use of electricity by industrial and commercial power consumers. The first purpose of Peak Shaving is to save on the electricity bill. How does peak shaving help to reduce costs? (9,1)

To understand the stakes of peak shaving, let's start by figuring out how the electricity bill is structured. The distribution company monitors power consumption at fixed time intervals every 15 minutes. The measurement of how much electricity is being consumed and at what rate it is in kW. In fact, for large users the electricity bill consists of two parts:

- **Energy consumption**: it corresponds to the primary energy charges for the total amount of electricity used throughout the billing period. The total amount of electricity used is measured in kWh.
- **Reserved Capacity charges:** measure the rate at which energy is consumed. The electric company charges its commercial customers a specific amount of money for each kW of Reserver Capacity which occurred in that month. This is, in a given month, the highest point of consumption for that month. It is measured in kW.

Customer should typically decide upfront on Capacity he expect to demand for certain fixation period. He is that charged based on this expected demand.

2 Scenarios

For the purpose of testing the possibilities of peak shaving using a connected battery system, we chose three different scenarios. Scenarios are represented by a real consumption profile data at the border of the regional distribution system and the local distribution system in a selected month. Each profile contains 2976 values corresponding to a 15-minute consumption data and has specific scenario characteristics that are highlighted in the article.

Profiles are collected using DLMS/COSEM (4) enabled smart-meters that are installed on M1 and M2 positions (see Fig 1). The IEC 62056 standards are the international standard versions of the DLMS/COSEM specification. The Protocol Suite describes the COSEM meter object model and the OBIS object identification system, where every value is represented by defined OBIS code number. This standardization model ensures interoperability between different vendor equipment.

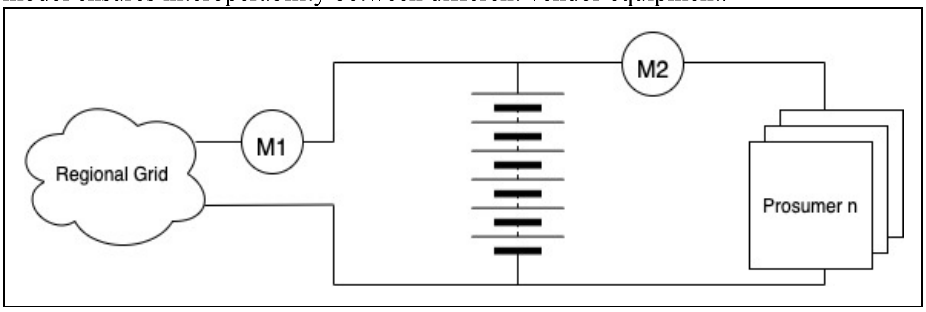

Fig 1: Connection schema

All profiles illustrated below are collected on the M1 meter (see Fig 1) which is identical with M2 if no storage system is present in network.

2.1 Scenario 1

In scenario 1 we follow the basic setup - very small microgrid with only two subscribers. One of the customers has an irregular and sudden consumption character (see Fig 2). Due to this extremely variable consumption, it is necessary to buy a large Reserved Capacity (RC) at the border to the microgrid, even though it is not needed for the vast majority of the month. The aim in this scenario was to press the necessary RC to the minimum possible limit, so that the purchase and operation of the battery system is profitable due to the saved reserved capacity.

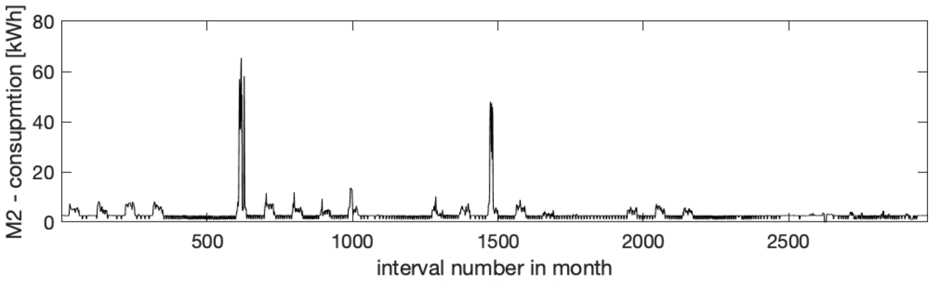

Fig 2: Scenario 1 – power consumption in selected month

2.2 Scenario 2

In the Scenario 2 we analyse the situation where the consumption profile corresponds to small industrial retail park where are about 30 equally large consumption points. The profile (see Fig 3) shows a very prickly character of consumption, which corresponds to the standard working time, every day the consumption rises to its daily maximum where it oscillates. In the evening, on the other hand, the consumption falls down to its regular minimum. The aim in this scenario is, similarly to the previous case, to compare the costs for the purchase of RC with costs associated with the purchase and operation of the battery system.

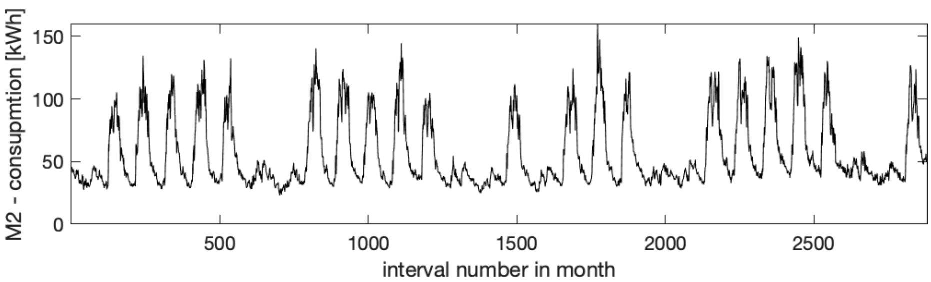

Fig 3: Scenario 2 – consumption profile

2.3 Scenario 3

In the latest scenario we use the consumption profile from the industrial park with about 20 customers, several of whom work in three shifts. Therefore, the consumption in this microgrid throughout the week, with the exception of the weekend (see Fig 4), is at the level of 800 kW to 1100 kW. During the weekend it drops to the level of 200 kW, the question arises whether it is possible to use in this microgrid system a battery system that would be charged during the weekend and discharged during the working week to keep electricity consumption from the parent system at a constant level. The possibilities of financing such a system are based, as in previous cases from the saved RC costs. At the same time, it is possible to save costs by cutting necessity of purchasing peak electricity consumption. However, the quantification of this saving is beyond the scope of this article.

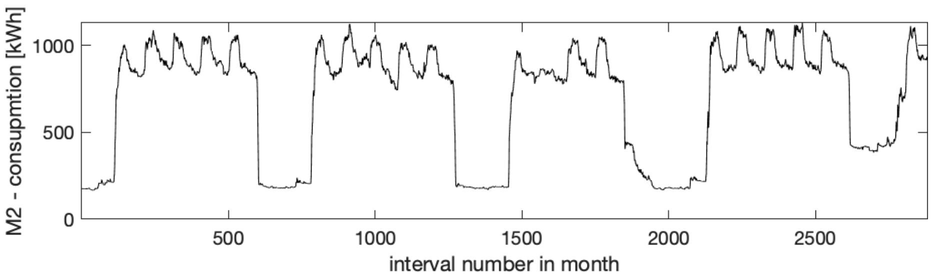

Fig 4: Scenario 3 – consumption profile

3 Energy Storage system

Energy storage is the capture of energy produced at one time for use at a later time. A device that stores energy is commonly called an accumulator or battery. Energy storage involves converting energy from forms that are difficult to store to more conveniently or economically storable forms.

Common methods of energy storage are the rechargeable battery, which stores chemical energy convertible to electricity, the hydroelectric dam, which stores energy in a reservoir as gravitational potential energy. Fossil fuels such as coal and gasoline store energy derived from sunlight by organisms that later died, became buried and over time were then converted into these fuels. Food (which is made by the same process as fossil fuels) is a form of energy stored in chemical form.

For the needs of simulation as well as cost estimation, we chose two alternative battery systems from Tesla (6) as one of most resonant vendors worldwide.

3.1 Powerwall

The Powerwall lithium battery system from Tesla Energy has made a big impact in the solar world and pushed home energy storage into the mainstream. Tesla released the first-generation Powerwall almost 6 years ago [5] with a 7 kWh Powerwall model. In comparison, the second-generation Powerwall 2 has over double the storage capacity and includes an integrated battery inverter/charger giving it much more power and flexibility.

The thermal management system enables the battery to charge at temperatures below freezing which is when many other lithium batteries suffer from severely reduced charge rates. Lithium battery cells cannot charge properly below 5 °C due to reduced diffusion rates on the anode. Powerwall can preheat the cells at low temperatures which it calls preconditioning.

The Powerwall warranty is 10 years with 70% minimum retained capacity. Tesla warrant the Powerwall 2 DC, for 10 years or until it provides 37,800 kWh of stored electricity (approx 3,200 cycles).

3.2 Powerpack

Tesla Powerpack is the company’s utility-scale rechargeable battery, designed to store energy for off-grid and supplemental power systems, including large facilities and the electric grid. Like Powerwall, Powerpack is based on lithium-ion battery technology. The batteries’ modular design is adapted from the technology used in those for Tesla's cars.

The Powerpack industrial unit is a cabinet-and-rack system which can theoretically be expanded by filling the racks with additional units for up to 500 kWh. Multiple units can be connected to create a capacity for ten megawatt hours.

Powerpack is more energy-dense now at 232 kWh per unit. Which brings the price per kWh to $744 before incentive or volume discount (3).

4 Battery system deployment Simulation

In this part, we describe performed simulation and related calculations for deployment of a selected suitable alternative battery system in individual scenarios so that we meet the requirements defined in them.

For the purposes of calculating the saved costs, we used the prices of the purchase of reserved capacity according to the table (**Chyba! Nenašiel sa žiaden zdroj odkazov.**) - these are real prices in Slovakia in April 2021 *(2)*. For all scenarios, we considered the most advantageous rate with a commitment of 12 months.

Similarly, in all cases we calculated the residual price of the battery at the end of its life at the level of 20% of its purchase value (1).

All of the simulations bellow are without any OPEX costs, which will be included in subsequent extension of work.

Table 1: Used reserved capacity prices

Type of Reserved Capacity	Price [Eur/kW]
Reserved Capacity – 12-month fixation	4,6005
Reserved Capacity – 3-month fixation	5,4124
Reserved Capacity – 1-month fixation	6,2243
Reserved Capacity overrun penalty	33,1939

4.1 Scenario 1

The aim of this scenario was to find such a Reserved Capacity together with the size and type of battery system which makes economic sense. For this scenario, we chose a solution based on a smaller PowerWall system due to the expected battery capacity, which is relatively low for higher solutions.

The battery system defined in this way is charged whenever the consumption of the microgrid is lower than the defined limit and, conversely, it is discharged when the energy requirement is higher than the limit. From the upstream distribution system point of view the system set up in this way is very stable with constant consumption.

Table 2: Scenario 1 - Parameters

Maximum power required	66 kW
Limit	12 kW
Battery Capacity	130 kWh

The state of the battery during this month in this scenario (Fig 2) is illustrated in Fig 5. Here you can see, the battery's capacity will cover consumption in two critical days when the instantaneous consumption was at level of 66 and 48 kW respectively. You can also see a longer charging time, which is caused by a large decrease of the RC from 60 kW to 6 kW.

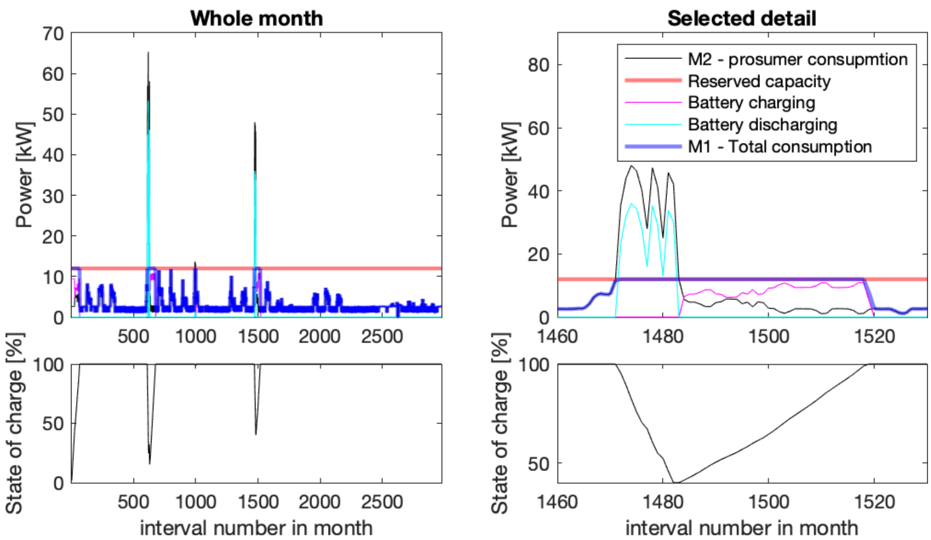

Fig 5: Scenario 1 – Graphs of important values during the simulation, RC=12kW

Based on this system setup, we expect savings calculated in Table 3Table 3 Scenario 1 over the life of the battery system, which we have set at 15 years.

Table 3 Scenario 1 Calculations

Original Reserved Capacity	60 kW			
Original RC price	276,03 €/month			
New RC	6 kW	12 kW	24 kW	48 kW
New RC Price	27,60 €/month	55,20 €/month	110,41 €/month	220,82 €/month
RC Savings After 15 Years	44 716,86 €	39 748,32 €	29 811,24 €	9 937,08 €
Battery Unit Price	7 200 €			
CAPEX	93 600 €	79 200 €	64 800 €	28 800 €
Residual Battery Value After 15 Years	18 720 €	15 840 €	12 960 €	5 760 €
Balance After 15 Years	**- 30 163 €**	**- 23 612 €**	**- 22 029 €**	**- 13 103 €**
RoI	**25,12 years**	**23,91 years**	**26,08 years**	**34,78 years**

Due to the technical specification of the PowerWall battery, it is necessary to take into account the need of peak consumption as well as the need for energy capacity of the battery when dimensioning the battery system. It is always necessary to choose the higher one of these two requirements. In this case, the peak consumption requirement was higher and therefore it is necessary to connect up to 13 PowerWall systems in order to fulfill the assignment.
Tables 3 shows a comparison of the CAPEX of the PowerWall system at 4 specific configurations distinguished by expected battery capacity, and calculated savings over the entire life of the batteries. This unflattering balance of project profitability can be improved by selling used batteries. We have estimated this residual value on the basis of articles (1) at 20% of the original price. Table 3 also illustrates expected RoI in years of all of projected alternatives. The most suitable alternative for this scenario seems to be alternative with 12 kW limit which indicates return of investment in almost 24 years. Therefore, in this scenario, the deployment has proven to be unprofitable.

4.2 Scenario 2

The aim of this scenario was, similarly to the previous one, to find such reserved connection capacity together with the size and type of battery system so that the purchase of a battery makes economic sense. For this scenario, we chose a solution based on a larger PowerPack system due to the expected higher battery capacity.
Based on the simulation created on the data from smart meter at the entrance to the area, we designed the system parameters described in Table 4.
The battery system defined in this way is charged whenever the consumption of the microgrid is lower than the defined limit and, conversely, it is discharged when the power requirement is higher than the defined limit. From the point of view of energy supply to the area, the system set up in this way appears to be very stable with constant consumption.

Table 4 Scenario 2 - Parameters

Maximum power required	170 kW
Limit	85 kW
Battery Capacity	380 kWh

The state of the battery in this scenario during this typical month is illustrated in **Chyba! Nenašiel sa žiaden zdroj odkazov.**. It can be seen in the graph that, as each working day, the battery discharges and recharges back to full during the night. At the same time, the battery is designed to be ready for the subsequent growth of the park and its consumption.

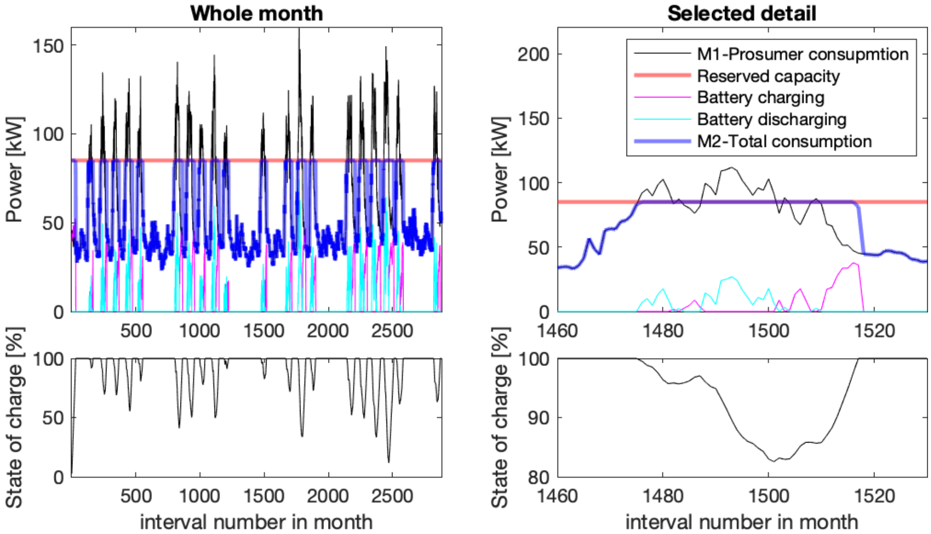

Fig 6: Scenario 2 – Graphs of important values during the simulation, RC=85kW

As in the previous scenario, we calculated the expected savings over the life of the battery system, which we set at 15 years at the level captured in Table 5.

Table 5: Scenario 2 - Savings calculations

Original Reserved Capacity	170 kW		
Original RC Price	782,085 €/month		
New RC	85 kW	100 kW	120 kW
New RC Price	391,04 €/month	460,05 €/month	552,06 €/month
RC Savings After 15 Years	70 387,65 €	57 966,3 €	41 404,5 €
Battery Capacity	350 kWh	220 kWh	50 kWh

Battery Unit Price	741 €/kWh		
CAPEX	281 724,14 €	163 103,45 €	37 068,97 €
Residual Battery Value After 15 Years	56 345 €	32 621	7 414
Balance After 15 Years	**- 154 992 €**	**- 72 516 €**	**11 749 €**
Roi	**48,03 years**	**33,77 years**	**10,74 years**

Due to the technical specification of the PowerWall battery, it is necessary to choose the PowerPack solution in this case. This will allow us to reach a projected level of 380 kWh with the battery capacity. To price this solution for the purposes of this calculation, we used article (3), which defines the price of the solution at the level of 741.38 €/kWh. Table 5 also quantifies the pricing of our designed system. As in other scenarios, we expected the subsequent sale of batteries at the residual price.
A comparison of resources in Table 5, similarly to the previous scenario, shows the unprofitability of purchasing and operating the battery system to this microgrid. The purchase price is at the level of 281,724 € and the total projected savings with the residual price of the batteries is 126,732.48 € which represents return of investment in almost 48 years.
We prepared also a second alternative of simulation with limit set to 120 kW. In this alternative only 50 kWh battery is required. The battery is used only for rarely peak shaving and RoI in this alternative is 11 years. Therefore, in this scenario alternative, we consider the deployment as profitable.

4.3 Scenario 3

The last microgrid is the largest in terms of the required capacity and peak performance of the required battery system. The primary goal was to size the battery system so that it was primarily charged during the weekend when the required power drops to 200 kW. Based on previous scenario we set limit to 1070 kW to achieve only simple peak shaving without everyday charging/discharging process. Table 8 summarize the battery system requirement.

Table 6: Scenario 3 - Parameters

Maximum power required	1 128 kW
Limit	1070 kW
Battery Capacity	200 kWh

The Fig 7 illustrates state of the battery in this scenario. It can be seen in the graph that, battery is continuously discharged during whole week and replenished fully during weekend.

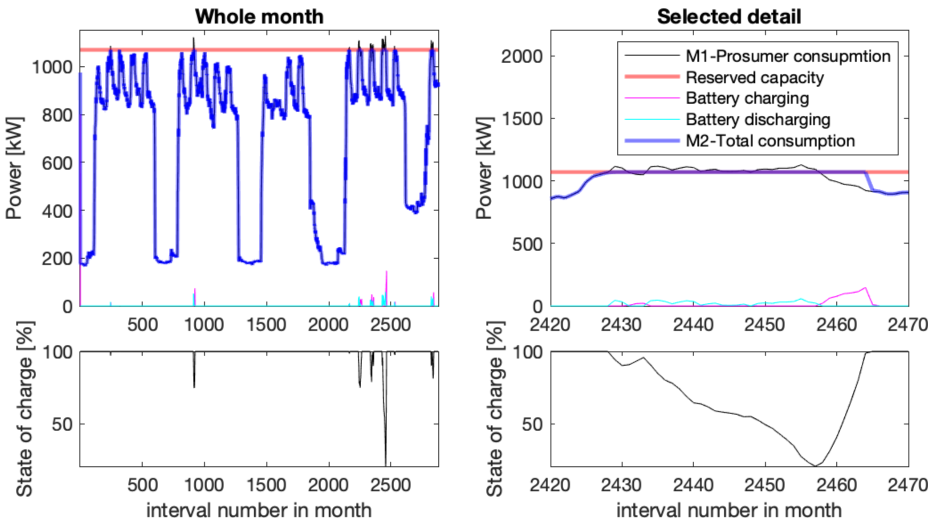

Fig 7: Scenario 3 – Graphs of important values during the simulation, RC=1070kW

Table 7 calculated the expected savings and RoI over the 15 years span, simillary to previous scenarios. We also preprared 3 alternatives of simulations with diferent projected RC limit and capacity.

Table 7: Scenario 3 - Calculations

Original Reserved Capacity	1300 kW		
Original RC Price	5 980,65 €/month		
New RC	900 kW	1000 kW	1070 kW
New RC Price	4 140,45 €/month	4 600,5 €/month	4 922,53 €/month
RC Savings After 15 Years	331 236,00 €	248 427,00 €	190 460,70 €
Battery Capacity	7500 kWh	900 kWh	200 kWh
Battery Unit Price	741 €		
CAPEX	5 560 344,83 €	667 241,38 €	148 275,86 €
Residual Battery Price After 15 Years	1 112 069 €	133 448	29 655
Balance After 15 Years	- 4 117 040 €	- 285 366 €	71 840 €
Roi	**201,44 years**	**32,23 years**	**9,34 years**

Due to the higher expected capacity system of choice for this case is also PowerWall battery. This will allow us to reach a projected level of 200 kWh. Price calculations for this solution are summarized in Table 7. As in all previous scenarios, we expected the subsequent sale of batteries at the residual price.

A comparison of prices in Table 7, shows the profitability of purchasing and operating the battery system to this microgrid when capacity of purchased battery will be only 200 kWh. Return of Investment is at 9 years, so in this scenario alternative, we consider the deployment as profitable.

5 Conclusion

We have prepared multiple different simplified scenarios with alternative peak shaving options. Two projected scenarios proved to be profitable in the simulations with slight peak shaving. As the demand for battery capacity increased, so did the payback period of the entire project increase. We believe that these simulations have shown the need for co-financing in the form of support from the state or the EU.

Another way to make a project for the battery deployment profitable is the possibility of connecting smaller batteries, which would be operated by individual customers. If the battery needs to be used by the microgrid operator, it will lease part of the capacity under precisely defined conditions.

This scenario can also be used when renting a battery to a regional distribution system. It is possible to create virtual batteries that consist of smaller batteries.

We see possible extension of this paper via incorporating maintenance costs and degradation of battery via charging cycles. Another extension of this work is possible in the form of adding photovoltaic panels to each microgrid system as an additional source of electricity. This extension would enable a further reduction in the consumption of electricity from the upstream grid as well as a reduction of necessary Reserved Capacity. It is also possible to consider other ways of alternative sources such as wind turbines or a diesel generator as a way of protection against exceeding the RC in case of unexpected increase of consumption and failure of another source.

It was also mentioned the possible expansion of work in the form of calculation of savings of the energy purchase in the case of a balanced consumption profile.

Acknowledgment

Research described in the paper was financially supported by the 313021W404 CE2 project and 2020-1-CZ01-KA226-VET-094346 DiT4LL.

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