Bidirectional Use of the Batteries in Modern Electric Vehicles

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Abstract: Recently, the climate and carbon neutrality are the largest challenges, both in the European Union and globally. In addition, an energy crisis caused mostly by the Russian-Ukrainian war, has made countries understand the importance of alternative sources of energy, harvested from renewable sources, instead of fossil based energies. Thus, the immediate challenge and need arises store the electrical energy harvested by the various different technologies. Additionally, the optimal and eco-friendly use of the stored energy needs clarification. The motive of the authors herein, is to explain a novel idea of using AI, both in the charging and discharging of batteries, that store the electrical energy harvested off-grid. For this purpose, they analyzed the measurement data and provided methods for that purpose.

Keywords: solar systems; electric vehicles; battery; fuzzy logic; sigmoid; bidirectional charging

1 Introduction

It is undisputable, that one of the largest challenges of the 21st Century is addressing the issues of climate changes that contribute to global warming. Undoubtedly, the conflict between Russia and Ukraine has led to an energy crisis, pointing out the deep dependence of several countries, on fossil fuels. [1] Eliminating the diversification of supply of different sorts of energies, in the past decade, has led many countries to shocking consequences in managing their economies and the everyday life in their society. Due to radical cut of availability of fossil fuels on the global market led to drastic rise of prices of fossil energies. [2]

Thus, it was a normal and adequate response to turn to renewable energies. Grandiose national programs were established, and many countries started to lean more and more, on these forms of energy. The majority of the investors and manufacturers acting in transportation and in automotive industry started to invest in e-mobility. [3] [4]

In Europe and also in Hungary, the most popular form of the renewable energy is solar energy. [3] [4] The solar energy harvested by factories or by different industrial sites directly covers the daily needs in electrical energy and is used immediately in the production or in different storage activity. The private individuals were highly motivated to mount solar panels in order to gain electrical energy, and in case of energy excesses they transferred electrical energy to the standard electrical grid using 'solar panel-to-grid' (SP2G) technology. [5] [6]

Due to the drastic increase of the amount of electrical energy harvested from solar panels the standard Hungarian electrical system, due to its technical weaknesses and disabilities, became to be unfit to receive further and to trade with the energy surpluses. Due to the unfitness of the main electrical grid in Hungary, starting from 2022, for new solar panel installations it is not supported further to upload solar energy to the grid. [7] [8]

Thus, in any new initiative arising to set up solar panels to harvest electrical energy the owner shall care about storage of the electrical energy harvested in his isolated electrical system. In other words, energy harvested in the given solar plant shall cover the needs of a single isolated electrical system, and the energy surplus shall be stored at the place at which it was harvested. The local storage of the electrical energy, of course, means setting up battery systems or different battery packages proper to store energy in that amount it was gained. [6-8]

The era of the green energy means that several problems should be addressed. In the transportation systems gasoline-powered vehicles are to be reduced both in numbers and in emissions too. The internal combustion engines are on the way to be substituted with hybrid, plug-in-hybrid or with full electric engines. This technique requires large amounts of available and affordable electrical energy. [5]

Recently, in suburban areas, it is very popular to set up rooftop solar panels; thus, in these households it is very cheap and simple to solve problems of the charging of e-vehicle's batteries. Long ago, it was pointed out, that in some 95% of the time electric vehicles are at idle and much of the built-in potentials remain unused. [8]

This is an opportunity, given the chance, for using the battery packs of the electric vehicles, for storage purposes, in the isolated electrical systems of different households, using bidirectional, SP2G and vehicle-to-home' (V2H), 'vehicle-to-building' (V2B), or 'vehicle-to-grid' (V2G) technology. In this project the authors set up a physical testing environment, to evaluate the idea, the efficiency and feasibility of the bidirectional, two-path charge of batteries in the electric vehicles. [9-11]

Relying on results of previous studies from the authors, it was proven, for commercial batteries available for public sale, can be overcharged by a small percentage, safely allowing for the storage of additional electrical energy.

Furthermore, it was also stated and proven, by the authors, that batteries available for public sale, can be safely discharged deeper, for a few percentages than it is recommended by manufacturers. Consequently, the authors decided to extend their scientific research to the more powerful batteries that are used in electric vehicles. [10] [11]

Based upon a thorough literature review, it can be stated, that both the European Union and the automotive industry face totally new challenges. One can experience core changes in the energy industry and in the automotive industry requiring a complex and new scientific research approach.

To merge the electrical systems of buildings and vehicles, into one, has become a key challenge nowadays. This article is based on the data gathered from the solar panel electrical system of a private household and the hybrid car (BMW 225 XE) connected to it.

The data gathered are provided and validated by the electrical energy supplier and by the vehicle charger system. The database shown, in this article, depicts an annual measurement process. During this research, the drivers' behavior was not considered and all measurements were conducted on-site, eliminating ideal lab conditions for measurements.

The main hypothesis of this research work is that battery electrical vehicles can be used very effectively in their bidirectional charge, controlled by AI both in the SP2G and in V2H, or in V2G meaning exceeding limits of the manufacturers derived both for the charged and discharged static state. On the other hand, the aim of this article is to evaluate, from theoretical point of view, how a solar panel electrical energy harvesting system and the vehicle, together, can supply electrical energy and to cover the needs of a household, when batteries are used as a temporary energy storage medium.

This paper investigates a theoretical approach of vehicle to grid technology and hybrid vehicles, which would benefit the residents of smart cities, in order to optimize energy consumption.

2 Classification and Comparison of the Solar Power Systems

Any solar system harvesting electrical energy shall be divided into three groups as given below [12]:

- Common SP2G systems
- Isolated electrical systems
- SP in synchronous mode with the isolated electrical system

The standard SP2G system is used to harvest electrical energy, and surpluses of energy are transmitted to the grid for further use. In this case there is no need to store electrical energy because the grid itself is used for this purpose. In SP2G systems the harvested DC power is inverted to AC power and if the energy remains unused it is uploaded to the grid, if and only if all conditions defined for voltages, frequencies and phase series for this act are met. The amount of the electrical power uploaded by the SP2G system into the grid is measured and the contracted partners receive balances in a timely manner, by means of the monthly invoices that the users are sent. [12]

This procedure means that mostly during daylight hours, when the majority of people are out of their house, being at work or at their study, etc., and the solar irradiance is at a theoretical maximum, electrical energy harvested, is uploaded in maximal amounts into the grid. In other words, we stored electrical energy into the grid, serving the rare purpose of a ‘battery’. Otherwise, we use electrical energy provided by the grid, when we are at home and there is little or no sunshine available. Such features in periodicity, can be identified when one compares summer and winter use of electrical energy, for different households. [12]

The second standard form the solar panel system is represented by the isolated harvest and storage of electrical energy off the grid. In this case, storage elements, batteries are needed to store the electrical energy. Depending on the need, electrical energy with DC12V or DC24V voltages, can be harvested. Moreover, in case of necessity, AC230 voltage can be inverted from DC energy. [12] Typical areas at which isolated electrical systems perform well are sparsely habited areas, farms and other settlements, where electrification of the rural area is not a challenging and a cost-effective project, for the grid owners. A few properties of the isolated electrical systems, are given as follows [12-14]:

- The isolated electrical system is autonomous
- Electrical energy is available from batteries, if solar panels do not harvest any energy at all
- If batteries are discharged to the level it is proposed, all users will remain without an energy supply

- Despite of positive trends in reduction of battery prices, batteries are still expensive devices
- Depending on battery pack sizes they still require quiet large space for mounting, and batteries may be non-aesthetic ones

Finally, the third class of the discussed Solar Power Systems is the SP in synchronous mode. In this case, the harvested solar energy by the SP's DC energy after inversion, is directly transmitted into the local electrical system. This is the simplest way to deliver energy to the users, however, it presents difficulties in the harvested power measurement.[12] Due to this specialty, the grid owner will consider such installations for isolated electrical system.

3 Electric Vehicles and Bidirectional Charging Possibilities

In previous chapters it was introduced that solar panel systems may store electrical energy into batteries in isolated electrical systems. Moreover, the V2H technology was brought, as an example, when batteries of electric vehicles were used for energy storage purposes.

It is well-known that there are two main categories of batteries used in automotive industry. The first is the lead-acid type battery, while the second is the Lithium-ion battery. Lead-acid batteries have large weight, requiring larger spaces to store them. Additionally, they possess inferior technical parameters such as life cycle, over the Li-ion batteries. In any case, they have lower prices, compared to the competing Li-ion batteries. The Li-ion batteries are lighter, require smaller spaces and their storage has better technical parameters, compared to the acid-based batteries. Thus, due to these advantages, Li-ion batteries are used widely in the automotive industry for electric powered vehicles. Li-ion batteries can be used both indoor and outdoor, having a wide operation temperature range of -20 to +50°C. [29]

Nevertheless, the Li-ion batteries are still very expensive items, costing more than $7000 USD. However, as electric vehicles numbers grow into the largest part of the transportation sector, their price lessens and they become more widely acceptable. Besides the Tesla company, the Chinese company, Huawei, also offers different technologies and solutions to store electrical energy. [13] [14] [29]

There are numerous scientific articles discussing "zero energy" building technologies and with optimization of different systems in these facilities, reducing their CO_2 emission. [15] [16] These landmark works, emphasize the idea that modern buildings and different facilities, should be able to charge electrical vehicles and shall be ready to optimize any battery charging procedures. [17-20]

3.1 Bidirectional Charging

The idea behind bidirectional charging is the multipurpose use of batteries in different cases. Normally, electrical energy harvested from solar cells, is used inside isolated electrical systems. In the case when a surplus of electrical energy is generated, it might be stored into the batteries of electric vehicles. For this purpose, a special gauge is required to fit the different forms of energy harvested. The first and the normal modality of energy transmission is the SP2V concept, when the harvested energy is used to charge batteries of the electric vehicle (Figure 1). The second modality of the energy transmission is when batteries of the electric vehicle in idle state are discharging to supply different users with electrical energy in the microgrid system of different households or facilities. [11] [21] [22]

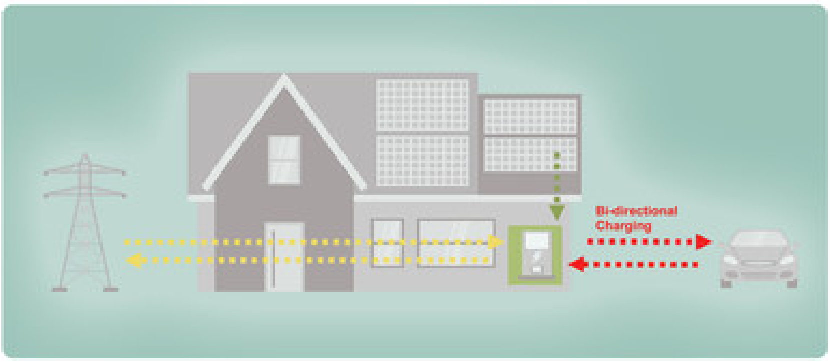


Figure 1
The scheme of the bidirectional charging [11]

An average amount of electrical energy required by a private stand-alone house is of 10-15 kWh per day. [21] The energy stored in a fully charged battery pack of an electric vehicle ranges from 30 kWh to 100 kWh. Thus, theoretically, a private house could be supplied with electrical energy stored in vehicle batteries during several days, as an average. [11] [22]

Nevertheless, if energy transmitted into the isolated electrical system of the private house covers only peaks in use of electrical energy gained from the grid, it is easy to agree that batteries of the electric vehicle can supply households during a longer period of time, if they are at idle.[21] [22]

Bidirectional charging has two basic forms [11] [21] [22]:

- **V2G, vehicle-to-grid:** When energy surplus is transmitted from the vehicle to the grid via DC/AC inverter of the 'smart grid'
- **V2H, vehicle-to-home:** When energy stored aboard the vehicle is transmitted directly to the 'house' via DC/AC inverter. The vehicle, in this case, functions like a power-bank of the electrical energy.

Many companies and state organizations recognized the importance of such kind of storage of electrical energy to get maximum efficiency during storage process. [23] [24] One of the main questions here is: what is the ratio and the amount of the electrical energy stored aboard the electric vehicle that can be subjected whether to use V2G or to V2H bidirectional charging?

When we discuss this question, it is worth to mention that bidirectional charge shall never lead to any degradation of accessibility of the vehicle itself. Moreover, a slight extension of the state of charge or state of discharge of the batteries may lead to proper and responsible use of energy stored aboard the vehicle. Additionally, this knowledge is required when developing the various charging devices. [25-28]

3.2 Batteries of Electric Vehicles

The electric vehicle conquers more and more space in transportation and in different segments of the economy. It means that batteries selected for the vehicles gain exclusive importance in machine design.

Thus, selection of batteries, for a given vehicle, has priority over other activities needed in the conceptual design stage of the vehicles. For this purpose, the batteries of electric vehicles can be described with and compared by, the following technical specifications [29]:

- Specific power [kW/l; kW/kg]
- Specific energy [(kW*h) /l]; [kW*h) /kg]
- Cycle life
- Efficiency (%)
- Self-discharge (%/day)
- Level of environmental friendship
- Total mass
- Physical size
- Accessibility

Relying on data given above and with addition of further criteria set on batteries the proper type can be selected. The battery shall be robust both in charging and discharging processes keeping its technical data and further parameters. The battery selected shall resist large load currents and deep discharges as allowed. [29]

The specific power will determine the dynamics of the vehicle, how it will accelerate. The specific energy will determine the distance the vehicle is able to maintain with a single charge.

The Tesla S model has approximately 660 km of range with a single charge, whilst the Nissan Leaf model, is able to reach 200 km, with a single charge. [31-33]

These data still lag behind the gasoline-powered engines for a few, however, the latest developments in battery design and manufacture are very promising beating the traditional engine's capabilities. Table 1 depicts the more important data of the batteries used currently. [29] [30]

From Table 1 it is clear, that the Nickel-based batteries are the best both in specific energy and specific power. It is important to point out that the Cadmium is a heavy metal which is dangerous to both the environment and human health. [29]

The temperature range of Na-Ni-Chloride batteries is very high reaching (+270 ÷ +350) °C. They are used mostly in series hybrid systems. To reduce thermal losses of batteries a double-walled thermos vacuum case is used to receive battery cells. To reach working temperature, the battery needs both heating and temperature control system, which imposes further difficulties and additional costs. [29]

Table 1

Data of Batteries [29]

Battery type	**Specific energy**		**Specific power**		**Lifespan**		**Price**
	(W*h) /kg	**(W*h) /l**	**W/kg**	**W/l**	**Cycle life**	**Year**	**EUR /(kW*h)**
Pb	30-50	70-120	150-400	350-1000	500-1000	3-5	100-150
Ni-Cd	40-60	80-130	80-175	180-350	>2000	3-10	225-350
Ni-metal hydride	60-80	150-200	200-300	400-500	500-1000	5-10	225-300
Na-Ni-Chloride	80-100	150-175	155	255	800-1000	5-10	225-300
Li-ion	90-120	160-200	~ 300	300	1000	5-10	275
Li-Po	150	220	~ 300	450	<1000	-	<225
Zn-air	100-230	120-250	~ 100	120	-	-	60

The Li-ion batteries are the most promising ones developing permanently. Many steps were made to reduce their high manufacturing cost. The Zinc-air batteries cannot be re-charged, thus after their use they should be replaced. [29] [30]

Aboard the modern hybrid and full electric vehicles, the status of the batteries is managed by the Battery Management System (BMS). Besides the standard problems handled and solved by BMSs, in the modern battery management systems several additional operations of the technical status diagnostics are handled. The BMS for batteries works like the OBD used aboard the gasoline-powered vehicles. [34-40]

It is evident that both overcharging and deep discharging regimes might lead to the deterioration of the technical status and parameters of the batteries. In case of overcharge, the battery can be overheated, threatening fires or explosions. Additionally, the deep discharges could lead to an internal physical damage of the battery.

3.3 Fuzzy Logic used in Battery Management Systems

Fuzzy logic is one of the most popular and widely used soft computing techniques, able to handle uncertain information and different anomalies. Fuzzy logic is widely used in mathematics, in informatics, in control engineering and also in language sciences. Its flexibility and ease of use, predestines this technique for use both in process and in system automation. [41]

In transportation engineering Fuzzy logic helps to enable maximizing vehicle radius [42], helps to optimize and manage braking process of the vehicle [43], helps to manage energy consumption of vehicles [44], and to assist vehicle drivers with different smart solutions like parking assist, lane keeping etc.

To represent results of the fuzzy logic sigmoid functions might be good solutions in analysis of manufacturing and service management systems. [45] It is proven that sigmoid functions can be used with support vector machine technique [46] or be implemented in neural networks. [47]

It may happen that in certain dynamic processes. we suffer from the lack of full system dynamic models or the of lack of a few parameters of the dynamic system. In this case, one can model system dynamics, with properly selected and parametrized sigmoid functions, often called logistic functions. [49-53]

In the 20th Century the logistic function was an important and widely used tool in modelling statistical econometry. In recent days, it is more of a deterministic basic function of the trend modelling.

In our experiments physical values measured increase in certain time domain to reach asymptotically their maximums when their increase tends to zero. The sigmoid function is a mathematical function that has an S-shaped curve.

The most common type of sigmoid function is the logistic function. The general form of the sigmoid function can be given as [49-53]

$$f(x) = \frac{1}{(1+e^{-x})} \tag{1}$$

where x is the input variable. [49-54]

References listed above have previously proven that fuzzy logic is a proper method and is widely used in technical system analysis. In this paper data analysis and data visualization were conducted using logistic function, which is a type of sigmoid function. Thus, the logistic function used further by the authors is as follows:

$$\mu_i(x) = \frac{1}{1+e^{a_i(b_i-x)}} \tag{2}$$

The fuzzy block parameters a_i and b_i were calculated using basic properties of the sigmoid functions, i.e.:

$$\left.\begin{aligned} \mu_i(x) = \frac{1}{1+e^{a_i(b_i-x)}} = 1 \\ \mu_i(x) = \frac{1}{1+e^{a_i(b_i-x)}} = 0 \end{aligned}\right\} \tag{3}$$

Parameters in equation (2) a_i and b_i are set to get the proper shape of the function. For proof of concept and to provide evidence of the efficiency of the bidirectional charge of batteries of electric vehicles, authors used data gained from an individual private house and a hybrid electric car, a BMW 225XE [48] that was involved in the experiments.

The main goal of the authors is to evaluate the idea whether the batteries of electric cars could be used as storages of electrical energy harvested from a solar panel electric system of the private real estate, supposing that energy stored into vehicle batteries are partly used to supply the house needs.

The Fuzzy logic is widely used in technical systems for different purposes. The article [55] deals with classification problems, analyzing decision making processes from their psychological aspects, based upon a case study.

Besides its technical aspects [56] applies Fuzzy logic in solution of economic problems. This article primarily uses the Delphi method and AHP furthermore. As a result of the defuzzification, the paper gives an optimized hierarchy of the financial needs of the start-up companies established.

Reference [57] uses two nonlinear approximations, namely the Extended Kalman Filter and the Takagi-Sugeno Fuzzy Observer with 32 rules. This approach was tested on a complex mechatronic system called aStrin Winding System.

The article [58] showed results in the field of multiplying power of the position control in electrical clutches. For setting up Fuzzy membership functions, the authors have used the Grey-Wolf Optimizer.

Reference [59] also introduced a new stability analysis method based on Takagi-Sugeno Logical Fuzzy Controllers. The system is designed using heuristic Fuzzy rules. In [60] a Fuzzy control system used in network control system is introduced.

Based on the reviewed literature, the fuzzy logic and Fuzzy controllers can manage the charge and the discharge processes not deteriorating the vehicle's technical parameters whilst leading to meaningful savings in use of electrical energy stored in car batteries.

Chapter 4 describes the bidirectional charging system. The solar panel system is the private property of one of the authors, and the vehicle electric system is developed by BMW GmBH.

The data gathered and used for scientific purposes are:

- The amount of electrical energy harvested monthly by the house solar panel system
- The amount of electrical energy used monthly by the hybrid car

4 On the Site V2H Bidirectional Charge Experiments

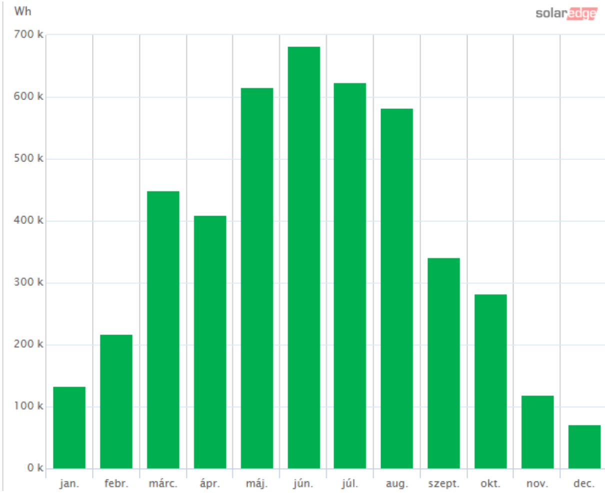
The roof solar panel system of an individual private house being investigated in V2H bidirectional charging of electric car batteries can be seen in Figure 2.

Solar panel system of the private real estate, Debrecen, Hungary

The SP system is designed to supply the house with electrical energy and to charge batteries of the owner's electric car. The amount of the electrical energy harvested by the SP system in 2022 is depicted in Figure 3.

Data related to the electrical energy of the SP system monthly harvested are depicted in Table 2.

The electric vehicle is a plug-in hybrid car BMW 225XE powered by a gasoline engine, and its data are tabulated in Table 3. [48]



Annual electrical energy harvested by SP system in 2022

Table 2
Monthly amount of energy harvested.

Month	Energy harvested (Wh)
2022.01	133135
2022.02	217031
2022.03	449153
2022.04	409428
2022.05	616519
2022.06	682849
2022.07	623372
2022.08	583178
2022.09	340549
2022.10	282424
2022.11	118482
2022.12	71418

Table 3
The hybrid car data [48]

Engine model	B38B15
Engine displacement	1499 cm^3
Number of cylinders	3
Engine power	136 Hp/220Nm

The car used in the experiment can move with electric thrust. The car's electrical system data are tabulated in Table 4. [48]

Table 4
Data of the electrical system of the hybrid car [48]

Gross battery capacity	7.6 kWh
Net (usable) battery capacity	6.1 kWh
Battery technology	Li-Ion
All Electric range	41 – 45 km
Performance	88 Hp/165 Nm

A private individual house and its electrical system was subjected for a one-year, on-site experiment. Data of the one year on-site measurement activity are tabulated in Table 5.

Table 5
Data of the on the site real measurements carried out

Month	**Total SP Energy Harvested (Wh)**	**SP2V charge (Wh)**	**Household energy consumption assumed (Wh)**	**Potential Electrical energy surplus (Wh)**
2022.01	133135	58000	10000	65135
2022.02	217031	86000	10000	121031
2022.03	449153	113000	10000	326153
2022.04	409428	59000	10000	340428
2022.05	616519	125000	10000	481519
2022.06	682849	83000	10000	589849
2022.07	623372	84000	10000	529372
2022.08	583178	134000	10000	394178
2022.09	340549	50000	10000	280549
2022.10	282424	91000	10000	181427
2022.11	118482	123000	10000	– 14518
2022.12	71418	87000	10000	– 25582

From Table 5 it is easy to conclude that the SP system harvests electrical energy with surpluses in the majority of the time, meanwhile, this excess of electrical energy reduces during autumn and winter period when solar radiation illuminating the SPs decreases as time progresses.

The energy with negative sign in Table 5 means that the owner had to purchase electrical energy from the electrical grid (Utility).

There is a rational question arising here: Whether the car's battery pack is able to cover extra needs of the house in electrical energy to obviate the need for purchasing of electrical energy from the grid, or not? Looking at Table 5 and the data tabulated inside, the answer shall be YES.

5 MATLAB Simulation of the Sigmoid Function

The most important data among which is given in Table 4 is the battery capacity. It is a well-known fact that the use of Li-Po batteries outside of the service range proposed by the manufacturer may lead to the overheating of the battery. The overheated status and the time spent in these circumstances may reduce the lifecycle of the battery.

In these experiments the main idea and the motive was to check whether any marginal parameters of the batteries such as their voltage levels proposed by the manufacturers could be changed while not threatening with fire or explosion.

This way, in SP2V more energy can be stored in batteries, and in case of V2H more energy can be transmitted to the householding, if energy harvested by SPS is not sufficient.

It is an interesting phenomenon that for the Li-Po batteries both the upper and lower voltage levels of the theoretical (that are proposed by the manufacturer) and the practical ranges may differ. These parameter differences might be traced back to the inaccuracies of the charger devices.

The second reason here is the experiences gained in the maintenance of batteries intentionally operated outside of the ranges proposed by the manufacturer.

Based on experiences gained from the use of different types of Li-Po batteries by many users it is possible to extend the ranges set prior the maintenance of batteries while not threatening neither safety nor security.

Taking for 100% of the car's gross battery capacity (see Table 4) it can be stated that even 104% of overcharge is allowed without any deterioration. Based on the battery data provided by the manufacturer, the battery has usable capacity of 6.1 KWh, which is approximately 80% of the maximum (7.6 kWh).

If one takes the usable capacity of the battery as 100%, the overcharge of 104% computes 6.344 kWh, which is 83.5% of the gross battery capacity. It means, that the proposed 'overcharge' will never exceed the capacity maximums provided by the manufacturer keeping all maintenance limitations.

Relying on these findings, the parameters of the sigmoid function defined by equation (2) has been selected as they are depicted in Table 6.

Table 6

Sigmoid function parameters

Parameter (*i*)	a_i	b_i
kWh	4.6051	101.9977

The sigmoid membership function can be seen in Figure 5.

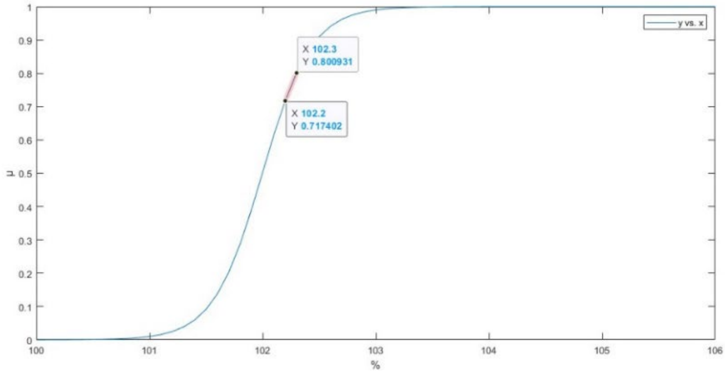


Figure 5
Sigmoid function

Using Figure 5 data were extracted for two pre-selected values of the membership function and were tabulated into Table 7.

Table 7
SoC of the batteries

kWh, [%]	
μ=0.717	μ=0.800
102.2%	102.3%

From measurement data depicted in Table 5 it is clear, that the last month of the year is the weakest in energy harvesting ability. From Figure 5 and from Table 7 it is easy to see that for given values of the membership function batteries are overcharged with no harms in any safety or security considerations. At μ=0.800 the SoC is 102.3%, which means usable capacity of 6.24 kWh.

This amount of the energy excesses covers 14 full charge cycles of the car batteries. For the year of the on the site test this energy surplus has meant 87.22 kWh, which means 7.27 kWh per month. This amount of energy covers some 25% of the energy needs of the tested private individual house, which is a considerable part of the total energy use.

5.1 Fuzzy Logic-based Solutions Applied Recent Days

Based on Fuzzy logic and Fuzzy controllers, there are several different solutions to handle and to optimize the V2G (Vehicle to Grid) or the V2H (Vehicle to Home) solutions.

Power Management Optimization

Using Fuzzy logic or Fuzzy controllers, intelligent V2G energy management systems can be designed and implemented. The Fuzzy logic can also be used in intelligent charging of the vehicle batteries meanwhile handling any problem of the electrical systems. [61]

The smart vehicle chargers can handle the periodic pricing of the electrical energy gained from the grid. Thus, leaning on these data, chargers can switch on or off the charging process in case of necessity.

During the charge or the discharge, the smart chargers can monitor the technical status of the batteries, can control the speed of the charge or the discharge, moreover, they can manipulate the electrical power of the solar panel system. [62]

Charging/Discharging Strategies

Using Fuzzy logic and selecting proper membership functions it is possible to optimize both the charge and the discharge process. This article has used this idea. [63] [64]

Uncertainty Handling

The Fuzzy logic can handle different the varying electrical loads of the batteries, and is able to make optimal decisions, given the uncertainty of the electrical power generated by the photo-voltaic solar panels. This way, the high calculation power and its low speed in monitoring systems, can be eliminated. [65] [66]

Conclusions

The authors have conducted an on-site, direct electrical measurement of a private household in 2022, in Hungary, to gather data on the electrical energy management of that house. For different reasons, it might happen that electrical energy harvested by SP systems should rather be used inside the isolated electrical system.

Using data gathered in 2022, it is evident that there were two months when the SP system was unable to harvest enough electrical energy to cover both the household needs and the electric car charging needs. Thus, in these months, the owner should purchase electrical energy from the grid.

Leaning on findings of the previous studies of the authors, in this paper, it was proven that an electric car battery can be 'overcharged' to a given percentage and not threaten the maintenance limits for the battery. This is due to difference between the gross battery capacity and the usable battery capacity, which is 80%.

In this study a BMW 225XE hybrid car was tested for electrical energy storage. Using a Fuzzy membership function, with sigmoid form, the authors proposed a safe level of 'overcharge' of 2.3%, leading to the novel idea of creating 'overcharge', used for storing electrical energy, when meaningful surplus of energy harvested from SPs is available, for further use, inside the isolated electrical system of a private house.

The importance of this idea is amplified when the SP system itself, is designed improperly, harvesting less energy than needed. Secondly, it may happen that due to a decrease of the solar irradiation, less energy is harvested than was calculated. Finally, due to the SP system ageing (degradation), it harvests less energy as time progresses, and the system will lose the ability to partially cover the energy needs of the residents of the individual household. In these cases, the batteries of the electric vehicle could serve as power-banks for use in the household energy demand.

In further research, the authors will focus on the design of more sophisticated on-site measurements, where more data can be gathered and registered, in order to get a more complex estimation concerning the isolated private household electrical system usage and requirements. Furthermore, special lab experiment is planned to discover the consequences of both “overcharges” and “deep discharges” on different battery sets. Consequently, new methods may be applied in the optimization of the charge and discharge processes.

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