DEVELOPMENT OF MODEL FOR INCREASING ELECTRIC VEHICLE CHARGING CAPACITY WITH LIMITED AVAILABLE GRID POWER

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Abstract. The article focuses on developing an operation model, how to decrease the necessary grid connection power for electric vehicle fast charging stations, based on the current electric vehicle (EV) charging tendencies in Latvia. In order to reach the goals of decreasing CO2 emissions in the transportation sector, Latvia has rolled out electric vehicle fast charging infrastructure on the main TEN-T roads. However, because this infrastructure will not be uniformly used all across Latvia, the maintenance and infrastructure costs are high. This article is examining a possibility of decreasing these costs by introduction of energy storage and renewable energy sources to lower the required grid connection power level. The specific task of the article was development of a model based on the charging data from EV charging sessions to reliably simulate possible charging scenarios as EV use will increase in the future. The model was then validated using Monte Carlo simulations and compared with the empirical results. The possibilities of grid connection power decrease were analysed. The results demonstrated that introduction of energy storage and photovoltaic energy would currently decrease the operational costs for 93 % of the EV charging stations in the Latvian fast charging network.

Keywords: electric vehicles, solar energy, EV charging infrastructure.

Introduction

In 2018 Latvia finished installation of the first phase of its electric vehicle fast charging network [1]. The establishment of fast charging network was determined in the Latvian electrical mobility plan as a mean to reach the goals of decreasing CO_2 emissions in the transportation sector [2]. The roll-out of fast charger infrastructure was seen as a prerequisite for successful introduction of electric vehicles in the country [2].

Latvia has rolled out electric vehicle fast charging infrastructure on the main TEN-T roads with the distance of 30 km between the charging stations, thus providing EV users with availability to travel all over the country without anxiety that their car will run out of energy.

Currently 50 kW fast charging stations require 3-phase 73 A connection [3]. There is no such standard connection available in Latvia, which has specified connection levels at: 16, 20, 25, 32, 40, 50, 63, 80 and 100 A [4]. Therefore, to provide the necessary current of 73 A, the charging station should be connected to 80 A grid connection [5]. In accordance with the energy rates in Latvia, the costs for energy distribution consist of fixed part payment for grid connection depending either on amps or kWh, depending on the type of the connection, and of the variable part depending on the chosen tariff plan. The example of costs for 80 A 3-phase connection to 0.4 kV line is shown in Table 1.

Table 1

Energy transmission and distribution costs for rapid charging station in Latvia

Amps	**Distribution costs [6]**		**Renewable energy tax [7]**	
	Fixed, $EUR \cdot A^{-1}$ per year	Variable, $EUR \cdot kWh^{-1}$	Fixed, $EUR \cdot A^{-1}$ per year	Variable, $EUR \cdot kWh^{-1}$
Tariff	14.20	0.04176	6.28	0.0268
Costs per 80 A	1136.00	x	502.4	x

This means that average energy costs in the Latvian fast charging network are extremely high, as the average monthly charging is low. Based on the information from the Latvian fast charging network first year of operation as presented in Fig.1, the transmission and distribution costs range from 359.5 to 0.0851 $EUR \cdot kWh^{-1}$ [8], depending on the station utilisation rate and subsequently the charge amount.

Only five charging stations in the network have the energy costs close to the costs of charging electric vehicle at home, which would be an acceptable level for users. The costs for all the other charging stations have to be subsidised by the government.

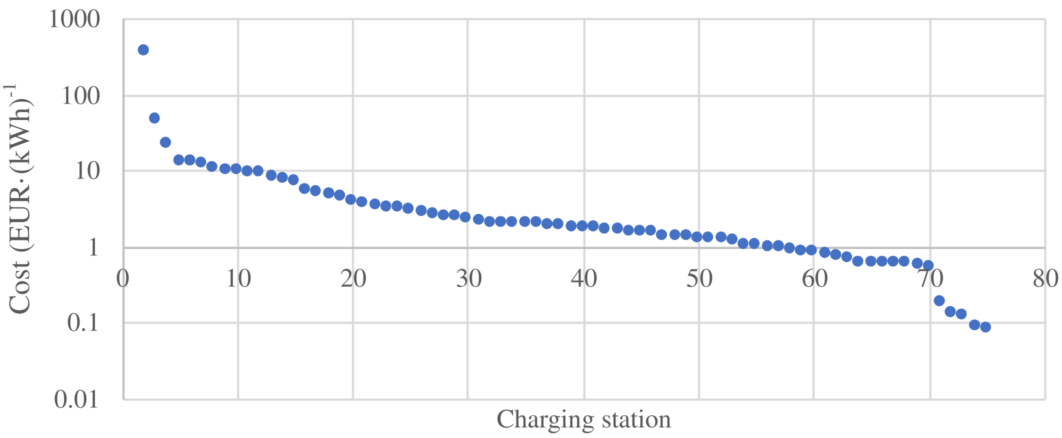

Fig. 1. **Average cost of transmission and distribution per kWh charged in Latvian national fast charging network**

Therefore, the aim of this research was to determine if it is possible to decrease the necessary grid connection power for the rarely used fast charging stations in order to decrease the operational costs and consequently decrease the need for subsidies for trans-Latvian electric vehicle fast charging network operation.

With the decrease in photovoltaic (PV) panel prices, PV energy as a viable renewable energy source has been suggested [9]. Because of the intermittent nature of PV energy, development of the energy storage equipment was following[10], but the research in this area was still scarce [11]. The use of such a system for decreasing the grid demand charges was suggested in [12] and later analysed in detail [13] including the investment costs, based on the situation in Canada. A heuristic storage system sizing was analysed in [14], however, it was for a different goal – to optimize the operation of 15 charging station pool. In [15] Monte Carlo simulation is used for realistic demand simulation for fast EV charging stations in Spain.

The scope of this article is limited to the energy costs and does not evaluate the capital expenses of the solar and energy storage system installations, nor operational costs for their support during lifetime.

Materials and methods

For the purposes of this model the input parameters of the model are divided in two parts, as presented in Table 2. The fixed parameters are the ones, which are not changed between simulations (e.g., we assume the battery charging curve to remain the same function, as long as we do not change the battery type), and the "variable" parameters are changed according to the modelled system configurations or changes in the environment.

Table 2

Fixed and variable factors in energy flow model

Electricity connection		Microgeneration		Energy Storage		Energy Consumption	
Fixed	**Variable**	**Fixed**	**Variable**	**Fixed**	**Variable**	**Fixed**	**Variable**
Voltage	Current, available options	Solar radiation schedule	Installed PV amount	Battery charging parameters	Installed storage amount	Charging schedules	Charger utilisation rate

Data from the JRC Photovoltaic geographical information system [16] for 11 years 2005-2016 about solar radiation and temperature were used to calculate the predicted amounts of energy. Monthly and hourly PV profiles described in [17] were used for solar energy production schedule simulation. The power generation scenario assumed generic microcrystalline solar cells with a 14 % efficiency.

In this article we have limited the maximum area for PV installation to that of three vehicle parking spots. This has been decided based on the real-life limitations in Latvia. The charging network is run by the governmental agency Road Traffic Safety Directorate, which, for the purposes of installing charging stations, has leased land for parking places from variety of land owners. Thus, the area available for PV installations is limited to the land area leased. Subsequently we have modelled three PV installation scenarios to cover the area of 1, 2 or 3 car parking spots. According to the data from Solisco it corresponds to 2.24 kW, 5.28 kW and 9.6 kW solar Mpp, respectively [18].

For the purposes of this simulation, generic Li-Ion battery charging parameters were used with charging / discharging capacity with 1C. Li-Ion battery chemistry was chosen to simplify the energy flow model in this paper, as it has sufficiently high charge acceptance. Lead-acid batteries are cheaper, and their cycle life is sufficient for the purpose of providing energy storage; however, their charging speed is inadequately low, and additional modelling would have to be carried out to find the sufficient size, which was beyond the scope of this article. The effects of battery chemistry will be analysed in forthcoming articles dealing with the installation costs and return on investment.

The amount of the installed battery capacity was varied from 0 to 24 kWh with 2 kWh increments. This would account for requirements of 95 % of all charging events – see Fig. 2. The average charge amount per session in 2018 in the Latvian fast charging network was 11.1 kWh, the median – 10.3 kWh and mode – 10 kWh (not counting 0 kWh, which represents errors starting the charging session and in 2018 accounted for 8 % of all charging sessions).

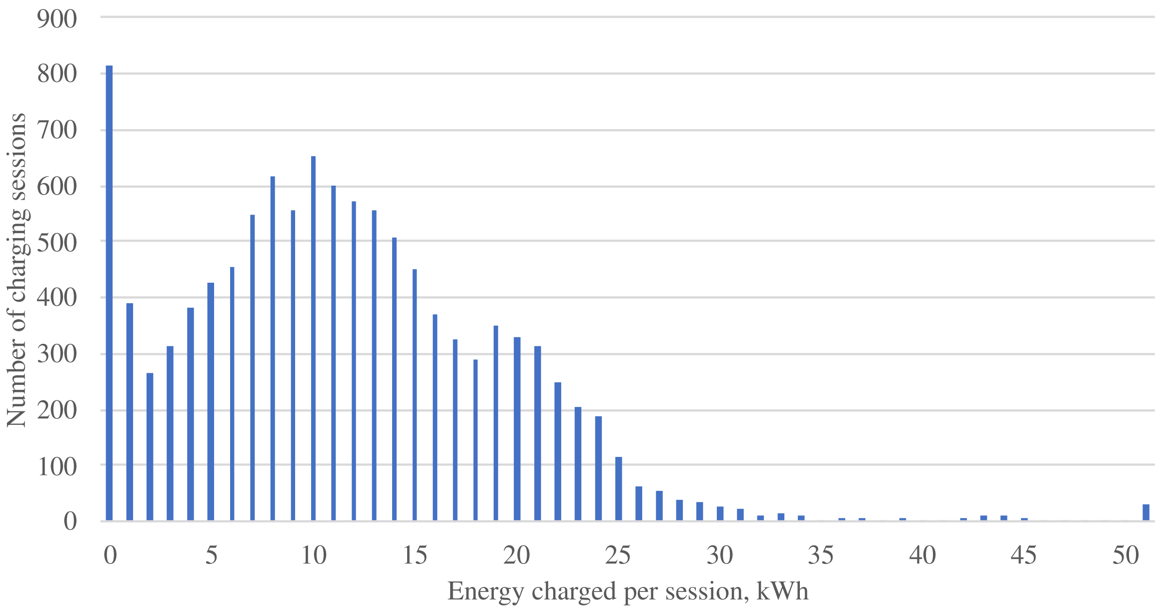

Fig. 2. **Energy charged per session in 2018 in Latvian national fast charging network**

An average hourly charging distribution was determined in [8] using the data from two most frequently used charging stations in Latvia. Average distribution of charging events is presented in Table 5, at the same time noting that no correlation was observed between the actual charging events or charged energy amounts in individual days.

This charging event distribution table was used as a basis for probability distribution to generate charging session schedules for a year using Monte Carlo simulation for various utilisation rates, based on actual charging station utilisation rates in Latvia, as described in [8] – 64 charging stations or 88 % of all were charging once a day or less.

The second step after the charging session schedule has been generated was to generate particular charging power for each session. The basis for the second stage power level generation was the charging power distribution table based on the empirical charge distribution data in the Latvian fast charger network Table 4.

To reach the goals set out in this task, the aim is to decrease the necessary grid connection amperage, therefore the algorithm is optimised to limit the incoming energy flow from the mains grid, with priority of providing energy security over the cost considerations.

A part of the general energy flow algorithm dealing with energy supply to the charger during the charging process is presented in Fig.4. The branch of the algorithm depends on the utilisation rate of the station and the installed capacity of the storage system. The locally generated PV energy is always used first, if available. For the energy requirements not covered by PV, the algorithm determines the optimum power source combination. As long as the installed storage amount is larger than the expected shortage of the main grid capacity, the priority is using energy from the battery, maximising locally produced energy. If the expected charging amount is larger than the storage amount, the priority is providing service quality and keeping battery reserves as high as possible.

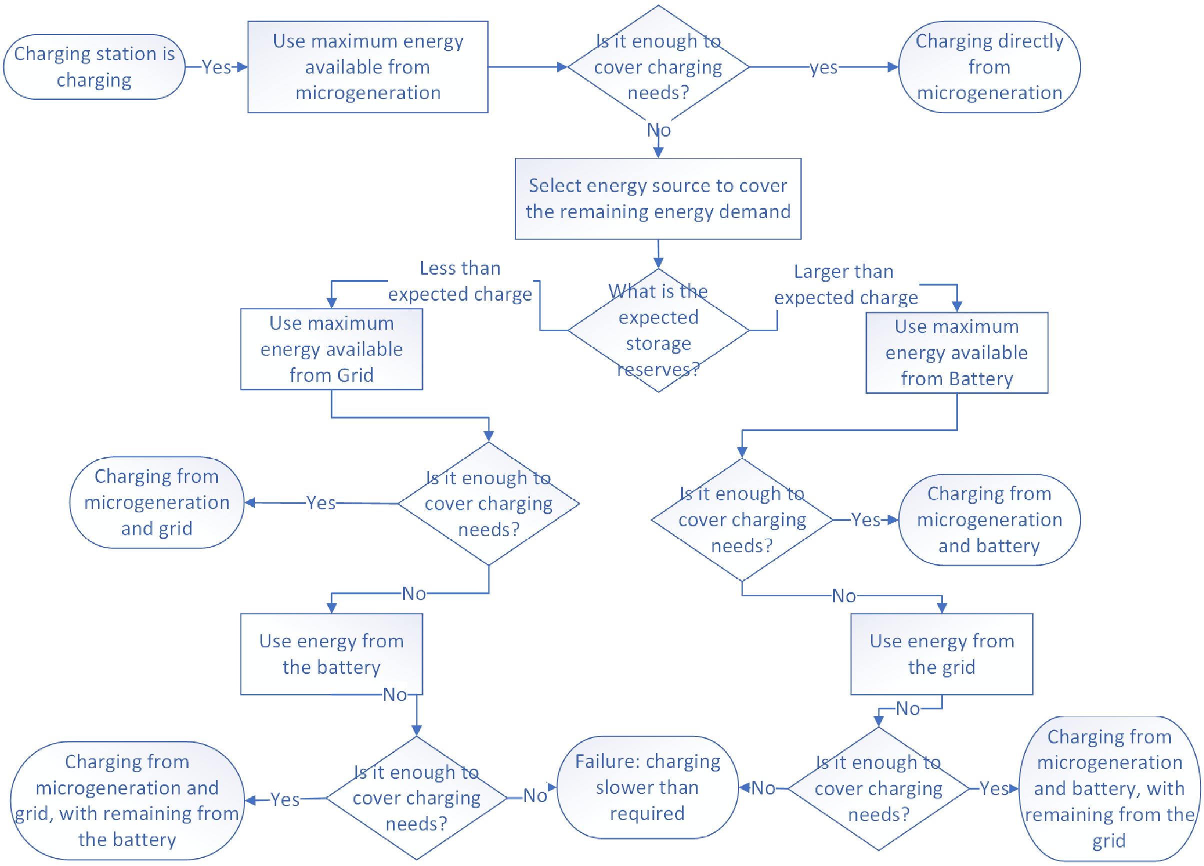

Fig. 3. **Energy flow algorithm during charging process**

For the time when charging station is not operating, the algorithm is simple – the first priority is charging up the energy storage system, then selling the rest of the energy produced from microgeneration into the grid.

Results and discussion

The model was validated in all stages of the data generation.

The results of the charging power distribution were validated first, and the results are presented in Table 3.

Table 3

Charging power distribution in Latvia by charging sessions

Charging power	**0-3 kW**	**3-6 kW**	**6-10 kW**	**10-22 kW**	**22-30 kW**	**30-43 kW**	**43-50 kW**	**More**
Empirical data	2.5%	1.8%	1.8%	12.0%	22.5%	51.1%	8.4%	0.0%
Generated data	2.0%	2.0%	2.0%	11.9%	23.3%	51.0%	7.7%	0.0%

Using both generated tables – the charging session table and session power table, the final energy consumption table was calculated, assuming that each charging session lasts 30 minutes, which is the charging session limit set by the Latvian fast charging network operator.

The results were compared to the initial charging energy distribution table to validate them, as presented in Table 4.

Table 4

Charging power distribution in Latvia by charging sessions

Hour	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00
Average empirical	4.9%	4.4%	4.3%	3.3%	2.6%	2.1%	2.4%	1.9%	2.1%	2.8%	4.6%	5.1%
Average generated	5.4%	4.7%	3.9%	3.3%	2.7%	1.9%	2.1%	1.6%	1.5%	2.6%	4.6%	5.6%
Hour	**12:00**	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**	**21:00**	**22:00**	**23:00**
Average empirical	4.8%	4.6%	4.7%	4.9%	5.1%	4.6%	4.5%	5.2%	5.9%	5.2%	5.3%	4.8%
Average generated	5.2%	4.4%	4.0%	4.9%	5.1%	4.5%	5.2%	5.3%	6.3%	5.1%	5.4%	4.8%

Anova analysis of final charging power distribution in real data and average generated data showed $p = 0.997$ with $F = 1.1*10^{-5}$ and $F_{crit} = 4.05$.

The scenarios for the charging schedule generations were created based on the real-life charging session distribution in Latvia, presented in Table 5.

Table 5

Charging station and scenario distribution in Latvia by charging sessions

Frequency of charging	Number of charging stations in Latvia in 2018	Frequency scenario applicable	Cumulative number of chargers scenario applies
Never	0	1	-
Once a month	5	1	7 %
Once a week	16	1	29 %
Twice a week	29	1	68 %
Once a day	14	1	88 %
Twice a day	4	2	93 %
Four times a day	2	5	96 %
Eight times a day	1	10	97 %
Ten times a day or more	2	10	100 %

As demonstrated, 93 % of all charging stations in Latvia are being used just twice a day or less. Thus, Monte Carlo simulations were run to see the effect of the installed energy storage system and solar panels.

The simulation results were analyzed depending on the possible outcomes:

- 0 – the total energy request was covered by the installed grid connection capacity. (In this case the locally generated energy from PV still would be used first, if available)
- 1 – the total request was larger than the installed grid connection capacity, but it was covered by the total available power from PV and grid.
- 2 – the total request was larger than the installed grid connection capacity and available PV energy, and the shortage was covered by the battery
- 3 – the energy was not sufficient to cover the energy requirements.

Examples of two simulation outcomes are demonstrated in Table 6, one being for 50 A grid connection with 9.6 kW Mpp PV panels, the other for 32 A grid connection with 2.24 kW Mpp PV panels. Each simulation used the same generated charging scenario, with 967 charging events (on average 2.64 events per day).

Outcome 3 is critical – it means that the energy was not sufficient to cover the requirements. In these examples at 50 A connection critical failures occur, if the battery is less than 10 kWh, while at 32 A and 2.24 kW PV microgeneration level there was 1 failure event already at 22 kWh and 20 kWh level. As it is about 0.1 % of all cases, the decision whether that is acceptable has to be a judgement call from the management depending on the charging network's policies.

Table 6

Examples of charging scenario simulation outcomes

Simulation outcome	**Grid Connection**							
	50 A, 9.6 kW PV				32 A + 2,24 kW PV			
Battery size, kWh	0	1	2	3	0	1	2	3
0	489	-	-	478	135	-	-	832
2	489	-	169	309	135	-	101	731
4	489	-	338	140	134	1	213	619
6	488	1	425	53	134	1	382	450
8	489	-	467	11	135	-	531	301
10	489	-	478	-	135	-	661	171
12	489	-	478	-	135	-	741	91
14	489	-	478	-	135	-	790	42
16	489	-	478	-	135	-	809	23
18	489	-	478	-	135	-	818	14
20	489	-	478	-	135	-	826	6
22	489	-	478	-	135	-	831	1
24	489	-	478	-	135	-	831	1

Table 7 demonstrates failure rates at 25 A, 32 A, 40 A and 50 A connections. The simulation at 63 A connection showed no critical failure rates.

Table 7

Examples of charging scenario simulation outcomes

Grid connection	**25A**			**32A**			**40A**			**50A**		
Battery Size, kWh \PV	2.24 kW	5.28kW	9.6kW	2.24kW	5.28kW	9.6kW	2.24 kW	5.28 kW	9.6 kW	2.24 kW	5.28 kW	9.6 kW
0	91%	91%	90%	86%	86%	86%	73%	73%	72%	50%	50%	49%
2	86%	86%	86%	76%	75%	75%	60%	60%	59%	33%	32%	32%
4	76%	75%	75%	64%	64%	63%	42%	42%	41%	15%	15%	14%
6	64%	64%	63%	47%	46%	46%	26%	25%	25%	6%	6%	5%
8	53%	53%	52%	31%	31%	29%	12%	12%	11%	1%	1%	1%
10	40%	39%	39%	18%	17%	17%	6%	5%	5%	-	-	-
12	23%	23%	22%	9%	9%	9%	1%	1%	1%	-	-	-
14	12%	12%	12%	4%	4%	4%	1%	1%	1%	-	-	-
16	7%	7%	7%	2%	2%	2%	0.2%	0.1%	0.1%	-	-	-
18	5%	5%	5%	1%	1%	1%	0.1%	0.1%	-	-	-	-
20	3%	3%	3%	1%	1%	0%	-	-	-	-	-	-
22	2%	2%	2%	0.1%	0.1%	0.1%	-	-	-	-	-	-
24	1%	1%	1%	0.1%	0.1%	0.1%	-	-	-	-	-	-

The results display that at these PV generation levels the battery storage amount is more important than PV generation. At 50 A grid connection level the system failed 50 % of time without battery storage, while adding 10 kWh storage eliminated failures completely. If the operator is prepared to accept 1 % failure rates, the grid connection can be decreased to 25 A. In practical terms it would mean that fast charging would take 1 hour instead of 30 minutes up to 10 times a year.

These results confirm the previous research – both [12] and [13] note that from the operational cost point of view adding PV and battery storage to the EV charging station greatly decreases the energy costs. Furthermore, the research confirms that PV decreases the overall electricity costs, while does not decrease the demand costs, while energy storage decreases the demand costs, marginally increasing the electricity costs. The research points out that because of the large initial investment overall feasibility of the investment would greatly depend on the particular location and electricity provider's pricing structure. Thus, [13] notes that currently in Canada PV and storage systems would not pay back within reasonable time, while in Spain they can improve the station's profitability [15].

These factors concerning the required capital investments and their payback shall be analysed in following articles to gain full perspective of feasibility of the PV and battery storage assisted EV charging stations in the Latvian national EV charging network.

Conclusions

The model based on the empirical data of the Latvian charging network proved that installing the energy storage system and renewable energy microgeneration source allows decreasing the grid connection power levels.

1. At the power levels consistent of the area of the car parking space, the battery storage amount affects the charging more than PV generation levels.
2. Adding 10 kWh energy storage it is possible to decrease the grid connection from 80 A to 50 A to provide faultless charging for 93 % of the Latvian charging stations.
3. Adding 24 kWh energy storage it is possible to decrease the grid connection from 80 A to 25 A with the failure level of 1 %.

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References

[1] CSDD Latvian electric vehicle fast charging network starts operating. 2019. [online] [27-01-2019] Available at: http://www.e-transports.org/index.php/jaunumi/205-darbu-uzsak-elektromobilu-atras-uzlades-staciju-tikls.

[2] Ministry of Transport of Republic of Latvia. Electric Mobility Development plan 2014-2016. Riga 2014.

[3] Efacec QC 45 quick charging station. 2015. [online] [29-05-2015] Available at: http://electricmobility.efacec.com/ev-qc45-quick-charger/.

[4] Sadales Tikli Tarrif calculator. 2019. [online] [24-01-2019] Available at: https://www.sadalestikls.lv/tarifi/tarifu-kalkulators/.

[5] Sadales Tikls Power load calculator. 2019. [online] [24-01-2019] Available at: https://www.sadalestikls.lv/en/customers/connections/new-connection-load-changes/power-load-calculator/.

[6] Sadales TiklsElectricity distribution differential tariffs., vol. 2016,. Riga, 2016.

[7] Pubic Utilities Commission of LatviaPar jaudas komponentēm no 2018.gada 1.jūlija (On power component)., no. 202. Latvia: Pubic Utilities Commission of Latvia, 2018, pp. 8-9.

[8] Rubenis A., Laizāns A., Zvirbule A. Latvian Electric Vehicle fast charging infrastructure: results of the first year of operation. Energy Procedia, 2019.

[9] Yee K. P., Ashique R. H., Salam Z., et al. Electric vehicles charging using photovoltaic: Status and technological review. Renewable and Sustainable Energy Reviews, vol. 54, 2015, pp. 34-47.

[10] Genovese A., Bertini I., Martirano L., et al. EV fast charging stations and energy storage technologies: A real implementation in the smart micro grid paradigm. Electric Power Systems Research, vol. 120, 2014, pp. 96-108.

[11] Aziz M., Oda T., Ito M. Battery-assisted charging system for simultaneous charging of electric vehicles. Energy, vol. 100, 2016, pp. 82-90.

[12] McPhail D. Evaluation of ground energy storage assisted electric vehicle DC fast charger for demand charge reduction and providing demand response. Renewable Energy, vol. 67, 2014, pp. 103-108.
[13] Yang L., Ribberink H. Investigation of the potential to improve DC fast charging station economics by integrating photovoltaic power generation and/or local battery energy storage system. Energy, vol. 167, 2019, pp. 246-259.
[14] Blasius E., Federau E., Janik P., et al. Heuristic Storage System Sizing for Optimal Operation of Electric Vehicles Powered by Photovoltaic Charging Station. International Journal of Photoenergy, vol. 2016, 2016, pp. 1-12.
[15] Domínguez-Navarro J. A., Dufo-López R., Yusta-Loyo J. M., et al. Design of an electric vehicle fast-charging station with integration of renewable energy and storage systems. International Journal of Electrical Power and Energy Systems, vol. 105, no. March 2018 2019, pp. 46–58.
[16] JRC European Comission Photovoltaic Geographical Information System (PVGIS). Joint Research Centre - Institute for Energy and Transport, 2014, p. 10.
[17] Rubenis A., Adrian L. R. Determining energy storage amount for development of novel microgrid energy flow optimization system with photovoltaic energy generation. Energy Procedia, vol. 147, 2018, pp. 428-437.
[18] Solisco Solisco EV-Ports. 2019. [online] [26-01-2019] Available at: https://solisco.co.uk/configure-stage-1/.