

hours distributed by two periods, from the 9:30 to 12:00 hours AM and from the 6:30 to 9:00 hours PM.

As it is possible to see in the figure, with the ESS, the power taken from the PG goes to zero and the energy stops to grow during the on-peak times. Also, it is possible to see that, at the end of the day, the amount of energy absorbed from the PG, with or without the ESS, is the same. In order to enable this scenario, it is necessary a storage capacity of about 1942 kWh. However, to avoid energy consumption during the on-peak times, it is necessary to absorb a constant power of 179 kW during the off-peak times, as it is possible to see in the figure. Although this value is slightly higher than the previous one, which implies higher installation costs, the energy costs can be significantly lower, making it a long-term best option.

5.3. Case Study C

As mentioned before, one of the advantages of the proposed FCS architecture is the possibility to easily interface renewables. Nowadays, solar PV panels are becoming the most promising renewable electricity generation source, growing 30% a year and being expectable to achieve the mark of 1270 GWp in 2022 [29]. As a consequence of strong investments in the PV technologies, the costs are lowering consistently, making the investment in this technology an economically profitable option. In the case of the FCS, the PV panels can be used to build roofs, which also protect users and EVs from the weather.

In order to analyze the possible benefits from the installation of PV panels, the case study C considers the integration of 100 kWp PV panels with the FCS. The data for the PV production used in this simulation scenario was achieved from the Photovoltaic Geographical Information System (PVGIS) for the Portuguese city of Guimarães, considering a PV panel optimum orientation. **Figure 16** presents the power and the energy produced by the PV panels, as well as the power and energy consumed by the FCS, with and without the ESS in the station. As it is possible to see, the PV power presents an evolution very similar to the power taken from the PG by the FCS without ESS. However, the maximum power is 5 times lower and with a misalignment of approximately one hour between the production and the most significant consumption. The total energy production of the PV installation during the day is almost 508 kWh and so, the total energy absorbed from the PG decreases in the same quantity. By controlling the bidirectional AC-DC converter to operate with constant power along the day, the maximum power taken from the PG with ESS and with PV panels is 120 kW and the minimum required storage capacity for the ESS is 1440 kWh. By comparing these values with the last ones, it is possible to reduce simultaneously the contracted power and the storage capacity, which is a very positive aspect. According to these results, the installation of a bigger PV installation can even allow a more significant reduction on the power and energy absorbed from the PG, as well as a

lower capacity of the ESS. However, it is necessary to guarantee available space for the PV panels, with proper orientation and avoiding shadows.

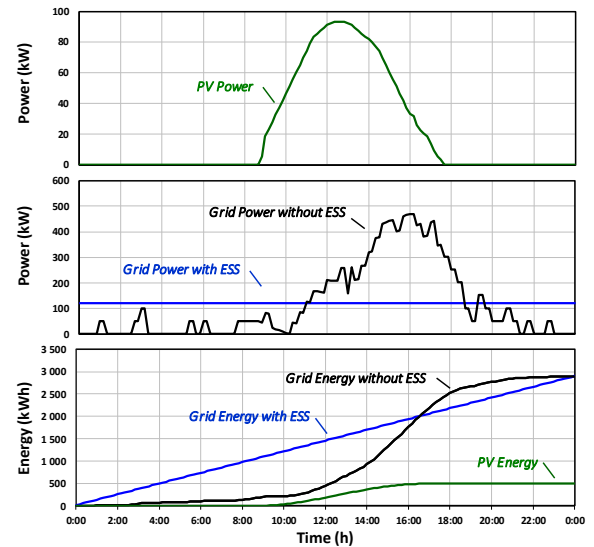


Figure 16. Simulated power and energy of the PV solar panels equipping the FCS, with and without the ESS, in case study C.

5.4. Case Study D

Finally, in the case study D, it was considered the integration of the 100 kWp PV solar panels and avoiding the energy consumption during the on-peak times. The results obtained in the simulation are presented in **Figure 17**.

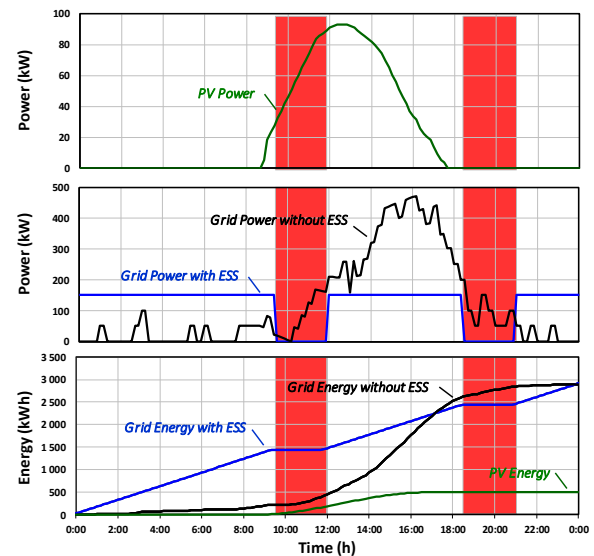


Figure 17. Simulated power and energy of the PV equipping the FCS, with and without the ESS, in case study D.

As it is possible to see in the figure, to avoid energy consumption during the on-peak times, it is necessary to absorb a constant power of 152 kW during the off-peak times and the storage capacity of the ESS increases to

1621 kWh. In order to counteract with the increase in costs with contracted power and with the storage capacity, this scenario allows a reduction of the energy costs, which can be advantageous in the long-term.

5.5. Final Remarks

According to the simulation results obtained for the four previous case studies, the operation parameters greatly influence the requirements of the FCS. In order to facilitate the understanding of the benefits resulting from each scenario, in Table 1 is presented a summary of the FCS main operation parameters for each case study. The table presents: The maximum power taken from the PG with and without ESS during the 24 h operation; The total energy consumed from the PG during the 24 h operations as well as the energy consumed during the 5 h on-peak time and the 19 h off-peak time with the ESS; The minimum ESS capacity for each scenario and the energy produced by the PV panels during the 24 h.

Table 1. FCS operation parameters.

Parameter	Case Study			
	A	B	C	D
PG maximum power (kW)	502	502	470	470
PG maximum power with ESS (kW)	142	179	120	152
24 h - PG total energy (kWh)	3400	3400	2892	2892
5 h - PG on-peak energy with ESS (kWh)	710	0	600	0
19 h - PG off-peak energy with ESS (kWh)	2690	3400	2292	2892
ESS minimum capacity (kWh)	1700	1942	1440	1621
24 h - PV energy (kWh)	0	0	508	508

As it is possible to see by the values in Table 1, the introduction of the ESS allows a huge reduction on the contracted power with the possibility of eliminating energy consumption at on-peak times. However, these objectives can only be achieved by using a very high capacity ESS. On the other hand, the introduction of PV panels contributes, simultaneously, to the reduction of the consumed energy and contracted power. With the integration of PV panels, the minimum capacity needed for the ESS is significantly reduced. It can be verified that, for scheduling the charging of the EVs considered in this study, there is a good correlation between the consumption and the energy production by the PV panels. In this way, increasing the PV panels installed power would significantly reduce the power and energy absorbed from the PG, as well as reduce the necessities of the ESS.

6. Conclusions

In this paper, a new concept of a DC Fast Charging Station (FCS) for Electric Vehicles (EVs) is presented. The main advantages of the proposed EV DC FCS architecture

are the energy storage capability and the easy integration of renewables. The Energy Storage System (ESS) in the proposed architecture can be mainly composed by batteries, reused from EVs. The proposed EV DC FCS is composed by a set of power converters: (1) One bidirectional AC-DC converter used to interface the DC-Bus of the charging station with the Power Grid (PG); (2) One bidirectional DC-DC converter for each one of the storage battery packs to exchange energy with the FCS DC-Bus; (3) Buck-type DC-DC converters, one for each fast charging post to perform the charge of the EV batteries; and (4) a simple DC-DC converter to the renewables with the FCS DC-Bus.

The proposed EV DC FCS architecture was defined taking into account the required power for each one of the converters. The proposed topologies and control algorithms of these power converters were validated through computer simulations, developed with the software PSIM.

In order to study the potentialities of the proposed EV DC FCS architecture, four different case study scenarios were analysed, and conclusions were obtained. The proposed architecture with the suggested ESS allows a significant reduction in the maximum power absorbed from the PG. The integration of photovoltaic (PV) panels allows reducing not only the power and energy consumed from the PG, but also the capacity of the ESS. The correlation between the power of the PV panels and the number of EVs in charge makes possible, by increasing the installed power, to use the sun as the main energy source of the EV DC FCS.

Acknowledgements.

This work has been supported by FCT – Fundação para a Ciência e Tecnologia within the Project Scope: UID/CEC/00319/2019. This work is financed by the ERDF – COMPETE 2020 Programme, and FCT within project SAICTPAC/0004/2015-POCI-01-0145-FEDER-016434 and FCT within project PTDC/EEI-EEE/28813/2017. Mr. Luis A. M. Barros is supported by the doctoral scholarship PD/BD/143006/2018 granted by the Portuguese FCT agency. Mr. Tiago Sousa is supported by the doctoral scholarship SFRH/BD/134353/2017 granted by the Portuguese FCT agency.

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