Solar Powered EV Smart Charging Station

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Abstract— **It is essential to facilitate integration of renewable energy sources (RES) in the rising demand of electric vehicle (EV) charging infrastructure to approach a completely carbon free future of E-mobility integration in the transportation sector. This paper explores the implementation of smart charging algorithms on a solar powered EV charging station and compares the effects on the power flow and revenue when a local storage solution such as the Tesla Powerwall is integrated into the EV charging infrastructure. Experimental results from the implemented charging algorithms using the Tesla Powerwall and the SolarEdge inverter set-up are presented.**

Keywords-component; formatting; style; styling; insert (key words)

I. INTRODUCTION

With the rise in popularity of EVs and increased awareness of RES, smart charging of EVs would be paramount to allow EV owners or EV charging facilities to effectively coordinate with available local RES generation, available charging time and to simultaneously maximize profits by considering the variation of grid prices. [1].

The three main fields of research that have been explored in this paper are:

- Grid tied PV charging systems
- Load demand of EVs in a work place environment
- Power management in RES integrated EV charging systems

In [2] the possibility in utilizing PV systems to charge EVs at a workplace environment is studied. It is concluded that Gaussian charging profiles are best suited as it nearly mimics the solar generation profile and that integrating local storage of even low capacities helps in palliating the variations in PV output. It was hence vital to explore the possibilities of such a local storage solution in this paper, for which the Tesla Powerwall is studied. [7] presents an overview on the design aspects of a PV charging station for electric bikes and scooters which were vital in this study to conceptualize the idea of a smart charging station for EVs. A thorough PV system design is explored with future recommended research on communication protocols for smart charging explorations and load profile study. [3] focuses on the charging methods of EVs by comparing fast charging and battery switching technologies. The unique position of this study is the usage of mobility survey results for the Netherlands [4] from which a model was created to map the different travel patterns of EVs. The various charging strategies are analysed in [5], factors such as static and dynamic electricity tariffs are considered.

II. E-HUB

The designed system is henceforth addressed as the E-Hub. The proposed E-Hub design is to facilitate charging for 10 EVs with the aid of

- Semi-quick AC chargers : 21 kW x 4
- Slow AC chargers : 7 kW x 6

The 6 slow chargers are intended to be utilized by employees over a work day of 8 hours, while the 4 semi-quick chargers present a charging solution for visitors in a shorter time frame. The studied energy requirement for the EV fleet is satisfied by a PV system of 19.5 kW peak power rating. The meteorological data for the PV system design is obtained from *Meteonorm* software for the chosen location at TU Delft campus.

A. EV energy demand

In this paper a mathematical model is constructed to determine the energy demand required for charging a fleet of 10 EVs. To approach a realistic scenario of a workplace environment, 7 employees and 3 visitor EVs are considered. The mathematical model considers the daily average round trip commute for employees and visitors from [4].

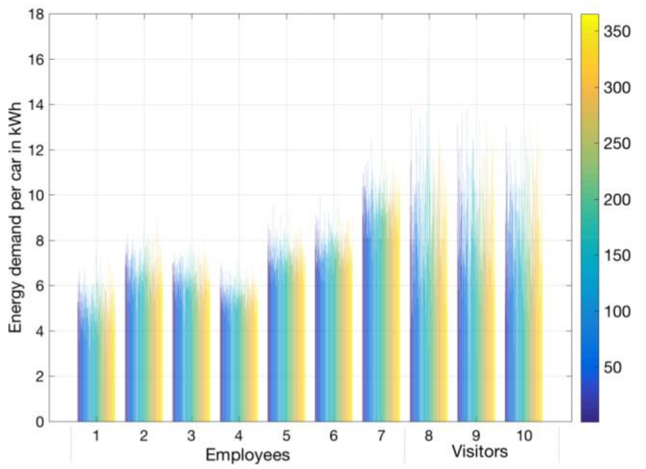

Figure 1 Energy demand of each EV in a year

This tool is of vital importance as it can be extended to effectively estimate the charging energy demand for other cases and can be efficiently used in scenarios where the presence of various variables makes the estimation of required charging energy demand arduous. A normal probability distribution function is used to calculate the cumulative driving pattern for all EVs in a year in km, which also considers miscellaneous driving situations like shopping, sports etc. The second parameter to be calculated is the cumulative driving efficiency for all EVs in a year in kWh/km. From the above parameters, the energy demand for charging is calculated in kWh. Taking into account the holidays in the year 2017, it was calculated that the average daily charging energy demand is 73.28 kWh and an annual estimated energy demand of 20.07 MWh.

B. PV potential

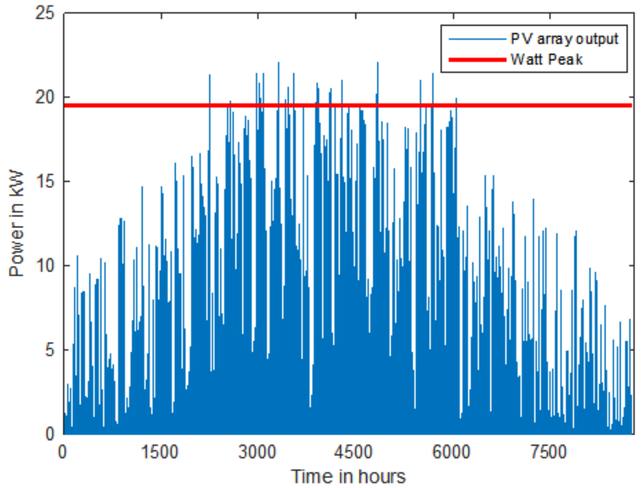

Figure 2 Annual variation of the designed PV array output power

For the chosen location calculations are carried out to consider the effects of weather, such as the effect of ambient temperature and wind speed on module performance. A thorough PV system is then designed. The PV system is designed with a tilt of 28° and an azimuth orientation facing south for yearly optimum PV module position for a grid tied system with battery backup [2][7]. The available energy for the chosen location in the year 2017 with the calculated tilt and orientation amounts to 1.193 MWh/m2. The yield per area for the Peimar 260P module of 260W rating amounts to 189.204 kWh/m2 [8].

III. System Design

The chosen 19.5kWp PV system is arranged in a layout of 25 modules in series with 3 parallel strings constituting a total of 75 PV modules. A pragmatic approach to choose the inverter is based on the PV power at STC. The central inverter is selected such that the nominal DC power of the inverter is upto 10% of the PV system power at STC [6]. The chosen inverter is 3phase, 20kW SMA Sunny Tripower. A EV charging pole with two chargers per pole is selected to facilitate both 7kW and 21kW charging. It is calculated that the ground area required for the PV system is 122 m2 and area for parking 10 EVs is 115.2 m2 [9], the PV system is hence physically feasible.

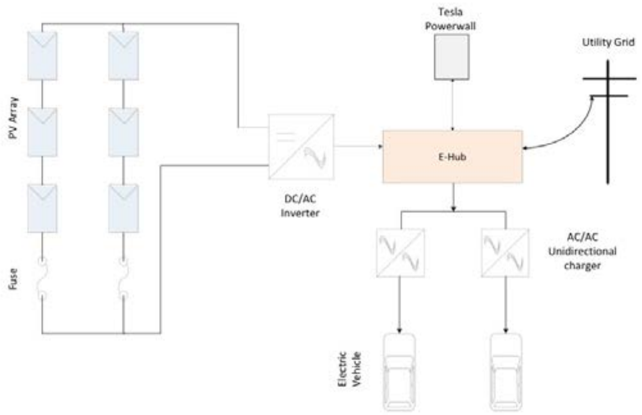

Figure 3 E-Hub system design

A thorough financial study is then performed the results of which are listed in Figure 4. The total investment costs for the E-Hub amounts to 50397.75 euros [10].

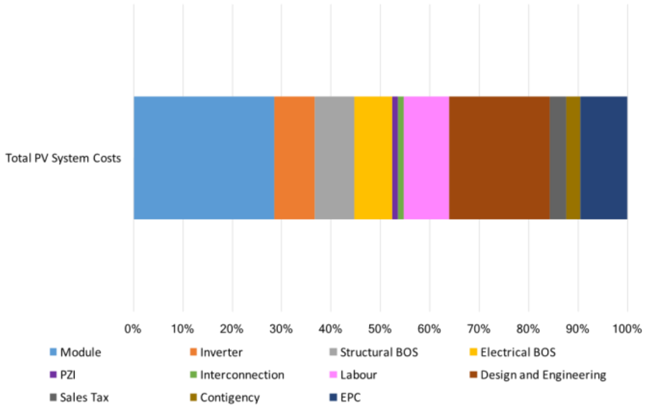

Figure 4 Cost breakdown of the designed PV System

IV. Smart Charging

Linear programming algorithm is used to realize the smart charging strategy. The various constraints that are applied to the model are:

- Cases with peak shaving
- EV charging and EV charger efficiency
- Capacity of the local storage
- Battery charging/discharging power limitation

The main governing equations for the optimization model are:

$$G_i = A_i - B_i - C_i \;\; \forall\, 1 < i < 24$$

where the exchange with the grid (import/export) in kW is depicted by G_i, the EV charging power in kW in A_i, the available PV output power in B_i, and the battery charging/discharging power in C_i. All the parameters are on an hourly basis depicted by 24 samples of i. The objective function (f) hence becomes

$$\sum_{i=1}^{24} \theta_i \times G_i = (f)$$

where θ_i is the local grid prices in €$/kWh$. The aim is to maximize profits by minimizing the value of (f). This results in 9 studied cases listed in Table 1. Each strategy is studied in detail to understand the power flow in the E-Hub, which leads to charter the hourly charging profile of each EV in the time-period of 09:00 to 17:00 on each working day of summer and winter.

A. Key results

The implementation of smart charging algorithms in summer makes the E-Hub grid independent even without the Powerwall. In winter with peak shaving and smart charging the peak grid import power is reduced by 88% which drastically helps in reducing demand charges levied on the charging infrastructure. It is also calculated that a fully charged battery at 09:00 on both summer and winter days help in maximizing the profit by combining smart charging algorithms with peak shaving.

Table 1 List of studied cases

Name	Charging strategy	Season	Peak Shaving	Battery
Case 1	Unregulated	Summer	No	No
Case 2	Regulated	Summer	No	No
Case 3	Unregulated	Winter	No	No
Case 4	Regulated	Winter	No	No
Case 5	Regulated	Winter	Yes	No
Case 6	Regulated	Summer	Yes	Yes
Case 7	Regulated	Summer	No	Yes
Case 8	Regulated	Winter	Yes	Yes
Case 9	Regulated	Winter	No	Yes

V. EXPERIMENTAL SETUP

An experimental test-set up was hence built to implement the designed smart charging algorithm. It was essential to explore the control of both the inverter and powerwall set-up to dynamically charge and discharge to deliver charge to the EVs. The schematic diagram of the test set-up is shown in Figure 6. The set-up was controlled through a cloud based monitoring portal to which pre-determined models were uploaded for cases of summer and winter and for other variations in grid prices. A set of 7 custom charge/discharge modes were identified and implemented in real time.

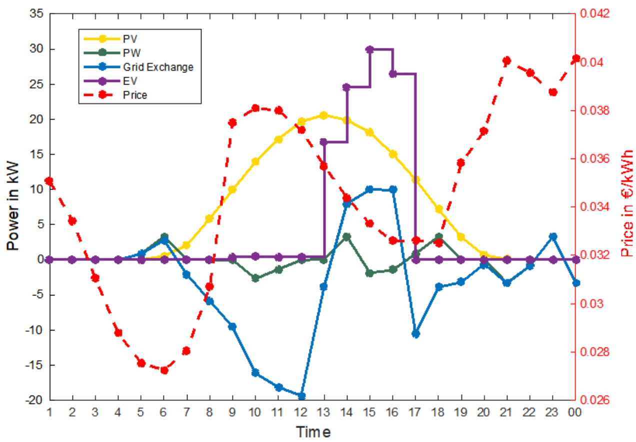

Figure 5 Power flow for Case 6

In Figure 5, the power flow in the E-Hub for case 6 is shown. It can be noticed that when the electricity prices are high the available PV power is fed to the grid to gain revenue and the peak is shifted to off-peak hours where EVs are charged with maximum grid import limited to 10kW to prevent excess demand charges. It is also interesting to observe that the Tesla Powerwall is charged and discharged with respect to grid prices for providing the most cost effective charging scenario.

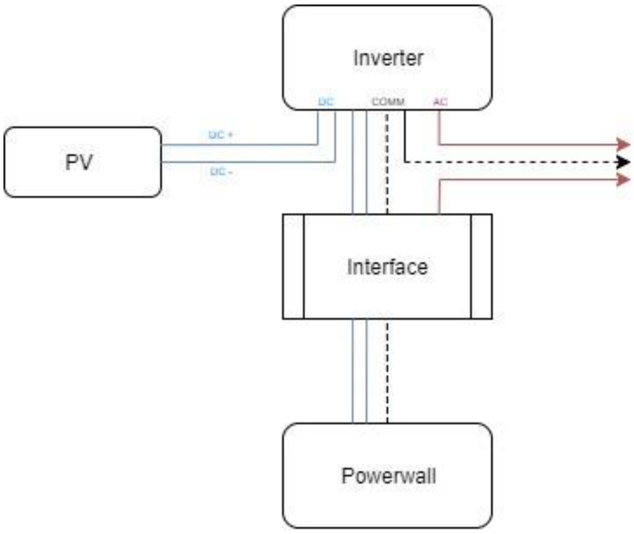

Figure 6 Test layout

The charge/discharge profile along with the corresponding state of charge of the Tesla Powerwall during the experimental validation in the Electrical sustainable power lab at TU Delft is shown in Figure 7.

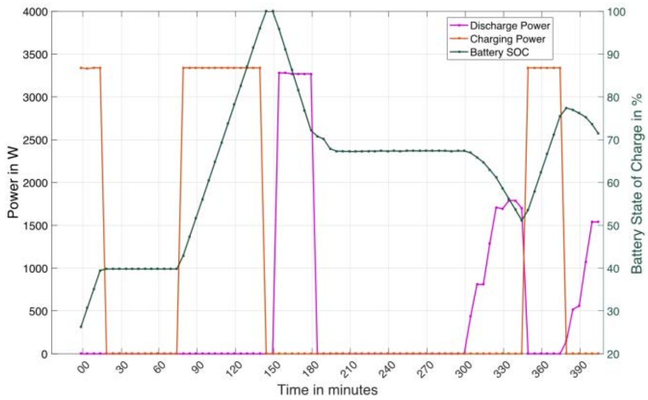

Figure 7 Charge/discharge profile of the powerwall during experimental validation

VI. CONCLUSIONS

In this paper the procedure to design and implement smart charging algorithms is analyzed in detail. A mathematical model is constructed to effectively estimate the energy demand required for EV charging and can be extended to other workplace scenarios and is extremely useful as it eliminates variables such as varying battery sizes and charging time. A thorough grid tied PV system is then designed with the studied load profiles which further offers flexibility in terms of local power generation. The idea of integration of local storage is then explored with the Tesla Powerwall. The inclusion of the powerwall helps in drastically reducing peak demand charges and helps in increasing revenue which is of significance especially in winter season. The designed smart charging algorithms are implemented in the experimental set-up with the identified charge/discharge modes. The set-up is effectively controlled to user defined functions which offers an adaptable smart charging infrastructure for custom demands.

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