# A Cost-Effective EV Charging Method Designed For Residential Homes with Renewable Energy

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***Abstract*—This paper presents a smart and cost effective EV (Electric Vehicle) charging methodology for residential dwellings which have renewable energy sources. The proposed method has many benefits, including reducing peak pressure on the grid, delivering cost savings to the consumer, as well as reducing battery degradation and preventing overcharge, increasing battery lifetime. The performance of the algorithm is verified by conducting simulation studies against running data of a Nissan Altra, which demonstrate that the charging time can be effectively shifted from peak time to off-peak time. The cost savings delivered by the algorithm are compared against data collected in the Beijing electricity market.**

***Keywords*—Electric Vehicles (EVs), EV Charging, Photovoltaic (PV)**

## I. Introduction

In recent years, there has been significant interest in charging electric vehicles (EVs) using 'excess' grid capacity available outside of peak demand times. Much of the existing literature focuses on charging groups of vehicles in situations such as parking garages where EVs could be expected to remain idle for long periods [1] [2]. Time-shifting charging in this manner has the dual benefit of reducing the charging cost to consumers and flattening overall load demand, which can in turn offset peak demand, however the majority of current studies do not look at how this can be done in a residential context. This study examines EV charging capabilities within a residential dwelling that has access to renewable energy sources such as Photovoltaic Panels (PV), in order to deliver these benefits directly to domestic users. In practise, such users are not well equipped to manually select the optimal off-peak charging period. Additionally, the risk of overcharging is present when charging is unsupervised for long periods of time. To mitigate these issues, an algorithm is proposed that automatically delivers optimal charging energy from both the main electrical grid and smart grid. The algorithm automatically optimized for price over the charge time based on known time-of-day electricity prices, as well as the availability of charge on an attached PV cell, all while minimizing cost to the consumer.

## II. Development of the Proposed Algorithm

An overview of the technique is explained in this section. The charging schedule can be selected by a programmable controller embedded in a household with a renewable energy source. This controller charges an electric vehicle from the grid, PV, or both according to the following criteria

### A. End Users Preference

To increase flexibility, the end user is allowed to supervise when and how much to charge their vehicle. The state of charge (SOC) is used to determine when to stop charging, thereby avoiding excessive charging or discharging phenomena. The state of charge is given by

$$SOC = SOC(0) + \frac{\delta_c}{C_N}\int_0^T i_t d_t \tag{1}$$

### B. Output and Consumption Measurement

PV output and appliance consumption measurements are performed using a smart meter, such as the Huayi DDSF3 [3]. Historical power consumption for the user can be loaded to select the correct load curve.

### C. Electric Vehicle charging

One objective of the proposed algorithm is to minimize the charging expenditure. When a certain quantity of electricity is taken from the grid or PV $Q(t)$ at time $t$ at a price of $P(t)$, the corresponding price of electricity at time $t$, the total price of charging an EV can be expressed as

$$C = \int_{t_0}^{t_0+T} Q(t)P(t)dt \tag{2}$$

where $t_0$ is the start charging time and $C$ is the total electricity price over the charging time $T$.

Figure 1 depicts the flow chart of the proposed algorithm. Depending on the selected charging parameters, the system will automatically select the best charging source for each charging interval, based on the energy available from each source (determined by a smart meter), and load curves derived from historical data or known demand curves.

## III. Simulation Results

Charging results for the proposed method both with and without PV are compared against un-optimized charging. All figures are produced with an initial SOC of 20% and a final SOC of 90% for each simulation. The charging time is chosen randomly ranging from 00:00 till 24:00 with different departure times and charge durations. All combinations of charging time and SOC are simulated, producing the price surfaces shown in figures 2 and 3.

Figure 2 shows the difference of un-optimized and optimized price with PV. When there is no electricity generated

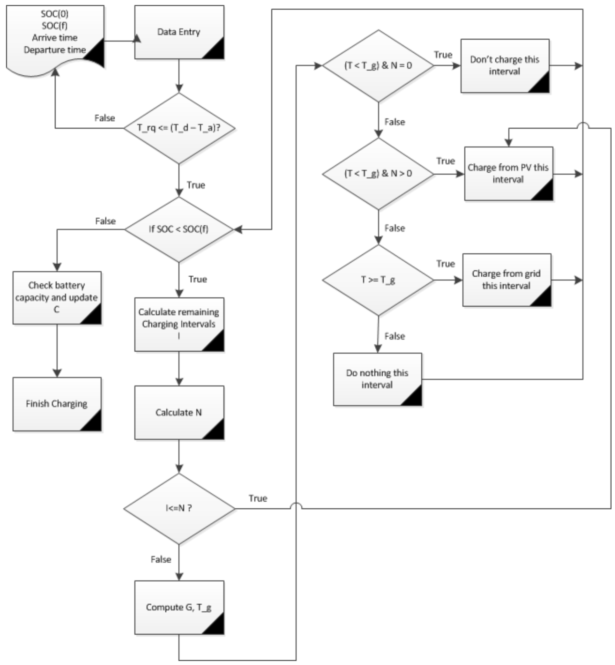


Fig. 1. Flow chart of this optimized charging algorithm

TABLE I. LIST OF PARAMETERS IN SIMULATION

| | |
|---|---|
| $SOC(0)$ | Initial State of Charge |
| $SOC(f)$ | Final State of Charge |
| $C_N$ | Rated Capacity |
| $i_t$ | battery current |
| $d_c$ | Current loss coefficient |
| $t_r$ | Removal Time |
| $t_p$ | Plug-in Time |
| $t_{rq}$ | Required Charge Time |
| $t_p$ | Proper Time Units |
| $I$ | Remaining Charge Intervals |
| $M$ | Remaining Energy of PV Storage System |
| $N$ | Remaining energy charging interval from PV |
| $G$ | Remaining charging interval from grid |
| $T_g$ | Minimum start charging time from grid |

by PV or there is a large amount of domestic consumption the electricity is taken from the grid. While the cost is higher without the additional electricity provided by the PV cell, the value of any optimized price is lower overall than the cost of charging without the optimized algorithm shown in Figure 3. This demonstrates the proposed smart charging method has the ability to shift the charging time from peak time to off peak time. In markets where there is a large price differential between peak and off-peak time, the algorithm can deliver significant savings to the end user. To demonstrate this, the optimized method is compared against the algorithm in [4] which is designed for a similar purpose. Both simulations are conducted without considering any PV input. The data is taken from [4], and is sourced from electricity prices in the Beijing market. The percentage saving in [4] for charging a single EV is given as 51.52%. The algorithm proposed here generates a maximum percentage saving of 73.25%, with an average saving over all random scenarios of 22.09%.

## IV. Conclusion

In this paper, an EV charging method for a smart residential dwelling which has a renewable energy system such as PV is proposed. Since the charging condition of each EV is different there is a diverse range of parameters affecting the charging cost including battery specification, input time, departure time and initial and final states of charge. However under any situation the algorithm has the capacity to select the best schedule prior to the departure time and PV output. It can be concluded from the simulation results that the proposed charging method takes full advantage of renewable energy, and can transfer electrical demand from peak time to off-peak time, thereby minimizing the charging cost.

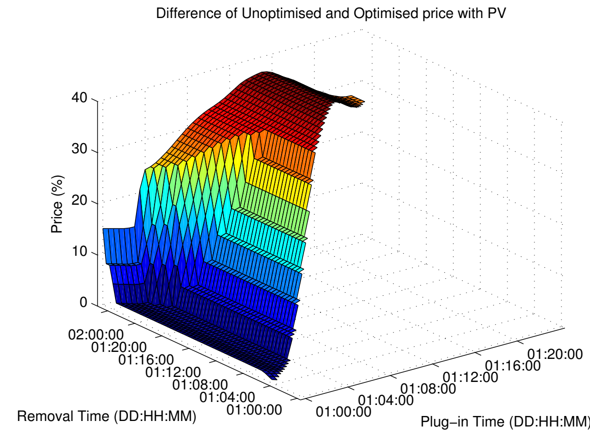


Fig. 2. Difference of un-optimized and optimized price with PV

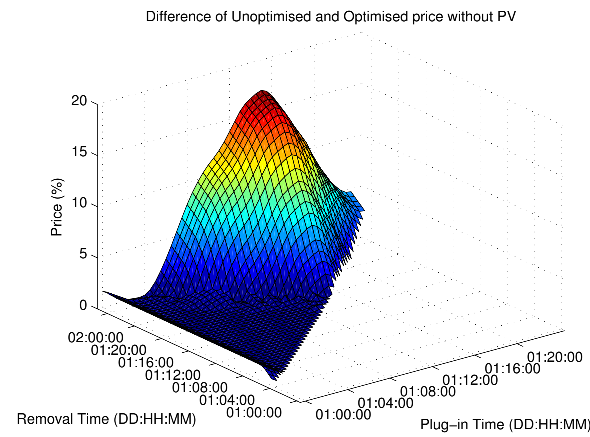


Fig. 3. Difference of un-optimized and optimized price without PV

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