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Smart charging of electric vehicles with photovoltaic power and vehicle-to-grid technology in a micro grid

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Abstract

The proposing a model that was created to investigate how smart charging of electric cars (EVs) and vehicle-to-grid (V2G) technologies may boost self-consumption of photovoltaic (PV) electricity. Previous research have mostly used big EV fleets in their models, but we are interested on a smaller scale. The methodology is applied to a microgrid in Lombok, a residential neighbourhood in the Dutch city of Utrecht. A 31 kWp PV system, an office, internet servers, three houses, and two electric vehicles make up the microgrid. Three control techniques are provided for managing the charging profiles of several EVs in real-time or utilising linear optimization with PV power and energy demand estimates. We run one-year simulations using data on solar power, electric vehicle usage, and energy consumption. The outcomes of the simulations are compared in terms of PV self-consumption and peak demand reduction. In addition, using a variety of metrics, we provide qualitative conclusions about battery degeneration caused by charging procedures. We also model changes in microgrid composition, such as adding more electric vehicles. Self-consumption rises from 49 percent to 62–87 percent in the models, whereas demand peaks fall by 27–67 percent. These findings clearly highlight the advantages of charging electric vehicles using solar energy. Furthermore, our findings provide light on the impact of various charging methodologies and microgrid configurations.

Introduction

Not only does the shift to low-carbon energy and transportation systems need widespread adoption of clean technology and efficiency measures, but it also necessitates innovative energy management methods to effectively integrate these advances into existing infrastructure. Issues with grid integration of clean technologies may arise on both the energy supply and demand sides, with technologies such as photovoltaics (PV) and electric cars, respectively (EV). Sophisticated energy management may assist in resolving these challenges and optimising resource allocation, such as charging electric vehicles using solar power rather than electricity from coal or gas-fired power plants. There is an imbalance between PV power supply and energy consumption in the residential sector. PV panels provide the greatest power throughout the day [1,2], whereas home electricity consumption peaks in the morning and evening. In addition, typical EV charging patterns contribute to current residential power consumption peaks1. Increased PV and EV adoption will increase power transit across the electrical system, necessitating infrastructure expenditures to avoid overloads [3,4]. Several European nations have begun to introduce laws to encourage the self-consumption of locally produced energy [5]. To guarantee grid stability and functionality, self-consumption of PV electricity should rise. A smart grid combines information and communication technology with a regular power grid or microgrid (i.e. a local, low-voltage distribution system) [6]. Load shifting is a key feature of smart grids, and it may be used to boost PV power self-consumption [7] and EV charging off-peak [8]. Vehicle-to-grid (V2G) technology allows EVs to be utilised as both a variable demand source and a storage option in smart grids, which is a significant benefit [9–13]. We utilise a case study to describe and simulate the implementation of smart charging algorithms for electric vehicles in this work. The majority of simulation research on employing EVs for PV grid integration utilise a high degree of EV aggregation in their models. Two studies, for example, have been discovered that investigate the use of parking lots to merge EV and PV. Tulpule et al. [14] conducted a research for a parking lot at a company in Columbus, OH, and Los Angeles, CA, and found that such a system is feasible in terms of costs and

CO_2 emissions when compared to home charging. Birnie [15] utilised a simple technique to discover that solar power could provide most driving demands in the summer but not in the winter at a parking lot in New Jersey, NJ, USA. Other studies look at electric vehicle fleets at the local or regional level. For example, Zhang et al. [16] demonstrate that combining one million electric vehicles with one million heat pumps may minimise extra PV power by 3 TW h in the Kansai Area of Japan. Drude et al. [17] investigate PV and V2G techniques in Brazilian cities. They come to the conclusion that EVs can help to stabilise the grid, but that sufficient energy rules are required to prevent destabilisation caused by too many vehicles giving storage for V2G. Tuffner et al. [18] modelled a distribution system (IEEE 123-node) for meteorological conditions in Phoenix, Arizona, USA. They conclude that for EV and PV to have a substantial influence on the network, penetration rates must be high (>50%), but that the synergy of these technologies provides large advantages for this high penetration rates. EV batteries, according to Guille and Gross [19], are too tiny to have a substantial influence on the system on their own. However, large-scale V2G implementation confronts several socio-technical challenges [20]. Our research intends to demonstrate the advantages of utilising electric vehicles and smart grid technologies in a microgrid, since such a small-scale project is feasible in the near future. These creative pilot initiatives are critical for realising the transformation of socio-technical systems like the energy system because they enable small-scale testing with alternatives to the present system [21–23]. In addition, researching this project enables us to integrate precise real-world factual data on PV power supply, load demand, and EV use. This research adds to the current literature by examining alternatives to large-scale deployment of electric vehicles (EVs) for PV grid integration. LomboXnet2, a firm that provides internet access to roughly 2500 individuals in Lombok, a neighbourhood in Utrecht, the Netherlands, is our case study. LomboXnet aspires to operate its operations on locally generated solar energy and now delivers PV electricity to three homes in the area. The firm has two battery electric vehicles (BEVs) that are utilised for car sharing. Car sharing is growing in popularity across the globe [24], including in the Netherlands3, and it has a lot of promise for reducing the environmental effect of personal transportation [25–27]. The EVs are routinely stationed at the charging station when utilised for vehicle sharing, making them appropriate for grid balancing. In contrast to other sorts of EV usage, like as commuting, this is a significant difference. LomboXnet is a good case study for examining the integration of clean technologies because to its mix of PV, EV, smart grid, and vehicle sharing. For LomboXnet, our study goal is to investigate the possibility for enhancing PV self-consumption with smart charging of EVs. Three alternative charging algorithms are simulated. The first method makes use of real-time data, the second makes use of real-time data and V2G, and the third is an optimisation technique that makes use of PV power supply and load demand projections as well as V2G.

Methodology

The microgrid receives power from the PV systems. In all, 31 kWp has been built, with a solar energy production of roughly 25 MWh per year and a performance ratio (PR) of 74% as of 2013. The PR is a measure of a PV system's total losses and is defined as the ratio of the PV system's final energy output in kW h/kWp to a reference yield that solely considers solar irradiation [2]. The average PR in the Netherlands is 78 percent [28].

The partial shade of some solar panels throughout the day explains the LomboXnet PV system's below-average performance. The PV power output is measured directly at the solar inverter and is accessible with a one-hour resolution.

LomboXnet measures the load requirement of the office and internet servers on an hourly basis. In 2012, the annual demand was 27 MWh. The bulk of this demand (19 MW h) comes from internet servers, which require roughly 2.2 kW on a continuous basis.

We use an estimate for the demand since there are no measurements available for the homes. Claessen [29] offered a data collection with 400 distinct home profiles, which was used to predict demand profiles. The data collection is based on observations from Liander, the Netherlands' biggest utility provider. We chose 153 families with an annual average power use of less than 30 percent of 3680 kW h, which is indicative of the dwellings in the microgrid. This figure is greater than the 3480 kW h annual average in the Netherlands [30].

A 24-hour load profile is shown in Fig. 2. The peaks at various periods generated by the various loads are plainly seen in the graph.

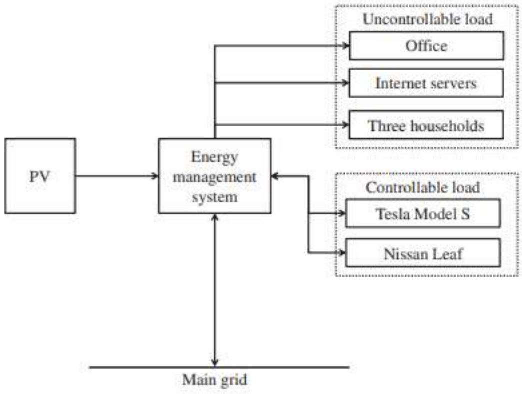

Figure: 1 block diagram

LomboXnet examines a number of microgrid expansions, which we also model. Extra solar panels (3 kWp), two additional houses, and three additional electric vehicles are all possible additions in the near future. The additional EVs are all Nissan Leafs, with one being utilised in the same way as the other Nissan Leaf and two being used for commuting. The latter EVs go every daily between 8:00 and 19:00, covering a distance of 60–90 kilometres in 6–10 hours.

We also perform simulations for various microgrid composition adjustments. We change the EV model, the typical home power use, and the amount of trips the EVs take every week. We show our three simulated control techniques in this section. One is based on linear programming, while the other two are based on real-time (RT) with and without the V2G option (LP). All algorithms are based on a centralised approach: the energy management system, not the individual EVs, determines EV charging patterns. These three charging schemes are used to compare the performance of the system using RT vs planned tactics, as well as the impact of employing V2G. The algorithms determine the charging patterns of electric vehicles, which are used as a flexible demand source and, in the case of V2G, as a power storage device. The purpose of implementing such a system for LomboXnet is to boost PV power consumption inside the microgrid. Other elements that could be of relevance in addition to PV self-consumption, such as energy price and power quality, are not included in our algorithms. The algorithms, on the other hand, are simple to develop and appropriate for our purpose: illustrating the possible function of electric vehicles in this microgrid.

Unless there is more demand than PV power to complete a trip, the EVs exclusively utilise PV electricity to charge the batteries using our first RT algorithm, RT Control. V2G is not accessible in this algorithm.

V2G technology has both technical and societal hurdles [20], thus it's worth looking at techniques that don't rely on it. The V2G option is offered in our second RT algorithm, RT Control + V2G. When there isn't enough PV power for the uncontrolled demand, the EV charges with solar power as much as possible and discharges energy.

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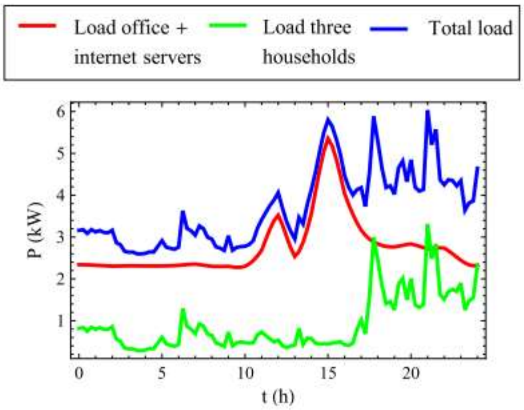
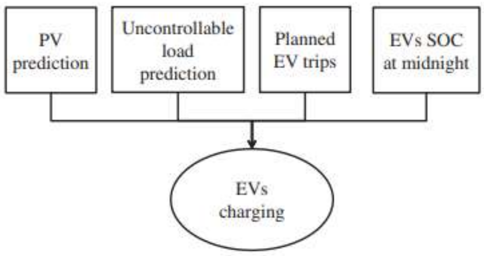
Results and discussion

For each time step t, the RT algorithms utilise the difference between PV power supply and load demand. The charging pattern is then determined, taking into consideration the EV's energy content. If there is more PV power than energy demand, the EV begins charging using the surplus PV power until the battery is fully charged or there is no more excess PV power available. When there isn't enough PV electricity to make a journey, the EV draws energy from the grid. If PV electricity is inadequate to meet load demand, energy may be taken from the electric vehicle.





Number of cycles, operating temperature, charge and discharge rates, depth of discharge (DOD), state of charge (SOC), and total energy extracted are all factors that affect battery longevity [36]. Cycle-lifetime is a term used to describe how long a battery lasts. Manufacturers often offer cycle-lifetime statistics as a function of DOD for a battery depleted from a 100% SOC. Because the charging pattern of the EVs in the simulations comprises for the most part of many, smaller cycles that do not start at a SOC of 100 percent, this data is unsuitable for our needs. To evaluate the influence of V2G on battery longevity, many models have been developed [36–38]. There are also various EV battery deterioration models that take into consideration shorter battery cycles [39–42].

However, since the main output of our model is the charging pattern of the EVs, using these models to our simulations would need making several assumptions about aspects such as operating temperature and voltage. The presentation of a comprehensive battery model is beyond the scope of this work. However, three indications are used to show the influence of the control algorithms on battery lifetime: energy throughput, rate of charge and discharge, and state of charge. Because the output of our simulations only include information on the charging patterns while the EVs are at the charging station, we ignore battery deterioration owing to the EVs' driving cycles.

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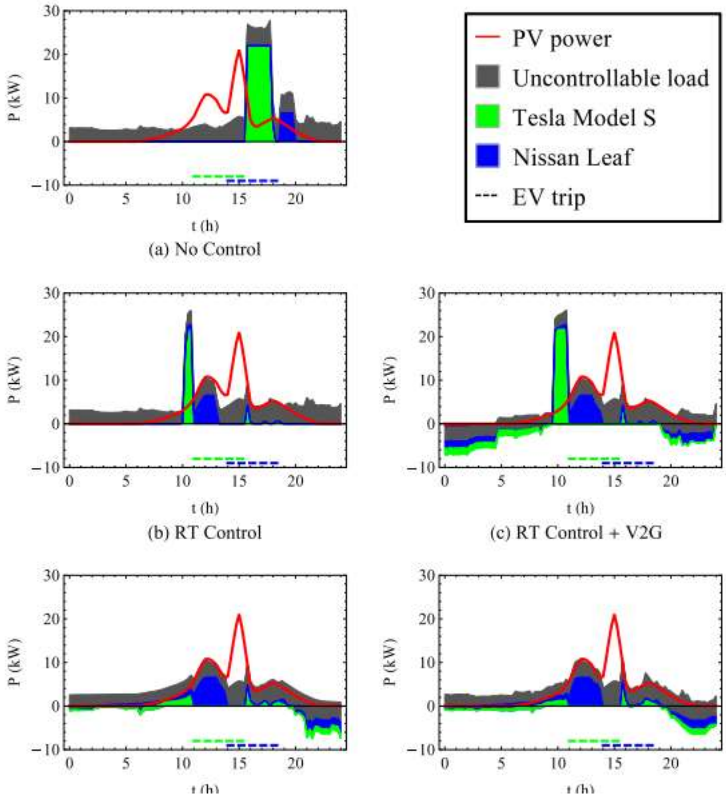

Conclusion

We offer a model designed to investigate the rise in PV self-consumption by smart charging EVs utilising smart grid technologies in this research. This model is used to the LomboXnet microgrid as a case study. Three EV charging control algorithms are proposed, and their effects on self-consumption and peak reduction are simulated. The simulation findings show that electric vehicles can make a major contribution to a well-balanced demand and supply.

Self-consumption is raised from 49% to 62% to 87 percent, energy transmitted to the grid is lowered from 12.4 MW h (26 percent of total energy demand) to between 9.1 (19%) and 3.4 (7%) MW h, and relative peak reduction scores vary from 0.27 to 0.67. Even when errors in forecasts are taken into consideration, our LP algorithm not only outperforms RT Control + V2G in terms of self-consumption, but it also halves the highest peak in demand when compared to real-time algorithms.

Because no more energy is charged than is required for EV journeys, and the charging rate and average SOC are lower than in the No Control reference case, the RT control algorithm has the least influence on battery lifespan. The usage of V2G significantly increases power consumption and has a major influence on battery life. The advantages of V2G must be evaluated against this difficulty. Because it has the lowest charging rates of the two V2G algorithms, LP will have the least influence on battery longevity. We hope to objectively assess the effect of V2G on battery longevity in future study at LomboXnet.

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