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Integrating on-site renewable electricity generation into a manufacturing system with intermittent battery storage from electric vehicles

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Abstract

Electricity storage capacity in electric vehicles (EV) can be used to compensate electricity demand/supply mismatches between (decentralized) variable renewable electricity and manufacturing. However, EVs need to be sufficiently charged for use and removing an EV results in immediate unavailability of stored energy. Effectiveness and challenges, e.g. reduced battery lifetime, for using EV batteries to increase on-site generated electricity demand from a manufacturing system is studied using a simulation approach. Results are compared to load shifting/energy flexibility options offered by the manufacturing system. A case-study based on an existing manufacturing line, on-site generation and EVs is used as application example.

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1. Introduction

Subsidy for electricity generated from renewable energy conversion was first introduced by the "Act on the Feeding of Electricity from Renewable Energy Conversion into the Public Grid" in Germany in the 1990s [1]. Since then, a steady increase of renewable energy (RE) conversion takes place. Although the provision of electricity by conversion of renewable energy reached a historical high of 160.6 TWh in Germany in 2014 versus an electricity demand of 578.5 TWh [2], the overall situation of the energy economy is not reproduced properly in these figures. The share of wind and solar energy (about 90.9 TWh, which corresponds to 56.6% of RE in 2014 [2]) are so-called variable renewable energy (VRE) sources. VRE is non-dispatchable and a large share of conversion is decentralized. In order to be able to obtain a realistic understanding of demand and supply matching, a time-dynamic comparison of electricity demand and variable renewable supply is recommended. The demand as well as the conversion of renewable energy is a distinct stochastic process and not congruent. Two strategies are conceivable to adjust feeding-in of electricity from renewable energy conversion and demand: reshaping of demand to match supply (demand side management) or storing electricity, e.g. in batteries. In the context of electricity storage, the use of electric vehicles (battery electric vehicles and plug-in hybrid electric vehicles) as intermittent electricity storage becomes more attractive with an increasing number of available cars. However, a central prerequisite is the ability to discharge electricity into the local grid. Without this option, EVs can be used to store (VRE) electricity for driving purposes, but not for other end-use cases. In Germany, within the third quarter of 2015, new registrations increased by 60% to 43,000 registered electric vehicles (EVs) compared to 2014. The German automotive manufacturers introduced 17 new models in the year 2014, with another twelve to follow in 2015 [3]. The potential of renewable energy conversing complemented by utilizing EVs as an intermittent electricity storage was also discovered by several enterprises. For example, LomboXnet, an internet service provider at Utrecht, Netherlands, utilizes photovoltaics to provide electricity for EVs [4]. Against this background, this paper

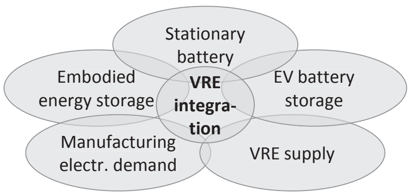

Fig. 1. Topic areas highlighted in this paper.

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presents a concept to integrate VRE into a manufacturing system with EV and stationary battery storage, supplemented by energy flexibility of the manufacturing system (figure 1). A case study is used to demonstrate the application of such a system in a simulation environment.

2. State of research

Several existing renewable energy system modeling approaches focus on hybrid renewable energy systems (HRES) stand-alone applications and/or a given demand structure. In [5], mathematical models for frequently included components (photovoltaics, wind, diesel, battery) of HRES are presented, as well as criteria for system selection and a review of modeling approaches. A comprehensive overview of optimization and simulation techniques used for design and control of stand-alone HRES, including cost objectives, can be found in [6]. On the manufacturing system energy demand and energy flexibility side, a strong focus is set on forecasting energy demand and/or adapting system energy demand to VRE by (operational) scheduling optimization. In order to analyze the impact of vehicle-to-grid (V2G) in an urban area, Drude et al. implemented a MATLAB simulation. They assumed a number of 250 EVs and a photovoltaics (PV) capacity of 7.9 MW_p on a rooftop area of 43,000 m^2. Using real solar radiation and electricity demand data they conclude that a potential for EVs exist to stabilize the grid by peak-load shaving [7]. In the domain of small micro grid implementation van der Kam and van Sark introduced an analysis to increase PV self-demand rate and peak reduction in relation to variations in EV trips using V2G strategies for an existing environment in the Netherlands [4]. López et al. present an agent based optimization model for controlled charging of EVs considering alternating selling market prices for electricity [8]. Advantages, challenges and optimization approaches for V2G applications including considerations as well as social factors and investment barriers are presented by Tan et al. [9]. The investigation on existing approaches has shown that the primary focus refers to the implementation of V2G technologies into smart grid environments. Considerations regarding an implementation within production environments do not exist so far. The method proposed in this paper presents an approach to evaluate effectiveness of V2G applications in the context of energy flexible manufacturing systems, i.e. a concept is proposed which allows to evaluate the effectiveness of V2G applications and compare V2G effectiveness to real-time demand response capability of an energy flexible manufacturing system.

3. Concept for evaluating VRE integration into manufacturing systems with EVs

In order to integrate decentralized VRE generation into an existing manufacturing system, several technical and organizational options exist. A key task is to accommodate (stochastically) fluctuating and non-dispatchable electricity generation output of VRE sources to minimize grid reliance (demand from grid and feed into the grid). Among others, additional, dispatchable supply sources can be installed (e.g. a CHP-plant or diesel generator), the electricity demand side can/needs to be adjusted to supply or surplus electricity from VRE is stored, e.g. in batteries.

3.1. VRE and EV integration concept

The following assumptions are made to limit the scope of this work:

- A manufacturing line with several processes/machines and buffers for intermediate product storage exists.
- EVs are connected to the local (company) grid, which in turn connects the manufacturing system and VRE electricity generation.
- VRE is generated on-site and economic (e.g. due to feed-in tariffs vs. grid electricity price) and environmental (e.g. lower carbon emissions) benefits exist to directly demand as much on-site generated electricity as possible.

The proposed framework for integrating VRE generation into a manufacturing system environment can be found in figure 2. It comprises six steps with the following actions and objectives:

1. A dynamic system model needs to be set-up to reflect time-dependent dynamics (material and energy flows) of all relevant system elements.
2. One or multiple hypotheses are formulated in relation to improved integration of VRE, including indicators for measuring improvement.
3. Scenarios are defined, reflected by a set of input parameters for the dynamic system model to test hypotheses. For the purpose of this approach, EV fleet changes and use case scenarios are central scenarios for evaluation, as well as energy flexibility of the manufacturing system.
4. For each scenario, model evolution is calculated and relevant indicator values obtained.
5. Based on evaluated scenarios and outcomes, conclusions on previously defined hypotheses are drawn. Dependent upon outcomes, implementation can be prepared and/or further hypotheses tested (e.g. if desired outcomes are insufficient or new, additional hypotheses towards improvement emerged).
6. Dependent upon conclusions, hypotheses are reformulated or new hypotheses are generated for testing.

In order to be applicable for multiple application cases, a generic model structure has been developed as part of step one. Its four main system model elements (manufacturing system, VRE supply, EV fleet, energy control) are described briefly in the following.

3.2. System elements

Mentioned four system elements exchange information and energy flows. Starting with VRE supply, electricity from on-site generation sources can either be directly demanded by the manufacturing system (first priority), used to charge connected EVs (second priority) or fed in to the connected power grid (third priority). The grid itself supplies electricity to the manufacturing system and EVs, if VRE supply is not sufficient to meet energy needs (see also figure 3). The manufacturing system and connected auxiliary systems' (e.g. compressed air (CA) generation) electricity demand is optionally controlled by a central electricity control which aims at matching processes total demand with VRE supply via controlling processes target states (e.g. idle/produce), similar to [10]. The EV fleet is charged with surplus VRE (if any) and can discharge VRE if required by the manufacturing system and if allowed by the EV, depen-

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