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Integrated Converter and Charging Algorithms

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Charging Electric Vehicles from Solar Energy: Integrated Converter and Charging Algorithms

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I. Introduction

500 million electric vehicles (EVs) are expected to be on the roads by 2030 [1]. At the same time, the current electricity grid is largely powered by fossil fuels. When electric vehicles are charged from this grid, a large part of the emissions is merely moved from the vehicle to the power plant. Hence electric vehicles are only sustainable when charged from sustainable sources of electricity like solar [2]–[4]. There are several advantages for charging EVs from PV:

1. Reduced demand on the grid as the EV charging power is locally generated from PV [5]
2. EV battery can be used as an energy storage for the PV
3. Long parking time of EV paves way for implementing Vehicle-to-grid (V2G) technology
4. Reduced cost of EV charging and reduced impact of changes in feed-in-tariffs [6]

Currently, to charge EVs from PV is to use a PV inverter to feed PV power to the grid and to use an AC EV charger to charge the EV [7]. However this is not cost effective and efficient due to two reasons:

1. PV and EV are fundamentally DC by nature, hence exchanging power in AC leads to additional conversion steps and losses [4][3].
2. Two inverters would be needed, one each for the PV, EV

The paper presents the development of a highly efficient, modular, V2G-enabled smart charging station for electric vehicles that is powered by solar energy. The EV and PV are connected on DC rather than AC and uses a single inverter to AC. The paper focusses on the system design, power converter development and charging algorithms. The charging station is designed for use in workplaces to charge electric cars of the employees as they are parked during the day. Industrial sites and office buildings harbor a great potential for photovoltaic (PV) panels with their large, flat roofs.

II. System Design

Research has shown that there is sufficient solar insolation to charge EVs from a PV array in Netherlands [5]. Simulations based on data from the Dutch Meteorological Institute (KNMI) have shown that a 10kW PV array produces on average 30kWh/day, with 10kWh/day in winter and 50kWh/day in

Fig. 1. Design of solar powered bi-directional EV charging station

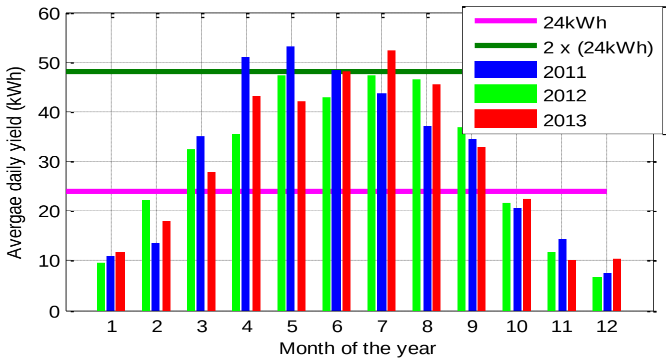

Fig. 2. Yield of 10kW PV system in Netherlands compared to Nissan Leaf EV

summer. This necessitates a grid connection to ensure reliable power supply, especially in winter. For 54% and 22% of the year, the daily yield is greater than 24kWh/day and 48kWh/day respectively (Fig. 2). 24kWh considered here corresponds to the battery capacity of a Nissan Leaf EV. The use of a local storage or a PV tracking system does not help in overcoming the seasonal variations in irradiance. However small sized storage of 10kWh helped in mitigating the day-day solar variations and reduced the grid energy exchange by 25%.

III. 10Kw bi-directional three-port converter

The optimal system architecture for EV charging from PV is an integrated three-port converter connected to the AC grid, as shown in Fig. 3 [8]. It has three sub-converters: a DC-DC converter for PV, a DC-DC isolated converter for EV and a DC-AC inverter to connect to the AC grid.

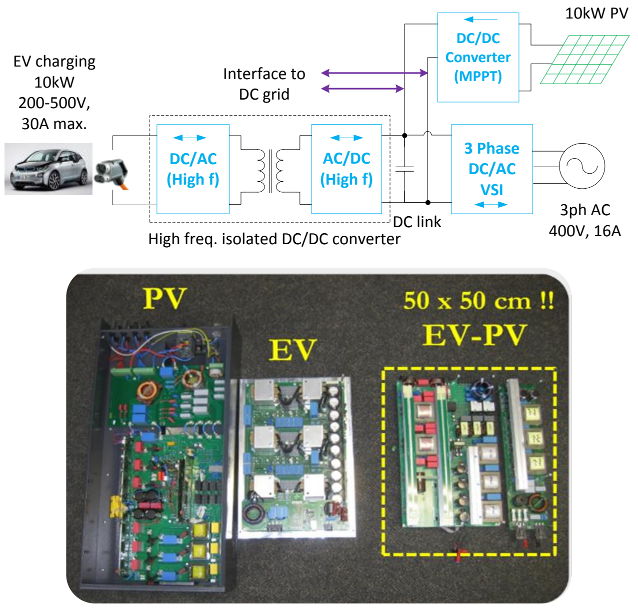

Fig. 3. Topology of power converter (top) and 10kW prototype of developed converter compared to a conventional PV inverter and EV charger (bottom)

A high-efficiency 10kW three-port converter has been designed and built that integrates the PV, EV and grid [8]–[10], shown in Fig. 3. An internal DC-link is used to exchange power between the PV and EV. The use of modern silicon carbide devices and low-loss powdered alloy core inductors has resulted in high efficiency and high power density. Fig. 3 shows a comparison of the developed converter with a 10kW PV inverter and DC EV charger based on ferrites and classic IGBT technology. The smaller size and higher power density are clearly seen.

The bidirectional power converter has V2G capability to discharge the EV battery to provide power to the grid. The converter is compatible with Chademo and CCS/combo DC EV charging standards. The converter has a stable closed loop control. The control is capable of executing four different power flows: PV→EV, PV→ Grid, Grid→ EV, EV→Grid and its combinations. The efficiency of the converter for charging EV and feeding PV power to the grid is shown in Fig. 4. The efficiency is compared with a conventional EV charger and the improved full load and partial load efficiency can be observed

IV. EV-PV Smart Charging

An energy management system (EMS) is used to optimally charge the EV fleet from PV and the grid. The aim is to minimize charging cost while reducing the energy demand from the grid by increasing PV self-consumption. The developed EMS consists of two components: an autoregressive integrated moving average (ARIMA) model to predict PV power production and a mixed-integer linear programming (MILP) formulation that optimally allocates power to minimize charging cost [11].

The charging of the EV fleet is optimized based on EV user preferences, PV forecast and dynamic energy prices in the grid. The results show that the developed EMS is able to reduce the charging cost significantly, while increasing PV self-consumption and reducing the energy consumption from the grid. For a case study with dynamic purchase and feed-in tariff (FIT), the EMS reduces charging cost by 118.44% and 427.45% in case of one and two charging points, respectively, when compared to an uncontrolled charging policy [11].

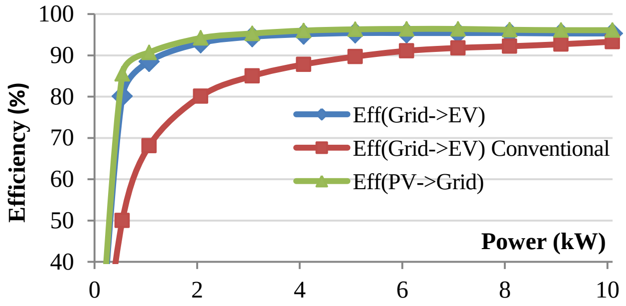

Fig. 4. Measured efficiency of the converter for PV→Grid, EV→Grid

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