Technical and Economic Analysis of One-Stop Charging Stations for Battery and Fuel Cell EV with Renewable Energy Sources

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Abstract

Currently, most of the vehicles make use of fossil fuels for operations, resulting in one of the largest sources of carbon dioxide emissions. The need to cut our dependency on these fossil fuels has led to an increased use of renewable energy sources (RESs) for mobility purposes. A technical and economic analysis of a one-stop charging station for battery electric vehicles (BEV) and fuel cell electric vehicles (FCEV) is investigated in this paper. The hybrid optimization model for electric renewables (HOMER) software and the heavy-duty refueling station analysis model (HDRSAM) are used to conduct the case study for a one-stop charging station at Technical University of Denmark (DTU)-Risø campus. Using HOMER, a total of 42 charging station scenarios are analyzed by considering two systems (a grid-connected system and an off-grid connected system). For each system three different charging station designs (design A-hydrogen load; design B-an electrical load, and design C-an integrated system consisting of both hydrogen and electrical load) are set up for analysis. Furthermore, seven potential wind turbines with different capacity are selected from HOMER database for each system. Using HDRSAM, a total 18 scenarios are analyzed with variation in hydrogen delivery option, production volume, hydrogen dispensing option and hydrogen dispensing option. The optimal solution from HOMER for a lifespan of twenty-five years is integrated into design C with the grid-connected system whose cost was $986,065. For HDRSAM, the optimal solution design consists of tube trailer as hydrogen delivery with cascade dispensing option at 350 bar together with high production volume and the cost of the system was $452,148. The results from the two simulation tools are integrated and the overall cost of the one-stop charging station is achieved which was $2,833,465. The analysis demonstrated that the one-stop charging station with a grid connection is able to fulfil the charging demand cost-effectively and environmentally friendly for an integrated energy system with RESs in the investigated locations.

We are living in a very exciting period because global energy systems are going through a major transformation. One of the main reasons for it is the climate shift which has made it necessary to shift from non-renewable resources to renewable resources in order to build a low-carbon, climate-safe future. In recent years, the demand of renewable energy systems has increased. After the 2015, United Nations Climate Change Conference (COP21) agreement in Paris, many countries have issued a statement regarding the ban on the use of the internal combustion engines (ICE) [1]. For example, in 2018, Denmark announced that it will ban the sale of new cars with ICE by 2030 and hopes to have one million electric and hybrid cars on the roads by then [2]. Electric vehicles (EV) will play a major part in smart grids with a high penetration of renewables [3,4,5]. The number of EVs and fuel cell vehicles has been on the rise in the past few years. It is also predicted that by 2020 the total cost of a personal use EV could be the same as an ICE [6,7]. However, even if the cost of the EVs goes down in the future, shortage of available charging stations and limited distance travelled on a single charge are the major reasons impeding the purchase of these EVs, as seen in Figure 1 [1]. Hence, it is quite important to develop an optimal design for an integrated charging station which is able to meet the needs.

Denmark has a well-established natural gas grid, and here hydrogen and biogas can play a complementary role in terms of providing stored, renewable energy in large quantities to the Danish energy system. Furthermore, the European Union has provided funding of EUR 40 million for the production of 600 hydrogen buses, of which one-third will be provided to Denmark [8]. With this green transition development of hydrogen refueling stations is quite imperative. Simultaneously, fuel cell electric vehicles (FCEV) are receiving more focus and stronger support. The charging solutions for both battery electric vehicles (BEVs) and FCEVs are developed and operated independently as they are often seen as two competitive technologies. These two types of charging stations can be integrated into a one-stop charging station, acting as an interface to an integrated energy system, which includes electricity, transportation, and gas. This one-stop charging station will cater to both the BEVs and FCEVs. These circumstances make Denmark an ideal place to demonstrate the power-to-gas solutions. To transform DTU-Risø campus into 100% renewable campus in the coming years, a case study was conducted by using a fleet of battery-operated electric cars. Adding to this, an integrated charging station for both electric and fuel cell vehicles will bring it one step closer to achieving the aim. To achieve this goal, an example will be set up for other campuses/community to convert into a climate-friendly future integrated energy system with high penetration of

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renewable energy sources (RESs).

So far, many researchers people have used the hybrid optimization model for electric renewables (HOMER) software to find an optimal solution for an electrical load with combinations of different energy sources for producing energy. For example, Edwin Moses in his research used HOMER to find an optimal solution for providing energy to a small village. In this paper the author used wind turbines, Photovoltaics (PV) and bio-diesel generator for producing energy for an electrical load for a small remote rural village. The optimal solution included the use of a hybrid system consisting of solar PV and a bio-diesel generator for producing energy for the village [9]. David Restrepo used the HOMER simulation for a scenario-based optimization. His work consisted of analysis of two different scenarios with the same load requirements for a location in Medellin, Columbia. The first case considered renewable energy sources and a diesel generator but in a stand-alone configuration. The second case also considered renewable sources but in grid-tied configuration. Both cases showed that PVs are significant contributions for power generation [10].

The work done by previous researchers showed that a multi scenario-based analysis with different source of renewables to obtain an optimal solution can be done. However, it does not include a charging station as they just use HOMER for power generation and a maximum of two scenario-based optimization analysis. The analysis in this paper takes advantage of two different models-HOMER and heavy-duty refueling station analysis model (HDRSAM), which were integrated to find an optimal solution for a one-stop charging station. The major differences which are included in this paper are the use of different types of loads—hydrogen load and electrical load; use of hundred percent renewables for energy production. Different design scenarios with different system connection setup and use of different types of wind turbines sets the research in this paper aside from the previous work done.

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