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Feasibility assessment of a solar-powered charging station for electric vehicles in the North Central region of Bulgaria

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Abstract. The paper discusses the topical issue related to the prospects of widespread deployment of electric vehicles and their associated infrastructure in Bulgaria. The main problems hindering the development of electric vehicle transport are summarized and the current status of charging infrastructure in the country is discussed. An approach is proposed for analysis and evaluation of the financial feasibility of investment in a solar-powered charging station for electric vehicles in North Central region of Bulgaria.

1 Introduction

The steady increase of the number of vehicles in the world and in Bulgaria translates into an increased consumption of petroleum products and significant air pollution by exhaust fumes which are highly toxic and hazardous to human health and to the environment. Findings of the World Energy Council show that approx. 17% of the greenhouse gas emissions released into the environment are produced by road transport [1]. The air pollution problem is particularly acute in big cities. Interest is therefore growing in electric and hybrid vehicles, hereinafter referred to as EVs. EVs are nowadays a major component of development programs of automotive industry producers and demand for them is steadily growing. Respected experts anticipate by 2020 a world market share of EVs of 5–20%.

The major problems hindering the widespread adoption of electric cars transport are associated with battery recharging and replacement and with the limited availability of charging and battery swap infrastructure. Other barriers to the large-scale EV deployment include their high cost as compared to the one of conventional cars, small driving range per one charge and long charging times [2,3]. Other considerations with regard to the low road transport electrification rates relate to the poor public awareness of the benefits of these environment-friendly vehicles. It is nevertheless irrefutable that normal EV functioning can only be secured through the presence of an adequate charging infrastructure, similar to the one of fuelling stations.

Use of renewable energy sources, photovoltaics (PV) in particular, in EV charging stations represents an opportunity for increasing their economic efficiency and shall essentially contribute to improvement of air quality and noise reduction in urban areas. However, initial investment in PV systems is still rather high and therefore requires a comprehensive technical and economic analysis and assessment of the financial efficiency.

The purpose of this paper is to analyze the use of PV modules in EV charging stations (EVCS) in North Central region of Bulgaria and to assess their economic feasibility and efficiency.

2 Basic aspects and overview of EVCS current state and development prospects

Charging stations are infrastructural elements enabling power recharging of electric vehicles including plug-in hybrids. Two distinctive principles for electricity supply in EVCS exist: the first one is based on a network of battery-charging stations and the second one uses a system of battery-switch stations. This paper addresses the first EVCS type.

EVCS can be divided into 2 categories based on the battery-charging speed:

– EVCS in which charging duration ranges from 4 to 14 h depending on the charging method, the battery capacity and its discharge level. Such EVCS are primarily used at parking lots, shopping centers, train stations and other public locations where vehicles are available for charging over a longer period;
– Fast (express) charging EVCS (CHAdeMo standard) providing full or partial battery recharging within 15–40 min. Recharging at such stations is delivered through electronic converters with special parameters/ power, voltage and frequency and current/.

Many countries have recently implemented policy initiatives to promote build-up of networks of EVCS, particularly in major cities, in an effort to facilitate wider

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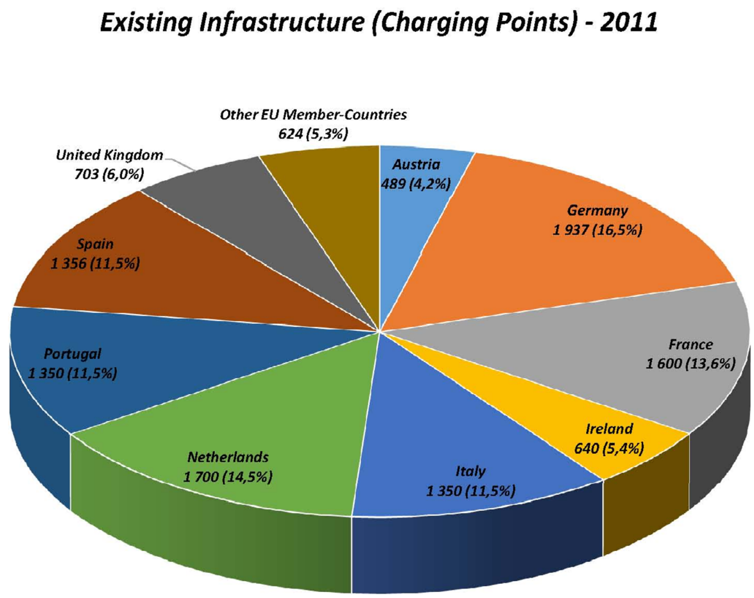

Fig. 1. Existing charging infrastructure by EU-Member Country [5].

deployment of electrified road transport. A large number of EVCS has been installed today – over 15 000 in the USA, over 8 000 in China, more than 5 000 in Japan [4]. The existing EVCS by EU member-country as of 2011 are shown in Figure 1 [5]. The EU members with less than 500 EVCS, inclusive of Bulgaria, have been included in the "Other EU-Member States" category. Bulgaria has currently deployed a total of 26 EVCS and charging points [6] and in this respect lags significantly behind most European countries – the latter hinders EV market development and requires active measures to address the problem.

In consideration of the growing problems related to the increase of greenhouse gas emissions and environmental pollution from transport and in view of reducing potential overdependence of EU member-countries on oil and petroleum products, Europe focuses on development of eco-friendly and sustainable transport with an emphasis on renewable energy sources and clean energy. In an effort to meet the targets set in 'Europe 2020: A strategy for smart, sustainable and inclusive growth' the Commission adopted a number of regulations, measures and policy incentives to promote deployment of alternative fuels and support the development of EV transport. Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the Deployment of Alternative Fuels Infrastructure obliges EU member-countries to establish national objectives to build-up a network of publicly available EV charging points by 2020 in order to ensure that EVs can circulate at least in urban/suburban agglomerations. Targets should foresee a minimum of one recharging point per 10 electric vehicles [7]. Given that Bulgaria currently has 497 registered EVs and 1031 hybrid vehicles [8] and the number of EVCS in the country is still very low, the government should take measures and increase the incentives to support building of EVCS in urban areas. It is particularly suggested that deployment of EVCS be promoted at public and corporate parking lots which could be used by working citizens during business hours.

3 Possibilities for use of photovoltaic modules in electric vehicle charging stations in Bulgaria

The geographic location of Bulgaria and solar insolation levels are favorable for deployment of solar-powered CS for EVs. The average duration of direct sunlight for the whole territory of the country is within the range of 2000–2500 h [9]. The average annual solar insolation in Bulgaria varies from 1450 kWh/m^2 to 1650 kWh/m^2 [9,10]. The present paper uses average annual solar insolation data at the optimum tilt angle of PV panels as reported by STS Solar [11].

Numerous theoretical models exist for predicting PV power output based on solar insolation levels. Some models have been experimentally confirmed by means of statistical analysis of data from operating PV systems in North Central region of Bulgaria [12,13]. The latter provides grounds for claiming that the electricity generated by 1 kWp solar-powered CS can be predicted accurately enough to calculate the economic efficiency of the project.

The structural diagram of a solar-powered CS is shown in Figure 2 [14]. The solar power output has a random pattern and is a function of solar insolation. The generated PV energy is directed through a controller either for storage to the battery bank or to the inverter/DC/AC or DC/DC/ from which it is fed through the distribution board to the charging device. Power can be used from the utility grid, if needed. The PV panels can be installed on roofs, shed roofs or on the roofs of nearby buildings (Fig. 3).

The specific EV energy use greatly depends on various factors such as vehicle type, road conditions and traffic, and driving style. For small EVs it is 130–200 Wh/km without considering heating or air conditioning [15]. Most widespread EVs have a driving range of 100–160 km per charge subject to the battery type and capacity. This driving range is sufficient for passenger vehicle city travel which is typical

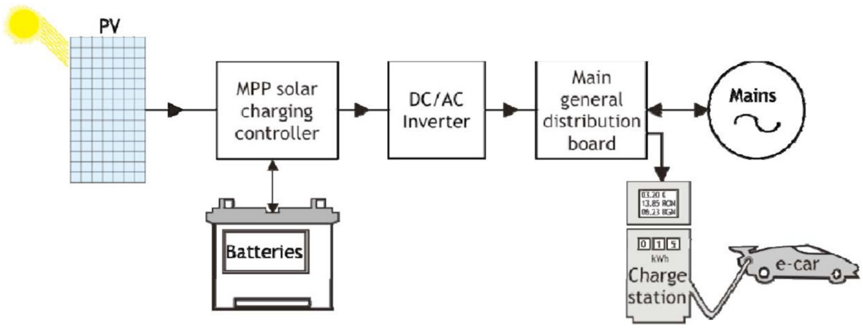

Fig. 2. Structural diagram of a solar-powered charging station [14].

Fig. 3. Solar-powered charging stations for electric vehicles.

for about 80% of daily commuting vehicles, driving average distances of 40–80 km per day [2]. An EV running in urban environment will consume 13–20 kWh of energy to travel 100 km. Having considered existing charging technologies and battery capacities it can be concluded that a network of EVCS is needed in urban areas whereas individual charging points may be conveniently installed on existing parking lots and garage roofs.

The number of registered EVs in Bulgaria is currently not substantial. The analysis of economic efficiency shall therefore consider the possibilities for modular structure of PV. The solar system configuration assessed in the present paper is 10 kWp with PV modules installed at the optimum tilt angle over 70 m^2 of building or shed roof at an administrative parking lot. The above approach enables integration of additional PV modules whenever EV number grows.

4 Financial feasibility assessment of solar-powered charging station

The economic efficiency of investment has been calculated for a 10 kWp PV system. Official data of the Bulgarian State Energy and Water Regulatory Commission for rooftop and building-integrated PV systems of 5–30 kWp installed capacity have been used as input parameters for performing the calculations [16]. The average annual value of PV electricity production (EP) is calculated using formula (1):

$$\mathrm{EP} = \mathrm{SI} \times \eta \times S, \quad (1)$$

where:
SI – average annual solar insolation at the optimum tilt angle for North Central region of Bulgaria – 1467 kWh/m^2;
η – average silicon PV module efficiency – 15%;
S – surface area of the proposed PV system.

Assumption is made in the paper that an EV is used 22 days/month and travels daily an average of 100 km consuming approx. 20 kWh. The power produced by the 10 kWp PV system will therefore be sufficient for charging 2 EVs within daily business hours. The average EV battery-charging cost in Bulgaria for a driving range of approx. 100 km is 8 BGN (4.09 EUR), which is 2–4 times cheaper than the cost of refueling a diesel-run vehicle for a 100 km drive in urban areas.

The annual positive cash flows over the useful life of the PV system will comprise of:

- the savings from recharging the two EVs with free solar electricity;
- the value of surplus PV power for self-consumption at an average retail electricity price of 0.20 BGN/kWh (~0.10 EUR/kWh);
- the monetary value of lowered carbon emissions calculated with a standard emission factor for Bulgaria of 0.819 (t CO_2/MWhe) [17] and a reference value of carbon allowances of 5.5 EUR/t CO_2 for 2015 [18]. Hazardous emissions of other greenhouse gases from combustion of petroleum products are not considered in the assessment but their monetary value will further enhance the economic efficiency of investment. To illustrate, the global warming effect of 1 kg N_2O emitted from combustion of petroleum products equals the effect of 310 kg CO_2 [17].

Table 1. Input data for calculation of the financial efficiency of a solar-powered charging station for electric vehicles.

Input parameter	Value	Unit
Investment costs (CAPEX)	1300,22	EUR/KWp
Operational and maintenance costs (OPEX)	11,80	EUR/MWh
Useful life of investment (t)	20	years
Inflation rate (i)	2	%
Discount factor, i.e. weighted average cost of capital (r)	7	%

The input data for calculating the financial efficiency indicators of the solar-powered EVCS are shown in Table 1 [16].

The results from the assessment show that the investment in a solar-powered EVCS is efficient as the net present value (NPV) calculated using formula (2) is EUR 18,949.32. The discounted payback period of the investment (DPBP) calculated using formula (3) shows that the original investment cost will be recouped in approximately 8 years.

$$\mathrm{NPV} = -\mathrm{CAPEX} + \sum_{t=1}^{T} \frac{\mathrm{NCF}_t (1+i)^t}{(1+r)^t}, \tag{2}$$

where:
CAPEX – investment costs;
NCF_t – net cash flow in year $t = 1, 2, \ ... \ T; \ T = 20$;
i – inflation rate;
r – discount factor, i.e. weighted average cost of capital.

$$\mathrm{DPBP} = \frac{\mathrm{CAPEX}}{\sum_{t=0}^{n} \frac{\overline{\mathrm{NCF}}_i}{(1+r)^t}}, \tag{3}$$

where:
$\overline{\mathrm{NCF}}_i$ – average inflation-indexed net cash flow calculated as an algebraic mean.

5 Conclusion

The present paper proposes an approach for analysis and evaluation of the financial feasibility of investment in a solar-powered EVCS. The results show that the investment is profitable even without considering all ecological and social effects from the use of PV modules. The steady improvements in the efficiency of PV technologies, the extended life of solar modules and other system components and the decline in PV module prices are further arguments supporting the conclusion that such investments are economically sound. In view of constantly rising fuel prices and the increasing number of EV in urban areas one can be confident that the financial efficiency of solar-powered EVCS will further improve in the near future.

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