Toward a Practical Solution for Residential RES Based EV Charging System

Topic number: TT4

***Abstract*-The world population depends highly on fossil fuels (for power generation, transportation, etc), this leads to oil price increases because of the depletion of fossil fuels. This paper is dealing with the use of RES in transportation. Pollution from the today transportation means, based on ICE (burning gas) especially in urban conglomerates and is off great concern. The renewable energy sources (RES) based microgrids (MGs) with energy storage facilities, can contribute to charge the future electric vehicles (EVs) based transportation system. Renewable energy charging stations can play a key role in the successful development and deployment of EVs contributing to polution reduction, too. The proposed charging station is powered by renewable energy sources such as wind and photovoltaic used in hybrid configuration with energy storage system. The target of it is the residential application in future Smart cities. The storage system can contribute to V2G peak shaving and power quality functions. This study focused on a practical solution for residential RES based EV charging station.**

I. INTRODUCTION

The evolution from conventional electric energy production, based on fossil fuels, to one based on renewable energies, in order to reduce big concerns related to the increasing pollution and its detrimental consequences, cannot neglect transportation means.

The increase of EVs of different kinds is more and more a necessity in order to meet sustainability targets. In the recent INTERNATIONAL ENERGY AGENCY publication [1] it si mentioned that the EVI (Electric Vehicles Initiative) ”20 by 20 target calls for an electric car fleet of 20 million by 2020 globally”. The Paris Declaration on Electro-Mobility and Climate Change is establishing a target of ”100 million electric cars and 400 million electric 2- and 3-wheelers in 2030”. An another IEA ambitious initiative, called 2DS , **”The 2°C Scenario (2DS)”** is forecasting emissions trajectory consistent with at least a 50% chance of limiting the average global temperature increase to 2°C , for which asks for a more ambitious target for electric cars, 150 million by 2030.

Meeting these targets implies substantial market growth to develop further the current 1.26 million electric car stocks in 2015. Already it is remarcable as evolution because this doubled the figure of EV fleet at the end of 2014. The market shares of electric cars increased above 1% in the following countries in 2015, the last three highly populated: Norway, the Netherlands, Sweden, Denmark, France, China and the United Kingdom. Market shares reached 23% in Norway and nearly 10% in the Netherlands.

But, if EVs are supposed to be connected to the electric power grid for charging, and in this respect there are many technical issues to be considered [3]–[6]. First, the indirect emissions of EVs areinfluenced by the energy mix of any regional electric power system. Unfortunately if the power generation of the electric power system is dominated by coal-fired power plants, the emission advantage for EVs is not obvious, see Fig. 1.

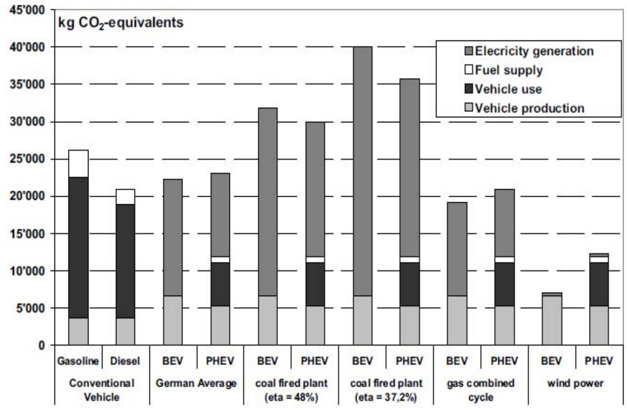

Fig. 1. CO_2 pollution by different types of vehicles [4]

Only the direct integration of RES (Renewable Energy Sources) with EV charging infrastructure ensures a way to effectively improve the emission reduction of EVs, meet charging demand, and reduce the dependence on the power grid [9]–[12]. Following the Fig. 1 one can see that only supplied by RES the pollution is reduced significantly.

Studies made are showing that the EVs are more efficient than Internal Combustion Engine Vehicles. EVs are ”zero” polluting too. But these qualities are valid only if the EV is supplied from renewable energy sources RES. The efficiency of an Electric Vehicle is maximum in this case as it can be followed according Table I.

In urban areas there is a lot of space unused like homes and enterprises roofs, parking roofs, etc. Also researches in development are creating transparent PV cells to replace windows or to cover facades. In cities the authors of the paper can consider the PV and small wind turbines as RES able to supply with energy the EVs until nowadays. Even if not always the produced energy is enough, there is a great energetic potential to be exploited by these RES in a Smart City. It is bringing the RES close to the consumer, so the transport lines are not overcharged and the customers are educated to consider the energy consumption carefully.

TABLE I

TYPE OF FUEL EFFICIENCY FOR ELECTRICAL VEHICLES [26]

TECHNOLOGY	WELL-TO-STATION EFFICIENCY	VEHICLE MILEAGE	VEHICLE EFFICIENCY	WELL-TO-WHEEL EFFICIENCY
TESLA ELECTRIC	52.5 %	110 Wh/km	2.18 km/MJ	1.14 km/MJ
HYBRID (gas/electric)	81.7 %	55 mpg	0.68 km/MJ	0.556 km/MJ
COMMUTER CAR (gas)	81.7 %	51 mpg	0.63 km/MJ	0.478 km/MJ
SPORTS CAR (gaz)	81.7 %	20 mpg	0.24 km/MJ	0.202 km/MJ
HYDROGEN FUEL CELL	52.5 %	64 m/km	0.57 km/MJ	0.348 km/MJ

The problem the paper deals with the realistic structure of a residential RES Based EV Charging System. The paper is structured as follows: section II is presenting the State of Art of RES Based EV Charging Systems; section III is trying to answer to the question: Is direct charging of EV is a good solution?; section IV is presenting some best candidates to Intermediate Storage Technologies and section V is proposing a proper EV Charging System diagram/structure. At the end conclusions follow.

II. STATE OF ART OF RES BASED EV CHARGING SYSTEMS

First of all we have to stress that the present discussion is focused on residential charging stations placed in a (Smart) city.

That means that the energy dedicated to charging EVs is rather low, around 30 kWh on a day, according to the limited surrounding space. This amount can charge one 4 and several 3 and 2- electric wheelers. The energy is enough to charge E vehicles like BMW i3 (22-33 kWh), Nissan Leaf (24-30 kWh), Renault Fluence ZE (22 kWh), Renault Twizy (6 kWh) Renault Zoe 2012 (22 kWh), Volkswagen e-Golf (24- 36 kWh) and others.

Secondly we are looking for solutions which can use the grid as a backup and a commercial partner, too. So stand alone solutions are out of question, because they are requiring greater reserves, consequently more large renewable power sources and asking for larger spaces, not available. The solution have to fit in the nowadays cities.

Thirdly, from economically point of view, the slow EV charging solution (in terms of paper [15]) is considered, where, for an about 30 kWh energy the charging time is around 6 hours.

Considering the above criteria a literature research, summarized by [15], in order to find dates about charging stations is giving some surprises. All (almost) the considered RES based charging systems are using only PV sources.

Charging stations with PV answering to our criteria are looking like the one in Fig. 2 [16], [17].

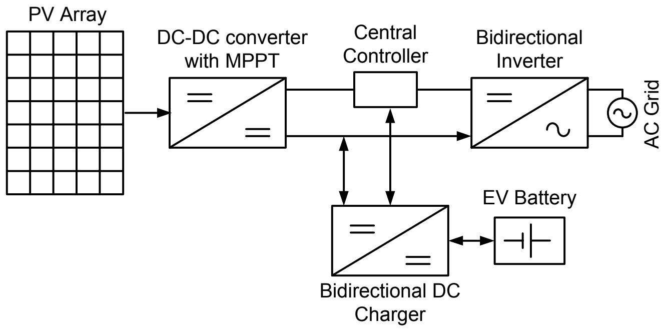

Fig.2. PV energized Charging station [16], [17]

Wind is considered only in two cases [18], [19] but without any arguments for the choice.

In the case [18], the wind turbine is connected on the ac grid side line that means relatively high power wind turbine, which is not the case for a residential EV charging station placed in a city.

In the case [19], the location being equatorial, practically the only reason to use wind is to have an extra-safety margin, since the potential evolution is the same.

We consider the wind source, too, because in the temperate climate zones and above, the wind source and solar source are complementary. Even if the wind turbines to install on buildings are rather small in comparison with the PV plants (usually about 4-5 times), wind RES contribution ensures a smaller storage effort and contributes to the safety of the supply, especially when the sun light is not present, see Fig. 3.

Besides the complementarities of the considered RES, the already build houses in present cities are not properly oriented or situated to fully exploit the PV capability. Small wind turbine can be installed where the conditions are proper.

Their inertia is reduced so they can exploit even small winds and offer a precious contribution even in smaller extent than PVs. Eventual environmental issues are smaller than the pollution ones due to fossil fuels and such problems can be properly mitigated with adequate technical solutions.

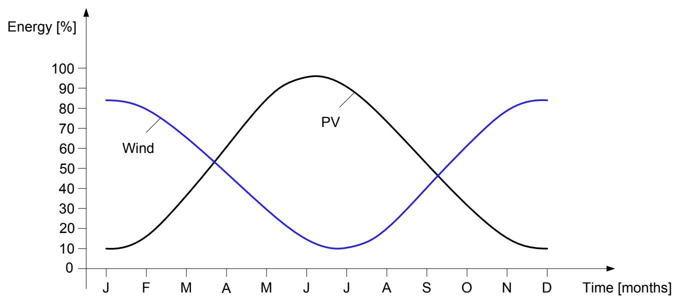

Fig.3. Wind/PV energy production in the temperate climate zones

This new component is increasing the complexity of the control solution, and previous studies that consider both sources are not presenting control solutions.

III. IS DIRECT CHARGING OF EV A GOOD SOLUTION?

From energy efficiency point of view direct charging of EV is the most efficient one.

Also the use of EV battery for grid support, the very much studied situation published nowadays, [15], would overuse it, provoking premature ageing of a very expensive component (30 % of the EV cost today). But the benefits of cannot be neglected. But peak power consumptions are happening during the day, when usually the EVs are out. The same is true for the power quality problems which are accompanying when the grid is heavily charged.

EV2G (Electric vehicle batteries supplying the Grid in case of need) is considered a possible useful application.

Benefits of EV2G are listed below:

- EV can as act as a power source for the electric grid:
- increases the reliability and lowers the system costs of power system;
- reduce frequency fluctuations in power grids (peak shaving);
- Grid connecting converters + the energy sources (including storage) of a charging station can contribute to improve power quality: power factor improvement, harmonics compensation ;
- stabilize the grid voltage.

Many times RES are generating, especially during daylight, the EVs are out, so if there are not peak shaving requirements from the main grid they cannot be fulfilled. Even if the energy is supplied to the grid, the price offered by the grid operator can't be very rewarding sometimes.

What happens if the RES are not available (no sun, no wind)? All the above EV charging stations useful properties cannot be used. It would be an economical and technical mistake.

So the answer for the section title question is NO.

To let the Grid to fully enjoy the above listed advantages a device able to supply energy is compulsory.

The above mentioned issues are driving to the idea to attach the EV Charging system an energy buffer. Which kind of buffer, or intermediate storage device, is advisable constitutes the topic of the next chapter.

IV. INTERMEDIATE STORAGE TECHNOLOGIES

For long term bulk storage there are three technically feasible candidates: Li-ion or Lead Acid batteries, redox flow batteries and a (maybe surprisingly for this energy range) pumped storage solution. The pumped storage solution is proposed by the authors of this paper according to the experience gained in related research [27], [28].

After a short description of each solution, the advantages and disadvantages of each will be listed in the following lines.

There are also other candidates in the literature like fuel cells but they are notoriously unreliable (membrane silting), with a low efficiency (~16% round trip), emotionally concerning the public (hydrogen storage) and expensive.

Lithium ion (Li-ion) batteries consists of a series of cells, each capable of storing a fixed amount of energy. There are many advantages to using a Li-ion battery, like [20]-[23]: high energy density, high power density ranging from 500 to 2000 W/kg; self-discharge; low maintenance and higher current levels and are ideal for power tools and electric vehicles. Like the use of any technology, there are some disadvantages that need to be balanced against the benefits. The Li-ion battery disadvantages include: high cost; life shorten by deep discharges, affected by temperature, fragile; needs protection for overcharge and overdischarge. The Li-ion technical parameters are given in Table II [31].

TABLE II
LITHIUM ION BATTERY PARAMETERS

Technical parameters	**Li-ion**
Technology	$LiFePO_4$
Nominal capacity	400Ah
Nominal voltage	51.2 V DC
Nominal power	20.5 kWh
Pack dimensions (W x D x H)	0.316 x 0.468 x 0.378 m
Weight (kg)	216
Operating temperatures (^{0}C)	-20 ÷ 60
Self discharge	<3% / month at 20°C
Battery configuration	four stack of 4 cells
Recommended/Operation charge voltage	57.6 V/51.2 V DC
Discharge cut off voltage	44.8 V DC
Recommended charge/discharge current 0.5C	200 A
Max. charge/discharge current 1C	400 A
Liftime at 80% Depth of discharge	< 2000
Recharge time	1-2 hours
Maintenance	Free

Even if the Lead-acid battery seems obsolete, it is a still making technological progresses and remains a competitive solution in many aspects in comparison with modern Li-ion batteries, especially in stationary applications like our case is.

The Lead-acid technical parameters are given in Table III [20].

TABLE III
LEAD ACID BATTERY PARAMETERS

Technical parameters	**Lead Acid-ESS**
Current Output	112 A x 4 hours
Output Voltage Range (VDC)	42-60
Dimensions (W x D x H)	0.81 x 0.76 x 2.28 m
Approx. Weight (kg)	1180
Temperature Range (^{0}C)	0 - 68
DC-DC Efficiency, round trip	75 %
Performance vs. Temp	IEEE/ANSI and manufactures derating
Containment	Cabinet drip tray
Lifetime (discharge cycles)	1.500
Depth of Discharge	From full to 80 % state of charge
Recharge Time	20 hours (5:1 charge/discharge ratio)
Speed of Response	1 ms
Overload Capacity	1.25 x normal rating
Maintenance	At least 4 times per year

The main disadvantage related to the use of above batteries is the reduced life related to the number of discharged cycles and the depth of discharge DoD limited to 80%. So, practically to implement such a battery as an intermediate storage device double the number and the costs of the EV batteries.

The vanadium redox flow battery (VRB) is an electrochemical cell divided into two compartments by an ionic membrane with acid vanadium sulfate electrolytes in each compartment. VRB has two kinds of electrolytes vanadium-based, supplying the electrolyte V^{3+} in the positive compartment and the electrolyte V^{2+} ions in the negative compartment. Both compartments are connected to storage tanks and pumps so large volumes of the electrolytes, which are defining the energy of VRB, can be circulated through the cell. The electrolytes are pumped through the compartments from two separate electrolyte tanks, see Fig 4. VRBs have many advantages comparing with other storage technologies, including operation over a wide range of power outputs, high storage efficiency, rapid response, low maintenance cost and long lifecycle [23], [24]. Also VRB can offer almost unlimited energy capacity simply by using larger electrolyte storage tanks; it can be left completely discharged for long periods with no ill effects. If the electrolytes are accidentally mixed, the battery suffers no permanent damage. The electrolyte is aqueous and inherently safe and non-flammable.

The VRB also has a short duration overload capacity and a long service life and can be used for power smoothing and load leveling applications. Thus, this relatively new electrochemical technology seems well suited for enhancing the utilization of RES.

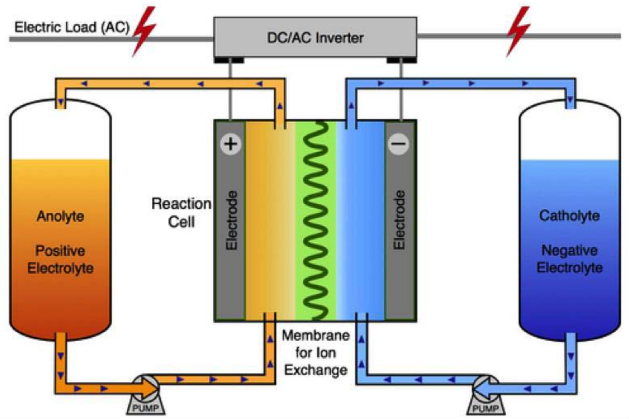

Fig. 4. The vanadium redox flow battery [29]

One disadvantage of the VRB is the power density. Because the solubility of the redox species in the working fluid is limited, the volumetric and specific energy densities are low. Therefore, the development of these systems focuses on stationary applications, like the case in our paper.

The power and voltage range of a VRB depends on the cell stack, while the energy capacity depends on the tank size. This independence between energy and power ratings provides high flexibility in terms of design. These characteristics make VRB suitable for RES based EV charging systems. The VRB technical parameters are given in Table IV [25].

TABLE IV
VRB PARAMETERS

Technical parameters	**VRB-ESS**
Current Output	5kW (112 A) x 4 hours
Output Voltage Range (VDC)	42-56
Dimensions (W x D x H)	0.81 x 1.82 x 2.28 m
Approx. Weight (kg)	3085
Temperature Range (^{0}C)	0 - 68
DC-DC Efficiency, round trip	70-78 %
Performance vs. Temp	Flat response over temp. range
Containment	Double containment of electrolyte storage
Lifetime (discharge cycles)	> 13.000
Depth of Discharge	From full to 20 % state of charge
Recharge Time	4 hours (1:1 charge/discharge ratio)
Speed of Response	1 ms
Overload Capacity	2 x normal rating
Maintenance	Annual inspection if desired

In the Fig. 5 the block diagram of a RES energized system, containing an Energy Storage facility based on pump-turbine system, is shown. The storage system consist in: an electric machine that operates in two regimes (the motor/generator PMSM/PMSG as in Fig.5, or an Induction machine, or DCBL machine, very suitable in low voltage DC bus grids), a bidirectional converter, a reversible hydraulic machine and 2 reservoirs, an upper, UR, and a lower one, LR.

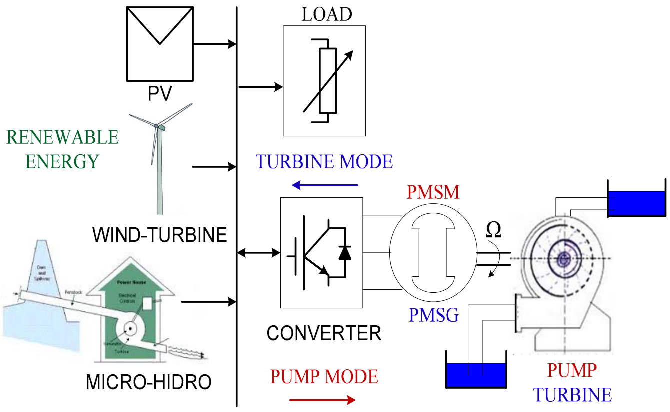

Fig. 5. Pumped storage energy storage system energized by RES [27]

As the wind turbine and the PV based sources are operating at partial powers and the load demand can be also variable (depending of the EV type battery), the available power to for the energy to be stored is variable. The height H between the LR and the HR and the mass of the working fluid is giving the amount of the stored energy, according to the well known definition of potential energy E_P:

$$E_P = m\, g\, H \qquad (1)$$

To run a variable power pump, the best solution from energy consumption or efficiency point of view is to vary the flow of the pump by varying the speed. This is asking for the electronic converter presented in Fig. 5.

As the water as a storage agent is too light and asking for large volume V containers or big H, an interesting alternative is to use heavy liquids. Relative new alternative water based, non-toxic heavy liquids like sodium polytungstate, SPT, solutions are available. With this heavy liquid densities up to 3.1 $g \cdot cm^{-3}$ can be obtained.

Besides its high solubility in water, SPT is non-toxic, non-flammable, odorless, reusable and additionally it has a low viscosity, which helps a lot in a good efficiency of a pumping system [30]. There are other good heavy liquids as candidates of a working fluid. So, considering a 30 kWh energy storage system, it comes out according to (1) with 2 tanks of 1.5 m^3 volume each at a height about H = 7m.

At this moment detailed table about the properties of such a storage solution cannot be offered as it is under research, but it is promising. The certain useful properties of the proposed pumped storage solutions (reasons for the authors to develop the research) are:

- indefinitely long life, as there are no critical components like membranes, stacks;
- system cost low since components have low prices, being mature technical components;
- flexibility in placement and shapes of containers.

V. ESTABLISHING OF A PROPER EV CHARGING SYSTEM DIAGRAM

Taking into account the above discussed considerations the authors of the paper are proposing the following diagram for a RES based EV charging station, see Fig.6.

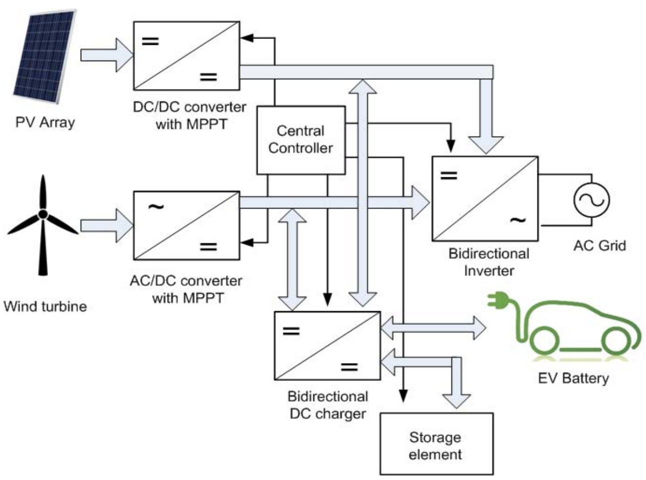

Fig. 6. RES based EV charging station diagram

One can see following the diagram from Fig. 6 the two electronic interfaces of the RES, with MPPT capabilities, able to supply the DC MG, at the established DC voltage. The power of each RES component would be established according to the local conditions. In our study case, The Research and Development Institute of Transilvania University of Brasov, the ratio between PV RES and wind RES is 4/1. The bidirectional charger is charging the EV or/ and the intermediate storage device when it is required. When the EV2G option is activated, the charger is reversing the power flow direction. The bidirectional inverter is used when there is energy from the RES in excess or when the EV2G option is activated. When there is lack of energy in the MG or the prices of the energy from the grid is competitive and the RES forecast is negative, the inverter acts as a rectifier.

The Central Controller has the mission to properly control the operation of the proposed residential RES Based EV Charging System. Due to their variable nature of primary supply and variable structure, it is difficult to properly control such a MG. There are many studies developed in the recent years dealing with the EV chargers. The paper [16] is dealing only with PV based chargers. The authors conclude after studying 117 papers: *For the energy management systems, researchers are highly relaying on optimization algorithms and soft computing*.

VI. CONCLUSIONS

The paper is proposing a practical structure for a RES based EV residential charging station with delivered energy content under 30 kWh. Considered RES are sun (PV) and wind (turbine).

The analysis shows that an intermediate storage device is required to fully satisfy the required functions for an EV charger like power quality, safety of supply and EV2G.

A special pumping storage based solution for the intermediate storage device is proposed and described.

MGs created by these sources in the Smart city, operating connected to the grid or in islanded, can contribute to charge the future EV based transportation system.

The RES based EV residential charging station is a pollution free solution, contributing to reduce the pollution in considerable amount and fulfilling **”The 2°C Scenario (2DS)”** requirements.

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