From Knowledge to Wisdom

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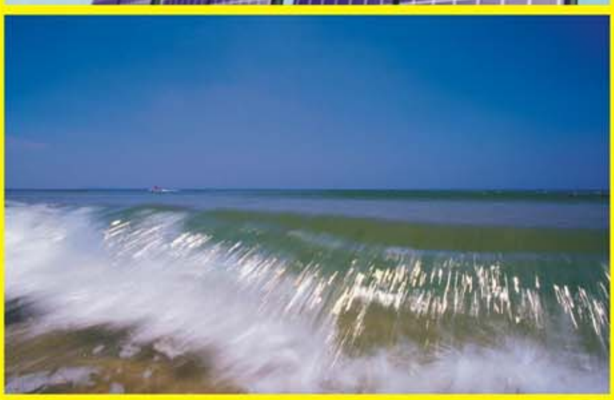

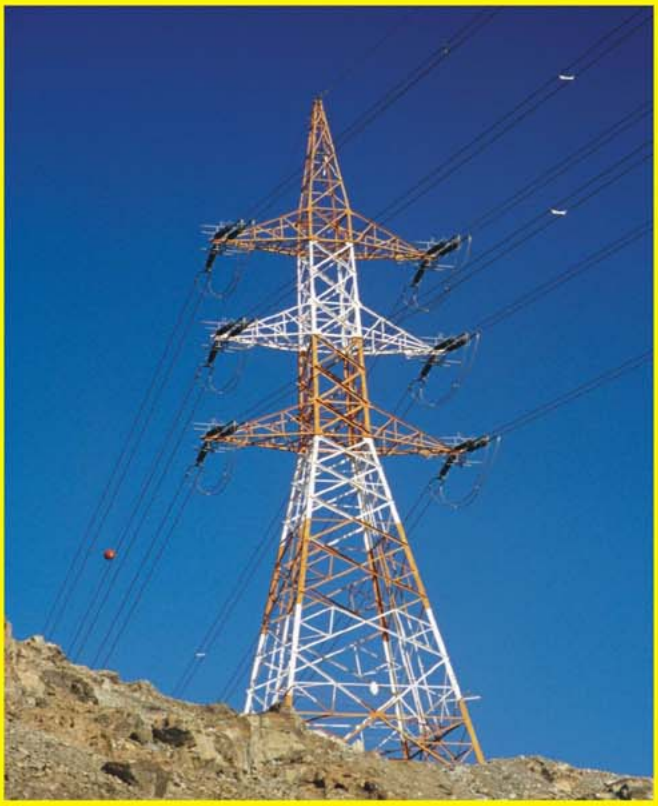

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Smart Solar Charging: Bi-Directional AC Charging (V2G) in the Netherlands

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Abstract: It is to be expected that the number of electric vehicles will be growing in the near future. This trend comes together with the development of smaller decentralized generation units, like PV (photo voltaic). Together with the change on demand side that comes with the global "electrification", this can lead to serious grid congestion in low voltage grids and massive grid investments in solving this congestion. Smart charging can partly solve this issue, but with using a connected EV (electric vehicle) as a small distribution unit, combined with bi-directional charging or V2G (vehicle-to-grid) technology, these investments can be reduced to a minimum. In Lombok, Utrecht, the Netherlands, an innovative pilot was initiated with smart solar charging stations, shared electric vehicles and AC (alternating current) V2G technology. This unique combination proves that EVs are an opportunity for the grid rather than a threat. A unique partnership with OEM Renault was established to develop an AC V2G vehicle product line and work on open standardized communication between the EV, the charging station and the grid.

Key words: V2G, battery storage, electric vehicles, bi-directional charging, OCPP (open charge point protocol), AC grid, DSO (distribution system operator).

1. Introduction

Since its introduction in the Netherlands in 2011 the number of EVs (electric vehicles) has grown to roughly 115,000 by the beginning of 2017 [1]. It is to be expected that this number will be growing even more in the near future. The national government has set an ambition which is that, by 2025, 50% of all new cars sold will have an electric powertrain and a plug, and that at least 30% of these vehicles (15% of the total) will be fully electric. The ambition for 2020 is that 10% of all new cars sold will have an electric powertrain and a plug [2]. All these cars have to be charged at some point, leading to a change in demand side of electricity grids.

At the same time, the traditional energy sector is changing from a centrally bulk production in large power plants, towards a trend of generation small distributed generation units, for instance PV (photo voltaic) systems. Since 2011, the Netherlands had an annual growth of solar generation of 91% [3].

Integration of these new types of systems, such as electric vehicles and PV systems, but also heat pumps and battery storage systems, leads to a different usage of the electricity grid with less predictable energy flows. Both the changes of flows on demand and supply side can result into serious grid congestion in low voltage grids and massive grid investments in solving this congestion.

2. Smart Charging

Grid congestion can be solved more (cost) efficient by using smart charging. Smart charging means charging the car at the proper time, with the proper power to cause as less impact on the grid as possible, but with the e-drivers charging needs to be taken into account. Smart charging is also the way to deal with decentralized produced energy, filling up the batteries of EVs with decentral produced energy which is not

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needed for primary goals at that time.

However, the holy grail of smart charging is not only controlling the demand of the EV. To use the entire flexibility from EVs as a connected asset to the grid, it is necessary to use the energy that is stored in the battery at times the demand is high but production is low, and feed this energy into the grid or its connected buildings. In this way, the power in the battery can be used to improve the quality and stability of the grid.

Smart charging using a connected EV as a small distribution unit means grid investments that can be reduced to a minimum. But discharging the cars battery may have other appliances such as peak shaving, pricing, back up capacity.

All these appliances [4] start with a form of controlled charging. To be more specific, the load is controlled so that the electric vehicle is only charged with a surplus of solar power (shown as Fig. 1).

With peak shaving as seen in Fig. 2, solar production is stored to later reduce the peak load to the grid.

In a system with variable pricing, solar energy can be stored and only used at times when electricity from the grid reaches a profitable price. This is called pricing (shown as Fig. 3).

3. Vehicle-to-Grid

The true holy grail of smart charging is bi-directional charging or V2G (vehicle-to-grid). Smart charging might also have a back-up function in the appliances above when V2G is integrated. Below is an illustration of solar production stored and used as a back-up solution for grid failure (shown as Fig. 4).

3.1 History of V2G in Europe

The concept of V2G was first described in 1997 by Ref. [5], who argued that an increasing share of electric mobility comes with a large volume of potential battery capacity available for ancillary services. Since then numerous studies have been conducted on the potential of V2G for balancing power systems and supporting the integration of renewable energy.

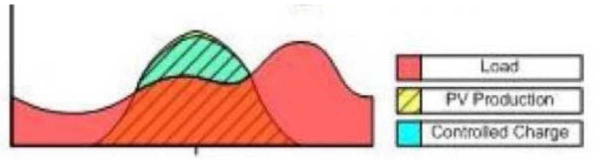

Fig. 1 Effect of controlled charging.

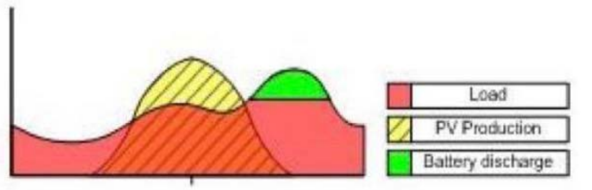

Fig. 2 Effect of peak shaving.

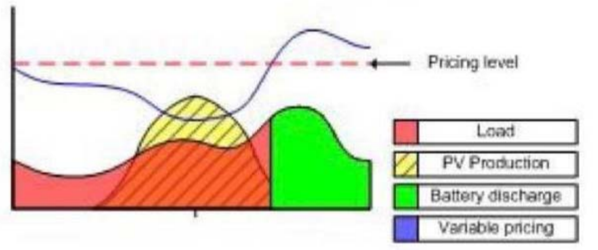

Fig. 3 Effect of pricing.

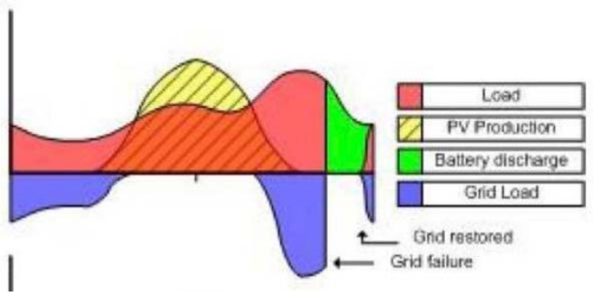

Fig. 4 Effect of back-up.

The time of studies was changed by a big misfortune in 2011. The Great East Japan Earthquake and subsequent tsunami in March of that year caused a meltdown at the Fukushima Daiichi nuclear plant. The subsequent electricity supply shortages and reliance on expensive fossil fuel imports has forced resource-poor Japan to remold its energy system, investing heavily in smart grid technology with the out-come of the first commercial V2G projects to targeted blackouts when shortages occur [6].

Without a sense of urgency such as in Japan, Europe took a little longer to start the first larger V2G projects. In March 2015 the Utrecht region presented a European first that combines developments in the area of electric car batteries and domestic use of stored energy. This storage system, a smart charging station for solar energy produced by Nissan and is based on DC (direct current) technique.

A second project has started by the end of 2016 in Denmark, also based on DC technique [7]. The Parker Project is applying grid-balancing services to a fleet of electric vehicles to demonstrate their potential to support the electricity grid as power resources.

3.2 Choice between AC/DC

The consortium [8] working at Lomboxnet in Utrecht on V2G soon found out that the usage of a DC-system has some major disadvantages compared to an AC V2G system.

To begin with, an average European DC (fast) charging systems have all different plugs, from ChaDeMo [9] to CCS (combined charging system) and the Tesla variety. This is in contrats to an AC charging station. This has one global charging standard (AC) and the Mennekes plug, in principle making this type of charging station suitable for all electric cars. One standard plug means less hassle for consumers, interoperability among stations and increases consumer adoption of EVs. Implementation of bi-directional V2G has also a busninesscase for the carmanifacturer on the component side of things. Less invertors means 15% weight reduction, less cables and connectors and cooling connections [10].

What’s more, this smart charging station is much cheaper than the current DC standard. This savings is achieved through a more compact design, optimization of the technology, lower operational costs on grid connection and large-scale, Dutch production.

In addition, the dimensioning makes this charging station suitable for installation in both public spaces and in any garage or drive. Compare the sizes of the chargers in Figs. 5 and 6. The last, the AC V2G has roughly the same surface as a Dutch curb stone, while de DC is as big as a refrigerator. Moreover, the AC V2G can charge two cars at the same time because it has two outlets, while the DC charger can only charge one vehicle.

4. Test Description and Inputs

Soon after the launch of the DC charging station, the consortium developed the world’s first solar-controlled, bi-directional AC charging station for

Fig. 5 DC V2G charge with a Nissan LEAF.

Fig. 6 AC V2G charger.

electric cars. This was presented on 9 June 2015 as Fig. 7.

4.1 The Practical Scale-Up in Size

Scale-up is very important in this test, not only to make technique more robust, but also to learn about different consumer behavior. This is why a testbed of 20 chargers were installed in the initial phase, being able to charge and discharge 40 EVs. The larger scale up was signed in November 2015 by aldermen of 15 cities neighboring Utrecht (Fig. 8). In this "city deal" the ambition was confirmed to become the first region in Europe with a regional energy system based on the AC V2G-project, requiring a total of 1,000 AC V2G chargers, 1,000 shared EVs and 10,000 new installed solar panels.

This scale-up is partially funded by the European union [11].

Fig. 7 Launch of 1st AC V2G with a BYD E6.

Fig. 8 Signing of the scale-up.

4.2 Architecture of Protocols

In order to work with controlled charging and discharging, there is a need for communication protocols. V2G technology affects the entire communication chain from the vehicle to the charging station, a back office and connected third party back offices. In a recent study [12] the full chain of EV related protocols are presented.

This means that an analysis of the protocol impact of V2G has to be performed and existing protocols are to be adapted to this technology. To ensure interoperability in the future with different brands of vehicles, charging stations and back offices, only open and/or standardized protocols are used and developed in the project.

With the architecture set, also possibilities for roaming and using and providing energy at different locations but from the same energy provider are investigated and developed.

4.3 Open, Royalty Free Protocols

The EV charging station market is expected to reach $12.61 billion USD by 2022, at a CAGR (compound annual growth rate) of 29.8 percent, between 2016 and 2022 [13]. Given the growth trajectory of this market, patent aggression on standards and protocols by companies that seek to constrain innovation and force adoption of sub-optimal proprietary solutions is not unusual.

Royalty free and open source standards and protocols give companies, consumers, governments and other users more choices, ensuring that they are getting the best possible technology for their needs.

The OCA (open charge alliance) hosts the OCPP (open charge point protocol) [14], considered the de-facto standard for charging infrastructure interoperability among charging equipment manufacturers, software and systems providers, charging network operators and research organizations

(Fig. 9). The OCA hosts technical, compliance and marketing workgroups that advance the protocol.

The development of the OCPP is accelerating adoption of electric vehicles as open standards among charging stations increase ease of both charging and billing. OCA expressed its commitment to open source software by joining the Open Innovation Networks patent pool and enabling patent non-aggression in key markets [15].

4.4 Universal Smart Energy Framework

The daily operation and interaction between the actors in Fig. 9 is operated by the USEF (universal smart energy framework) [16]. Central position in USEF is taken by an aggregator. The aggregator is responsible for acquiring flexibility from customers who not only consume electric energy but produce it as well (prosumers). In a next step, the aggregator aggregates this in a portfolio, and offers this flexibility services to different markets and market players [17].

For the aggregator four possible different market players are distinguished [18]:

(1) Prosumer;

(2) DSO (distribution system operator);

(3) BRP (balance responsible party);

(4) TSO (transmission system operator).

For V2G appliances, most interaction will be between prosumer and DSO. The process in the framework starts with a day-ahead load forecast provided by the system aggregator. This is a prognosis based on 96 Program time Units (PTU, 15 min values) and covers the loads and generation which are represented by the aggregator. This forecast will be sent to USEF who will forward this message to the DSO.

After receiving the aggregators' load forecast the DSO completes the load data which are not represented by an aggregator and performs a grid safety analysis. In the grid safety analysis for all predefined congestion points the expected loading is determined for all 96 PTU values. In case of no grid congestion USEF will be informed by the DSO and USEF sends a message to the aggregator that no grid congestion will be expected hence the aggregator can proceed as scheduled. Because per congestion point the available grid capacity is known, it can also be determined how much flexibility is needed to relieve the grid and solve the grid congestion [19].

The combination of a forcasting in USEF, real life monitoring and the use of OCPP enables the system to avoid a load curtailment by charging and discharging with different flexpower profiles.

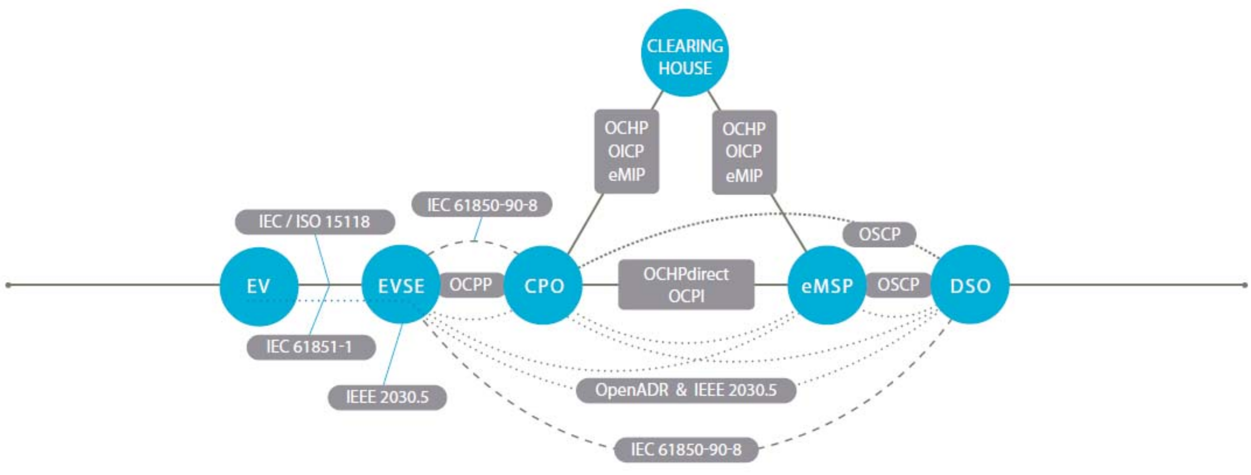

Fig. 9 Overview of actors and related protocols.

4.5 Different Aggregators

Together with a scale up, a widening of scope is also necessary to make a true regional energy system within to open market economy of the Netherlands.

The consortium started with one aggregator [20]. An aggregator manages the charging of your electric car, based on the balance between production and consumption of renewable energy. By selecting the optimal charging moments—when the prices are at their lowest—the aggregator increases the share of renewables in the energy mix. Aggregators are commercial parties who often share the financial reward generated with their customers. The year 2017 will be used to add a second, and maybe a third aggregator to the test, robusting the system. During this same year, research is conducted by the Erasmus University [21] on the possibilities of integrating blockchain to this system.

4.6 Different Suppliers

Next to the integration of different aggregators, different EVs must also be tested. The consortium started innovation with the BYD E6. March 2016 Renault announced they would supply a fleet of 150 Renault ZOE models through 2017 to the city of Utrecht. ElaadNL would handle management of infrastructures and the smart-charge standard, and LomboXnet would take charge of installing the network of unique public charging terminals powered by a 44 kW grid connection. Grid operator Stedin would be involved to balance supply and demand of the grid.

In a second stage, the 150 Renault ZOE models will be changed by AC V2G models, which will be capable of both charging feeding energy stored in the batteries of parked EVs onto the grid to meet demand peaks [22].

5. First Results

Since the test runs from the start in 2015, some first results may be harvested, both on consumer behavior and regulatory issues.

5.1 Consumer Behavior

Most Dutch EVs are not used for about 90% of the time, which makes their batteries available for other purposes. A model was developed by simulating the potential value of V2G for one year. The model used minutely settlement prices of the Dutch RRP (regulating and reserve power) market from 2014 to 2015, along with charging and driving characteristics of Dutch EV drivers. Results show substantial effects of RRP provision in terms of monetary benefits, battery throughput and SOC (state-of-charge) distribution. Provision of RRP resulted in monetary benefits in the range between €120 and €750 annually per EV owner, depending on EV and user category. This is accompanied by increased battery throughput and lower SOC distributions [22].

5.2 Regulatory Issues

It is often said that when the English prime minister asked 19th Century scientist Michael Faraday what the usefulness of his electromagnetic device was, Faraday replied, “Someday you can tax it.” True or not true, still this quote is a reality. The sifting from central to decentral energy production, combined with V2G, gives some perverse incentives. For the Netherland the following tax barriers which hinder smart charging are identified [23].

(1) The lack of netting for charged and discharged kWh in case of bi-directional charging leads to unintended double EB (energy taxation);

(2) No adequate EB incentive for efficient use of locally generated renewable energy in combination with smart charging;

(3) No level playing field between public and private charging points; as a consequence, the incentive for smart charging, if any, varies considerably from site to site;

(4) Netting scheme does not provide incentive for

optimising own use by means of smart charging;

(5) Consumption cannot be clustered, neither physically nor virtually; this complicates free choice of energy provider and causes additional administrative burden;

(6) VAT liability for EV drivers upon receiving compensation for providing an EV for bi-directional charging.

Fortunately, there are possible solutions for breaking these tax barriers. Some are short-term possible solutions. For example, storage may be interpreted in regulation as a service in respect of EB in case of bi-directional charging. As such, EB would only be due on net amount of charged kWh by power provider. This may provide a solution for multiple EB taxation in situations with and without netting scheme.

Clarification of netting article should be done: To the extent that netting applies in the context of smart charging that uses storage. As such, EB will only be due on the net balance consumed. It is the government to provide clarity on VAT approach of EV drivers and virtual netting. All these solutions can be fixed on a short term in the regulatory frame.

But also long-term solutions are needed. One of the possible solutions for a slightly longer term includes introduction of a fixed (lower) rate, for charging EVs with renewable energy, in which the service provider can be designated as the taxable subject and the EV driver as user. This will create a more level playing field for charging electric vehicles by means of public and private charging stations. Consequently, the level of the rate will no longer depend on the site of charging. This rate may be applied to offer incentives at peak power demand hours and also provides government with better options for control and insight.

Further (European or even global) study is required to give concrete form and elaboration to these possible solutions, for instance into the question what an efficient level of EB rate is for EVs as users in respect to other consumers. Is an incentive for optimising peak consumption an option? What is the impact of a change to electrification of our national/European fleet on government revenues? Who owns the data needed for tax collection? And finally, what is the impact on position of grid operators and other stakeholders due to amended systems, mitigation of costs of grid upgrades?

6. Conclusions

Energy transition, new techniques, behavior but also regulations, to speed these up we need an open market, with open protocols which are royalty free. Besides solving technical issues such as standardization, much attention has to be paid on involving the customer, building a (financially) sustainable business case.

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