Future System Services Provided from Electric Vehicles

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Abstract – **This paper describes the needs and possibilities of interaction between charging of electrical vehicles and the electrical system. Barriers to be treated and necessary communication is discussed.**
Keyword component; Electric vehicle, smart charging, interaction, barriers, communication.

I. Introduction

The electric power system sees a new & increasing load via charging of electric vehicles. Today (2018) this is foreseen to grow in intensity. Due to high per capita electricity consumption in Sweden it is expected to be about 10% of additional new electric energy consumption if all cars, buses, and trucks will be electrified.

With Electric vehicle (EV) charging a new type of load is introduced having characteristics different from conventional loads that have been used up to now. Differences relate to power consumption, duration, similar point of time of operation, control abilities, as well as potential flexibility.

This paper mainly relates to power levels of charging where there are good possibilities of controlling charging power and when to charge. While fast charging priority is "as fast as possible", the possibilities are more limited to deliver system services, but might be an option at ultra-fast charging possibilities.

The aim of this paper is to give input to further discussions from a perspective of the electrical system on what happens if we introduce uncontrolled charging and how to improve the interaction between the electrical system and the EV. Some obvious topics are benefits that might be attained from EVs in the electrical system, and how to introduce a system that includes future end users in a way that supports all stakeholders in the electricity system. As "end users" we include both users of EVs and other users of the local electrical installation including also prosumers. In the described "electrical system" we include the end user installation, because we believe it has a key role in the interaction.

Some actors are not included in the electrical system , e.g. e-mobility operators, aggregators etc. that are not discussed in this paper but might have a role in the future support of different stakeholders. This paper focuses at the electric properties and the basic information needed to control the electric system with high transparency and freedom of choice for the end user.

II. Paper outline

The paper is organized as follows: Section III contains prerequisites for the discussed matters by describing how EV charging influence the electrical system, expected benefits of interaction between EV charging and the electrical system, and barriers for interaction. Section IV describes matters that are related to how to design a system for interaction between EV charging and the electrical system. Section V makes remarks on treated issues/subjects and sketches future work and finally section VI contains conclusion of the paper.

"The electrical system" in this paper is defined as containing Generation, Transmission, Regional grids, Distribution grids and the end user´s installation behind the electricity meter.

III. EV charging interaction with the electrical system

A. *EV charging influence on the electrical system*

Table 1 shows areas of interest at EV charging in the electrical system at mass introduction of EVs. Since the total consumption from EVs might be concentrated in time to already existing peaks in consumption, for instance in the afternoon at 17-19 it is of high interest to plan and shift in time this new load. Problems may occur both in the electrical system and for the EV to be charged itself. The situation might be problematic if we introduce uncontrolled relative fast charging to a large portion of EVs and there are no measures to handle this. By identifying and handling the potential problems there is however a possibility to turn them into potential solutions at the introduction of frequent EV charging [1], [2]. But also, for the coming situation in the electrical system when conventional end users convert to prosumers and at introduction of more fluctuating generation.

The time perspective of need for interaction between EVs and the electrical system is "within a few years", i.e. from now, but with focus at widespread implementation in 2020-2030 when EVs are expected to be much more common.

TABLE 1 MAJOR FOCUS AREAS FOR INTERACTION BETWEEN EV CHARGING AND THE ELECTRICAL SYSTEM INTRODUCTION OF EVS.

	Possible negative influence by EV charging on the electrical system			
Characteristics of uncontrolled EV charging	**Generat-ion**	**Regional grids**	**Distribu-tion grids**	**End users wiring**
Simultaneous load pattern in time	Overload regulation market. Overload Day market	Overload, capacity restriction	Voltage sags, Overload, capacity restriction	Voltage sag
Increased power need	Overload regulation market. Overload day market	Overload, capacity restriction	Voltage sags, Overload, capacity restriction	Overload, capacity restriction, Voltage sags, Harmonics, High grid costs caused by peaks
Asymmetrical loads (AC)			Overload	Overload, capacity restriction
Harmonics (possibly)				Overcurrent in the neutral (N) if weak wiring

B. What do we want to attain?

By interaction between the electrical system and EV charging, benefits can be attained by generation, grid and end user.

Generation benefits:

- Production planning
- Emergency power as a global system service (by charging control or by reversed power flow)
- Primary frequency control as a global system service (by charging control or by reversed power flow)
- Peak shaving (by scheduled charging)

Grid benefits:

- Peak shaving locally and regionally (by scheduled charging).
- Support to the local installation and/or the distribution grid (by reversed power flow)
- Voltage support (by support of reactive power, by the chargers converter and by flexible charging in time)
- Even out unbalanced phases and peaks on one single phase (by dynamic current control)
- Balancing to avoid regional and local bottlenecks as a regional and local system service (by scheduled charging)
- Voltage control as a local system service (by signals from the grid to selected end user/users along each distribution line).

End user benefits (EV user, site owner):

- Local load-shift in order to use the subscription locally in the most optimal way to reduce the grid fee and to increase the availability of electricity. (by load shift by adjustments of power, time and phases)
- Confident charging (main fuses dos not break. Handeled by dynamic current control)
- Secure energy for charging (Enough transferred electricity guarantees that the EV is always charged when needed)
- Peak shaving (by scheduled charging)
- Prosumers local optimisation (by local energy management system)
- Co-ordination with other local loads (by local energy management system)
- Convenient, reliable, quick, at-time charging (by controlled charging by local energy management system)
- Possibility to sell primary frequency control
- Possibility to participate in microgrids

Some system properties of interest:

- Not more communication exchange than necessary
- Decentralized decisions by the end user increases the end user satisfaction
- Possibility for end users to use service providers to handle the local system of the end user
- Centralized overriding control might be necessary in special situations, e.g. if there are capacity restrictions.
- Local standalone systems possible
- Low complexity
- High customer flexibility of choices of behaviour

- Common information topology and Communication protocols
- Incitements for end user behaviour
- Future safe solutions for coming needs

C. Smart charging

Smart charging of an EV can be described as when **the charging cycle can be altered by external events, allowing for adaptive charging habits, providing the EV with the ability to integrate into the whole power system in a grid- and user-friendly way.** To achieve those goals in a safe, secure, reliable, sustainable and efficient manner **information needs to be exchanged between different stakeholders**.

It is important to mention that both EV charging and other local electric equipment are both of importance to handle together if we want to integrate in a "grid- and user friendly way". This is attained if we optimize EV charging and other electrical equipment together.

Advantages when also including the local system downstream to the electricity meter are:

- Both EV charging and other local electrical equipment are coordinated to optimize the total end user experience (EV user and building user).
- Both EV charging and other local electrical equipment are handled and treated together in the interaction with the electrical generation and distribution system. This will facilitate smooth shift over to effective interaction with future end users/prosumers including a mix of different kinds of loads, storage and local generation.
- Smooth control model by Electricity system (generation/sales/distribution) send prerequisites (near time price schedules) to end user site that optimize its behavior using received information together with current contract and tariff.
- External overriding control model might also be used at special situations of capacity restrictions, including end user´s contract and preferences by local settings.
- A system open for on-site optimization both by end user´s own system or by services offered by external actors.
- The end user can choose according to own preferences the behavior of the whole local installation, e.g. the priorities of EV charging and use of other equipment respectively, or how to interact with the grid.

D. What barriers exist?

- **Distribution tariffs** with enough incitements for demand-response. Present distribution tariffs mirror today´s load profiles. With high penetration of EVs, the distribution grid have to be protected against overload e.g. to avoid massive costs for strengthening the grids and customer issues. Much more flexible distribution grids tariffs might be a tool together with new type of contracts in the whole range between fully flexible tariffs to fully fixed tariffs reflecting future distribution costs of a relevant re-investment cost/time perspective for EV charging of alternative power profiles and power levels.
- **Energy and power tariffs** with enough incitements for demand-response. Field tests has shown that only demand-response energy tariffs might not give enough incitement to change behaviors.
- **Standards for communication and power transfer between the EV and the charging station** are in place, but under further development. ISO15118-series *Road vehicles – Vehicle to grid communication interface* and IEC61851-1 *Electric vehicles conductive charging system - General requirements*.
- **Standards for communication between charging station and backend of service providers** are under development, the IEC63110-series, *Protocol for Management of Electric Vehicles charging and discharging infrastructures*. However, we need further development to also handle other kinds of local equipment than only EV charging stations, enabling local optimization of the total local electrical installation and its functionality.
- **Standardized communication** from the electric grids or the electricity provider to send overiding control signals to the local installation as well as price schedules in a way that enables efficient demand-response functionality.
- **Real time information on tariffs and short-term forecasts** from the distribution grid and the electricity provider to end user, needs to be developed in order to transfer power in both directions.
- **Negotiation mechanism** (if required) between customer site, distribution- and electricity provider to be developed. However, negotiation might be too complicated at a large numbers of end users that need individual treatment.
- **Availability of local site power/energy management systems** handling local electrical equipment altogether (EVs, other loads, local storage, local generation) and interacting with the external electrical system.
- **Lack of distribution grid control systems and strategies** to guarantee each end user, along a specific distribution line appropriate voltage level when the need for power is larger than the rating of the actual distribution line (it may be of interest to divide the total load between the end users to avoid unfair availability of power).
- **Possibility to convert every end user site contract** to a potential prosumer with requirements on the aggregated qualities of interaction with the

distribution grid by all equipment of interest (e.g. controllable loads, uncontrollable loads, fixed or dynamic loads, electrical storage, electrical generation).

- **Technical and economic factors** may limit the range of possible solutions of end user services to the grid. Examples: Requirements of short response times to the regulation market, optimum placement of electrical equipment (more or less decentralized), control of many loads with similar behavior, complexity of negotiation with a large number of charging sites/end users for optimum distribution grid function and generation, availability of systems minimizing the communication needs between the electricity system and the EV charger/end user, systems for giving appropriate control input data to every single end user in a distribution grid in order to handle local overload/voltage drop in every part of the distribution grid etc.

IV. AT WHAT SYSTEM LEVEL DO WE WANT TO HANDLE INTERACTION BETWEEN ELECTRICAL SYSTEM AND EVS?

A. What do we wish to achieve, and in which way?

Here we delimit to a technical perspective. Measures to handle problematic situations for the electrical system and for the EV may be handled by different measures (measurements, communication, analysis, control equipment) located at different places in the system.

The optimal placement of measurements for control and control equipment is a question of a range of different aspects, e.g. technical, economical, functional, robustness, safety, security etc. A main subject is if the steering model should be centralized or decentralized.

Types of controls and topics to be observant on:

- **Frequency control** – How to avoid instability caused by similar charging behavior by algorithms. Also latencies in communication and components might be of importance. A large number of decentralized equipment might be more complicated to control than a few centrally placed in the electricity system.
- **Balancing of asymmetric charging** – Is this only a question of interest inside the end users installation or will the load also be asymmetrical in the distribution grid? Should asymmetric loads be handled by the EVs or inside the end users installation by special equipment?
- **Providing of reactive power** – Should the EV (not standard) or other equipment close to the EV provide reactive power if possible?
- **Elimination of harmonics** – The EV shall follow EMC standards, but how to handle possible harmonics that might exist in special situations, e.g. many EVs connected close to each other or in weak end user´s wiring.
- **Avoidance of too high charging power** (current) – This might be highly dependent on the design of the end user´s installed electrical equipment, control possibilities and the design of the present contracts regarding handling of power consumption.

B. EV – One function/load/appliance beside other electrical appliances/functions – The local site installation has a key role.

Instead of talking about EV charging, we should talk about the properties of the local system (including EV charging):

- Controllable loads
- Uncontrollable loads
- Dynamic/fixed loads
- Storage (electrical)
- Local generation

"The needs for buying or selling electricity to the electrical system" is the important information to communicate. Then forecasts about power and time is of interest. What type of equipment used (e.g. EV) is not the main importance on what information to be transferred, but it is of importance for understanding what services might be delivered to the electrical system.

This results in possibilities to use electricity from the electrical grid or to provide electricity to the electrical grid at different times.

C. Necessary communication – minimizing content, flexibility

Some alternative control strategies:

1. Demand-response by price signals and different possible tariffs within the whole range between fixed price to fully real time pricing.
2. Demand-response by overriding central control (in the event of supply limitation).
3. A mix of price signals and firm control
4. Totally decentralized local control dependent on local measurements
5. No dynamic control at all (only by fixed strongly progressive tariffs)

In the first three strategies information from the grid to the end user energy management system is necessary to give incitements to control or to force the end user into behave in a certain way. One way communication to the end user might be sufficient if geographical information on the relevant receivers is included, e.g. geographical IDs to tell which end users that should react on the signal. Bi-directional communication and negotiation might be too complex with a large number of end users, and is probably not necessary.

The fourth strategy might be the most relevant for regulation power. Control is done by local frequency measurements and algorithms (that might be updated by one way communication). The fourth strategy might also be relevant for local voltage control in the local distribution grid but might need some local coordinator to guarantee that all end users along a local distribution line get enough electricity.

The fifth alternative doesn´t need any technical communication system, but need carefully designed tariffs to avoid any problems in the electric system.

V. REMARKS AND FUTURE WORK

A. Remarks

Electricity companies should be more active in development of IEC standards of importance for the electricity system at EV charging. Standards of interest are standards for communication between local electrical equipment (e.g. charging stations and other end user equipment) via a local energy management system to an external backend service supplier. It is of importance that this communication can take in the information and formats of interest for the electricity companies.

A probable issue to be noticed is the risk that end users upstream in the distribution grid use too much power so that the end users further downstream get less power due to voltage drop along the feeder impairing the possibility to charge.

B. Future work

Need for further work:

- Introduction of grid tariffs that reflect future grid costs as a function of expected charging behavior in the expected electrical system.
- Development of customer site energy management systems that can handle the end user/EV user preferences.
- Develop communication between building energy management system and EV with enough capabilities to support both the EV, EV user and the end user site with enough information to plan and optimize the local electrical functionalities.
- Communication standards for EV charging involved in interaction with the electrical system should be designed to enable communication that is relevant for the grids and can be smoothly integrated.

VI. CONCLUSION

If EVs are to be charged with more than 10/16 amperes there is a need for implementation of interaction between end user installation and the electrical system to guarantee that the electrical system will not be overloaded. There are benefits for all parties within the electrical system as well as the EV user to get reliable and convenient charging at time.

Treat EV-charging as other inverter connected electrical equipment among other loads at. the end user´s site. Utilise auxiliary services that the EV can provide, as is becoming other inverter based network loads like home PV with battery systems.

Enable total optimization of the whole end user´s site to 1) avoid congestion problems inside the end user´s site and in the grids, 2) optimize the functionality and economy, and 3) be able to include all end user´s electrical equipment to interact with the electrical system.

Minimize the communication needed between the customer site and the electrical system by 1) broadcast distribution price signals/price forecasts to each end user´s site, 2) establishing end user contracts allowing an individual mix of "real time pricing" and "fixed tariff".

Direct the communication to the relevant end users by sending control-, network congestion and/or price signals.

Controlled charging is a major key to avoid overload in the electrical system. There is a need for starting planning the implementation of interaction between EV charging and the electrical system to be ready when the expected high volumes of EVs are coming within a few years.

VII. REFERENCES

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IX. BIOGRAPHY

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