MEASUREMENTS OF NETWORK IMPACT FROM ELECTRIC VEHICLES DURING SLOW AND FAST CHARGING

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ABSTRACT

Electric vehicles (EV) are by many seen as an integral part of the transformation to a green economy, and are thus expected to increase in number. The charging of EVs is a new challenge to distribution networks and the possible impact of EV charging has recently come to the attention of network companies. This paper presents high resolution measurements of the network impact from EVs during slow and fast charging and some conclusions based on what the measurements indicates.

INTRODUCTION

Electrification of transport is seen by many countries as an opportunity to reduce the dependency of oil, reduce global and local emissions and thus improve the health of inhabitants. Norwegian authorities have introduced strong incentives promoting electric vehicles and a resource group appointed by the government concluded on a goal of 200 000 electric vehicles in Norway within 2020. The total number of electric vehicles and plug-in hybrid vehicles in Norway passed 10 000 by the end of 2012 (less than 400 plug-in hybrid), three times the number in 2010. In 2012 4 358 new electric vehicles were sold in Norway. The share of electric vehicles compared to total amount of vehicles sold is higher in Norway than in any other country (2011) [1].

Although electric vehicles must be considered as being at an early stage, Norway has come quite far in encouraging use of such in an extensive incentive system. The following incentives apply for electric vehicles in Norway [2]:

- No import tax (High import tax for fossil fuel vehicles)
- No value added tax (VAT)
- Very low annual road tax (between 10 and 20 % of fossil fuel vehicles)
- Free parking in public parking places
- Free charging at public charging stations
- No toll when driving through toll stations
- The privilege of driving in the bus lane with busses and taxis
- No charge/toll for the car on national ferries (only pay passenger rate for driver)
- Increased mileage allowance in the public sector
- 50 % discount on company car taxation

The increasing number of electric vehicles has made Norwegian Distribution System Operators and energy companies more aware of both business opportunities and challenges following a large scale electrification of the transport sector. Such possible challenges include overloading of network components and reduced power quality for end users due to charging of electric vehicles. There were 3 746 public available normal (slow) charging stations and 70 public available fast charging stations in Norway by the end of 2012. In some of the largest cities the number of charging stations grows at a rate of 20-30 % per year.

Theoretical contributions and simulations on EV's impact on distribution networks are numerous [3]. This paper presents detailed real-life measurement results from voltage and current measurements performed during charging of electric vehicles (both slow and fast charging). The measurements are performed on different types of electric vehicles and on different charging technologies. The results show that the vehicles have different signatures and thereby different impacts on the connected low voltage network.

MEASUREMENT SYSTEM DETAILS

The measurements in this paper have been performed with a power quality measurement system, recording the continuous waveform of 3 phase voltages and currents with a resolution of 1024 and 512 samples per 50 Hz cycle. This makes it possible to view most parameters with as high time resolution as cycle by cycle values in addition to be able to view the actual waveform at any point/time in the measurement.

NORMAL/SLOW CHARGING

Normal charging of electric vehicles usually involves a charging interval of 5 to 8 hours from empty to full traction battery for most electrical vehicles available on the market the most recent years. This is normally performed in the car owner's home/garage, at public charging stations in shopping/business areas or at parking lots at work where employers supply their employees with such opportunities. Normal chargers are in Norway connected to a single phase 230 V outlets with 10 to 16 A fuses. Measurement results from slow charging of three different EV models are presented here.

Measurements

Advanced electrical measurements have been performed on 10 different electric vehicles. A few of these are from the same type of car with the same configuration of traction battery (battery type and energy capacity) and charger. This was practical for verifying the charging pattern (charging signature). There were 5 different electric vehicles in terms of different configuration of batteries and chargers. Charging patterns from 3 of these 5 are shown in this paper. None of the electric vehicles have a completely rectangular load profile as power simply being turned on and off. All charging patterns have significant load variations during the charging cycle. The measurements are performed in the point of connecting the electric vehicles charging cable to the charging outlet.

Electric vehicle A

Measurements from a charging cycle of vehicle A is presented in Figure 1. Electric vehicle A represents a quite good and stable load considering voltage quality. The load (power/current) during the charging cycle is however not completely rectangular, simply switching on and off to a predefined power level (as in the typical simplified presentation of EV charging). First of all, it seems like charging of electrical vehicles in some cases includes at least 1 charging pause, possibly due to battery status check (battery management system, BMS). The reason for the charging break (observed in several cars) has not been investigated and verified. Second, the load decreases towards the end of the charging cycle as the traction battery gets close to being fully charged. Voltage variations are limited during this charging cycle and both flicker values and harmonic voltages are moderate to low.

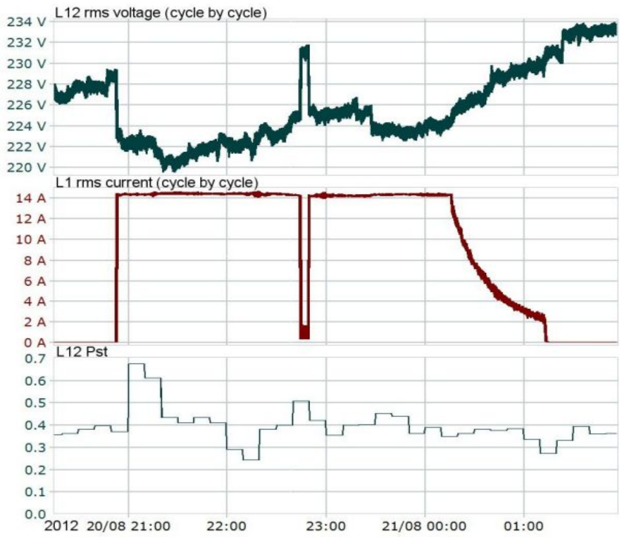

Figure 1: Load current, voltage variations and flicker level (Pst) during charging of Electric vehicle A.

Electric vehicle B

Measurements from a charging cycle of vehicle B is presented in Figure 2. This electric vehicle represents a voltage quality challenge when the car is being charged from an outlet (point in the network/installation) with low short circuit capacity. The charging cycle load pattern can best be described by two charging stages with full power in the beginning and somewhat reduced power the last few hours. In both these two charging stages there is quite many short duration charging breaks where the load drops to zero. This causes several fairly large rapid voltage changes and a moderate impact on the flicker level of the installation where the electric vehicle is connected if the electric supply has a low short circuit capacity. Low short circuit capacity in this context is considered as twice the network impedance (or more) of the reference impedance [4]. Flicker from the lighting equipment was reported as annoying in the garage where the car is connected for charging. Visible flicker was however less evident (though visible) from lighting equipment in the rest of the electrical installation of this residential home.

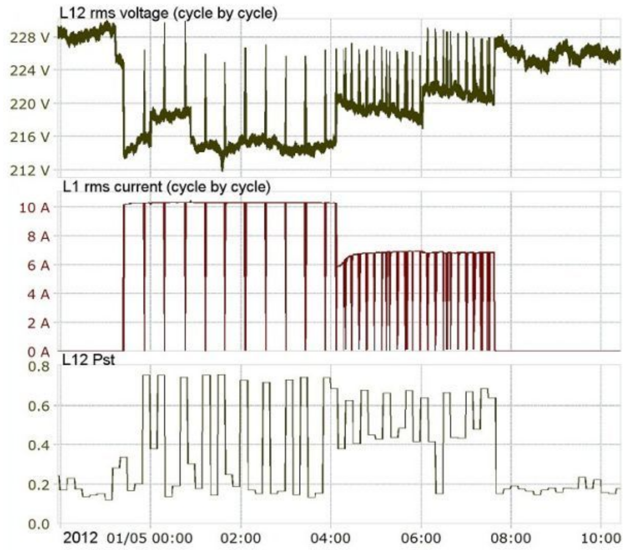

Figure 2: Load current, voltage variations and flicker level (Pst) during charging of Electric vehicle B

Electric vehicle C

Measurements from a charging cycle of vehicle C is presented in figure 3. With respect to voltage quality this car was the most challenging one of the different electric vehicles measured. It was not the main charging cycle that may be a concern rather the maintenance charging. When the main charging cycle is finished the charger continues with maintenance charging of the traction battery until the car is unplugged for driving.

During the main charging cycle this electric vehicle's contribution to voltage disturbances is low for both flicker and harmonics and moderate for rms variations. However, maintenance charging (puls charging) of this electric vehicle is causing a large number of fairly large rapid voltage changes and a large contribution to the flicker level from one single load. This electric vehicle will, like vehicle B, have potential to cause unacceptable local voltage quality for end-users where short circuit capacity is low (poor).

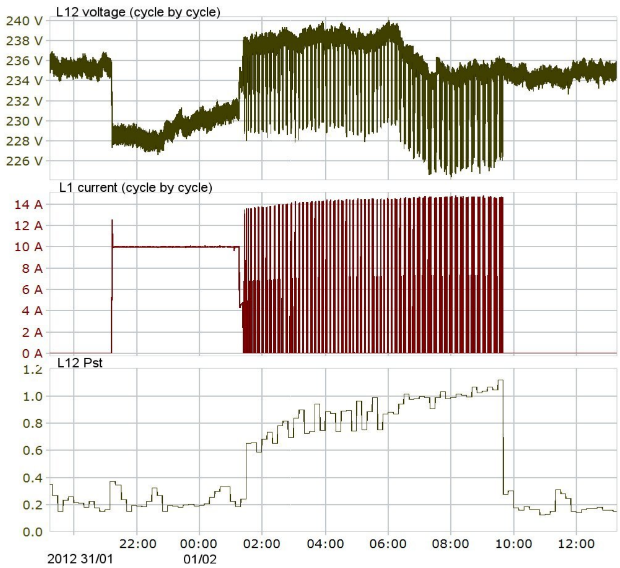

Figure 3: Load current, voltage variations and flicker level (Pst) during charging of Electric vehicle C.

Large scale charging and coincidence factor

Measurements are also performed on a charging location in the City Centre of Trondheim, Norway with 15 outlets for charging up to 15 electric vehicles at one phase 230 V 16 A. Figure 4 show the load pattern with a significant "working day pattern" and almost no load during weekends. Figure 5 shows the typical load distribution during a working day. Unfortunately the maximum load from these 15 charging outlets coincides very much with the existing late afternoon/evening peak load of the power system in Norway [5].

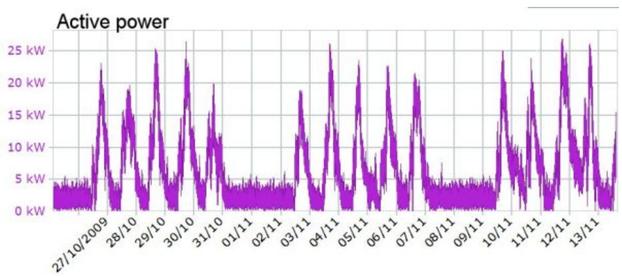

Figure 4: Power drawn by an EV pool of 15 vehicles over a period of three weeks.

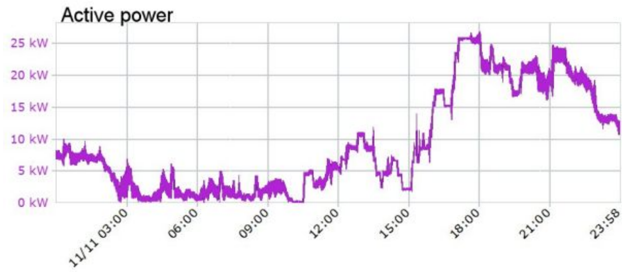

Figure 5: Power drawn by an EV pool on a typical day. The peak load occurs at 5 PM.

FAST CHARGING

The fast charging stations are available at a rapidly increasing number in Norway, mainly in and around the largest cities. Maximum current from the already available fast charging stations is typically 70 A and the charging stations are usually connected to strong 400 V supplies. Measurements have up to January 2013 been performed at two different locations.

Measurements

Figure 6 shows the active power drawn by the fast charger in location B over one day. The measurement indicates significant variations in the charging signatures from different electric vehicles also at fast charging. Different charging duration is expected as vehicles can have very different levels of remaining energy when being connected for fast charging. There are however also significant differences in the maximum power and rate of power decrease throughout the charging cycle. The largest observed power drawn is close to 50 kW.

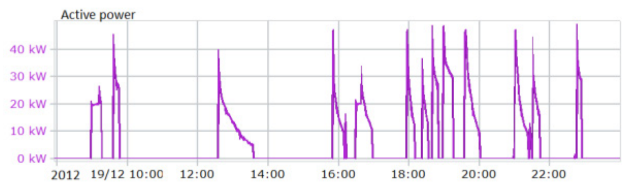

Figure 6: Power drawn from the EV charger at location B during a typical day.

A fast charging cycle from location A is presented in Figure 7. The charging cycle starts at 48 kW for one minute before the charging power starts declining. At the end of the charging cycle (after approx. 33 minutes) it draws a power of 12 kW. It is observed that the EV charger normally operates with a power factor of 0.9 capacitive. At the maximum load, the charger delivers 7.5 kVAr, declining to 5.5 kVAr at the end on the charging. The voltage quality impact seems to be minimal for both the mentioned fast chargers. The total harmonic distortion (THD) in the current is relatively low, around 4 %, and no significant effect of the charging can be observed on the voltage THD.

Figure 8 shows a charging cycle from location B with a different charging signature than the one in Figure 7 (location A). This is because the signatures are from two different types of vehicles. The electric vehicle charging in Figure 7 typically has a maximum load of 45-50 kW while the electric vehicle charging in Figure 8 has a maximum load of typically approx. 20 kW.

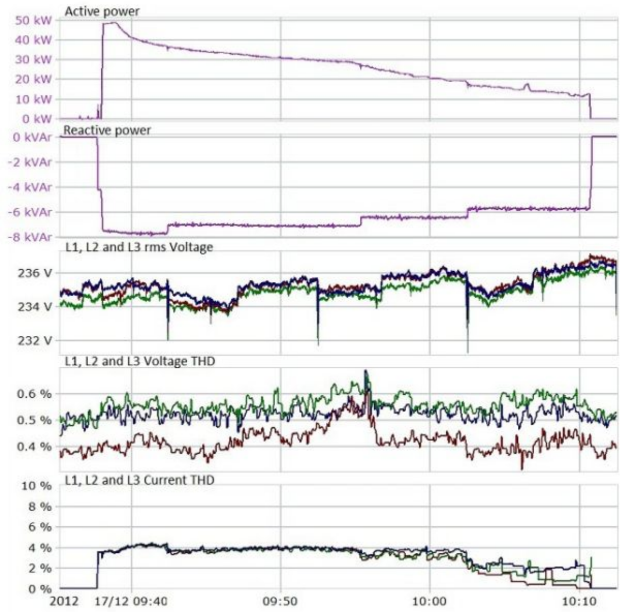

Figure 7: One EV fast charging characteristics in location A. The RMS value and THD of the voltage is not significantly affected by the charging current.

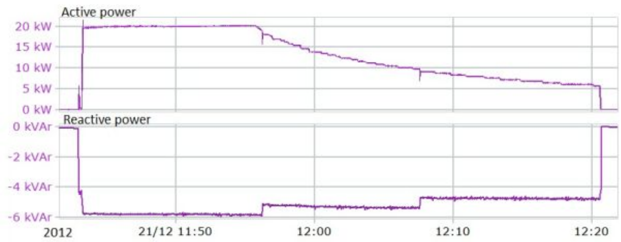

Figure 8: One EV fast charging characteristics in location B. In this specific case power is limited to 20 kW (by the car).

DISCUSSION ON NETWORK IMPACT

The measurements presented in this paper indicate that charging of electrical vehicle can be a challenge and cause poor voltage quality in locations with a weak grid. The charging signatures vary greatly between different types of electrical vehicles in particular for normal/slow charging. The most challenging charging signatures should and could easily be avoided if the manufacturers of electric vehicles have focus on the vehicle not being an unnecessarily disturbing load.

With strong grids/networks neither normal charging nor fast charging should be a cause for local voltage quality problem. Thorough planning by the network operator is very important before installing fast charging stations. Both fast charging stations presented in this paper are connected in strong networks.

The coincidence factor of large scale charging of electric vehicles might be a reason for concern and smart charging to minimize additional load during existing peak power hours should be taken seriously. During some of the coldest winter days in Norway the last four years peak load situation have been close to critical in several areas of the Norwegian distribution system. Large additional loads due to future large scale charging of electrical vehicles during peak load hours might become very costly if they trigger large network reinforcement costs.

ACKNOWLEDGMENTS

The results presented in this paper have been made possible due to all the participants in the Ecar project. We would also like to thank Transnova, NTE Nett AS and BKK Nett AS for additional support for measurements on electric vehicle fast charging stations.

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