INTEGRATION OF ELECTRIC VEHICLES TO THE DISTRIBUTION GRID

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ABSTRACT

Electric vehicles (EVs) charge their batteries with power from the grid. As EVs get more common, their impact on the distribution grid will increase. This paper reports the results from a study that investigated the load pattern from EVs. Power and energy measurements were carried out to establish load characteristics. Power quality measurements were also performed. For the specific case studied in a strong urban grid, the power quality performance was well within the limits given in the Norwegian Power Quality (PQ) Code.

INTRODUCTION

In Norway, there are many incentives that are promoting EVs. They have no taxes or annual fees. Toll roads, ferries and parking are free, and driving in the bus lane is permitted. Today, in 2010, only about 0.1% of the Norwegian vehicles are electric [1-2]. It is expected a substantial influx of EVs and plug-in hybrids over the next decades and the power companies, especially the Distribution System Operators (DSOs), should prepare for this development.

Charging of EVs will be a new contribution to the load in the electric grid. EVs are today charged at home over night or at work. The expected cost impact will mainly be experienced in the distribution systems as the energy impact is not severe compared to the normal load growth in Norway. An increased EV load may cause local problems in areas where the distribution system already is heavily loaded and in weak grids. A study has been carried out that focus on EVs as load in electric distribution systems. Only full electric vehicles were considered. Energy, power and power quality measurements were carried out on a car pool consisting of 15 cars of type *Think City*. They charge in a garage in downtown Trondheim. The vehicles are reserved for use by municipal employees during their working hours. The results are reported in this paper.

APPROACH

The EV loads were investigated by using energy and power quality measurements. Two different measurement instruments were used.

- Energy meters were installed at each of the 15 outlets, called charging stations.
- An advanced power quality measurement instrument was installed at the common point of the charging stations.

The energy meters measure the active power for the load with one minute time resolution. By analyzing the data, daily load profiles for a single charging station and the entire car park are investigated. Annual duration curves are established as well as parameters such as coincidence factors and utilization times.

The advanced power quality measurement instrument collects waveforms for all currents and voltages and can report all relevant load and power quality indices such as active and reactive power, harmonics, unbalance, transients etc. The results were used to investigate the power quality of supply at supply terminal to the electric vehicles.

MEASUREMENT INSTRUMENTS

Power Detective

The energy meter Power Detective from the Danish producer SL Electric was used for the energy meter measurements.

Figure 1: Power Detective from SL Electric[3]

The instrument has the following features [3]:

- Integration period 1, 5, 10 , 15, 30 or 60 minutes
- Able to record loads in the interval 0,2 – 3600 W (max 2% failure)
- Configuration by power line or internet (through router) connection
- Display of kWh, costs, minimum and maximum load plus actual load, current and voltage
- Data are transferred to a data collector unit by the m-bus protocol
- Remote reading by Internet router by TCP/IP 10/100 base T(TX) protocol
- Can be connected to relay for demand response (load management)

Elspec G4500 Blackbox

The advanced power quality measurement instrument that was used is called Elspec G4500 Blackbox.

Figure 2: Elspec G4500 Blackbox [4]

The G4500 has 8 channels that can measure four voltages and four currents: all three phases and neutral. The instrument has a sampling rate of 1024 samples per 50 Hz period and an internal memory of 8 GB. The user selects accuracy between 0.1% and 1%. The amount of data produced is dependent on the accuracy and the level of disturbances. The instrument stores every sampled cycle in a compressed PQZip format which is transferred to a PQScada database for processing [4]. The instrument is therefore not based on the trigging concept where events are stored only when measurements are outside of predefined values. During the measurements, the accuracy was set to 0.2 % for voltage and 0.5 % for current.

ENERGY MEASUREMENT RESULTS

The energy measurements were made with one minute resolution. The energy meters were plugged in for about two weeks.

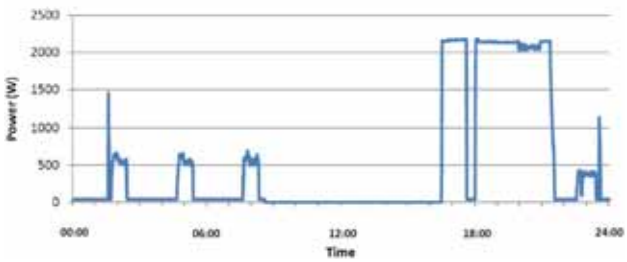

Figure 3: Typical daily load pattern for a single charging station

A typical daily load pattern for a single charging station is shown in Figure 3. A fully charged car is plugged in until 8.30 am. Then, the station is empty until 4.30 pm, when another car plugs in and starts charging. The car is fully charged at 9.20 pm. The total energy consumption is 11.6 kWh. The charging power is about 2.2kW, and is more or less constant. A while after the charging starts, the power drops to almost zero. This is caused by a controller in the car's charging system. According to the car manufacturer, the interruption in the charging is to make measurements on the battery to determine the state of charge.

When the car is plugged in and fully charged, it still draws some power from the grid. The standby power is 35-40W. This is for dashboard lights and other devices on standby.

Think City uses ZEBRA batteries. These batteries use plain salt and nickel as the raw material for their electrodes in combination with a ceramic electrolyte and a molten salt. The specific energy and power are high, so the batteries are suited for use in electric vehicles. The conductivity of sodium-ion is temperature-dependent. To get a sufficient value, the temperature of the battery needs to be between 270 and 350°C [5]. The batteries are placed in an insulated container. When the car is plugged in, the battery is heated with power from the grid. In Figure 3, the peaks around 500-600W are due to heating of the battery. The power varies a lot during these peaks.

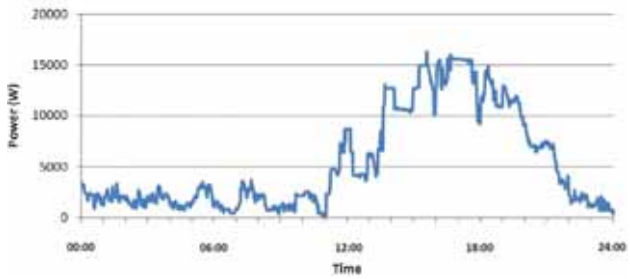

Figure 4: Total load from 11 charging stations

Figure 4 shows the total load for one day for 11 charging stations (4 of the 15 measurement series were incomplete due to data loss). The peak load is 16.2 kW at 3.36 pm. The heaviest load is in the time interval 3.15 to 6.15 pm.

Compared with the single charging station measurement given in figure 3, the coincidence factor *cf*, is calculated.

$$cf = \frac{P_{11,\max}}{11 \cdot P_{1,\max}} = \frac{16{,}2kW}{11 \cdot 2{,}2kW} = 0{,}67 \qquad (1)$$

where

$P_{11,\max}$ – Max. peak load 11 charging stations
$P_{1,\max}$ – Max. peak load one charging station

UTILIZATION TIME

Duration curves were made and utilization times were calculated from the collected data. A duration curve shows the load for one year. As the measurements were made only for one week, they were in principle repeated to construct a one year duration curve. The load from electric vehicles is expected not to be much dependent on the outside temperature. However, the load is lower during public holidays and during summer/winter vacations.

As such periods where not covered by the measurements, the annual energy consumption in reality is lower than estimated. The true utilization time is probably lower than the one calculated in this section.

The calculations were made for one minute time resolution, 10 minutes average and 60 minutes average. Figure 6 shows the duration curve based on 1 minutes average measurements.

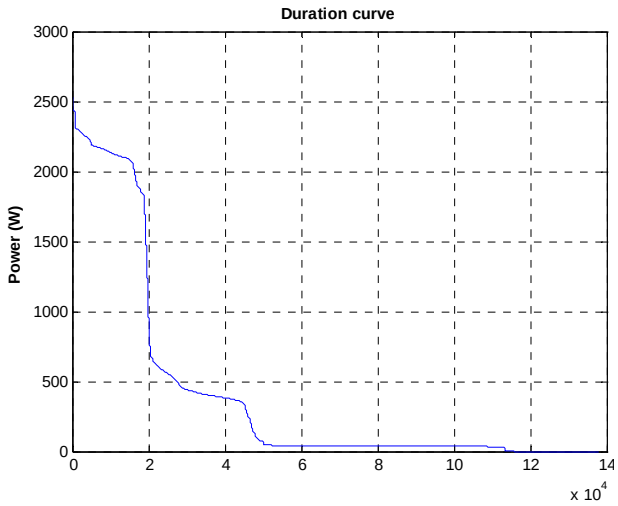

Figure 6: Load duration curve – 1 minute resolution

Table 1 Estimated of utilization times.

Parameter	Time resolution		
	1 minute	10 minutes	60 minutes
P_{max} (kW)	2.530	2.515	2.487
W (kWh/yr)	3610	3608	3604
T_u (h/yr)	1427	1435	1449

As shown in table 1, the time resolution has not a large influence on the results.

POWER QUALITY MEASUREMENTS

The power quality measurement instrument was installed for three weeks. It measured the currents and voltages at the supply terminal for all the 15 charging stations.

A charging station is a large, nonlinear single phase load. It is expected to cause some voltage disturbances, especially unbalance and harmonic distortion. Figure 7 shows the voltage THD between the different phases.

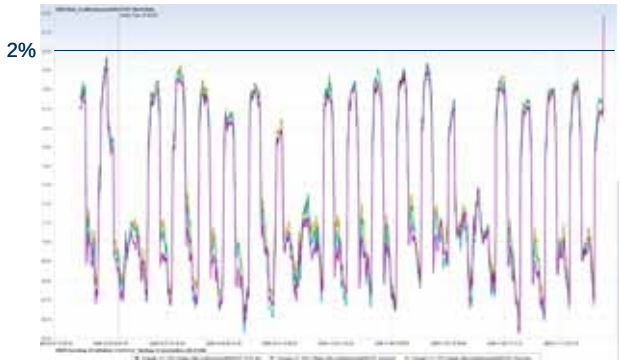

Figure 7: Total Harmonic Voltage Distortion – measurement period 22 days

The voltage THD value stays between 0.7 and 2% which is well below the 8% limit given by the Norwegian PQ Code [6]. The dominant harmonics are 7th, 11th and 13th order. The 7th order harmonics is in the range 0.3 to 1.4%, while the 11th order stays between 0.2 and 0.7%, and the 13th order harmonics is between 0.1 and 0.5%. The PQ code limits for these order harmonics are 5.0%, 3.5% and 3.0% respectively, so the values are well within the limits of the code. The current THD peaks at 6.8%, but most values were below 4%. The PQ code does not give any limits for current THD.

Figure 8 shows measurements of the average voltage unbalance (U_-/U_+). The measurements show maximum values around 0.6% which also is well below the Norwegian PQ Code limit of 2%.

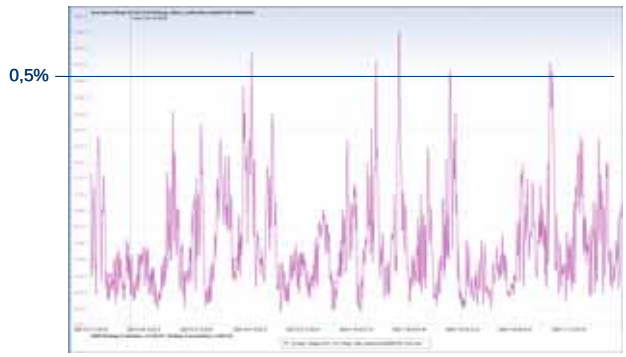

Figure 8: Voltage unbalance – measurement period 22 days

In general the measurements at this site does not show any values close the PQ code limits, but it is observed high values for current harmonics with very short durations.

CONCLUSIONS

This study shows that peak power for the charging stations that were investigated occurs in the afternoon, between 3.15 and 6.15 pm. The vehicles investigated in this study were used during working hours. All the cars were parked and plugged in before 5 pm. A family car will be used more in the evening than the cars investigated here. That will probably shift the peak load from electric cars to a later time by a few hours. The peak power from charging of family cars will most likely occur around the same time as the peak of a family house. The peak power is the dimensioning factor in a power grid. An increase of the peak power will require a stronger grid.

The quality of supply for the connection point of the charging stations was investigated. The power quality was overall good compared with the limits given by the Norwegian PQ Code.

Battery chargers are nonlinear loads. Even so, the values of voltage THD were less than 2% which is well below the PQ code limits. The values for current THD were higher, at most 6.8%. A problem that can arise is symmetry as the chargers use single phase circuits. At times there was a significant unbalance in the supply voltage. This unbalance was within the limits of the PQ code, but unbalance can cause problems if electric vehicles get more common. The DSOs should consider voltage unbalance as a consequence of a large influx of EVs and do measures to reduce the impact of charging on the grid.

It should be emphasized that the charging stations that were investigated are located in the city centre of Trondheim where the grid connection is strong. In rural areas with weak grids, installation of many charging stations may cause quality problems.

With the expected increase of EVs over the next decades, fast charging stations will be established. Several market participants are looking into fast charging as a business concept. This development will give much higher charging powers with more severe consequences than reported in this study.

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