NEW ELECTRICAL EQUIPMENT AND APPLIANCES CAUSING VOLTAGE QUALITY CHALLENGES IN THE DISTRIBUTION NETWORK

Helge SELJESETH
SINTEF Energy Research – Norway
helge.seljeseth@sintef.no

Kjell SAND
SINTEF Energy Research – Norway
kjell.sand@sintef.no

Ketil SAGEN
Energy Norway - Norway
ks@energinorge.no

ABSTRACT

The strong focus on global warming the recent years has contributed to a change towards a more climate friendly and energy efficient energy system. New energy efficient electrical appliances have clearly shown to be a challenge in the Norwegian distribution system and in the low voltage network in particular. These types of electrical loads have shown to increasingly often cause voltage disturbances exceeding the quality limits in both the EN50160 [1] and the Norwegian voltage quality regulations [2]. This have shown to cause everything from only irritation among customers based on poor lighting quality to malfunction and trip of electrical equipment.

Estimates made by Norwegian network operators indicate that the necessary network reinforcement investments in Norway are in the range 2 to 12 billion Euros if all customers are being allowed to install and use the most challenging electrical appliances. These challenges will probably be similar in other countries if not necessarily as large as in Norway. Performed investigations indicate a high percentage of low voltage networks in Norway with relatively low short circuit capacity as between 40 and 50 % of the low voltage networks seem to have a higher impedance than the European reference impedance.

Norwegian Distribution System Operators (DSOs) are raising the question whether all electric appliances should be treated as "normal" equipment that can be used unconditionally or whether there is a need for changes in the rules for what equipment the DSOs must be notified about before the load is connected and used.

INTRODUCTION

This paper presents results from two projects that have been dealing with the challenges and impact many energy efficient appliances and equipment have on voltage quality in the low voltage network. These projects are:

- "Handling new challenging electric loads": Energy Norway 2012.
- "Voltage quality in smart grids": Norwegian Research Council, Energy Norway, Norwegian water resources and energy Directorate and 11 Norwegian network operators 2012-2016.

The development of a climate friendly and energy efficient energy system causes increased challenges with respect to power quality in electric power system in general – especially in the distribution systems. Increased use of heat pumps, tankless water heaters, charging of electric vehicles, increased use of load management and the introduction of distributed generation are all examples that might involve network reinforcement investments to achieve satisfactory voltage quality.

New energy efficient electrical equipment and appliances have in many cases been verified to cause larger and faster load variations, larger distortion of the voltage waveform and large start currents. The fact that Norway is one of very few countries with high percentage of 230 V IT delta systems (230 V between phases) instead of 230/400 V TN network (400 V between phases and 230 V between phases and a neutral) have caused additional challenges in Norway. These additional challenges are amongst others caused by poorly adapted appliances and quite often poorer levels of network impedance/short circuit capacity.

Several Norwegian network operators are already struggling with an increasing number of customer complaints due to recently installed challenging electrical equipment. This equipment is "off the shelf" available equipment that should comply with international standards for conducted disturbance emission levels but yet large voltage disturbances are documented. In many of the customer complaint cases the Norwegian power quality regulations disturbance limits are exceeded (and often also the EN50160 limits). It is not so often that the r.m.s. supply voltage variations are outside limits, rather short duration disturbances like a high number of quite large rapid voltage changes (RVC's) and voltage dips. Flicker levels are also quite frequently exceeded (both P_{st} and P_{lt}). SINTEF Energy Research have finished a pre-project on how to handle new challenging appliances and the work is planned to continue as one of the work packages of the new project "Voltage quality in smart grids". Some of the plans for this work package of the new project:

- Develop a guide with recommendations and methodology for how new challenging load equipment should be handled with regard to grid connection and (if necessary) mitigation.
- Evaluation on what should be regarded as normal versus challenging electrical equipment.
- Evaluate possible minimum requirements on short-circuit performance in 230 V delta networks with respect to voltage quality.
- Is better knowledge on voltage quality necessary amongst electricians? How to improve?
- Measurement campaign (load profiles and power quality) on a range of challenging loads including charging points for electric vehicles (both fast charging and normal charging).

EXAMPLES OF CHALLENGING ELECTRICAL APPLIANCES

For several years there has been a transition from the old and energy inefficient incandescent lamps towards energy saving lamps (fluorescent and later also LED lamps). In theory these lamps could cause poorer voltage quality due to much more distorted load current than incandescent lamps. In practice the energy saving lamps are on the other hand such a small percentage of the load in most installation (at least in Norway) that almost no problems are reported so far. The same trend in terms of improving energy efficiency is however also seen for electrical appliances that have much higher power consumption than lamps (e.g. water heaters). Additionally the use of other energy efficient equipment like heat pumps is increasing.

Tankless water heaters

In many countries it is common to heat up tap water with gas or with solar energy. In other countries like Norway, the most common water heaters are electric. A typical water heater in Norway is a 200 litre insulated tank with a 2 kW electric heater. A thermostat ensures the desired temperature for the water in the tank and this is usually so high that it is necessary to mix with cold water for tap water (showering etc). Even though insulation levels of such water heaters have improved there are still certain energy losses from such waters heaters. During the last few years tankless water heaters have started to get more popular and the advantages that are advertised are amongst others:

- More energy efficient
- Reduced use of indoor space
- No hot water (energy loss) when all taps are closed
- Ideal for cottages and vacation homes
    - Hot water immediately when you arrive
    - Easier/quick to drain for winter season

A tankless water heater has a very small water volume and only heat up the water "as it flows" when a tap is opened. The needed power for heating up the water is large compared to a water heater with at large water tank that can even out the power consumption over time. The rated power of such tankless water heaters is usually in the range 5 kW to 30 kW and single phase versions are available up to at least 12 kW.

The challenges with tankless water heaters are not only the significant increase in rated power compared to water heaters with large tanks. The largest problem is that the high power is frequently turned on and off to rapidly adjust the water temperature and ensure tap water with small temperature variations. The heater element can be turned on and off in short intervals like for example 1/2 second to 2 seconds intervals. The voltage variations cause by such a tankless water heater is shown in Figure 1.

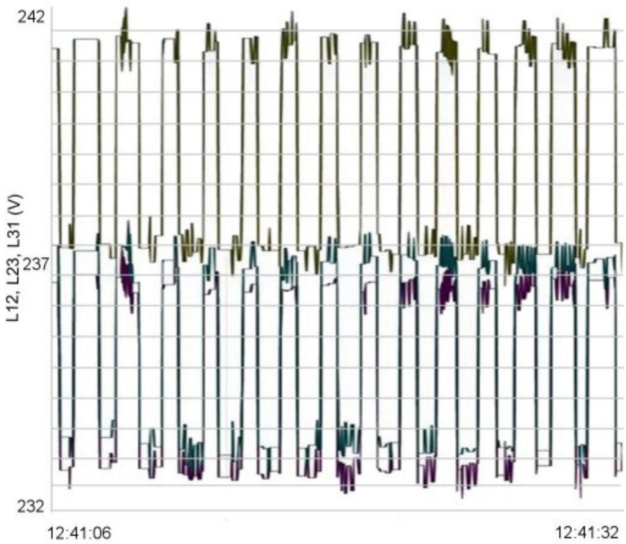

Figure 1. Approximately 0.5 Hz voltage variations due to a 9 kW tankless water heater.

In Norway such water heaters have during the last years also been installed for water-borne heating of residential buildings (homes). Even for such heating systems some suppliers have used heaters that turn on and off the heater element as often as every 2 seconds and a picture of such an "off-the-shelf" CE marked heater is shown in figure 2 below. In the Norwegian 230 V IT (delta) system this tank turns on and off 22 A every 2 seconds. Figure 3 shows the variation in the customer's voltages and currents due to the impact from such a water heater.

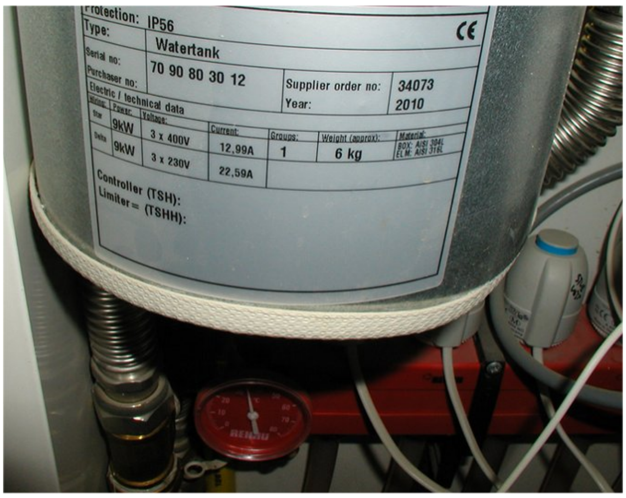

Figure 2. Tankless water heater for heating of a residential home.

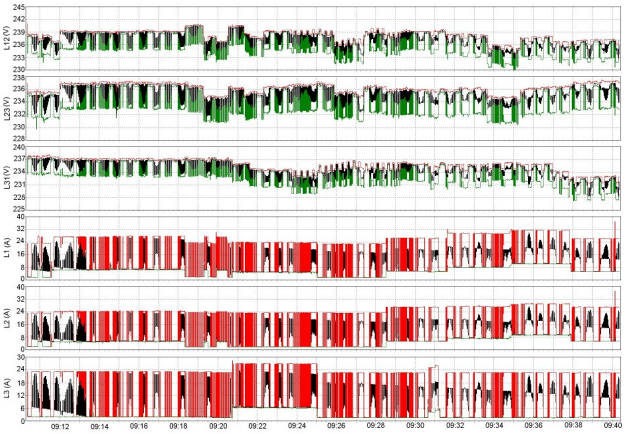

Figure 3. Very frequent load changes (red/black current) and voltage changes (green/black) due to tankless water heater in a residential home (turn on/off approximately every second).

Heat pumps and motor starts

Asynchronous motors in electric equipment and appliances where the motor is started directly (no soft starter or frequency converter) will cause rapid voltage changes. The magnitude of the rapid voltage changes depends on the motor and motor load as well as the supply impedance. Whether the voltage changes in the installation or even outside the installation are sufficiently large to cause enough annoyance to generate customer complaints and/or values exceeding regulations and standard limits, depends on the power rating of the motor and the network impedance. Figure 4 shows an example of rapid voltage changes and voltage dips caused by a heat pump direct started compressor motor.

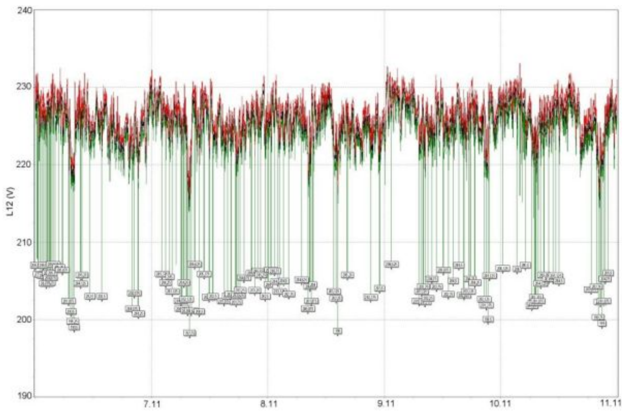

Figure 4. Voltage drops from a residential home 6 kW geothermal heat pump with direct started asynchronous compressor motor.

While air-to-air heat pumps used in Norway very often have inverter control of the compressor motor, heat pumps with thermal energy supplied from the ground quite often have no soft start of the compressor motor. Explanations that has been presented from heat pump suppliers have been amongst others to keep down the price of an already expensive system. Some manufacturers simply cannot supply a three phase inverter controlled compressor for the Norwegian 230 V delta-system. One example was a case where the large international manufacturer did only have 400 V three phase inverter controlled heat pump and ended up installing the compressor with the same power rating as a single phase 230 V direct started compressor.

Electric vehicles

Electrical vehicles have gained a lot of focus the last few years as one out of several possible solutions for reducing the CO_2 emissions from transport and for reducing the air pollution in the cities. The Norwegian authorities have set the ambitious goal of 200.000 electrical vehicles by 2020 (10 % of all vehicles in Norway). To achieve this, the authorities have implemented many incentives for buyers and drivers of electrical vehicles and by the end of 2012 there were approximately 10.000 electrical vehicles in Norway. This new load in the distribution systems will be a new challenge for the Norwegian DSOs.

Several Norwegian distribution system operators have reported that parts of their low voltage and medium voltage systems are close to overload during the coldest winter days as experienced during the recent cold winters of 2009/2010 and 2010/2011. Charging a high number of electrical vehicles during the coldest winter days in cold climate countries may thus be a significant challenge depending of the strength of the distribution systems.

Additionally some of the electric cars being in use today have a load current under normal (slow charging) that is not desirable for ensuring a good voltage quality. Figure 5 and 6 shows examples of the variations in load current, the voltage variations and flicker levels when two different electric vehicles (different brands) are connected to an ordinary 10/16 A low voltage outlet. It is important to note that the voltage variations are measured in the wall outlet for connecting the electric vehicle and not at the customer's entrance. Voltage variations will be somewhat smaller at the customer's supply terminal.

Electric vehicle "A" turns off the charging current to zero for a short moment several times during charging the traction battery. This causes significant voltage variations and even significant increase in the flicker values. Electric vehicle "B" continues to perform pulse charging (maintenance charging) as long as the car is plugged in after the main charging interval is finished. This single load causes flicker levels (P_{st}) to increase from between 0,1 to 0,4 (background level) up to above 1,1.

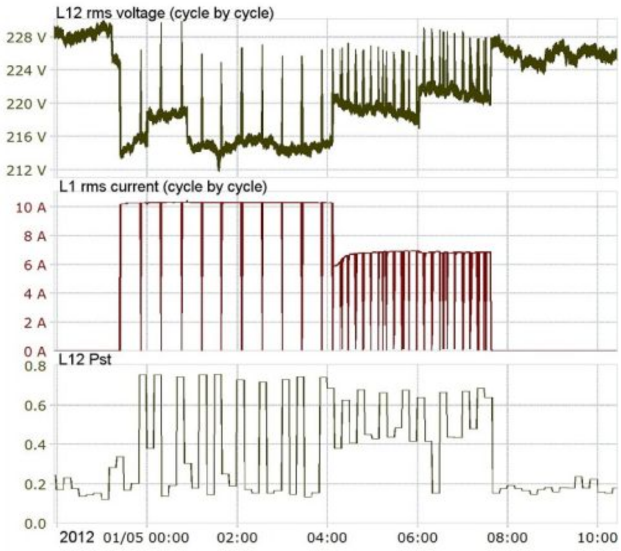

Figure 5. Voltage and current variations as well as variations in flicker during charging of electric vehicle "A".

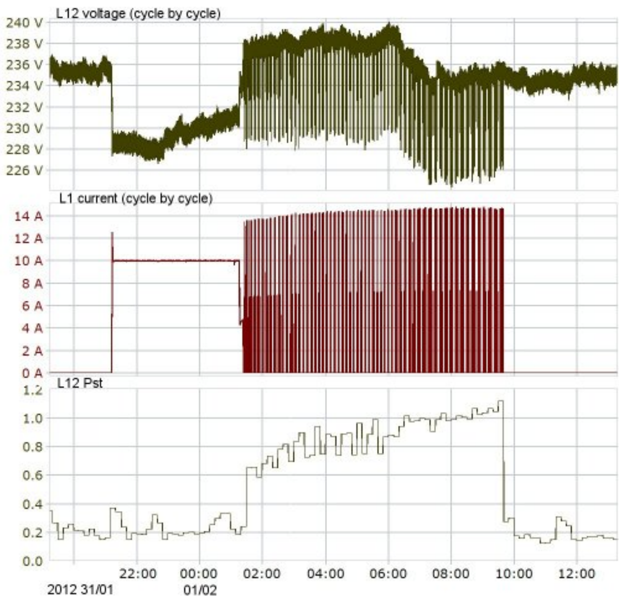

Figure 6. Voltage and current variations as well as variations in flicker during charging of electric vehicle "B".

CONCLUSIONS

High focus on the environment and energy efficiency has contributed to new energy efficient electrical equipment and appliances and more widespread use of them. This equipment causes more challenges to ensure an acceptable level of voltage quality. Many Norwegian network operators are raising the question "what is a normal electric appliance" and what should be considered "challenging and disturbing" appliances. With such an approach it is very important to consider several issues like:

- Is it socio-economic efficient to simply always reinforce the network to meet the challenges from the new loads?
- Is it rational to distinguish between "normal" appliances that might be connected without any notification and "abnormal" appliances that require a more stringent connection procedure?
  How to deal with slow changing load versus rapidly changing loads and coordination with fuse characteristics (A, B, C, D)
- Relationship between rated power and size of fuses in amperes
- Permanent installed equipment versus plug-in appliances

The recently started project "Voltage quality in smart grids" with support from the Norwegian Research Council will work with these questions and challenges together with the Norwegian regulator NVE and several Norwegian network operators.

REFERENCES

[1] EN 50160 Voltage characteristics of electricity supplied by public distribution networks CENELEC 2010

[2] The Norwegian regulation on quality of electricity supply, The Norwegian Water Resources and Energy Directorate (in Norwegian).