Influence of the supply voltage on the performance of household appliances

Jan DESCHEEMAKER
Ghent University – Belgium
Jan.Descheemaeker@Ugent.be

Michiel VAN LUMIG
Laborelec – Belgium
Michiel.VanLumig@laborelec.com

Jan DESMET
Ghent University - Belgium
JanJ.desmet@ugent.be

ABSTRACT

The rise of small scale decentralized production units has increased the complexity of maintaining a rigid electrical grid. For a distribution network operator, knowledge of both the energy demand and supply of his customers has become very important. The discrepancy between the production of renewable energy sources and consumption of a household leads to higher voltages and voltage unbalance during sunny days. Consequently, it is very important to balance demand and supply. Allowing a broader voltage range could be beneficial for the distribution network operator and energy supplier. But one has to be sure that household appliances still work adequately. Therefore in this paper, the influence of the voltage on the proper working of household appliances will be tested in order to investigate the influence of a broader voltage range on the comfort of the end user.

INTRODUCTION

The voltage is limited through the standard EN 50160 to 230 V±10%. Allowing a larger voltage range could be beneficial for the distribution network operator (DNO). Because demand and supply do not coincide, as shown in Figure 1, it is very important for a DNO to know his energy profile. PV panels mainly produce energy during the day, whereas the consumption is mainly during the morning and evening. The excess of energy during the day is injected into the distribution grid with the possibility of higher voltages and voltage unbalance as a consequence.

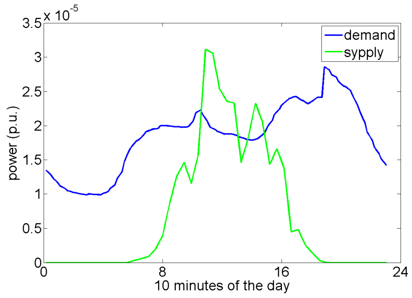

Figure 1: Supply of PV panels (green) and consumption of a house (blue) on an arbitrary day of the year.

Additional to technical advantages of allowing a broader voltage range, there also exist economic advantages. When there is a deficit of energy, this energy has to be bought at the energy market at the latest moment. Which will be very expensive. Conversely, when the energy supply is large, the electricity price will decrease.

In the past, the supply of energy was adapted to the demand. Due to the introduction of decentral energy sources (PV, wind,…) there is a huge increase of injection points. Demand Side Management (DSM) and smart grid technologies try the opposite by adapting the time of the demand to the energy production at that moment. This would lead to a shift on the energy market.
Even when the energy supplier can only control a small part of the demand, he would still be able to actively participate on the energy market. The controllable demand will get an economic value which will lead to lower energy prices, which is advantageous for the end user.

Injection and power take off the net lead to an increase and respectively decrease of the supply voltage. Allowing more variation on the voltage, could lead to more possibilities for power balancing by DSM. But we have to be sure that household appliances still work adequately. In the research, the performance of different household appliances will be tested at voltages between 230 V±15%. For each measurement, the instantaneous power and the overall consumed energy is monitored. The instantaneous current and harmonics will be logged and most important will be checked if the appliances still work accordingly and the comfort of the consumer is not negatively affected by changing the supply voltage. If this is the case, the consumer will not notice the broadening the voltage range. Main goal of the article is investigating the effect of broadening the voltage range on the performance of the appliances and the comfort of the end user.

In [1] a total of 62 electric appliances were tested for immunity against voltage swells until damages occurred or the maximum output voltage from the test generator of 230 V+40% was reached. Many of the tested electrical appliances (televisions, computers, computer screens, music systems) are able to handle relatively severe voltage swells, 40% overvoltage for up to 100 seconds. In [2] was shown that a high percentage of these appliances handle quite severe overvoltages from +15% up to +74% overvoltage with duration of 10 cycles up to 30 minutes. In [3] was shown that during a period of overvoltage, the appliances mostly break down during the first 5-10 seconds. They do not go gradually broken.

In a first section, the method used to study the influence of the voltage on the working of household appliances will be discussed. The following section will discuss the obtained measurement results. These measurement results will then be used to investigate the impact of broadening the voltage range of the comfort of the consumer.

MEASUREMENT METHOD

A schematical overview of the measurement setup used to study the influence of the voltage on the working of household appliances is shown in Figure 2. A free programmable three phase powersource (Spitsenberger and Spies, basic EMC system DM 240000/PAS) delivers a sinusoidal voltage with the desired voltage level. With a power quality analyser (Fluke 434), the voltage and current at the appliance are measured. The Fluke is a measurement apparatus with three independent channels on which three appliances can be connected. With the Fluke, the desired power quality parameters (PF, dPF, THD,…) and the power can be obtained.

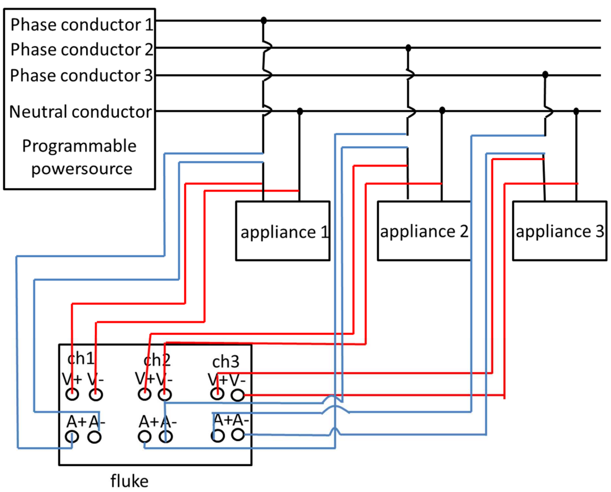

Figure 2: Measurement setup used to study the influence of the voltage on the working of household appliances.

Following research questions will be answered for the different appliances when the voltage is changed:

- Do the appliances still perform as they are expected to do?
- How is the energy consumption affected by a change in voltage?
- How are the power quality parameters affected?
- Is the standard IEC61000-3-2 satisfied at the different voltages?

Measurements were performed on following household appliances:

- refrigerator
- freezer
- dryer
- washing machine
- dishwasher
- oven
- different kinds of lightning
- laptop
- television
- drilling machine
- grinding wheel

The RMS-current, fundamental current, PF, dPF and power will be measured as a function of time for different voltages. The consumed energy during a cycle was measured for every voltage. Depending on the measurement results, the DNO will be able to give more tolerance to the supply voltage.

In the next section, the measurement results will be discussed.

DISCUSSION MEASUREMENT RESULTS

In this section, measurement results about the influence of the supply voltage on the working of some appliances will be discussed. From these measurement results it will be possible to check the influence of broadening the voltage range on the comfort of the end user.

Washing machine

Figure 3 shows the power consumed by washing machine A+++ (washing program 30°C, delicate wash) at different voltages. The lower the voltage, the lower the power. And consequently the more time the washing machine needs to heat the water and the longer the washing cycle will take. At 195.5 V, the washing machine heats the water for a shorter period and the consumed energy is less than at 207 V. The question rises if the water will be hot enough at this voltage.
Measurements were performed for different washing machines. The relation between voltage and energy consumption and between voltage and the harmonic currents, was different for each washing machine. The standard IEC61000-3-2 was satisfied for every washing machine at every voltage. Power quality parameters like PF and dPF were independent of the voltage and close to 1.

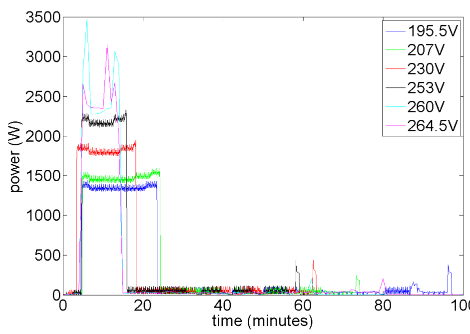

Figure 3: Power consumed by washing machine A+++ at 30°C and lightly filled at different voltages.

Figure 4 shows the power consumed by washing machine A++ when she is fully filled (washing program 30°C, synthetic). The lower the voltage, the longer the washing cycle takes. The washing machine does not work anymore at 195.5 V. Measurements at 207 V were performed multiple times. The washing machine did not always work. When the washing machine worked, the power consumption was less than at higher voltages. The question rises if the water will be hot enough at this voltage. 207 V seems to be a voltage limit where the washing machine just works, or just do not work anymore. This can also be seen in Table 1, where the energy consumption and harmonic current components of the washing machine for the different voltages are shown. The current harmonics are higher at 207 V and the energy consumption is lower at this voltage. This already suggests that the washing machine does not work anymore as she is expected to do. The energy consumption is lower at voltages above 253V. Question arises if the water will be hot enough at these voltages.

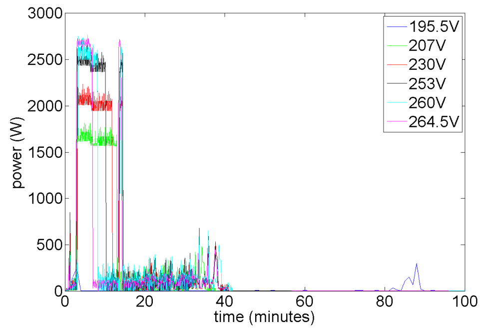

Figure 4: Power demand of washing machine A++ at 30°C and fully filled at different voltages.

Table 1: Energy consumption and ratio of the harmonic current components to the fundamental current, to the maximal limits in procent of washing machine A++ at 30°C and fully filled at different voltages.

Voltage (V)	Energy (kWh)	3th harmonic	5th harmonic	7th harmonic	9th harmonic
195.5	/	/	/	/	/
207	0.31	43	78	22	22
230	0.37	28	11	1	8
253	0.39	27	10	9	7
260	0.30	29	11	10	9
264.5	0.28	27	11	9	8

Dryer

Figure 5 shows the power consumed by the dryer with energy label B at different voltages when he is fully loaded. The energy consumption during a dry cycle is given in Table 2. The higher the voltage, the higher the consumed power. Due to the shorter dry cycle, the consumed energy decreases when the voltage increases between 195.5 V and 207 V. At higher voltages, the dryer stops working at certain moments. This leads to a longer dry cycle and consequently a higher energy consumption.

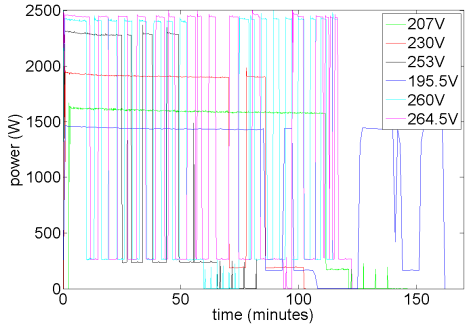

Figure 5: Power demand of the dryer with energy label B when he is fully filled at different voltages.

Table 2: Energy consumption of the dryer with energy label B during a dry cycle when he is fully filled at different voltages.

Voltage (V)	Energy (kWh)
195.5	2.85
207	2.93
230	2.56
253	2.40
260	2.66
264.5	2.66

When the dryers were lightly filled, the relationship between the voltage and energy consumption and between the voltage and harmonic current congestion, depended on the appliance.

Dish washer

Figure 6 shows the power consumed by a dish washer at different voltages. The higher the voltage, the higher the power and the shorter the washing cycle. Table 3 shows that the energy consumption during a washing cycle is constant for voltages lower than 253 V. The energy consumption decreases at higher voltages due to the shorter washing cycle. The high power at higher voltages can possibly lead to a shorter lifetime of the dish washer. The harmonic currents are independent of the voltage and obeys the standard IEC61000-3-2. The same result were found for a second dish washer.

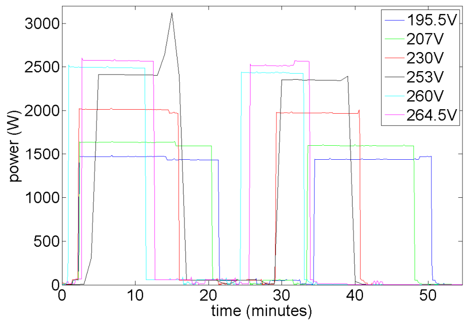

Figure 6: Power demand of a dish washer at different voltages.

Table 3: Energy consumption of a dish washer during a washing cycle.

Voltage (V)	Energy (kWh)
195.5	0.86
207	0.89
230	0.85
253	0.91
260	0.80
264.5	0.79

Lightning

Table 4 shows that a traditional TL lamp consumes more energy at higher voltages. One has to be aware that the increase of the consumed power will lead to a shorter life time of the lamps. The harmonic current congestion decreases with increasing voltage.

Table 4: Current, Power and THD(I) for two traditional TL lamps at different voltages.

Voltage (V)	I_{rms} (A)	Power (W)	THD(I) %
195.5	0.71	84	18
207	0.88	103	15
230	1.2	133	11
253	1.5	161	10
260	1.5	171	10
264.5	1.6	180	10

As can be seen in Table 5, high frequent TL lamps consume a constant power. As the voltage increases, the current will decrease to keep the power constant. Unlike traditional TL lamps, the harmonic current congestion is independent of the supply voltage.

Table 5: Current, Power and THD(I) for high frequent TL lamps

Voltage (V)	I_{rms} (A)	Power (W)	THD(I) %
195.5	0.52	101	5.3
207	0.50	101	4.9
230	0.45	101	4.7
253	0.41	100	5.3
260	0.40	101	5.5
264.5	0.41	104	5.3

Measurements were performed for other kinds of lightning (CFL, halogen, LED, light bulbs). The relationship between the voltage and energy consumption depends on the type of lightning. For some lamps (light bulbs, CFL, traditional TL), the power will increase with increasing voltage. This can have a negative impact on the lifetime of the lamps. Whereas other types of lightning (TL, High frequent TL, LED and LED TL) consume a constant power. Changing the voltage has no influence on the brightness of the lamps in this case. Also the relation between the voltage and harmonic current congestion depends on the type of lightning. For LED and traditional TL-lightning for example, the harmonic currents decrease with increasing voltage. On the other hand, for CFL, the harmonic congestion increases with increasing voltage. Also the influence of the voltage on PF and dPF depends of the kind of lightning. Lamps like CFL do not obey the standard IEC61000-3-2. For the other tested lamps, there are almost no problems. We do not know if this will be the case for lamps of another brand.

Laptop

Table 6 shows that the laptop consume a constant power. The current decreases with increasing voltage. The harmonic current congestion increases at higher voltages. The standard IEC61000-3-2 is satisfied for none of the voltages.

Table 6: Current, Power and THD(I) for a laptop

Voltage (V)	I_{rms} (A)	Power (W)	THD(I) %
195.5	0.19	15	227
207	0.18	15	229
230	0.17	15	235
253	0.16	15	238
264.5	0.16	15	244

IMPACT OF CHANGING THE VOLTAGE ON THE END CONSUMER

Main goal of the article is investigating if the broadening of the voltage range will affect the comfort of the consumer. From the measurement results discussed in the previous section, it can be concluded that both at high

and low voltages, the comfort of the consumer can be in danger.
At low voltages, some appliances need more time to perform their task. The dry cycle and washing cycle of a dryer and washing machine will be longer. The brightness of some lamps (light bulbs, CFL, halogene spots) will decrease at low voltages. One washing machine does not work anymore at voltages below 207 V.
When the voltage increases, the power of some appliances (drilling machine, grinding wheel, light bulbs, …) will increase, which can have a negative impact on the lifetime of these appliances.

CONCLUSION

Due to the growing number of decentralised production units, the complexity of the electrical grid has increased a lot. For a distribution network operator it will be important to know the demand and supply in his profile. Because a discrepancy between the demand and production of renewable energy sources could lead to higher voltages and voltage unbalance. Therefore it will be very important to balance demand and supply. Allowing a broader voltage range could be beneficial for the distribution network operator and energy supplier. But one has to be sure that household appliances still work adequately. If this is not the case, there could be an undesired loss in the comfort of the end user.

Measurements to investigate the influence of the supply voltage between 230 V±15% were performed for a wide variety of household appliances. Some tested appliances (television, laptop) are not affected by the voltage and perform as they are expected to at every voltage. Other tested appliances (light bulbs, grinding wheel, drilling machine, dish washer) will consume more energy at higher voltages, which may reduce the lifetime of the appliance. But this can not be decided with certainty from these short term tests. One has to be aware of this at the upper limit of the voltage range.
The brightness of some lamps will decrease when the voltage is lowered. One washing machine did not work at voltages below 207 V. This will negatively affect the comfort of the consumer at the under limit of the voltage range.
Major conclusion of the paper is thus that both at low and high voltages, the performance of end appliances is affected, leading possibly to undesired loss in comfort for the end user.

Secondly can be concluded that the relationship between the voltage and the energy consumption and between the voltage and the harmonic current congestion is dependent on the type of appliance. It can even be different for 2 washing machines or 2 dryers. It will thus be very difficult to find the optimum voltage where the most energy can be shifted or the optimum voltage where the harmonic congestion is the smallest.

REFERENCES

[1] H. Seljeseth, K. Sand, K.E. Fossen, 2009, "Laboratory tests of electrical appliances immunity to voltage swells", *Proceedings CIRED conference*, Prague, paper 0781

[2] H. Seljeseth, T. Rump, K. Haugen, 2011, "Laboratory tests of electrical appliances immunity to voltage swell, overvoltage immunity of electrical appliances laboratory test results from 60 appliances", *Proceedings CIRED conference*, Frankfurt, paper 946

[3] R. Schainker, 2005, "Effects on temporary overvoltage on residential products"