Harmonic Behavior of Residential Low Voltage Appliances for Load Signatures Formulation

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➤ *Energy Efficiency* and *Renewable Energy* are the twin pillars of sustainable energy policy

➤ Buildings energy efficiency:

  ➤ Reduce energy use (e.g. insulating a house, substitute old and energy consuming appliances with new ones etc.)

  ➤ Install Renewable Energy Resources (e.g. rooftop PV units)

  ➤ <u>Understand our consuming behavior in order to increase the efficiency of energy use (e.g. peak shaving, load shifting)</u>

  ➤ Need for simple and accurate tools for detailed and real time recording of our consuming behavior
  ➤ Information about energy consumption for two types of categorization:

  appliance and activity energy consumption

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➢ ***Non-Intrusive Load Monitoring (NILM):*** one sensor installed at the main feeding panel of the installation

➢ Measurement and recording of aggregated signals

➢ NILM algorithms decompose the signal to its components in order to assign each one to the respective appliance

➢ The information provided describe the duration and energy consumption by each appliance and detailed information about how the activities of the residents are distributed within various time periods

➢ The efficiency of NILM algorithms depends on:

  ➢ How unique and distinct are the load signatures (fingerprint of each appliance describing its operational status)

  ➢ The matching procedure in order to recognize each appliance

➤ ***Aim of this work:*** investigate whether the odd harmonics could enhance load signatures and constitute an additional efficient feature towards more unique signatures

➤ The harmonic behavior of LV residential installations is examined under measurements referring to aggregated signals at the main feeding panel of each installation

➤ Each installation has been measured for approximately 24 hours under two sampling frequencies:

  ▪ **1 sample/min** (0.0167 Hz) **–** meets specifications of commercial smart meters

  ▪ **1 sample/10 sec** (0.1 Hz) **–** increased density of extracted information from the signal may provide more robust signatures

➢ *Measurement parameters:*

➢ For each installation a detailed record regarding the activation/deactivation of each appliance was filled in

➢ Thus, the decomposition of the aggregated signal was performed based on the information regarding the appliance event for each appliance

➢ Two installations (each measured twice with different sampling frequency) are presented

Residence	
1	**2**
TV	TV
Oven	Oven
Laptop	Washing machine
Washing machine	Desctop
Hair dryer	Laptop
Electric iron	Electric water-heater

➢ 3rd harmonic for the 1st installation (between 15:05-17:38) with a sampling frequency of 0.016 Hz (1 sample/min)
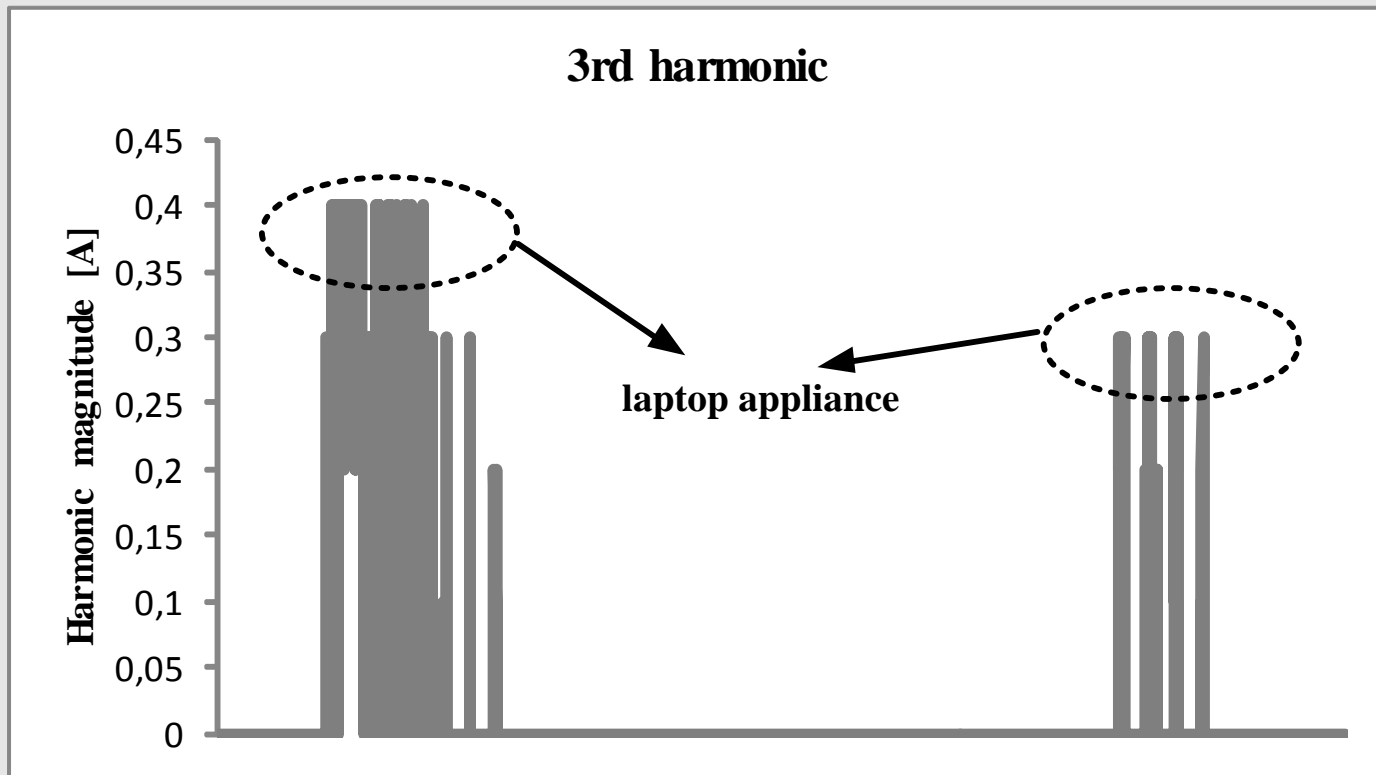
➤ Dotted frames denote time periods with the 3rd harmonic present

Time period between 15:05 – 23:10
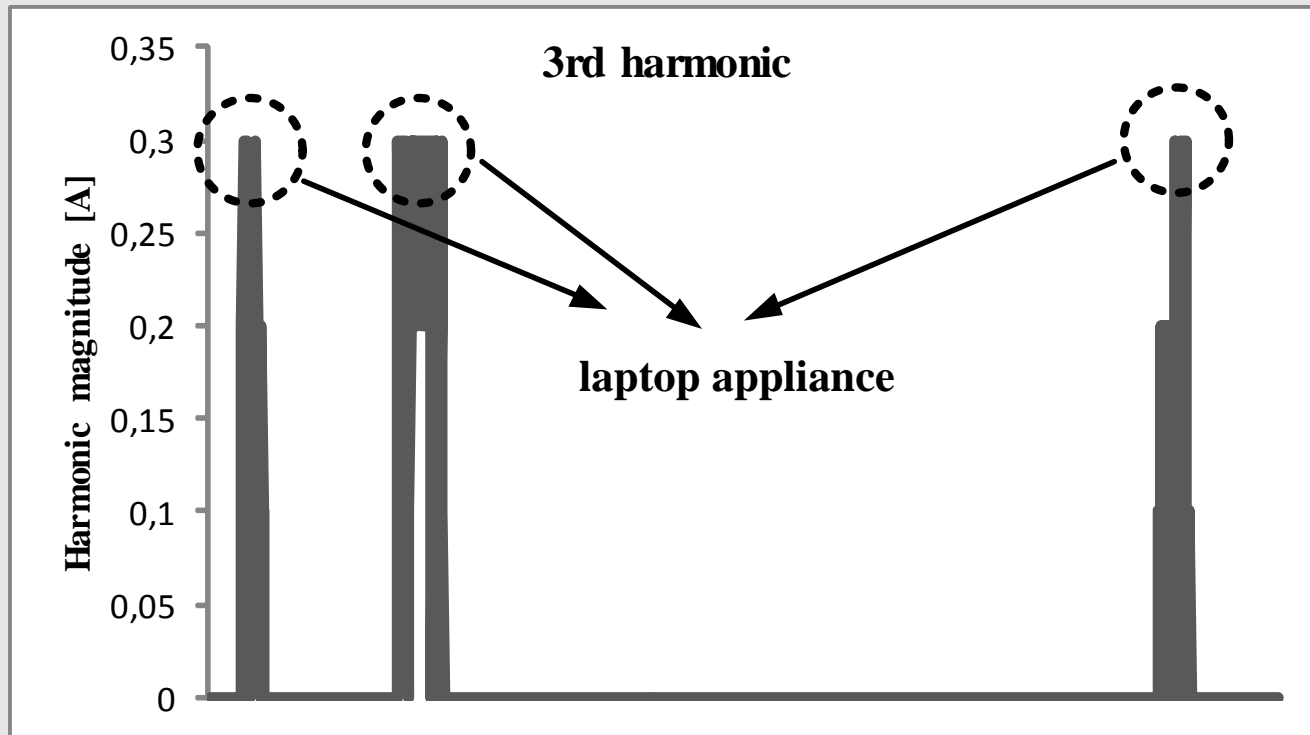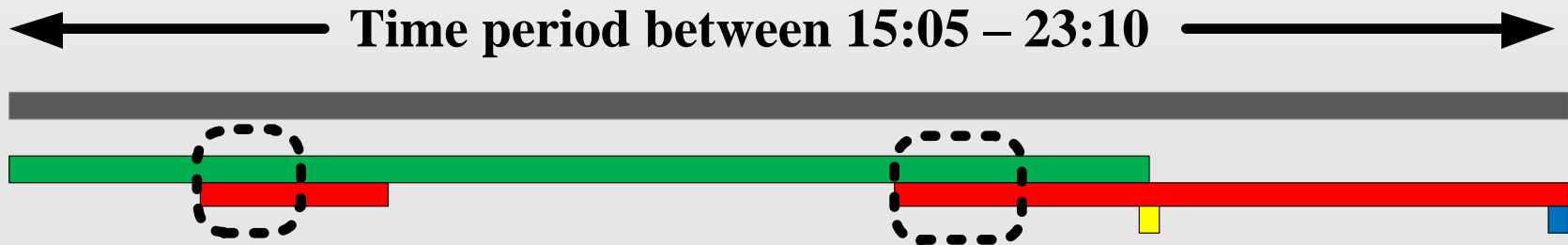
■ **TV: 15:05 – 21:06**

■ **Laptop: 15:55 – 16:48 and 19:45 – 23:10**

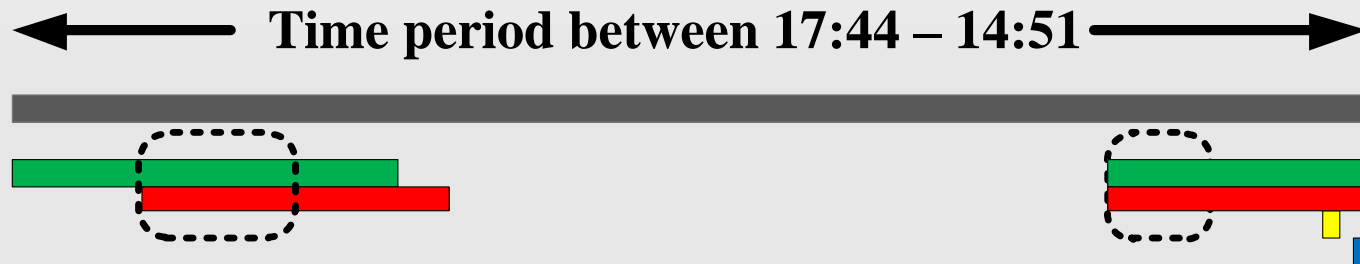■ **Oven: 21:01 – 21:09**

■ **Hair dryer: 23:00 – 23:10**

➤ 3rd harmonic is produced by either the TV or the laptop appliance

➤ For individual operation of TV appliance the 3rd harmonic was not recorded

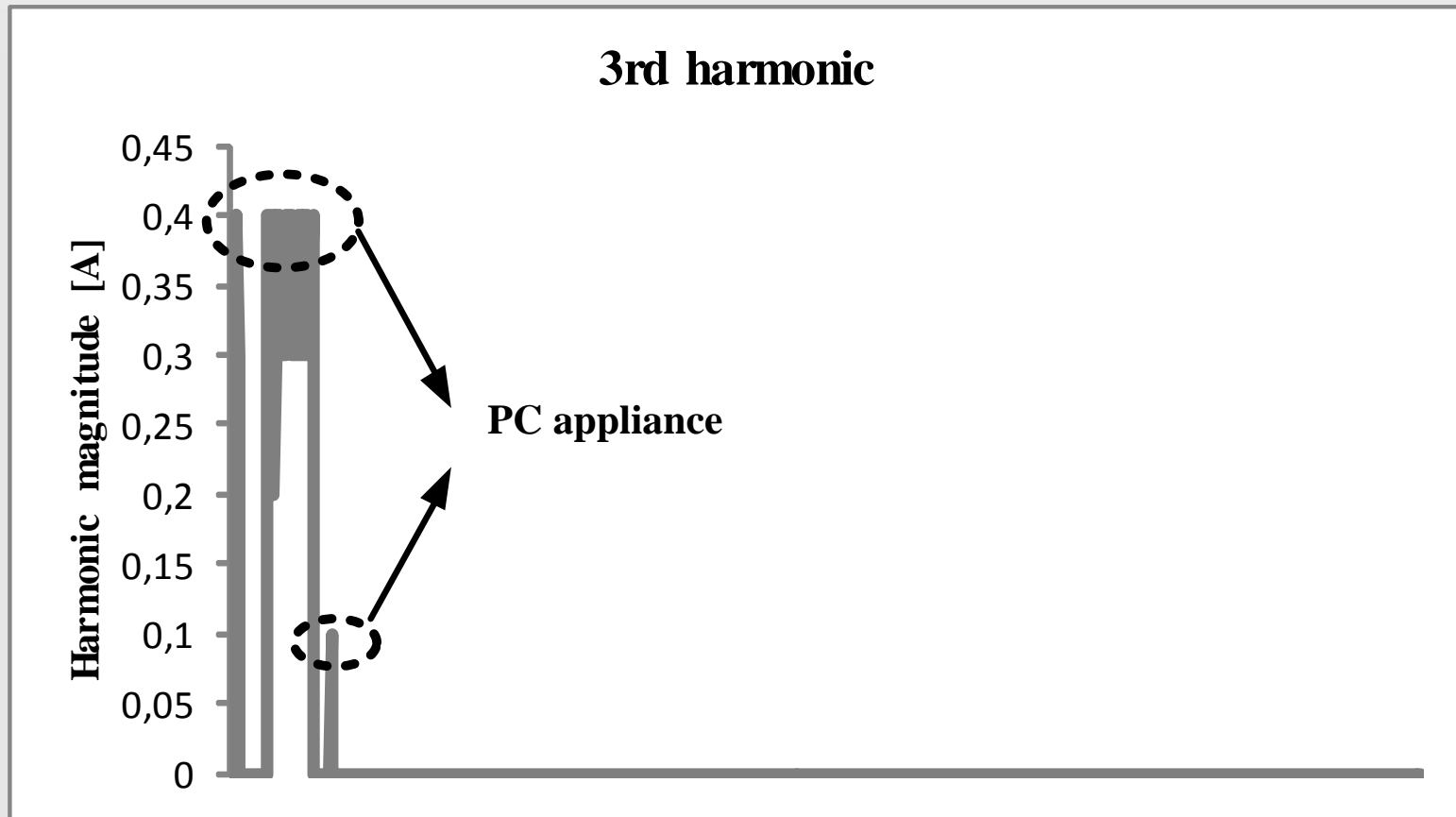➢ 3rd harmonic for the 1st installation with a sampling frequency of 0.1 Hz (1 sample/10 sec)

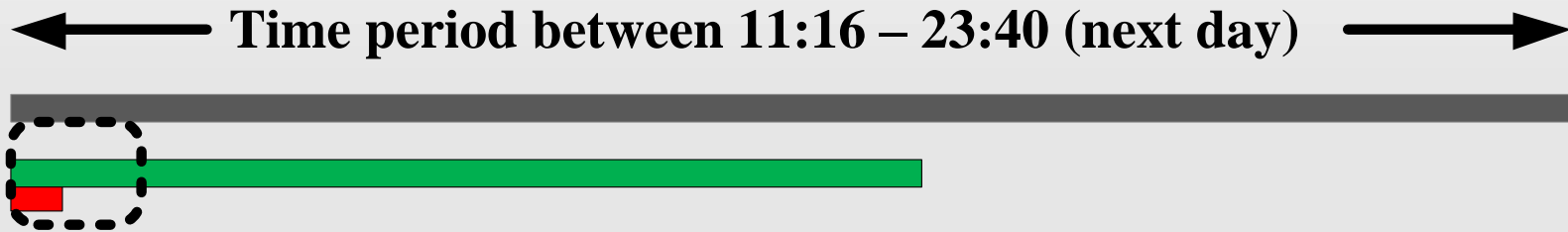➢ Dotted frames denote time periods with the 3rd harmonic present

Time period between 17:44 – 14:51

■ **TV: 17:44 – 23:30 and 10:38 – 14:51**

■ **Laptop: 19:44 – 01:26 and 10:38 – 12:445**

□ **Oven: 13:55 – 14:25**

■ **Electric iron: 14:45 – 14:51**

➢ Again the 3rd harmonic is produced by either the TV or the laptop appliance

➢ When the TV is operating alone the 3rd harmonic is not recorded even with the higher sampling frequency of 0.1 Hz

➢ The recording 3rd harmonic coincides with the activation of the laptop

➢ 3rd harmonic for the 2nd installation with a sampling frequency of 0.016 Hz (1 sample/min)

3rd harmonic

Harmonic magnitude [A]

PC appliance

➤ Dotted frames denote time periods with the 3rd harmonic present

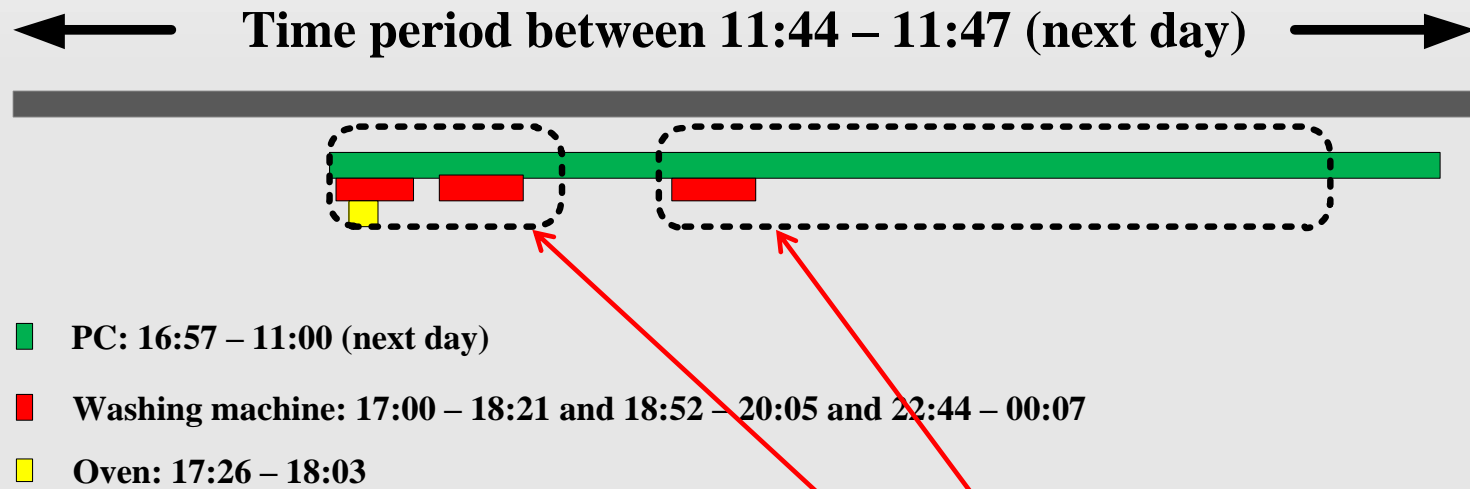**Time period between 11:16 – 23:40 (next day)**

🟩 **PC: 11:18 – 01:23**

🟥 **Electric water-heater:11:19 – 12:10**

➤ The electric water-heater is a purely resistive load
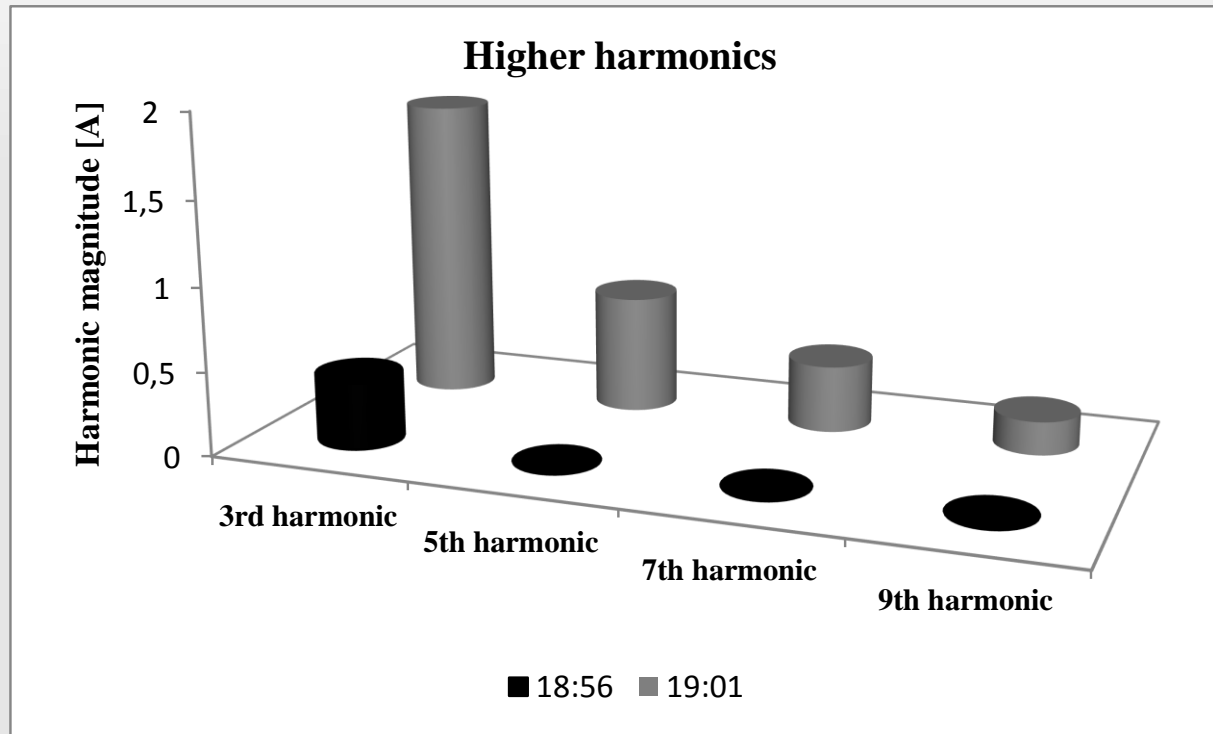
➤ The 3rd harmonic is produced by the PC appliance

➢ Dotted frames denote time periods with the 3rd harmonic present (now the sampling frequency is 0.1 Hz – 1 sample/10 sec)

Time period between 11:44 – 11:47 (next day)

- ■ **PC: 16:57 – 11:00 (next day)**

- ■ **Washing machine: 17:00 – 18:21 and 18:52 – 20:05 and 22:44 – 00:07**

- ■ **Oven: 17:26 – 18:03**

➢ The basic problem concerns the origin of the 3rd harmonic

➢ Based on the previous sampling frequency one source is the PC appliance

➢ The additional candidate source is the washing machine appliance

➢ The measurements showed that only the PC produced 3rd harmonic values at the magnitude of 0.2-0.4 A

➢ The simultaneous operation of the PC and the washing machine produced 3rd harmonic values at the magnitude of 0.2-0.6 A

➢ It is not clear the contribution of each appliance to the harmonic content (regarding the 3rd harmonic) formulation

➢ For this measurement set, higher harmonics were also recorded

➢ During the simultaneous operation of the PC and the washing machine

Higher harmonics

Harmonic magnitude [A]

3rd harmonic
5th harmonic
7th harmonic
9th harmonic

■ 18:56   ■ 19:01

➢ For stand alone operation of the PC appliance higher harmonics have never been recorded

➢ Thus it is high possible that these higher harmonic were produced by the washing machine – utilize these higher harmonics for a unique load signature regarding the washing machine

➤ **Conclusions:**

➤ Sampling frequencies at the order of 1 sample/min could still capture the harmonic content of LV installations

➤ Utilization of the 3rd harmonic could prove to be an efficient feature for the development of distinct load signatures

➤ Simple measurements could provide information about the most harmonic polluting appliances (TV, PC, etc.)

➤ Higher odd harmonics (up to 9th or 11th) could be utilized for specific appliances → formulate respective unique signatures → improve the efficiency of NILM algorithms

➤ More measurements with stand alone operation of each appliance could validate these early conclusions

Thank you all for your attention !