KNOWLEDGE EXTRACTION FROM HIGHLY-VARIABLE POWER PROFILES IN UNIVERSITY CAMPUS

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Knowledge extraction and information loss, in case of daily load power profiles of UPB student campus buildings can be achieved by high reporting rate measurements and accurate models of the energy transfer. In this paper we use averaged power profiles instead of those obtained from smart meters with 2s (or 1s) time reporting rate derived from extensive local measurements using Unbundled Smart Meters (USM), set on 1s reporting rates.

Keywords: smart metering, high-reporting rate, power profiles, university campus

1. Introduction

The distribution energy systems are increasingly based on high-level of Renewable Energy Sources (RES) penetration and consequently the system operators (e.g., distribution system operators – DSOs) will need new insights and more information to better handle the performance of the grid and how to optimize their operations financially. More information translates into electrical parameters describing the energy transfer with high resolution both spatially and temporally. Technological and operational challenges associated with distributed energy resources (DER), reverse power flows, limited grid hosting capacity of intermittent generation sources and load balancing will require active, real-time large scale integrated management of distributed generation. Together with the need to increase the grid's robustness, flexibility, and ability to adapt and anticipate changing conditions in power system operation in a smart, secure, and cost-efficient way, creates the opportunity of open ecosystems and platforms to empower the customers, prosumers, and potential new players by emergence of new services. As per the context of Smart Cities [1], key factors for sustainable development are openness, interoperability, empowerment of customers and the provision of tools and conditions which facilitate competition and stimulate strengthening of the energy digital ecosystem. The active participation and

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involvement of European consumers and prosumers in the energy grid and market through diverse flexibilities (RES generation, consumption, and storage) will reduce customers' electricity bills and their energy dependency but it will also help DSOs achieving more balanced and stable distribution grids [2]. The win-win situation, benefiting both the grid and the customers, shall be based on smart metering but also on emerging control of smart home appliances, storage capacities, electrical vehicles etc. Smartening of the distribution grid includes technological solutions to gain advanced monitoring and awareness of variable loads and generation. At the same time, new communication infrastructures are available offering low latency and high availability services enabling data driven control. One direction of evolution of the energy sector is increasingly focused on energy as a service. A solution to this new issue is implementation of smart meters in the context of a smart grid, this concept helps to an efficient monitor and control of power profiles [1]. It is important to have smart meters connected to IoT (internet of things) as to integrate all the smart devices enabling data transfer in the network, which is already a best practice for Smart Grids [3]. For the DSOs, it is important to have available and understand power profiles and patterns and for the users to track their daily profiles as a significant tool for user awareness; the smart meters are performing all of this and communicate information according to power quality standards [4].

2. Smart Meters functionalities and specifications

A modern smart metering system is built upon smart meters, control devices and a communication link. Advanced metering infrastructure (AMI) is an integrated system of smart meters, communication networks and data management systems that enables two-way communication between utilities and customers [5]. Several characteristics and advantages of smart meters are customer awareness for energy efficiency, better comparison of service offerings, improved network control and monitoring, easier recognition of network failures, better quality control, energy balancing through better forecasting, new services for special requirements, accessible data for authorized users [6] (as described in [7], related to clients, distributors, and suppliers). A recently published CIGRE report [8] underlines the importance and capabilities of smart metering as a first step towards controlling the active distribution networks able to create value proposition for different stakeholders in the energy sector. The two major issues, right now, for large scale deployment of smart metering systems are, on one hand, communication and, on the other hand, the active involvement of consumers/prosumers. There are several potential communication solutions to choose from, which can be split between radio, broadband and power line carrier which are well summarized in [4], but also today, an increasingly number of SM use radio communication [8]. Smart Metering is still expected to be the tool to encourage consumers/prosumers to be actively involved in the energy/electricity management. The consumers will be more and better informed on their power profiles (real-time feedback, correct billing, online data) and will be involved in dynamic tariffs, such as Time of Use, flexibility incentives, easy switching to another supplier. All these initiatives will increase the number of costumers which can become (following investment decisions) local energy producers (prosumers). Regarding the capabilities of the smart meters, the more functionalities being offered by a smart metering system, generally the more benefits are provided to all interested stakeholders. General functionalities, as described in [9] are for example, meter reading, load management, power quality indicators, advanced tariff systems, remote connection control, secured communications, fraud prevention/detection.

3. Next Generation Smart Meters

A new generation of smart meters need to comply with three main demands: lower cost, high quality information (for example, using reporting rates like 1 frame per second or higher) and ensuring privacy or cyber security of data. At the same time, it is necessary to have certain abilities, like extracting load signatures using nonintrusive aggregation of measurements, to estimate the network states or to improve load and supplier forecasting. The main ideas and features of the next generation smart meters used in this work are identified as to have a closer look of the dynamics of the LV nodes and to use appropriate statistical metrics within the meter itself [17]. An example of smart meter answering to those requirements is the Unbundled Smart Meter concept, developed around two components: Smart Metrology Meter (SMM) which is the metrological part and covers all the hard real-time functions with fixed (frozen) functionality and the Smart Meter eXtension (SMX), which has a high grade of flexibility and brings new functionalities to the SMM for supporting the future evolution of smart grid and energy services. The SMX part was designed to work either with a Raspberry Pi 3 board or with a BeagleBone Black Industrial board. They both are single on a chip computer, allowing users to develop various implementations in an easy way. Their main features include general I/O ports, RAM memory, several communication ports [10], [11].

For the measurement campaign, it has been made use of two types of USMs. The SLAM meter [12] is an advanced high-reporting rate (2s resolution) multi-function digital single-phase smart meter Class B in active energy and Class 2 in reactive energy, which complies with European legislation related to energy meters (MID) EN 50470-1 and EN 50470-3. It includes a Linux based module which allows to deploy new features during its lifetime. This module adds the capability to interface with different actors in the Energy Market like aggregators, ESCOs, grid operators and consumers. The other type of USM is a high reporting rate (1 frame per second) measurement equipment consisting of a SMX connected to a commercial smart meter LandisGyr [13] [14] that is a three-phase energy meter (IEC 62053-21 class 1) and reactive energy (IEC 62053-23 class 2).

4. Motivation for highly-variable, high-time-granularity load power profiles

It is recognized that residential appliances have a large variability in their energy use (e.g., short periods of time with peak demand and lower demand during most of the time during the day). Despite this, most of network impact studies for RES at LV grid still rely on hourly aggregated load or in the best case on 30 to 15 minutes aggregation. It is acknowledged in [13] that near real-time information and data communication is a critical technical requirement for the operation of LV grids. In the same time, [15] highlights that high-resolution smart meter data are not used at their full potential as they can enhance distribution grid monitoring and control based on large deployment. As stated in [17] and [18] high-reporting rate smart meters data, in compliance with the highest standard for costumers privacy, could provide significant insightful information in terms of quality of supply in a bidirectional power flow, enabling a dynamic decision making mechanism of higher quality in terms of overall energy efficiency. A first example to introduce the motivation of the work in this paper is highlighted in Fig. 1 that shows information loss when using averaged power profiles instead of those obtained from smart meters with 1s time reporting rate, in case of daily load profiles for a typical household.

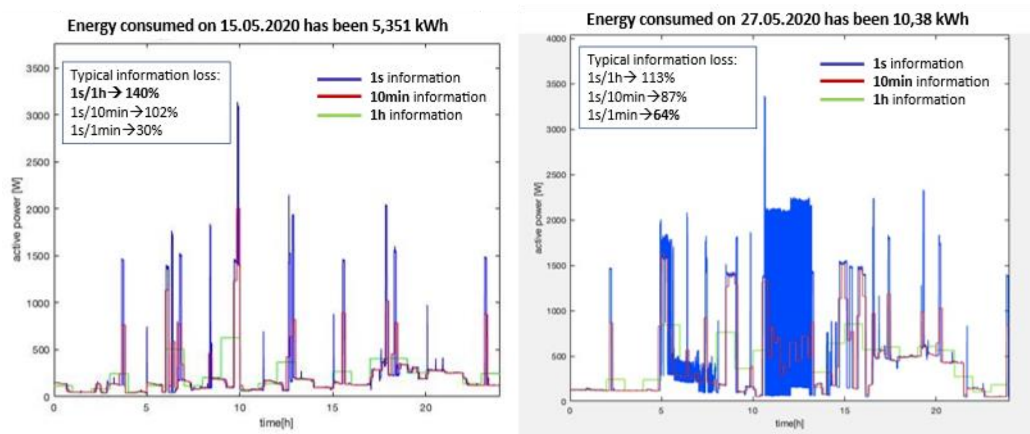

Fig. 1. A first example of a comparative information loss for two different daily load profiles, with 1s resolution, 1min, 10min, and 1h - average values, respectively. (to keep the graph as visible as possible, the line for 1 min aggregation was omitted).

The information loss can be as high as 140% for hourly profiles, which completely mask, in this case the in-rush currents of the refrigerator (observed with 1s resolution). We used as metrics for the information loss the standard deviation of the real (1s) profile compared to the aggregated power profile.

5. Trial site description

The pilot site chosen for demonstrating and implementing a strong and reliable smart metering infrastructure was the student campus (Regie) of the University POLITEHNICA of Bucharest (UPB). There were multiple reasons for setting up the trial in the campus. The main resort enabling this action was the missing energy metering capabilities of the campus, as there were no up-to-date individual electricity meters installed for the student buildings at the time that the pilot was set-up, which means no awareness over the power profile behavior. Moreover, the energy bill is issued for the total electricity consumption of the campus based on a single meter installed in the point of common coupling (PCC). This practice does not give insights over specific power profile habits nor the possibility to improve the load and lower the bill as the students pay a fixed and equal monthly amount for energy use. Another reason taken into consideration refers to a reported sudden increase of the energy consumption in the campus that could have been caused by the usage of electricity for “crypto currencies mining”. Furthermore, a key role for choosing the campus for the pilot site was the students living here which were considered an important category of end-users, the young professionals with a high degree of awareness of the usefulness of modern technologies and their role in limiting the waste of energy resources [16]. Following the office type nonlinear loads, there is a potential of non-symmetric loading conditions on each phase which might give rise to several PQ issues, or even interruption in power supply. A thorough analysis of the network needs synchronized information (from all buildings) with high time granularity.

For the actual implementation of the site trial within the campus, for 5 of the total 27 student buildings smart meters were installed insuring a coverage of almost 20% of the entire power profile. An overall simplified topology of the pilot site can be seen in the picture below, in Fig. 2. The metering infrastructure includes two types of systems developed within the research projects, Nobel Grid (funded by the EC through H2020) [12] and ITCity (funded by ERA-NET LAC) [19]. The buildings targeted for the pilot site were P7, P22, P23, P24 & P25. Fully deployment (including server connectivity and meters configuration) consists of 39 one-phase SLAMs (Smart Low-Cost Advance Meter) and 12 three-phase USMs (Unbundled Smart Meter). These measurement systems are covering the energy supply for 1840 students. The information used in this paper was extracted from energy meters installed in a student building with 30 rooms and 60 students per floor.

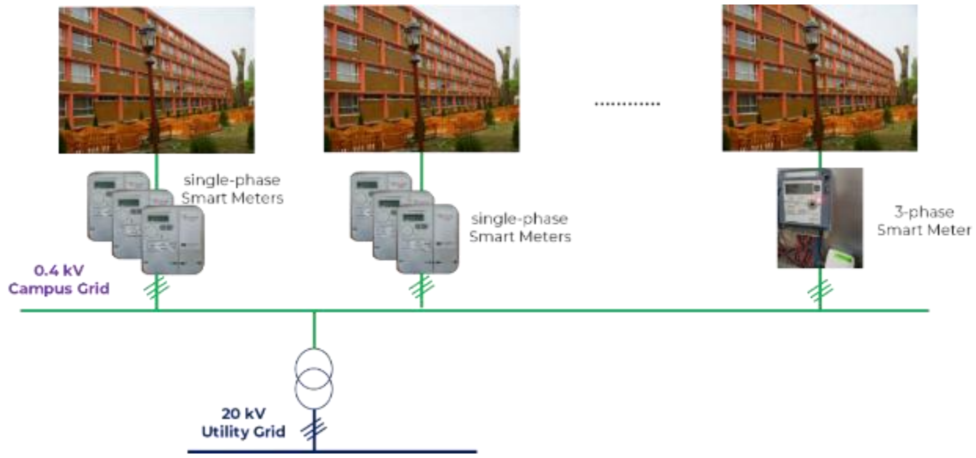

Fig. 2. Simplified grid topology of the campus with smart meter installation

The use was for single-phase energy meters installed on each floor. The information is for the same student building but divided on the considerations in chapter 7.

6. Methodology

The averaged power profiles were computed for 1 min aggregation, 15 min aggregation and 1h aggregation. It has been used a simple averaging algorithm of the 2s (1s) information received from the field smart meters. A visual representation of the process for information aggregation can be seen in Fig. 3.

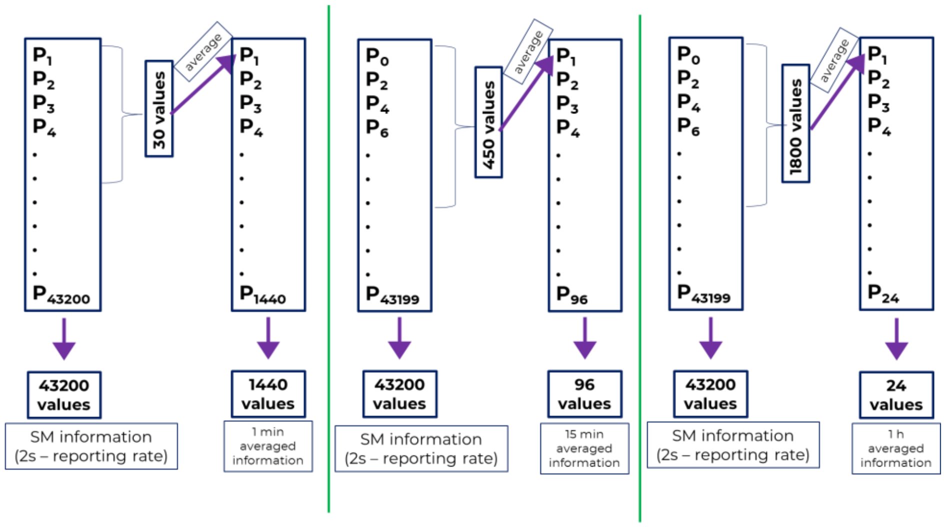

Fig. 3. Information aggregation for 2s reporting rate smart meters

Let us name each reported measurement for active power by the smart meter (with 2s resolution) P_x where x is ranging from 1 to 43200. Thus, active power reported in one day consists in 43200 values (ranging from P_1 to P_{43200}).

As such, for 1 min aggregation, the information is computed by arithmetic average of sets of 30 values (number of reported measurements in 1 min with 2s resolution). A generalization of the averaging process for 1 min aggregation is given in equation (1)

$$\overline{P_i^{1min}}[t] = \frac{P_{i\cdot 30+1} + P_{i\cdot 30+2} + \cdots + P_{i\cdot 30+30}}{30} \quad (1)$$

where *i* ranges from 0 to 1439.

For 15 min aggregation, the information is computed by arithmetic average of sets of 450 values (number of reported measurements in 15 min with 2s resolution). A generalization of the averaging process for 15 min aggregation is given in equation (2)

$$\overline{P_i^{15min}}[t] = \frac{P_{i\cdot 450+1} + P_{i\cdot 450+2} + \cdots + P_{i\cdot 450+450}}{450} \quad (2)$$

where *i* ranges from 0 to 95.

For 1h aggregation, the information is computed by arithmetic average of sets of 1800 values (number of reported measurements in 1h with 2s resolution). A generalization of the averaging process for 1h aggregation is given in equation (3)

$$\overline{P_i^{60min}}[t] = \frac{P_{i\cdot 1800+1} + P_{i\cdot 1800+2} + \cdots + P_{i\cdot 1800+1800}}{1800} \quad (3)$$

where *i* ranges from 0 to 23.

The information loss algorithm was computed using the standard deviation formula between 2s information and mediated information for each of the studied cases

$$std\_agg_{interval} = \sqrt{\frac{\Sigma(P_x - \overline{P_i})}{N}} \quad (4)$$

where P_x is the reported active power (2s resolution) and $\overline{P_i}$ is the averaged value (depending on the case, 1min, 15min, 1h) corresponding to the interval where P_x belongs. *Interval* indicates that the standard deviation is computed for all the studied cases (1min, 15min and 1h).

The result was then divided by the 24h mean of the respective day (as per equation (5), resulting the final value of the information loss (as per equation (6)).

$$P_{mean}^{1\,day} = \frac{\sum_0^{N-1} P_{2\cdot i}}{N} \quad (5)$$

where N is the total number of reporting measurements in one day (in our case 43200).

$$info\_loss_{interval} = \frac{std\_agg_{interval}}{P_{mean}^{1\ day}} \quad (6)$$

, where *Interval* indicates that the variable is computed for all the studied cases (1min, 15min and 1h)

The information loss is the final number with significant importance for our paper and it can be found in the following figures and in the comments of the manuscript.

7. Experimental results

To highlight the information loss when using averaged power profiles instead of those obtained from smart meters with 2s (or 1s) time reporting rate, in case of daily load power profiles of student campus buildings, several scenarios were studied given the three-phase connections. The main aspects considered when studying the power profiles were as follow:

- Temporal features, for days of the regular university semesters (when students were in the campus).
- Type of days of normal behavior, depending on weekday or weekend day.
- Climate consideration, for winter and summer days, when students make use of a lot of heating and cooling systems.
- Electrical features, given the three-phase system of a student building, 1-phase studies, and three-phase studies.

Following subsections will highlight the main cases under analysis for winter and summer days, for weekday and weekend days, but only some examples of the power profiles will be plotted and presented.

Scenario for a single-phase power profile for one of the floors of the student building.

Measurements results for 24h operation during winter and summer for both weekdays and weekend days are presented. The information is for phase 1 of the second floor of the student building, considering the equal distribution of loads on each phase. For this type of building, the measurement system consisted in single-phase energy meters installed on each floor (one meter per phase per floor). The power profile depicted in the following figures is for the second floor, on phase 1. It can be observed the classical power profile with high demand during the evenings and mornings and low demand for afternoons and nights. To be noted that the building is not equipped with air-conditioning systems (to be used for summer days) and for the winter, the students might get additional private systems for heating purposes (such as space heaters and hot air heaters).

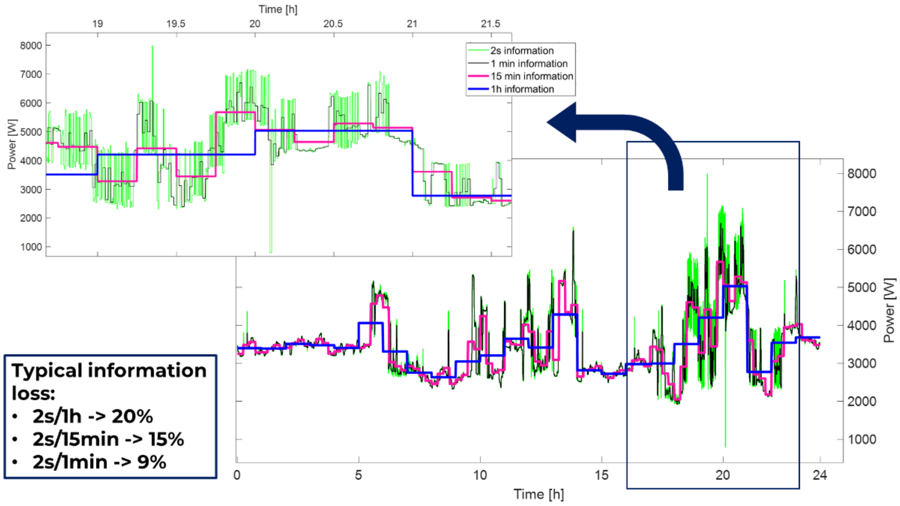

Fig. 4. Power profile for the second floor of a student building - for phase 1 – on a weekday in winter

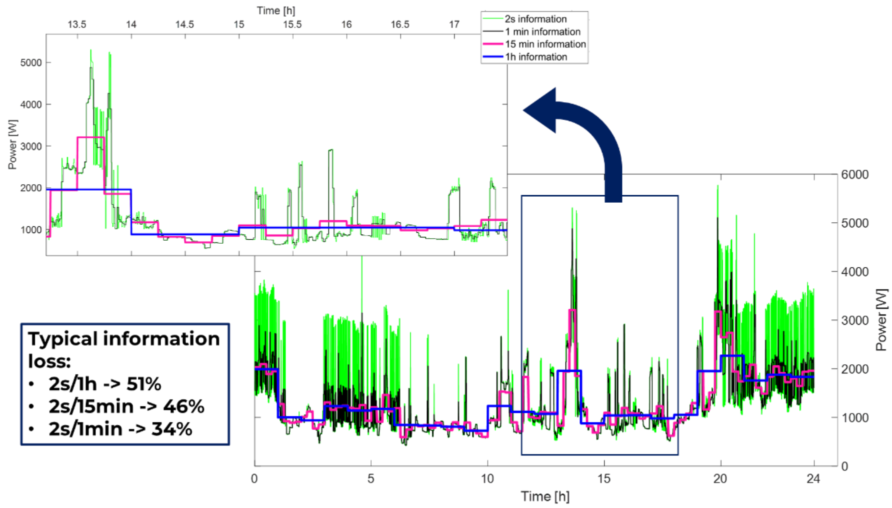

Fig. 5. Power profile for the second floor of a student building - for phase 1 – on a weekday in summer

Scenario for a single-phase power profile for the entire student building (spatial aggregation).

Measurements results for 24h operation during winter and summer for both weekdays and weekend days are presented. The information is for phase 1 of the entire student building, considering the equal distribution of loads on each phase. The measurement system consisted in single-phase energy meters installed on each floor (one meter per phase per floor). The power profile depicted in the following figures was computed by summing up the active power information extracted from each meter on phase 1 (as suggested in equation (7)).

$$P_1[t] = P_1^{et\,0}[t] + P_1^{et\,1}[t] + P_1^{et\,2}[t] + P_1^{et\,3}[t] + P_1^{et\,4}[t] \quad (7)$$

Scenario for the three-phase power profile for the entire student building.

Measurements results for 24h operation during winter and summer for both weekdays and weekend days are presented. The information is for the total active power on the three-phase system of the entire student building (total three-phase active power for a student building) (with a total of 15 rooms and 300 students). The measurement system consisted in single-phase energy meters installed on each floor (one meter per phase per floor). The power profile depicted in the following figures was computed using the equation (11) by summing up the active power information extracted from each meter on each phase (using equations (8) – (10)).

$$P_1[t] = P_1^{et\,0}[t] + P_1^{et\,1}[t] + P_1^{et\,2}[t] + P_1^{et\,3}[t] + P_1^{et\,4}[t] \quad (8)$$

$$P_2[t] = P_2^{et\,0}[t] + P_2^{et\,1}[t] + P_2^{et\,2}[t] + P_2^{et\,3}[t] + P_2^{et\,4}[t] \quad (9)$$

$$P_3[t] = P_3^{et\,0}[t] + P_3^{et\,1}[t] + P_3^{et\,2}[t] + P_3^{et\,3}[t] + P_3^{et\,4}[t] \quad (10)$$

$$P_t[t] = P_1[t] + P_2[t] + P_3[t] \quad (11)$$

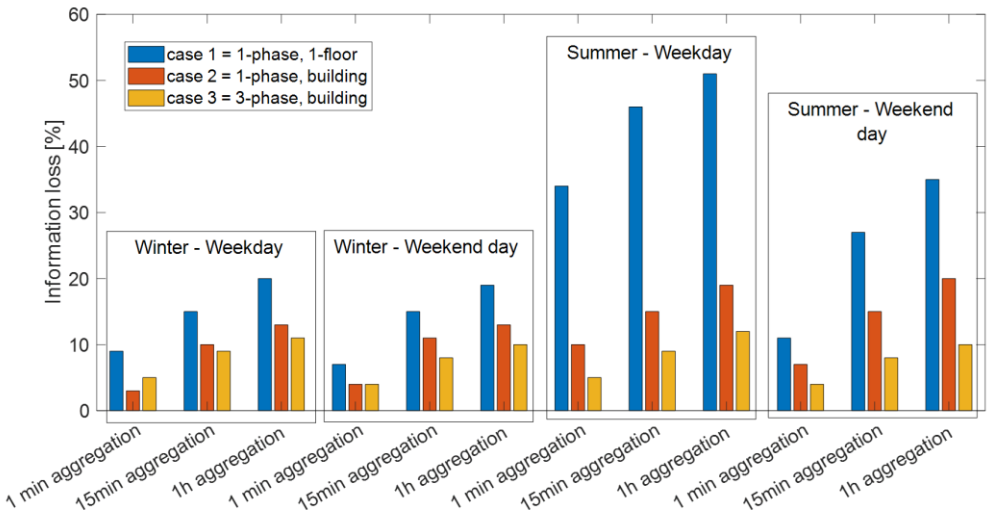

Fig. 6. Summary of information loss for all the studied cases

8. Conclusion

In Fig. 6 above, it can be observed the information loss variation for all the cases studied and described in this paper. It can be summarized here all the case based on the data plotted below, studied for winter and summer, weekday, and weekend day.

- 1-phase, 1-floor information, temporal aggregated over 1-min, 15-min, and 1-h. (single-phase power profile for one of the floors of the student building.)
- 1-phase, building information, with temporal aggregation over 1-min, 15-min, and 1-h (single-phase power profile for the entire student building).
- 3-phase, building with temporal aggregation over 1-min, 15-min and 1-h (three-phase power profile for the entire student building).

Those findings are in line with the assumption that spatial aggregation (customers supplied on each floor) is acting favorably in what concerns the levelized power profile (temporal aggregation) and therefore the need of high reporting rate (1 frame/s) is limited to individual customers. However, when combining such patterns of electricity usage with non-distributed power profiles (for example, high-power, fast EV charging units), the need of high RR is becoming relevant to assess investment solution, either for deferring DSO investment or to decide on local generation (PV), storage and flexibility provision [20]. acknowledgment

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