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Smart grid, smart home, smart car? Technology development leads to the many new opportunities

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Executive Summary

In this paper, the authors (Eaton European Innovation Center and Poznan University of Technology) will focus on smart grid, smart home and vehicle to grid cooperation. Those areas can increase the quality of service for grid customers, while helping grid operators. The discussion will address all complex issues, starting from the increased demand in an average household, towards making the home "smart". The authors will also analyse the impact of the electric vehicle charging on the house grid and power demand, while considering the benefits of having an electric car.

Eaton European Innovation Center (EEIC) is a R&D facility located near Prague (Czech Republic), hosting international experts from all of Eaton's divisions. EEIC supports R&D activities in chosen technologies, such as Arc Modeling, Smart Grids, Hydraulics, E-mobility and Energy Storage.

Poznan University of Technology (PUT) is a technical university located in Poznan (Poland), with approximately 21,000 students graduating each year as experts in their field. The University encourages the participation in many competitions, such as Formula Student or SAE Aero Design, where students gain the necessary experience to be competitive.

Key words: smart grid, smart home, smart car, photovoltaic, stationary energy storage system

1 Introduction

1.1 Smart solutions

The global warming reversal efforts and the energy transition initiatives are mainly focused on achieving long term results, admitting short term sacrifices for the user: lower temperature in homes, reduced transportation autonomy, higher prices for green technology. This effect is reducing the chances of success for the proposed solutions, as users are reluctant to adopt them.

As smart devices are emerging, enabled by the Internet of Things applications, a more practical approach is possible, by implementing sustainable technology and habits without compromising the comfort of the user. [1] [2] [3] [4]

Historically, the first approach in this direction was the possibility to schedule the use of energy consumers in the home. Although the nature of energy consumers in homes is evolving, heating and lighting are still using most of the energy (as seen in the Figure 1), optimizing the use of these loads will have significant impact.

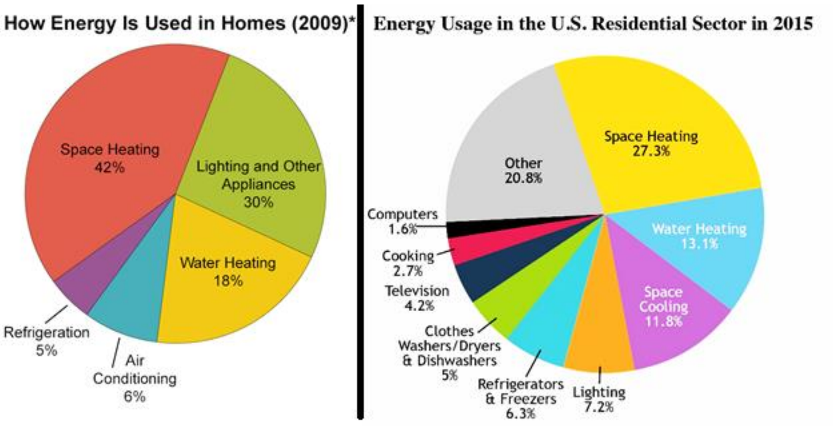

Figure 1. Energy consumption in homes [5]

Present advances in communication allow remote control of the appliances, as well as notifications when user intervention is recommended. As the market for smart home appliances increases every year, anything in your house can be smart: clocks, speakers, lights, doorbells, cameras, windows, window blinds, hot water heaters, appliances, cooking utensils, including Nest thermostats and smoke detectors, August smart locks, Ring video doorbells.

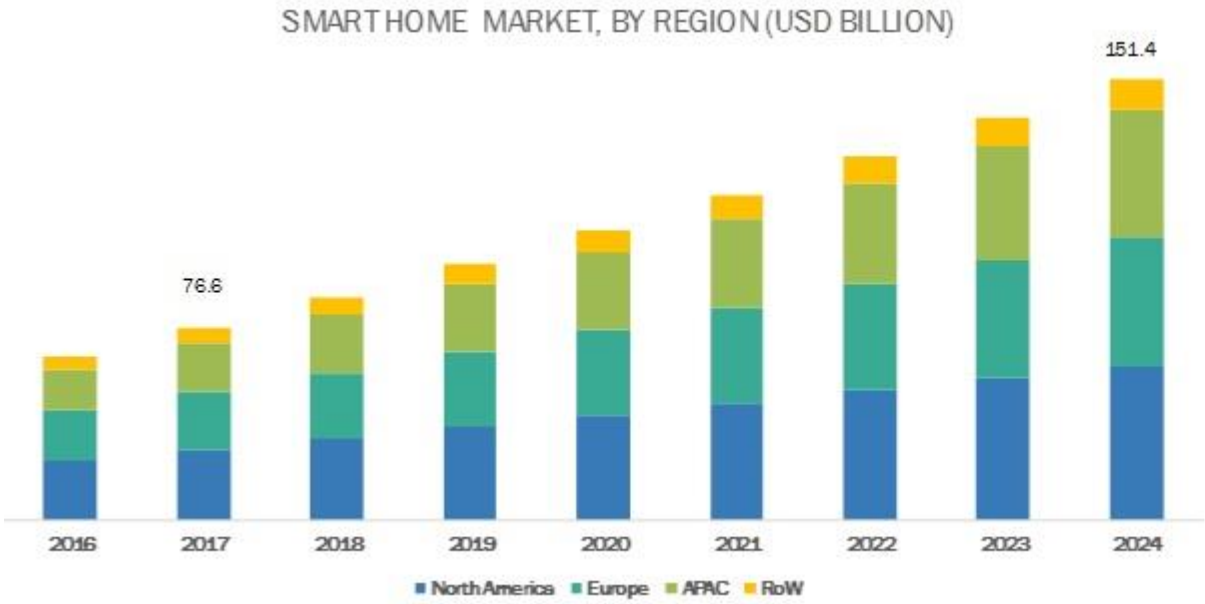

Figure 2. Projection of the smart home market [6]

The functionality is enhanced by integrating more functions in one device (like xComfort console from Eaton) or when natural speech is used to control the devices, with personal home assistants like Google Home, Bosch's Mykie and Amazon's Alexa [1].

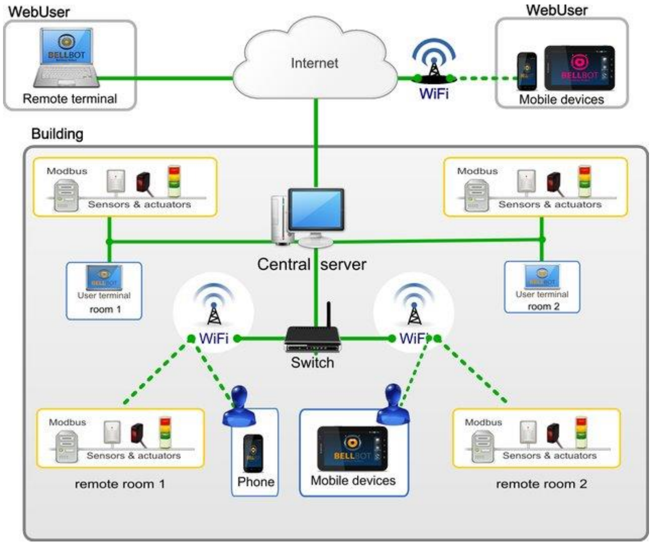

Figure 3. Overview of a home automation system [7]

Nowadays, besides the enhanced user experience and advanced flexibility of available features, energy management and energy conservation are also considered when deploying sophisticated smart home systems. However, the performance of energy management systems is highly influenced by user behaviours and adopted energy management approaches. Significant benefits can be achieved when a holistic approach is considered. Home automation systems (like xComfort from Eaton) can reduce the consumption while enhancing comfort and safety, by dynamically managing the loads (based on current consumption/renewable generation). The customer has full control of his house and gets informed when some incident occurs, via e-mail or a text message. The savings resulted from a system approach were reported as reaching 30% [8].

Home automation systems of tomorrow will be based on Artificial Intelligence algorithms that can take decisions and optimize energy transfer, including Machine Learning that improves its performance based on historical data [9]. The system would be responsible for setting up control parameters, according to historical measurements from sensors in the home, employing decision making using artificial neural network. This solution will gradually increase user comfort over time, with minimal intervention required.

In some of the proposed scenarios for energy savings, implementing benefits at the neighbourhood level, the users are asked to accept disadvantageous consequences. In these situations, additional measures need to be taken as incentive. For example, a smart home that is equipped with renewable generation and energy storage can be configured to provide electricity to the neighbourhood, in a Smart Community [10] system. The greater benefit is at the neighbourhood level, by shared use of all available generated energy and energy storage. The distributed resources pool can be extended to the electric vehicles that spend 95% of the time in the parking spots [11]. Electric Vehicle to grid (EV2G) protocols have been developed and allow the use of the vehicle battery as an additional asset within the Smart Home system. A user in the Smart Community can access green energy even if his own systems are not available for the moment or can have the energy produced by his renewable sources further stored, even if his own storage system is full. The benefits are maximized at the system level.

As this practice will increase the wear on the battery, a proper compensation system should be implemented. The amount of energy exchanged between homes is monitored and the net producers in the system are compensated accordingly, either by energy credits or by cash payments from the net consumers. The technology that will allow monitoring of energy exchange and compensation mechanisms is still a research subject, with several experimental methods proposed [12] [13]. Although the blockchain technology has been considered a promising approach, recent studies [14] have revealed the disadvantages of the method and the need for more efficient algorithms.

1.2 Stationary energy storage systems

An increase in interest is seen for stationary energy storage systems, as a viable solution towards increasing the reliability of renewable energy sources. [15] [16]
Electrical power grids, especially in the case of micro and smart grids, require energy storage systems for efficiently integrating renewable energy systems with multidirectional power flow. Battery Energy Systems (Lithium-Ion technology is most common) are recently becoming the solution for smart home, which can store energy from a local distributed generation for later consumption, enabling the possibility of off-grid operations (systems like Eaton xStorage Home and Tesla Powerwall). An Energy Management System assures the required power quality and resiliency even in critical applications like hospitals.

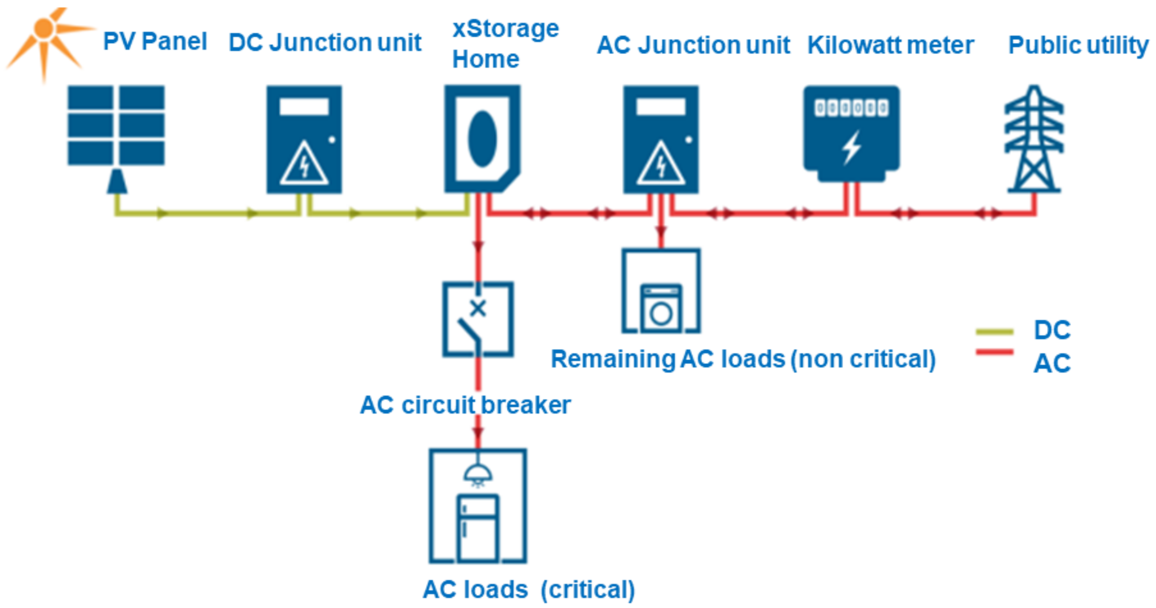

Figure 4. Residential installation system overview

Residential system presented on [Figure 4] allows to maximize use of energy from PV or other renewable sources. Energy can be accumulated in xStorage Home, while is generated by renewable source or grid energy cost is low and the xStorage Home device can provide energy to the residential system, while grid energy's price is relatively high, or energy can be sold to the grid (as a part of Distributed Energy Resources – DER)

1.3 Smart grid

In order to address the fast-growing demand of electricity and, at the same time, promote decarbonization, Renewable Energy Sources (RES) are used for reliable, affordable and sustainable energy. However, there are some challenges. The solution is to develop a new concept of power network which can deal with distributed generation, electric vehicles and storage systems. It integrates sensors, actuators, and PLCs in automation systems supervised by control algorithms (i.e. SCADA). The consumers can participate actively in the energy market due to local generation and bidirectional power. Finally, smart grids promote clean and renewable energy, combined with the development of electric mobility. The possibilities of smart grid network work are multi-level what is shown in Figure 5.

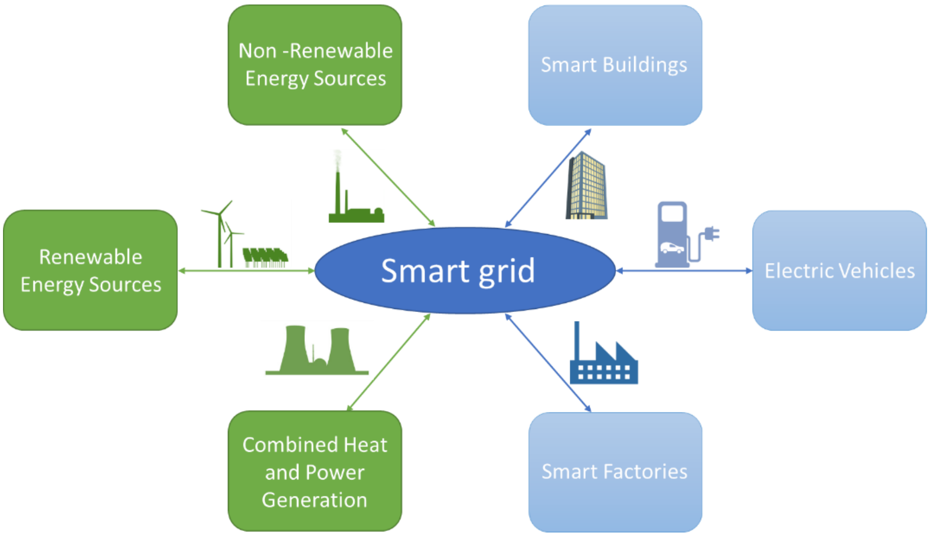

Figure 5. Idea of Smart Grid [17]

The smart grid integrates the activities of all its connected participants, such as generation, transmission, distribution and other loads. The main purpose of this type of power grid is to provide energy safely, economically and permanently in quality. The key extension of the standard grid is the significant expansion of smart energy meters. It allows to control the operation of the grid and their all participants and to program its most favourable state in real time [18]**.** The main advantages of smart grid solution are presented in Table 1.

Table 1. Parameters and features of EV charging standards [19]

Benefits related to the power system	Benefits related to electricity
• Reducing operating and maintenance costs of the grid; • Reducing of requirements related to grid expansion and construction of large generating power plant units; • Reducing transmission restrictions; • Possibilities of system support by many small energy producers; • Increasing reliability of grid operation.	• Flexible working conditions; • No need for long starting time of large power plant units; • Increasing security of electricity supply; • Lower unit investment cost; • Ability to reduce energy reserves in the system;

It is worth noting that the smart grid network with bidirectional power transmission is particularly beneficial in relation to the operation of electric vehicles and the possibilities of their cooperation with the power system. There are many models of cooperation of electromobility with the smart grid (VTG - vehicle to grid) as well as electric vehicl with a smart home (V2H - vehicle to grid) [20] [21]**.** Batteries installed in the vehicle can be used as a source of energy at the time of high demand and as energy storage in the low demand of electricity demand. It is worth noting that intelligent network solutions additionally support the development of electromobility. Then, electric vehicles have a significant impact considering the environmental efficiency in transport and support power grid and their all participants security and reliability of energy supply as well.

2 State of art technology for a better living

With the energy transition to decentralized production and electric cars, the lifestyle of many people is changing. Many car manufacturers provide dedicated solutions for users to schedule or remotely control features such as start/stop of EV charging or Air Conditioning. [3]

Technology development among smartphones in recent years led smart devices manufacturers into creating "more smart" devices, starting from smart TV, towards wireless audio and video streaming possibilities to sophisticated wireless controlled environment. For last couple of years most of the devices were present as single solutions or small systems, however the missing link was the way how to connect them. Sensor fusion allows to collect and process the data from disparate sources, integrated with a proper gateway for connected environment, allows the final user to control desired features, using only dedicated app - Figure 6.

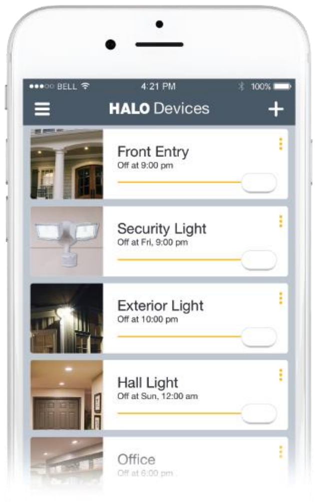

Figure 6. An example view of dedicated mobile app [22]

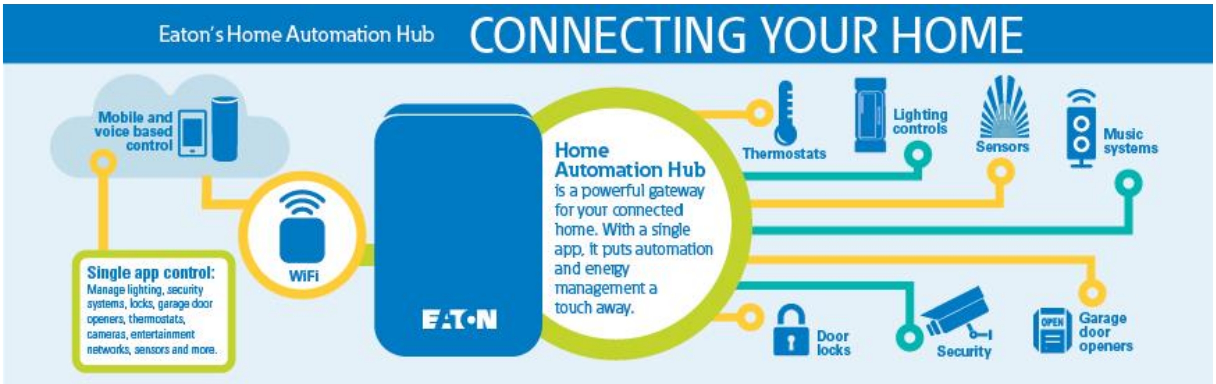

Figure 7. Eaton's Home Automation Hub overview [23]

Figure 8. Eaton's Halo Home example [22] [24]

Users can buy devices, which are complying with industry's standards, like Bluetooth Mesh [22] [24]

Figure 9. Hyundai's mobile app to control some vehicle's features [25]

Recently car manufacturers noticed growing interest in creating bigger, smarter systems for people. Making daily routine more convenient is possible thanks to integrating smart systems also in the vehicles. Newest cars in the market can support virtual assistants like Google Assistant, Siri or Amazon Alexa and therefore integrated with the most popular smartphone systems like iOS and Android [Figure 9].

Majority of passenger car manufacturers provides dedicated app, which has features such as locking/unlocking the car, locating car possibility or even comfort features. Car climate comfort control starts with simple remote control of heating, ventilation and air conditioning (HVAC), towards dedicated pre-programmed routines (defrosting windows and reaching 18°C in the interior before user enters the vehicle), to complex environment control in the future (pre-programmed routine, smart home link, smart vehicle charging with V2G). [26]

Vehicle to Grid (V2G) connectivity allows for smart cooperation between vehicle and the grid. Vehicle can be charged only, while power demand in the grid does not exceed grid possibilities, energy is cheaper or even if user wants to use only green energy.

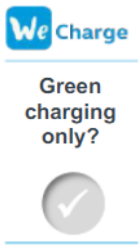

Figure 10. Volkswagen's We Charge app [27]

Car manufacturers discovered a big business potential in providing complete system solutions, not only for the final customer (private user, fleet users), but also for energy providers. Elli, the start-up company owned by Volkswagen [28], provides complete solution. Other service Volkswagen launched is "We Charge", which allows not only for car-sharing feature, but also select if charger should only use renewable energy (Figure 10, [27]).

3 Transition from ICE to electric vehicle. Benefits for a household

3.1 Vehicle electrification

Vehicle electrification is not only a necessary step to reduce exhaust emission and guarantee a sustainable future, but also a technological revolution which can bring several economic and practical benefits. They are beneficial for both grid operators and householders allowing an intelligent power management of the charging process and also a possible exploitation of energy stored in the vehicle battery.

To take advantage of these opportunities the electric vehicle charging must be controlled in such a way to minimize the impact on the grid and therefore to avoid the overload of electric lines with the voltage drop and unbalance. This charging control management can be performed differently and with different time shift depending on the applications and use cases (charging station in offices, supermarkets, household chargers etc.) but it is essential for reducing the undesired impact on the total electricity demand, and maybe in some case also improving the energy balance by the peak shaving method and vehicle to grid (V2G).
For this article's purposes, it was assumed that an electric vehicle owner, who has an average daily commuting distance of 50 km. Considering as an example vehicle 2018 Nissan Leaf with a 40 kWh Li-Ion battery and 241 km of EPA range, then 8.3 kWh of energy is consumed daily. It means that using a standard residential EV charger and charging by AC single-phase power (230 V, 16 A) at 3.6 kW the charging will be completed in a minimum of 2.5 h charging with a constant power. Considering it is done immediately at the end of the working day, between 6 p.m. and 9 p.m., it coincides with the peak power demand, causing an overload on the grid, with the consequence listed above.
For these reasons, a smart control management of the EV charging should be performed, and it includes important features like peak shaving, minimizing electricity cost, auto-consumption with DER (Distributed energy resources) and V2X (Vehicle-to-everything).
When it comes to EV charging, different car owners behaviour should be considered:

- people who charge their cars at any public charging stations or at parking lots in their workplaces;
- people who own wall mounted residential EV chargers at their houses

For the first group of electric vehicle owners the behaviour of the load required by the electric charge, sometimes, can be managed by supplying the energy from renewable local generation (e.g. parking lots with solar panels) without stressing the grid peak load.
The second category of owners, instead, can charge their vehicle at home, and for these people instead the power management and charging scheduling is the only solution to face overload/undervoltage issues. Moreover, the need for re-charging depends on many factors that range from the personal use rate of the car to the day of the week and also the time of the year. According to a study [29], the overall month to month trend shows that more charging power is required during the colder months compared to the wamer ones, because each vehicle will use more energy to supply on board electric heaters, and also batteries perform elss efficiently in cold temperatures.

During the daily time there are 3 charging power peaks (early evening, overnight and morning) reflecting 3 categories of EV domestic charging station owner behaviour: people who charge in the early evening after return home from work, who don't use the charging schedule; people who schedule the charging in the time range late evening-early morning exploiting a cost saving strategy; and people who schedule the charge to occur in the early morning to warm up the battery before leaving home.
The benefit of smart charging would be to increase the number of people behaving like in the 2nd category which will provide either economical and grid support advantages as well.
The EV charging has the opportunity, and also the duty, to be done during off-peaks periods without affecting the usability of the vehicle [30]. In addition, controlling the charging rate might help electric grid operators to gain an higher degree of control over the network by means of voltage control, frequency regulation, operating power reserve (spinning reserve) through V2G operations.
In fact it is possible to prevent electric loads peaks by delaying the charging to off-peak time, and this strategy is called load shifting. For example it is reasonable to delay the time of charging to after-midnight hours, where the total domestic electric consumption (and also for the whole electric network) is at the minimum level.

3.2 Smart solution for EV charging

There are already many available products in EV market where the key features of smart charging and power management in EV charging station are implemented. In Figure 11 is shown Eaton's electric vehicle charging station "xChargeIn" includes four different series of product: A, X, M and S, with different application areas from simple wall mounting in a private house to the use in commercial buildings, company offices and public parking areas. On the top of that, this system offers a range of accessories that make the charging solutions more innovative, for example through the intelligent power management which enables the smart charging aforementioned, improving the efficiency and the cost-effective characteristic.

Figure 11. Eaton xChargeIn EV charging station

The X, S and M series charging stations can be externally controlled from the user/householder in order to manage the whole charging process (time scheduling and power rate). Via the "Smart Home Controller (SHC)" it is possible to implement load control management. The "load shifting" and "peak shaving" principles are used for this purpose to interrupt the charging process during periods of high power consumption and bring the system back online once consumption levels have returned to normal.

Figure 12. Eaton xComfort

If "Eaton xComfort" (Figure 12) is used in combination with the "SHC xChargeIn peak control" mechanism (fig. 3.3), it is possible to prioritize the supply of the more important devices at any time, scheduling the EV charging also according to this priority.

Figure 13. Eaton Smart Home Controller for xChargeIn Peak Control.

The optimal power management of the EV charger thus is allowed by a cross-products operability with the xComfort Smart Home System which is a wireless home automation system that brings comfort, safety and energy management into the home, offering a perfect control and management of the power consumption and power flow directions in the house.

3.3 Benefits of smart charging strategies

An essential key factor of the EV charging power management is to control the time and the power supplied during the charge in order not fall in local overload issues. It is also to take into account the need to prevent an undesired voltage drop at the buses of the network, which is related to the overload issues. The EV supply, in fact, can be adjusted in such a way to maintain the voltage and power stability within the standard requirements (according to the European standard EN 50160 "Voltage characteristics of electricity supplied by public distribution network"), especially if there is an effective co-operation between EV charger owner and the electric grid operator/ electricity provider.

Similar matter about the phase unbalance, in the case of low power single-phase domestic EV charging, because the excessive unbalance is also regulated and limited by the standard EN 50160 and it is dangerous for the voltage and power stability of the grid. Furthermore, with an higher level of control and communication, the EV charging can be used as a tool to provide a re-balance to the existing unbalanced network, to that to improve the voltage stability.
Recently it can be observed a trend that energy providers and car manfacturers started to look for new business opportunities of using electric car's battery as a storage system thanks to battery capacities bigger than 60 kWh (2019 Chevrolet Bolt, 2019 Hyundai Kona or all generations of Tesla Model S). Theoretically they could be perceived as a great candidates for V2G (Vehicle-To-Grid) operation. Currently all activities in this field are under development and they are the matter of several standard working groups or initiatives [31].
In fact, the V2G and V2X (Vehicle-to-Everything) describe a system operation in which a PEV (Plug-in Electric Vehicle) or PHEV (Plug-in Hybrid Electric Vehicle) communicates with the power grid to provide back electrical energy, exploiting the battery storage capability to exchange power in a rate suitable for the battery, the charger and the EVSE (Electric Vehicle Supply Equipment).
The applications for this charging strategy are, as aforementioned, the electric ancillary services, storage additional capability during power outages and home energy management services.
Currently the V2X communication and bidirectional power flow is featured under the standardization made by CHAdeMO and it is planned to be supported by the new specifications that will be released from CCS (Combined Charging System), which are also the two electrical connector standards that enable the DC fast charging of electric vehicle by means of direct current, up to 350 kW.

Tab. 1: Parameters and features of EV charging standards

Connector type	Power level	Connector/pins layout	Electric features	Charger	V2X bi-directional
Type 1 SAE J1772	AC level 1 and 2	L1, L2, L3, N, PE, CP, PP	1ϕ, 120/240V, 16/80 A, 1.92/19.2 kW	On-board	no
Type 2 IEC 62196	AC level 1 and 2	L1, L2, L3, N, PE, CP, PP	1ϕ/3ϕ, 230/400V, 32/63 A, 7.4/43 kW	On-board	no
CHAdeMO	DC level 3	Vdc+, Vdc-, PE, CAN, Analog pins	200-1000 V, ≤ 400 A, 400 kW	Off-board	yes
SAE/CCS Combo	DC level 3	Vdc+, Vdc-, PE, PP, CP	200-1000 V, ≤ 400 A, 350 kW	Off-board	planned
Tesla US	DC level 2	Vdc, Vdc, PE, CP, PP	400 V, 300 A, 120 kW	Off-board	no

Another electrical ancillary service which can be provided by the electric vehicles development and spread is the frequency regulation, which is by definition a strategy employed by the electricity grid operator to adjust the grid frequency around the standard values 50/60 Hz, when, usually due to an unbalance between load and generation, it assumes values different from the nominal one.
This essential service can be improved with the integration of a large number of EV charging stations into the existing grid, requiring, obviously, very high level of synchronization and communication between the EVSE and the network.
Electric vehicles are a future promise for providing the frequency regulation service thanks to their fast regulating characteristics. But this is also challenging due to the difficulty in achieving the optimal power dispatch into the grid, respecting and controlling the battery SOC (State of charge).
In [32] was proposed a V2G control strategy with EV's participation on the SFR (Supplementary Frequency Regulation) considering the regulation from a centralized control center and respecting the desired battery SOC levels from the EV owners. It was thus proposed a closed-loop hierarchical V2G control for the EVs participation in SFR, which include the co-operation between the EV aggregator, the EVSEs and each individual vehicle. In order to achieve the frequency regulation and to meet the EV charging demand as well it was considered an uncertain dispatch in the control center and it was performed a real-time correction of the scheduled V2G power levels in the charging stations to ensure the expected SOC levels of batteries.
In particular the focus was on the achievement of both the regulation dispatch from the control center and the expected battery energy levels as well. The expected and desired SOC levels are taken into account being one of the most important concerns for EV owners and they have been categorized into three types: increasing

the battery SOC to increase the range, decreasing the SOC for selling energy by V2G and maintain the battery energy avoiding depth discharge cycles.
With the participation of EVs in SFR, vehicles undertake part of the ACE (Area Control Error), that measures the supply-demand mismatch, for the regulation; moreover the FRC (Frequency Regulation Capability) is calculated in real time as the V2G power, which determines the FRC, is usually varying with time due to the smart scheduled charging.
The use of EV as a storage battery system for bidirectional applications anyway is still a technology which led to many discussions and different perspectives amongst experts and car manufacturers. In fact, despite being already tested with some cars model, it requires a very high level of communication and synchronization between the EVSEs, the increasing number of vehicles and the DSOs (Distribution System Operators).
Furthermore, it is even more important to highlight the fact how the EVs batteries are affected by high number of charge and discharge procedures, which leads to accelerated capacity (more frequent cycles with V2G operations implemented in the existing systems in a comparison to systems where no V2G operation is performed).
As discussed in [33] battery performances, in fact, deteriorate over time, temperature and rate of usage. And in particularly what is interesting from the V2G and quick charging of EV points of view is the frequency and rate of charging/discharging processes (the deeper discharge cycle, the faster capacity fade can be observed).

3.4 EV Charging from DER systems

A way to maximize the benefits arising from the e-mobility revolution is the concept that electric vehicles can be charged in sustainable way, mainly by photovoltaic modules.
This opportunity can be exploited either in household and commercial buildings application as well. An emblematic example is the one of parking lots with solar panels on the roof, which employ the double function of shading for cars during the parking time and power supply for plug-in electric vehicles. This is the case with the highest level of renewable energy exploitation for EV, because the presence of the vehicle plugged to the charging system during the day ensures the supply of power from PV (especially during sunny and productive days), without stressing the power grid voltage level with excessive injection from DER (Distributed Energy Resources) and high demand from EV charging.
In [34] is analysed the state of art technology for charging electric vehicles from solar power sources, with also a focus on the environmental and economic benefits of PV charging of EV.
In fact, the two key benefits which immediately come out from PV-EV charging are sustainability and economics.
From a sustainability perspective has to be taken into account that the well-to-wheel efficiency if an EV is charged by solar power results in much higher value and also in much lower emissions which can have negative impact on the environment. On the other way the economic benefits come from the decreasing prices of PV systems and electricity produced by them (which is already cheaper than the traditional one almost everywhere) and also because the total cost of ownership of an electric car is lower than the one of an internal combustion engine [35]. Finally, it deserves to be mentioned that controlling the charging in such a way to exploit the PV production allows a possible reduction of tariff to be paid to the grid operator and increases the PV self-consumption (ensuring a return of investment for the solar system).
To make the solar charging of EV attractive from an environment, sustainability and cost perspectives thus is required a connector standardization which facilitates the communication and control between the EVSE and EV in order to provide the smart charging and all the above mentioned functionalities.

3.5 Power management and storage systems for household applications

The integration and increasing number of PV as a distributed power generation in the low voltage network and in private houses often requires a certain level of storage capability in order to exploit optimally the power flow deriving from the intermittent and unpredictable energy generation. In order to face this need a few smart storage systems for houses have been proposed in the market.

“Eaton xStorage Home”, for example, is a product which helps householders to store energy and control how and when to use it providing a reliable service for the house and also a power support for the grid by a bidirectional power exchange, if permitted by the local regulatory law.
It consist of a unit with a DC input suitable for PV system connection with an unidirectional power exchange, an AC input/output for a bidirectional power flow with the external grid and supply of AC non critical loads within the house, and finally also an AC output to supply AC critical loads during a power outage or lack of power.
The battery pack inside this unit is a Li-Ion battery (LMO and NMC cell chemistry) from Nissan, available with nominal capacity of 4.2 kWh, 6 kWh and 10.08 kWh, depending on the user requirements.
By intelligent control modes this battery enables charging/discharging cycles by the DC input (limited to 4.8 kW of power from the inverter), the AC input (limited to 6 kW) and AC output (limited to 6 kW in total critical + non critical). The electrical connection and input/output of this system are shown in Figure 14.
Settings of this unit allow also to control the discharge and charge of the battery in such a way to keep always a SOC in a range not dangerous for the battery lifetime.

Figure 14. Eaton xStorage Home

Thanks to the controllability of this unit there are several advantages which can be helpful for the user:

- Lowering electricity bills, because if connected to residential renewable energy source (e.g. PV system) this device helps to save money by charging up from the DC input when solar power is available or from the AC grid during the night (when electricity is cheaper), and eventually releasing the energy stored into the battery when load demand and electricity cost are high. This goal can be achieved by the Peak-Shaving operation mode Figure 15 that is a relevant strategy when the maximum power consumption of the household is limited by the energy provider (i.e. the utility contract). The peak consumption above the limit established can penalize the householder with additional energy costs, and a smart way to avoid these costs and still have the required power availability, is cover this gap with the energy stored in xStorage. The unit can be set and controlled in such a way that the power flow comes either from the solar DC input during the day or either from the grid overnight; the output power flow also can be controlled in order to dispatch the power flow to the AC critical loads within the house when it is necessary or into the grid to sell power.

- Optimizing the use of residential DER as it was already mentioned, the xStorage system guarantee to the householder that all the PV generation is used (by self-consumption or by the grid) favoring the return of investment. And of course, when PV generates power, it will first power up the house loads and then charge the battery or inject power into the grid, performing an intelligent operation mode Figure 20.
- Providing constantly an essential power reserve for the house, which ensure reliability and a continuous supply of residential loads, ensuring the electricity locally also during a power outage from the external grid.

Lowering the CO2 footprint of the householders, by storing, consuming or selling renewable energy back to grid. In this way householders can contribute to the decarbonization of the energy supply, maximizing self-consumption on site.

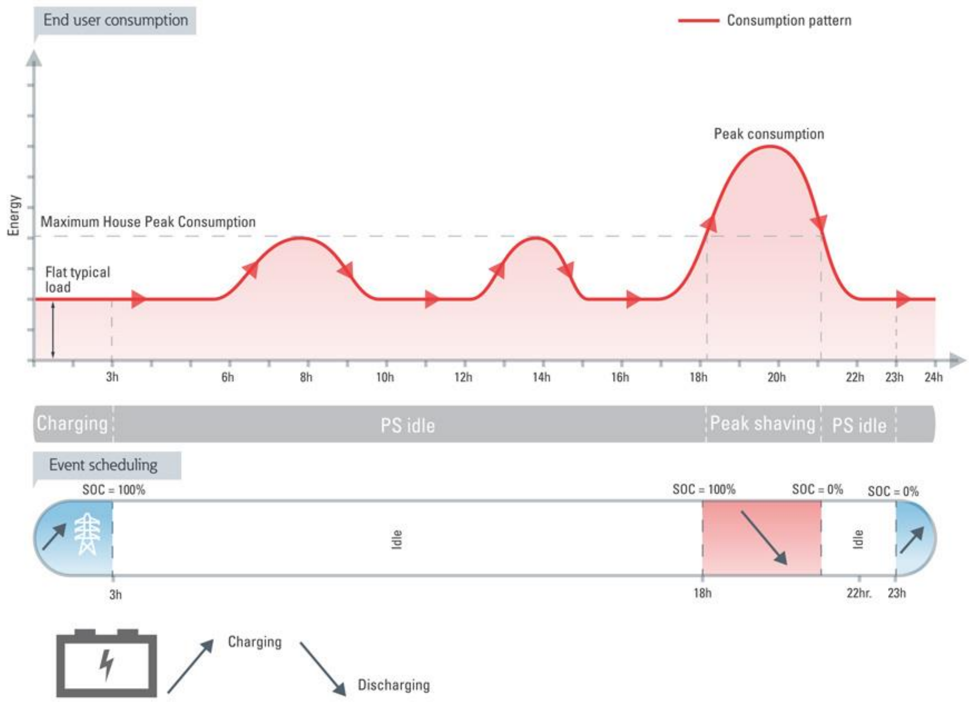

Figure 15. Eaton xStorage home Peak Shaving strategy

To maximize the benefits for householders Eaton is currently also working on xStorage home and buildings improvement in conjunction with EV charger.
In fact the possibility to allow the connection of the EVSE to the DC or AC input/output may create an important value by lowering peaks and for house owners with solar PV system maximizing self-consumption and promoting the green behavior. A smart integration with the xChargeIn could be improve the effectiveness of the residential power management adjusting the load according to optimization criteria (e.g. peak shaving, energy bill reduction, maximizing charging from PV power, etc.).

4 Modern household energy consumption. Renewable sources

Authors analysed electric power load profile of an individual household [36]. This examined household is not equipped neither with renewable energy source (like PV panels), nor with energy storage system.

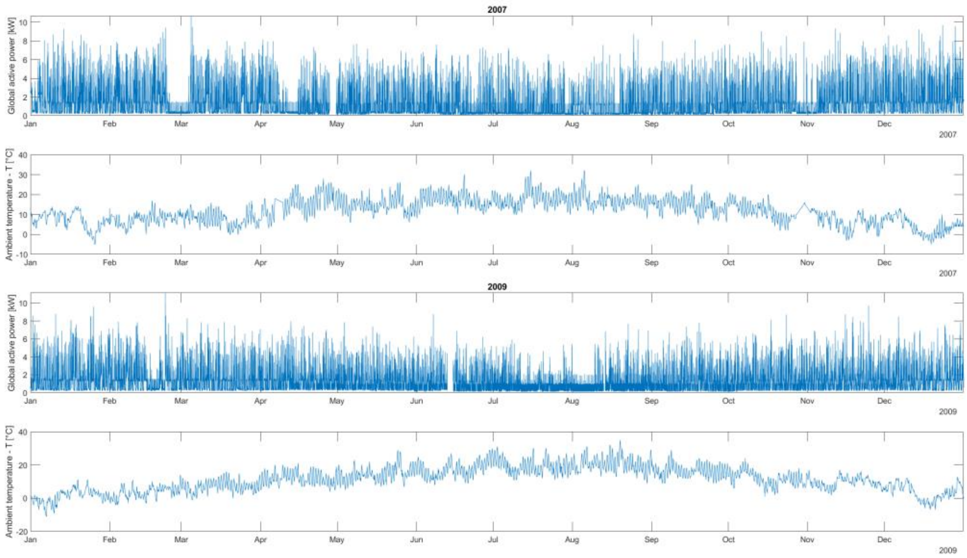

Figure 16. Comparison of electrical power load and temperature profiles for 2007 and 2009 [36]

It can be observed annual profile of electrical power load is similar for both examined years. Authors selected particular days to analyse pattern of daily energy consumption for examined household.

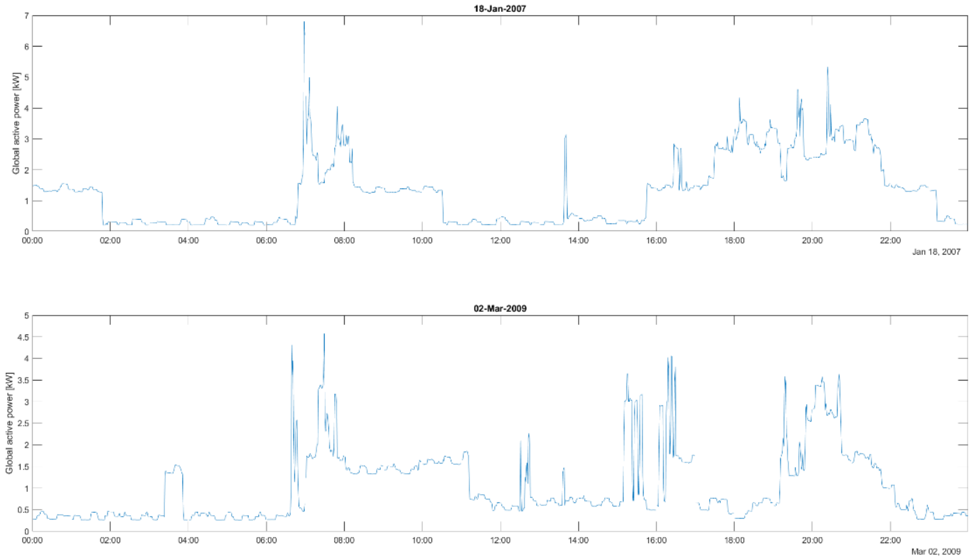

Figure 17. Daily electrical power load [36]

There were selected two days: January 18th, 2007 and March 2nd, 2009. Both days are the working days, which shows the morning and afternoon/evening peaks. Authors used available data to analyse constituents of power load in particular circuits.

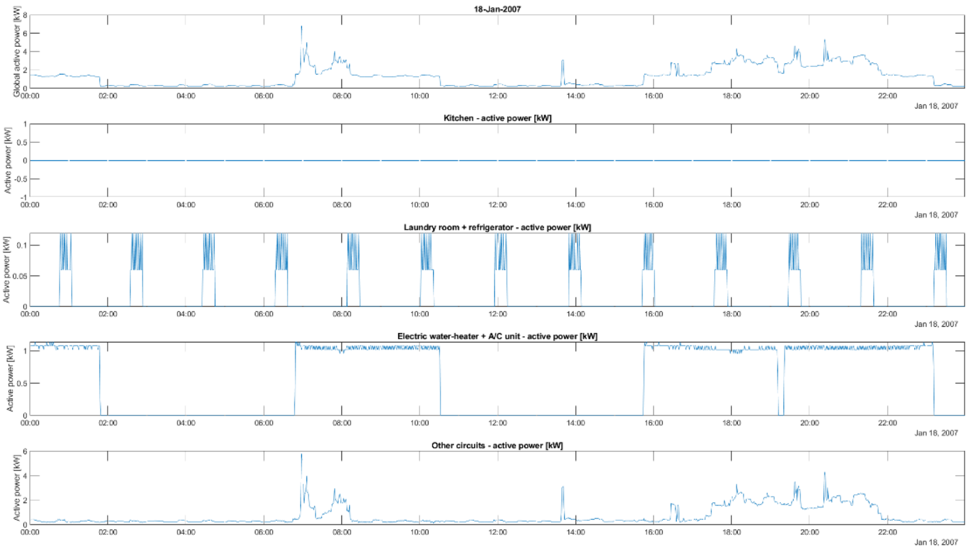

Figure 18. Detailed daily electrical power load: January 18th, 2007 [36]

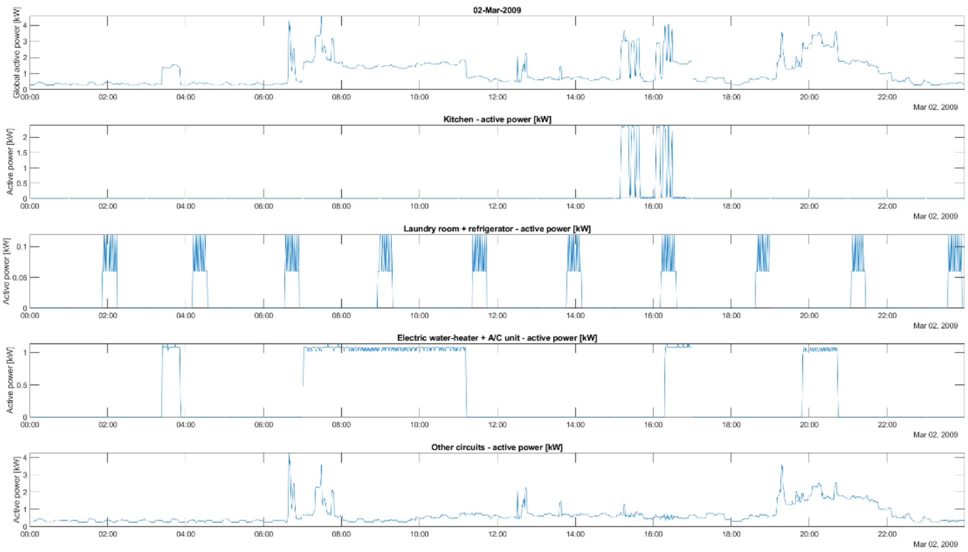

Figure 19. Detailed daily electrical power load, March 2nd, 2009 [36]

One of recurring power loads is work of refrigerator, what can be observed on both figures above. It can be also observed that electric water-heater works longer in January, however the peak hours remain almost the same in both cases. Other circuits, like lighting system, are also used in similar time as water-heater.

In both days, the power load in peak hours exceeds 2 kW, with a higher values in certain periods (even up to 11 kW). In overall, average power is 1.07 kW. Owners of this particular household, as well as any other customer of electrical utility company, have to pay for the power supply capabilities, which are required in the peaks. Significant number of households, which increase power demand in certain morning and evening hours are a big challenge for the grid. One of solutions, with mutual benefits for the both sides, is to use energy storage system to reduce peak power demand from a household to the grid. In this solution, grid provides standard, almost constant power, to the household (for example 1 kW), and the remaining power demand is covered by the household's energy storage system – overall power is provided to the customers, but the influence on the grid remains intact.

This strategy is called peak-shaving and it is the most beneficial for the customer, when it is combined with renewable energy sources – batteries in energy storage system are charged from the photovoltaics or wind turbine, which not only reduces energy used from the grid, but maximizes profit of having renewable energy sources thanks to maximizing utilization rate.

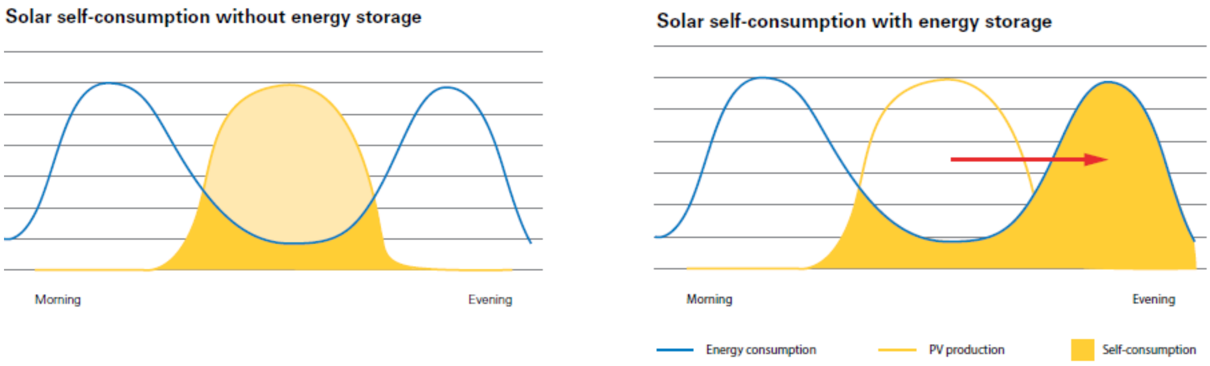

Figure 20. Comparison of solar-self consumption in a household without and with energy storage.

Figure 20 presents a comparison between the solar system with (right) and without (left) energy storage. While system does not contain energy storage system (ESS), energy is instantly consumed in the system or sent to the grid. User has no influence neither when energy will be sold, nor the selling price. This solution does not provide any grid independence, when energy is not generated by the PV system, as well it might be not beneficial for the grid system either, because of limited possibility of peak-shaving (energy might be not generated, when grid power demand reaches the peak).

While system has additional energy storage situation is significantly more beneficial for both, customer and energy provider (grid). Energy can be accumulated in the energy storage system and used in any convenient time for the system controller (maximized usage of generated energy, selling the energy for the best price, supporting grid in peak hours) [37] [38] [39]. An example of residential installation with xStorage Home is shown below (Figure 21)

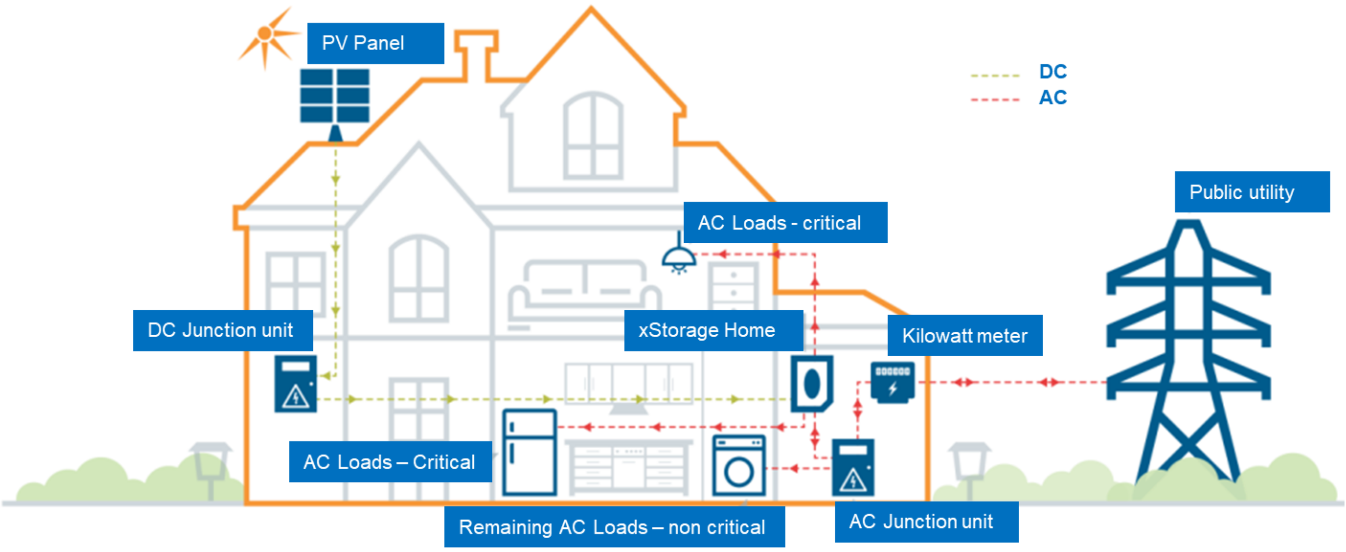

Figure 21. Residential installation with xStorage Home

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