

Impact Evaluation of the New Self-Consumption Spanish Scenario on the Low Voltage Terminal Distribution Network

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Abstract—The recently approved regulation about Self-Consumption in Spain will change dramatically the level of penetration of photovoltaic distributed generation combined with storage devices at residential level in the short term. In the present paper, we will make a study to assess which is going to be the impact of the massive installation of such technologies under the constraints imposed by the new regulation over the terminal distribution network. As it will be demonstrated this impact will be drastic in terms of energy demand, voltage profile and load curves.

Index Terms—Self-Consumption, Prosumer, Low Voltage Distribution, Power Flow, Net Balance, Energy Storage, PV Generation, Electric Vehicles, Peer-to-peer, Blockchain, Energy Sharing, Prosumers.

I. INTRODUCTION

Self-consumption combined with energy storage has been recognized as one of the most efficient and reliable approaches to integrate renewable energy in terminal distribution systems [1]. Recently, many authors proposed techniques for integrating energy storage systems combined with photovoltaic (PV) generation at residential level.

Nearly 20 years ago, the term "Microgrid" was first introduced as the solution to managing portions of distribution networks where there was both consumption and distributed generation, usually with high renewable penetration [2]. Today, emerging technologies such as the Internet of Things (IoT) or Web of Things (WoT), BlockChain technology, the democratization of platforms for using BigData and Artificial Intelligence (AI) and a reduction in costs in solar generation systems and energy storage systems [3], along with an increase in environmental awareness that has imposed major regulatory changes throughout the energy and transportation sectors are important revulsives that will somehow allow reinventing electricity distribution. New models will be generated and also very important business opportunities that, as a common denominator, will give a very active role to the so-called "prosumers".

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One of the cutting-edge concepts right now is the energy sharing among prosumers using the peer-to-peer concept. There are some pilot programs in this regard and many ongoing research related to this topic. A description of how the bilateral contracts could be implemented in order to deploy the peer-to-peer energy sharing can be found in [4], [5]. Other examples of clustering prosumers using PV generation and how the energy transactions between them can be implemented are described in [6], [7]. This change of paradigm will require a gradual adaptation of the distribution systems. It can be found in the literature some studies that try to quantify the impact over the distribution network of this "futuristic" systems [8], [9]. For instance, in [10], a very detailed analysis of the impact of PV-based residential system over the strategy of an electrical aggregator is presented. In [11] the concept of virtual storage is analysed in order to deal with high levels of PV penetration in distribution networks.

It can be found in the literature many studies about which is going to be the impact of these new technologies and paradigms in the distribution network [12]. For each specific regulation and configuration an impact study must be carried out before the real deployment. For instance, the study presented in [13] is focused specifically on the influence of self-consumption on distribution network operation in the Slovenian case.

In some cases, the impact can be positive if all the resources are correctly sized and operated [1]. However it is perfectly demonstrated that the uncoordinated penetration can create problems in the grid, as for instance, huge overvoltages in PV dominated distribution grids [14]. The study presented in [15] demonstrate the negative effect of the residential prosumers owning also EV fast chargers over the life of the distribution transformers. A probabilistic approach of the impact of PV system in a self-consumption scenario is developed in [15]. The authors in [16] proposes also an expansion planning methodology for distribution network depending on the self-consumption penetration. Other operation proposals allow to coordinate prosumer's energy storage devices for providing ancillary services like voltage control [17].

There are also many studies proposing many kind of sophisticated methodologies for managing distributed resources, sizing and placing them for all kind of applications. Many of them use analytical or metaheuristic optimization procedures as it is the case of [18]. In [19], the selection of the battery sizes is calculated through an optimisation procedure considering the seasonal variation of the demand

and generation in the prosumers and also the interaction between the low voltage and medium voltage networks. The study presented in [20] consider the interaction between the PV panels and storage systems but it also considers heat pumping. In [21], a building management system to coordinate electric loads, thermal loads and PV generation is proposed. In [22], the authors proposed an algorithm to plan the optimal charge and discharge schedule of the prosumer batteries in a microgrid. In the case presented in [23], the coordination is made at neighborhood level considering smart households comprising electric vehicles (EV), energy storage (ES) and photovoltaic generation. What all of these works have in common is the adoption of an optimization strategy that coordinates the different prosumers.

There is no doubt that the above mentioned approaches will set the tone in the medium/long term. However, in the short term, and in the vast majority of the cases, prosumers are installing the devices in an uncoordinated manner following *selfish* approaches and trying to maximize only their own benefit without considering any social welfare function.

The present paper aims to assess the impact of EV, PV and ES technologies over the distribution network in a very specific scenario, the new one created in Spain after the recently published Royal Decree that establish *Urgent Measurements for Energy Transition and Consumer Protection* [24]. It is expected that this regulation will create the conditions to drastically increase the penetration levels of photovoltaic systems combined with energy storage at domestic level. For carrying out this study, it has been considered that there is no coordination between the different households.

The paper is structured as follows. The following section briefly explains the new regulatory framework for self-consumption in Spain and compares it with the previous situation. Section III explains the household electricity management system and section IV describes the scenarios considered for carrying out the study. In section V the results obtained will be presented and in section VI the authors will expound the conclusions of the study.

II. SELF-CONSUMPTION SPANISH SCENARIO

The Spanish scenario for Self-Consumption and Net-balance of consumers connected to the low voltage network changed drastically since October 6th, 2018 with the publication of the Royal Decree-Law 15/2018 [24]. The previous scenario was regulated through the Law 24/2013 of the Electric Sector [25] and multiple Royal Decrees among which the Royal Decree 900/2015 stands out [26]. Limitations imposed by the previous regulation prevented domestic consumers from mass installation of PV panels in combination with storage devices, even when the price of panels and batteries has been significantly reduced in recent years, along with an increase in efficiency.

The new regulation establishes two modes of self-consumption depending on whether or not there is a physical device that prevents the injection of excess energy into the network. In the first case, the whole installation can be considered as a consumer and the administrative burden for

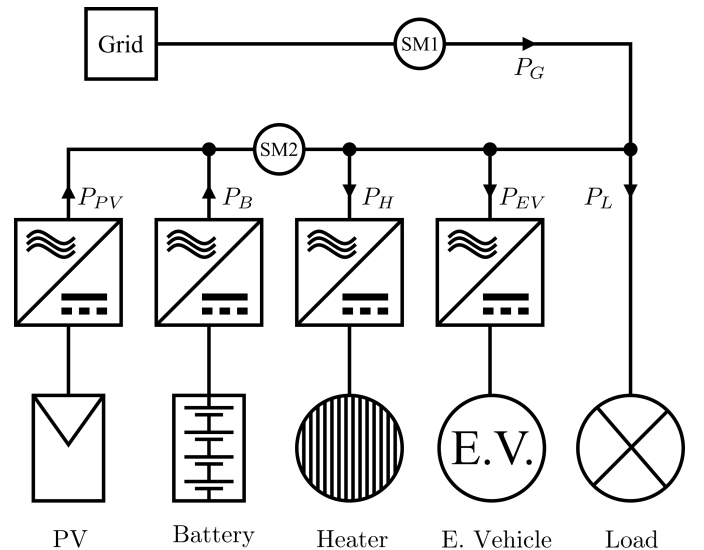


Fig. 1: Simplified scheme of a dwelling electrical installation including PV panels, batteries, controllable electrical water heater, electrical vehicle charger and the conventional load.

the legalization of the system is very small. For this reason, the vast majority of households are expected to use this system in the near future. The second mode allows the injection of surplus energy, but in this case, the electrical installation must be divided into two from the administrative point of view (Consumer and Producer).

In order to explain the actual conditions and the improvement with respect to the previous situation from the point of view of the domestic consumer, we are going to consider a simplified scheme like the one depicted in Fig. 1. In the previous scenario, it was mandatory the use of two different smart meter devices (labeled in the 1 as SM1 and SM2). The first device (SM1) read the total net power injected and consumed from the network. The second device reads the net power of the set (PV panels + batteries). Negative readings were not allowed on SM2, so the battery could only be charged with energy from the PV panels.

There was also a restriction imposing that the contracted power at the point of SM1 should be greater than or equal to the installed power. This limitation was repealed with the new Regulation. In the previous situation, if we installed PV panels with a peak power of 10kW, we should contract 10kW for the consumer even if it is not necessary. It should be noted that the electricity bill in Spain is binomial, with one term depending on the energy consumed and another depending on the contracted power. This second term can be very important and in the previous situation it was not possible to reduce it through the installation of PV panels or accumulation systems.

In addition to the energy and power terms, the *prosumers* as well as the rest of the agents in the system must collaborate to maintain the electrical system. For this reason it is necessary to pay extra charges and tolls for using the grid. We have two kinds of charges, the fixed and the variable ones. The fixed charges usually depend on the contracted power. The

Input: $P_{PV}, P_L, P_{EV}, C_{B0}, C_{B_{max}}, C_{B_{min}}, P_{B_{max}}, \eta_B$

Output: P_G, P_B, P_H, C_B

1. **FOR** $k = 1$ **TO** 86400 **DO**
 2. $P_{LT}^k = P_L^k + P_{EV}^k$
 3. **IF** $P_{PV}^k \geq P_{LT}^k + P_{B_{max}}$ **AND** $C_B^{k-1} < C_{B_{max}}$
 4. $P_B^k = -P_{B_{max}}; P_H^k = P_{LT}^k - P_{PV}^k + P_{B_{max}}$
 5. $P_G^k = 0; C_B^k = C_B^{k-1} + \eta_B P_{B_{max}} / 3.6 \cdot 1e^6$
 6. **ELSEIF** $P_{PV}^k \geq P_{LT}^k$ **AND** $C_B^{k-1} < C_{B_{max}}$
 7. $P_B^k = P_{LT}^k - P_{PV}^k; P_H^k = 0$
 8. $P_G^k = 0; C_B^k = C_B^{k-1} + \eta_B (P_{PV}^k - P_{LT}^k) / 3.6 \cdot 1e^6$
 9. **ELSEIF** $P_{PV}^k \geq P_{LT}^k$ **AND** $C_B^{k-1} \geq C_{B_{max}}$
 10. $P_B^k = 0; P_H^k = P_{LT}^k - P_{PV}^k;$
 11. $P_G^k = 0; C_B^k = C_B^{k-1}$
 12. **ELSEIF** $P_{LT}^k \geq P_{PV}^k + P_{B_{max}}$ **AND** $C_B^{k-1} > C_{B_{min}}$
 13. $P_B^k = P_{B_{max}}; P_G^k = P_{LT}^k - P_{PV}^k - P_{B_{max}}$
 14. $P_H^k = 0; C_B^k = C_B^{k-1} - \eta_B P_{B_{max}} / 3.6 \cdot 1e^6$
 15. **ELSEIF** $P_{LT}^k \geq P_{PV}^k$ **AND** $C_B^{k-1} > C_{B_{min}}$
 16. $P_B^k = P_{LT}^k - P_{PV}^k; P_G^k = 0$
 17. $P_H^k = 0; C_B^k = C_B^{k-1} - \eta_B (P_{LT}^k - P_{PV}^k) / 3.6 \cdot 1e^6$
 18. **ELSEIF** $P_{LT}^k \geq P_{PV}^k$ **AND** $C_B^{k-1} \leq C_{B_{min}}$
 19. $P_B^k = 0; P_G^k = P_{LT}^k - P_{PV}^k$
 20. $P_H^k = 0; C_B^k = C_B^{k-1}$
 21. **END IF**
 22. **END DO**
-

Algorithm 1: Battery Management Algorithm

previous situation made nearly impossible to reduce this term since it was not possible to reduce the contracted power. The variable charges were affected by the energy demanded by the consumer as well as the self-consumed energy. The payment of this variable charge depending on the self-consumed energy was really unpopular, and generally known as "sun tax". In the new scenario, this tax has been revoked and the users can contract the power that they really need independently from the installed generation capacity. From now on, we will adopt the first mode in which a physical device prevents the injection of excess power into the grid.

III. HOUSEHOLD ENERGY MANAGEMENT SYSTEM

In Fig. 1, the simplified diagram of each household is depicted. The load profiles were extracted from project ADRES-CONCEPT [27]. This project provides real power consumption profiles of 30 different households in upper-Austria during 7 winter days and 7 summer days, a total of 420 daily power profiles sampled with 1 second resolution. The base consumption of each of the houses in this study was obtained from one of the above-mentioned profiles and it is represented by P_L . Additionally, it has been considered that each house is equipped with an electric car charger. We considered that the average driver in Spain makes 45km per day. The number of kilometres driven by the electric car on the previous day was calculated using a random function with an average value of 45 km. The charger is protected with a

TABLE I: Comparison of the aggregated values obtained for summer and winter in the household represented in Fig. 2.

	Summer	Winter
P_{LT} (Average) (W)	737.8	897.4
P_{LT} (Max) (W)	6902.7	5230.8
P_L (Average) (W)	987.9	1203.7
P_L (Max) (W)	6902.7	6638.1
P_G (Average) (W)	158.6	698.1
P_G (Max) (W)	5640.8	6638.1
P_{PV} (Average) (W)	1118.2	505.5
P_{PV} (Max) (W)	3107.6	2150.2
P_B when ($P_B > 0$) (Average) (W)	442.4	229.7
P_B when ($P_B < 0$) (Average) (W)	-418.6	-229.7
E_{LT} (kWh)	23.7	28.9
E_L (kWh)	17.7	21.5
E_G (kWh)	3.8	16.7
E_{PV} (kWh)	26.8	12.1
E_B when ($P_B > 0$) (kWh)	10.6	7.2
E_B when ($P_B < 0$) (kWh)	-10.1	-7.2
E_H (kWh)	7.5	0

32A breaker but its power is limited to 5200W. All cars start the charging process at a random hour between midnight and 03:00 a.m. The charging power is represented by P_{EV} .

In the present document, we will consider different levels of penetration of houses that use solar panels combined with accumulation systems. In such cases, we assume that consumers are adopting mode 1 described in the previous section, so they have a physical device that prevents the injection of excess power into the network. In this case, this device has been modeled as a thermal device but it could be a system that reduce the power reference provided to the PV converter. The power surplus has been denoted by P_H .

For the calculation of PV production it has been considered that each house can be equipped with photovoltaic panels with a peak power of 3200W. The theoretical radiation was obtained for Gijón (A city in northern Spain) according to the model proposed by ASHRAE [28]. The power generated by the PV panels is labeled as P_{PV} . When a household is equipped with PV and battery, the battery selected was the LG RESU 10LV. This battery has a capacity of 10kWh with a total energy usage of 85% and a rated charge and discharge power of 5kW. The power in the battery is considered positive in discharging mode and it is denoted as P_B . A markov based weather model has been incorporated in order to simulate three different scenarios [29]. For a specific day in summer or winter, we consider also three conditions (sunny, cloudy, heavy clouds).

The coordination between the different systems is described in Algorithm 1. The authors are fully aware that this is not the optimum strategy nor for the consumers neither for the distribution system, however it is the strategy followed by most of commercial systems and it is expected that this situation will continue at least in the mid term. For this reason, we will consider this non-optimal conditions in order to evaluate the impact of the system in the network. C_{B0} , C_B , $C_{B_{max}}$ and $C_{B_{min}}$ represent respectively the initial, actual, maximum

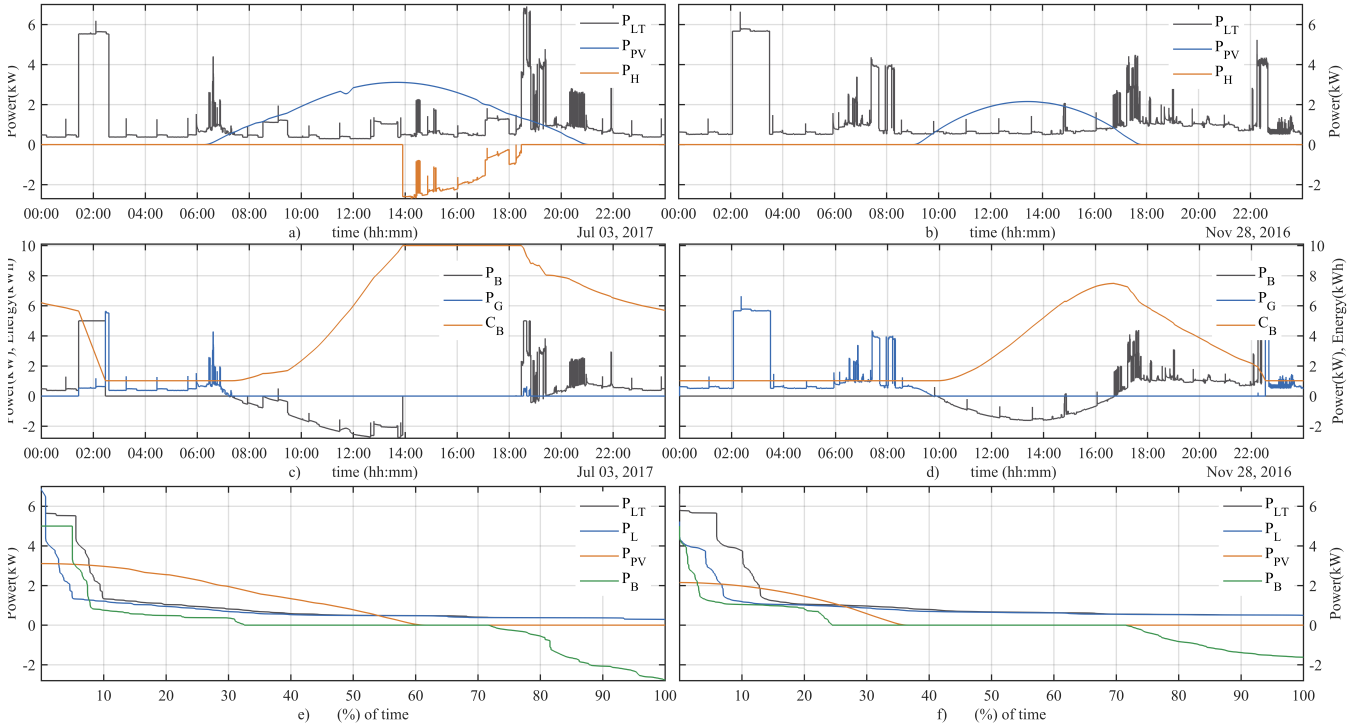


Fig. 2: Case of study of a specific household. Subfigures a), c) and e) represent a summer day while subfigures b), d) and f) represent a winter day. Subfigures a) and b) represent the total power consumption (P_{LT}), the power generated by the PV panels (P_{PV}) and the power "burned" by the physical device that prevents from the grid injection (P_H). Subfigures c) and d) represent the power of the battery (P_B), the power imported from the grid (P_G) and the state of charge of the battery (C_B). Subfigures e) and f) are the load duration curves containing the sorted values of all powers.

and minimum state of charge of the battery. η_B stands for the efficiency of the battery (90%) and P_{LT} is the total load considering the conventional household consumption plus the EV charger. As it can be observed in the Algorithm 1, the system assigns priority to the load and after that to the battery. We have different scenarios described in the algorithm but basically:

- If the PV panel produces enough energy to feed the load, the extra power is used to charge the battery (if is not full), if the battery is full or the extra power is greater

than the maximum charging power of the battery, the surplus is used for the heater

- If the PV panel does not produce enough energy to feed the load, the required extra power is obtained from the battery if it is not empty or the required extra power is greater than the maximum discharge power of the battery, the power deficit is obtained from the grid.

In Fig. 2, the behaviour of a specific household during a summer day and a winter day can be compared. As it can be observed, in the summer day the battery is full at 14:00 hours, so the physical device that prevents injection into the network is "wasting" energy for about 4 hours. This is only in the most favourable case on a sunny summer day with moderate consumption. Installing a battery with more capacity is not a good option as most days we will not have this behavior. For instance, on a sunny winter day the maximum level of charge of the battery does not reach 80% of its capacity. During the summer day (best scenario) the home is self-sufficient for almost 18 hours, during the winter day this interval drops to 12 hours. On a summer day, the battery charge level allows the user to charge a significant percentage of the EV battery during the night, while the battery charge level at the end of the winter day is nearly always the minimum. Table I contains the maximum and average powers during the summer and winter day for the same house represented in Fig. 2 and also the aggregated energies. It must be noted that, as it was expected, the average power consumption during the winter

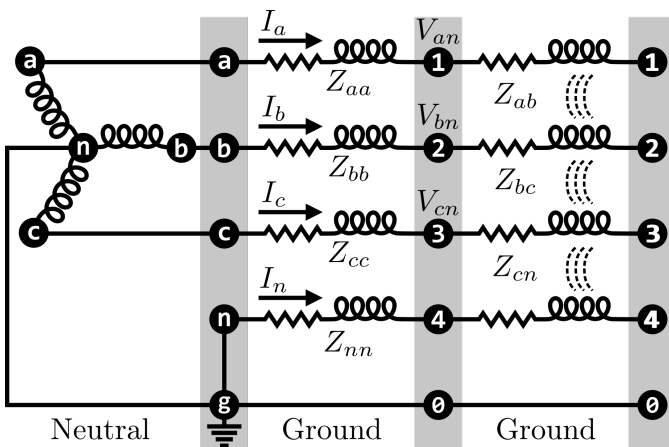


Fig. 3: TT grounding scheme

TABLE II: Summary of the behavior of 5 houses placed at nodes 3, 10, 35, 49 and 53 with and without prosumer set installation in the different weather and seasonal scenarios.

Season Weather Scenario	Summer				Winter				House
	Load	Sunny Load+Sys	Cloudy Load+Sys	Heavy Cl. Load+Sys	Load	Sunny Load+Sys	Cloudy Load+Sys	Heavy Cl. Load+Sys	
Net Energy (kWh)	27,2	5,4	6,8	11,9	26,1	10,9	14,0	17,7	Node 3
Maximum Power (kW)	8,5	4,0	8,5	6,1	6,8	6,8	8,3	6,7	
Average power (kW)	1,1	0,2	0,3	0,5	1,1	0,5	0,6	0,7	
Net Energy (kWh)	19,4	2,5	5,0	9,0	66,3	51,5	56,9	56,3	Node 10
Maximum Power (kW)	6,6	6,1	6,1	6,1	11,3	11,3	10,8	11,3	
Average power (kW)	0,8	0,1	0,2	0,4	2,8	2,1	2,4	2,3	
Net Energy (kWh)	17,9	4,0	6,8	8,4	22,3	12,1	13,2	16,9	Node 35
Maximum Power (kW)	7,8	5,7	6,6	6,4	6,3	6,3	6,4	6,4	
Average power (kW)	0,7	0,2	0,3	0,4	0,9	0,5	0,6	0,7	
Net Energy (kWh)	34,3	2,4	7,8	26,8	25,4	12,9	14,2	22,8	Node 49
Maximum Power (kW)	9,7	5,9	6,6	8,7	7,6	6,6	6,5	7,4	
Average power (kW)	1,4	0,1	0,3	1,1	1,1	0,5	0,6	1,0	
Net Energy (kWh)	20,8	0,5	0,5	7,1	25,7	6,5	13,7	19,4	Node 53
Maximum Power (kW)	6,0	1,1	1,2	6,3	6,4	6,4	6,6	6,3	
Average power (kW)	0,9	0,0	0,0	0,3	1,1	0,3	0,6	0,8	

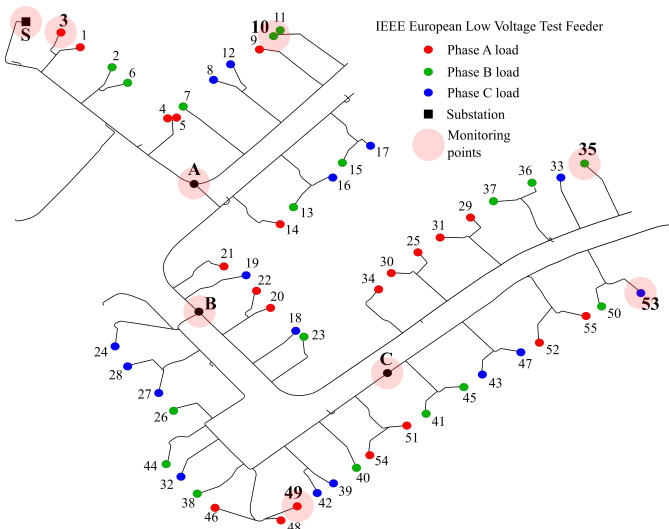


Fig. 4: IEEE European Low Voltage Test Feeder modified for TT distribution systems

day is slightly higher than during the summer day. However, the average power obtained from the grid in the summer is just 158.6W versus the 698.1W of average power consumed during the winter day.

IV. PROPOSED SCENARIOS

In order to evaluate the impact on the grid, the IEEE European Low Voltage Test Feeder was selected. As it was mentioned, the loads were substituted by the ones provided by ADRES project and also the lines were modified considering a 4 wire system in order to represent better the European terminal distribution networks with a TT grounding system.

The TT grounding system is represented in Fig. 3, the neutral wire is grounded at transformer level and the grounds in the different households are not participating in the electric scheme unless there is a fault in the system. In the original test feeder, only three wires are considered. It should be noted that when Kron reduction is applied to transform a 4-wire system into a 3-wire system, it is assumed that the neutral is grounded at each node, which is far from representing reality in TT systems, as will be demonstrated later.

The 420 load profiles provided in the ADRES database are randomly assigned to the 55 load nodes present in the IEEE Low Voltage test feeder represented in Fig. 4. A set of 30 different scenarios was generated. We considered two different prototype days, summer day and winter day, as a summer day July 3rd of 2017 was considered and as a winter day we selected November 28th of 2016. For each day we simulate the three wather conditions (Sunny, Cloudy and Heavy Cloud) and for each combination of season plus weather we obtain the results with 5 levels of penetration for houses with a "prosumer system" (PV panels combined with batteries) (0%, 25%, 50%, 75% and 100%).

V. ANALYSIS OF THE RESULTS

A first analysis is made to 5 individual prosumers placed at nodes 3, 10, 35, 49 and 53. Nodes 3 and 49 are connected to the phase A, nodes 10 and 35 are connected to the phase B and node 53 is connected to the phase C. Table II summarizes the behaviour of the 5 houses for all possible combinations of season and weahter conditions in conventional mode (Load) and in prosumer mode (Load+Sys), this last case consider the battery, the EV and the PV installation. The table provides data about the net energy absorbed from the grid in each house, the maximum power and the average power during the day. As it

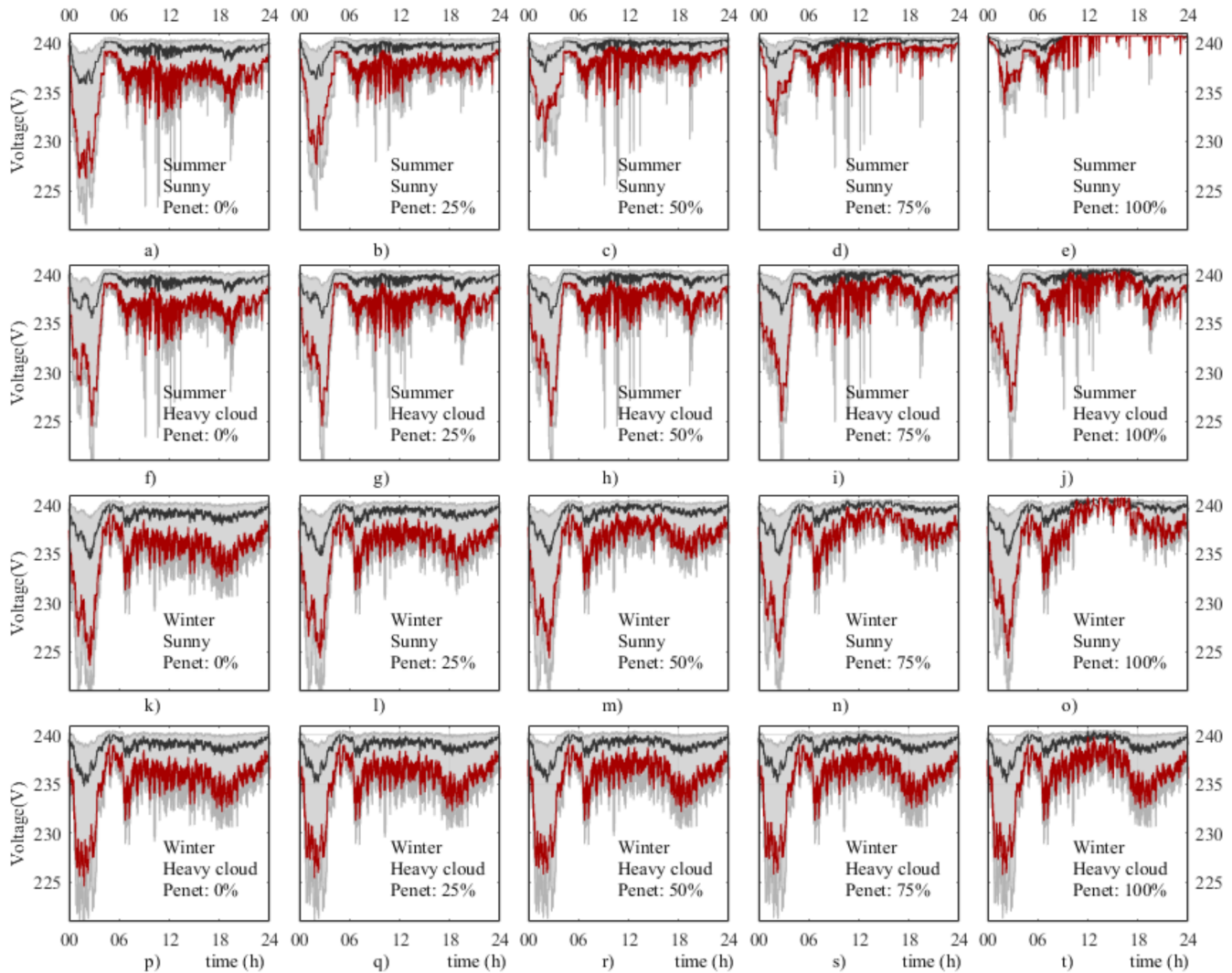


Fig. 5: Voltages in the nodes in the different scenarios. First two rows represent the summer scenarios in sunny (first row) and heavy cloud conditions (second row). The rows 3 and 4 represent the winter scenario in sunny and heavy cloud conditions respectively. Columns 1 to 5 represent respectively the five levels of penetration of households with PV and batteries from 0% to 100%. The grey color represents the voltage involute that contains the voltage in all the nodes of the system. In black, the voltage in the home placed at node 3 and in red the voltage in the house placed at node 53.

can be observed not all the houses behave in the same way, some of them increase the consumption in a typical winter day, like for instance houses in nodes 35 or 53, or even more, house in node 10 that has a net consumption in the summer of 19.4kWh that rises to 66.3kWh during in the winter. Other houses like the house connected in node 49 have a significant consumption reduction in winter days. A reduction of the consumption in winter days can be observed also in the house connected in node 3, but in this last case this reduction is just around 1kWh. It is interesting to analyse the significant net demand reduction when the prosumer system is installed in all cases for summer days and how this reduction is affected by the weather conditions. The influence of the weather does not have the same impact in all cases because it is also very important the consumption pattern of the different users. For instance, in the house of the node 49, in a winter day the net energy consumption in a heavy cloud condition decreases

from 25.4kWh to 22.8kWh, just 10% of reduction (2.6kWh). The house in the node 3, has a reduction from 26.1kWh to 17.7kWh, which represent a 32%, and if we analyse the house number 53, this time in summer, we observe that installing the prosumer equipment can make the house nearly self sufficient in sunny and cloudy days and the reduction of the demand in a heavy cloud day is really important passing from 20.8kWh to 7.1kWh, a reduction of 65%. In Fig. 5, we can observe the impact of the different scenarios in the voltage profile. In the first two rows we can observe the summer scenarios with the sunny day in the first row and the heavy cloud day in the second. In the same way the rows 3 and 4 represent the sunny winter scenario and the heavy cloud winter scenario. The grey envolute represent the maximum and minimum voltage in all the phases and all the nodes of the grid. The voltage in houses placed at node 3 and node 53 is represented in black and red respectively. The best situation in terms of voltage

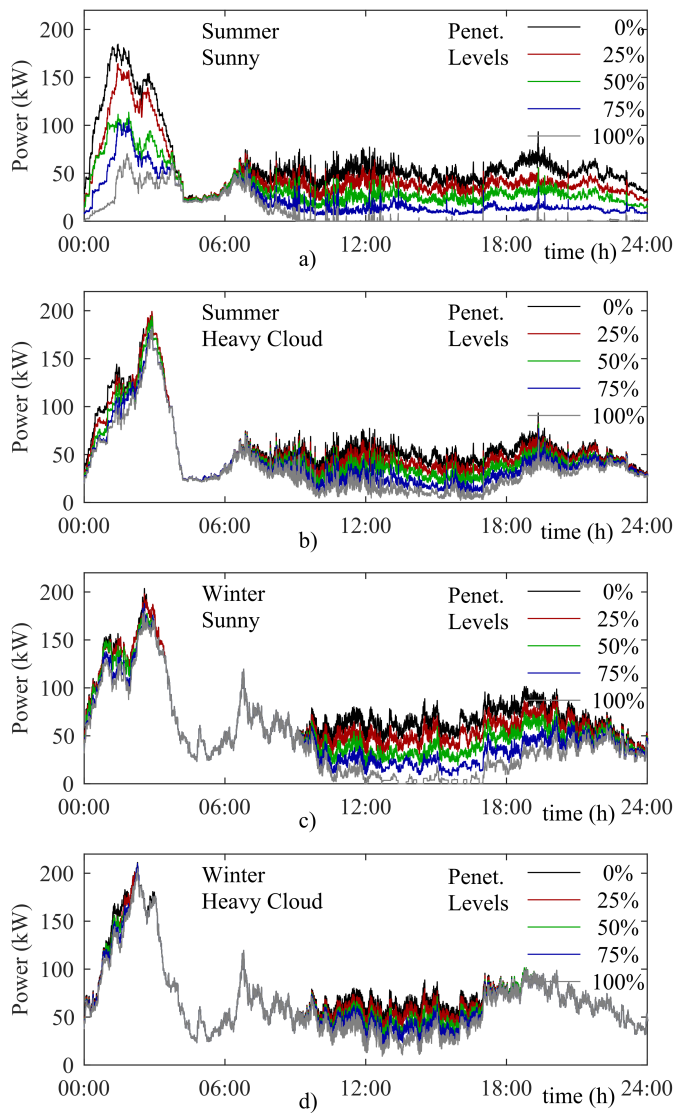


Fig. 6: Level of load at the power transformer at all penetration levels (0%, 25%, 50%, 75% and 100%). a) Summer sunny scenario. b) Summer heavy cloud scenario. c) Winter sunny scenario. d) Winter heavy cloud scenario.

profile is obviously in the 100% penetration scenario during a summer sunny day. This is the only case that really mitigates the effect of the EV chargers during the night, and it creates a nearly plain voltage profile during the day. In the rest of the cases, the strategy of concentrate the EV charging during the night creates an important voltage drop in the system. It is also interesting to evaluate and quantify the voltage drop correlation with the weather and season conditions. As it can be observed, even in the worst scenario, winter and heavy cloud day, the effect of the prosumers is not negligible.

Fig. 6 represent the load of the system measured at the substation level in different scenarios, only sunny and heavy cloud days have been depicted in summer and winter scenarios considering all penetration levels. It is worth to mention that only in the sunny summer scenario the increasing in the penetration level has a significant impact in the load reduction

during the night due to the EV chargers. This is because only in sunny summer days the batteries at midnight have a significant amount of energy that can be used to charge the vehicles, in the rest of the cases, the charge during the night provokes a peak power at the power transformer that cannot be mitigated adding PV generation or energy storage in the grid, at least in the way defined by the new Spanish regulation. During the day, the effect of the penetration in all cases is clear. Obviously it is more drastic in summer sunny days, when the system is nearly self-sufficient from 09:00 to 24:00. In winter heavy cloud days the impact of the prosumers is only important in the interval from 10:00 to 17:00.

The graphic representation is very important to provide a first analysis of what is happening in the system. However, a very interesting quantification is presented in the table III. In this table we provide data about the net energy and average power in different points of the network (The nodes S, A, B and C of Fig 4). All season, weather and penetration levels are considered. Analysing the data obtained at substation level, we can observe that in this case, the consumption increases clearly during the winter days from 1454kWh to 1765kWh. In the summer scenario, the energy reduction varies in a range from 10% in a heavy cloud day with the 25% of penetration (with 1304kWh) to 82% in the best case scenario (sunny with 100% penetration) with a demand of only 258kWh at substation level. The energy reduction varies nearly in a linear way with the level of penetration, so even in a small case of a single power transformer with 55 loads with quite different behavior the aggregated behaviour of all of them can be estimated using a linear model. Analysing how the weather affects to a specific day with the same level of penetration we can observe for instance that in a summer sunny day with 25% of penetration, the energy provided to the system is 1136kWh, and it increases only 4% if the day is cloudy and 14% if we have a heavy cloud day. These variations are non extrapolable to other scenarios. For instance, in the same day (summer), with a 100% of penetration, the energy provided to the system in a sunny day is 258kWh and in a cloudy day increases 51%, in a heavy cloud day it increases 243% up to 887kWh. The energy increasing proportions for a given day due to the poor weather conditions are maintained in all the points of the network (A, B and C). The number of houses downstreams points A, B and C is respectively 43, 13 and 8. The behavior of the system during the winter is quite different since the energy increase due to the weather conditions is not so drastic neither in absolute or relative terms. For instance, in a winter day, the substation provides 1765kWh with 0% penetration and 1594kWh with 25% penetration in a sunny day, a total reduction of around 10%. When comparing a cloudy day with a sunny day we can see that the energy increase is only 3%, and comparing a heavy cloud day with a sunny day the energy increase is around 6%. With a 100% of penetration level, the energy provided to the system in a sunny day is 1047kWh, a reduction of 40%. Comparing a cloudy day with a sunny day the energy increase is around 20%, and if we make the comparison between the heavy cloud and the sunny day the increase is 44%. We observe that, obviously the weather affects more the scenarios with high penetration levels but the

TABLE III: Quantification of the prosumers penetration level impact in different points of the network (Substation and points A, B and C of the modified IEEE European Low Voltage Distribution test feeder represented in 4). All weather, seasonal and penetration combinations were considered. We used the next abrevaiations. Sun.: Sunny, Clo.:Cloudy and H.Clo.:Heavy Cloud.

Season		Summer												Substation
Penetration	0%	25%			50%			75%			100%			
Wheather		Sun.	Clo.	H.Clo.	Sun.	Clo.	H.Clo.	Sun.	Clo.	H.Clo.	Sun.	Clo.	H.Clo.	
Energy (kWh)	1454	1136	1182	1304	834	912	1161	544	642	1022	258	390	887	
Av. power (kW)	61	47	49	54	35	38	48	23	27	43	11	16	37	
Season		Winter												
Energy (kWh)	1765	1594	1642	1696	1405	1504	1628	1228	1389	1580	1047	1255	1513	
Av. power (kW)	74	66	68	71	59	63	68	51	58	66	44	52	63	
Season		Summer												Node A
Energy (kWh)	1289	1017	1060	1170	763	835	1061	514	607	955	231	358	821	
Av. power (kW)	54	42	44	49	32	35	44	21	25	40	10	15	34	
Season		Winter												
Energy (kWh)	1571	1430	1473	1523	1273	1359	1472	1129	1267	1435	951	1135	1369	
Av. power (kW)	65	60	61	63	53	57	61	47	53	60	40	47	57	
Season		Summer												Node B
Energy (kWh)	949	736	777	865	579	643	797	312	392	682	170	279	624	
Av. power (kW)	40	31	32	36	24	27	33	13	16	28	7	12	26	
Season		Winter												
Energy (kWh)	1107	1003	1036	1079	904	964	1045	747	861	1005	665	798	978	
Av. power (kW)	46	42	43	45	38	40	44	31	36	42	28	33	41	
Season		Summer												Node C
Energy (kWh)	227	160	174	196	87	112	173	66	91	161	47	78	151	
Av. power (kW)	9	7	7	8	4	5	7	3	4	7	2	3	6	
Season		Winter												
Energy (kWh)	238	202	208	229	167	183	217	148	172	213	135	163	209	
Av. power (kW)	10	8	9	10	7	8	9	6	7	9	6	7	9	

impact is much more dramatic during the summer days.

In Fig 7, the neutral voltage in the house located in node 53 is represented for all scenarios in sunny and heavy cloud conditions. As it can be observed, the effect of increasing the prosumers penetration over the neutral voltage is nearly negligible in heavy cloud scenarios. In the sunny scenarios a reduction is observed during the day (from 9:00 to 24:00 in summer and from 10:00 to 17:00 in winter). However, during the night and due to the EV charging, there is no significant neutral voltage reduction, the same effect was observed in the power analysed in Fig 6. Neutral voltage issues can have extraordinary importance in terminal distribution systems, the modification of the IEEE Low Voltage Distribution Test feeder for study this problems is a mandatory task in order to avoid the use of the Kron reduction for obtaining an equivalent 3 wires system.

VI. CONCLUSIONS AND FUTURE WORKS

In this paper, it was demonstrated that the new Spanish Self-Consumption regulation will have a drastic impact on the network reducing the total demand. These kind of studies are of significant importance in order to estimate not only

the economic impact of new regulations over the systems but also the technical impacts. As in this specific case, the conditions for simulating the different scenarios must emulate the regulatory and technical conditions of the real cases. It was demonstrated that energy savings can be higher than 80% in the best case scenario (sunny summer day) and around 12% in the worst case scenario (Heavy cloud winter day) when the penetration is 100%. It has been also demonstrated that for a specific day (weather and season) the energy reduction varies linearly and inversely proportional to the level of penetration. In the case that the EVs are charged during the night, it will be impossible to reduce the maximum power at substation level. Incentive policies to coordinate storage systems could benefit both consumers and distributors. In the short term, more studies should be conducted on more complex scenarios in order to design incentives to coordinate devices appropriately. In the mid and long term technologies like the peer-to-peer energy trading will change completely the role of the prosumers within the systems. The impact studies for considering this peer-to-peer energy sharing should include not only technical variables but also social variables to model the possible behavior of the prosumers.

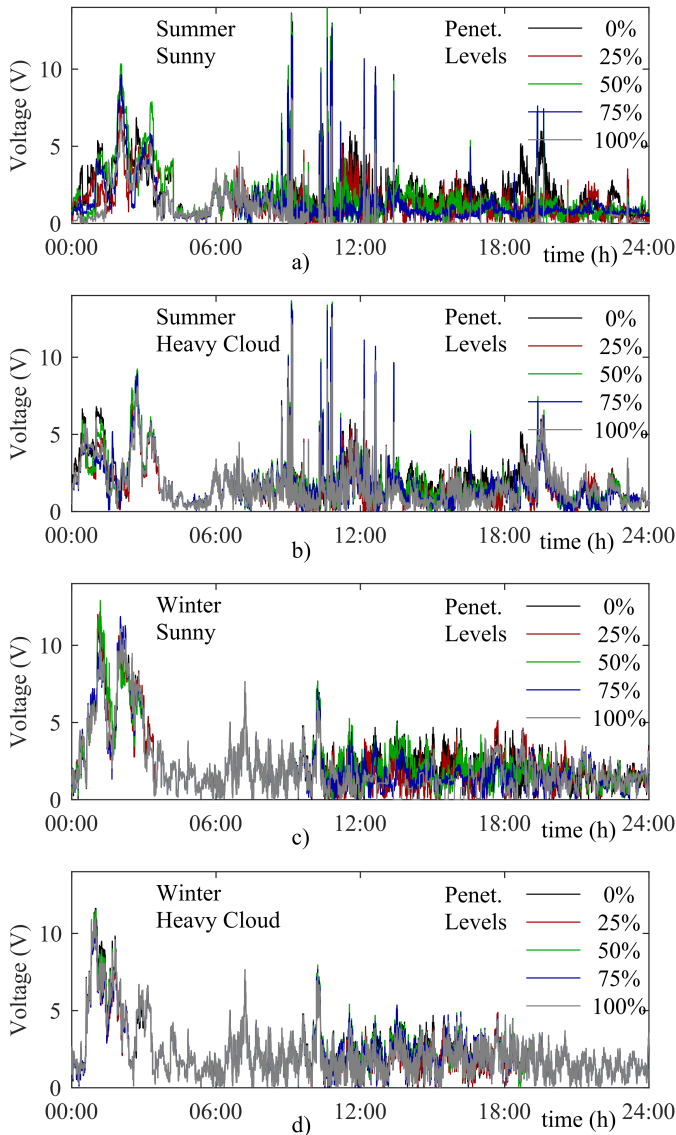


Fig. 7: Neutral voltage at the house placed in node 53 with different penetration levels (0%, 25%, 50%, 75% and 100%). a) Summer sunny scenario. b) Summer heavy cloud scenario. c) Winter sunny scenario. d) Winter heavy cloud scenario.

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