Up and Down-Regulation of Residential BESS for Local Flexibility in France

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***Abstract* — This study deals with an application of residential Battery Energy Storage Systems (BESSs) to ensure flexibility Ancillary Services (ASs) of electrical Distribution Grid (DG), in particular using of the up and down-regulation. This AS is implemented by the aggregator, which reserves the entire or the part of prosumer's energy storage and manages it by charging (Up) or discharging (Down) in accordance with a DG flexibility call signal with corresponding original and presented previously methodology. It was applied for one-year large-scale operational and economical evaluation based on the real French prosumer's data. The technical analysis shows that the use of residential BESS is much more efficient with AS participation that without for considered case. The economic analysis presents the significant decrease of prosumer's electrical energy price due to mixed up and down participation for all considered possible operation cases, which accelerates prosumer's return on investment. From another side, this AS is the promising and relatively easy deploying source of additional local flexibility for DG.**

Keywords— Microgrid, Self-consumption, Auxiliary services, Up and down-regulation, Energy Storage Battery, Electrical Distribution Grid.

I. INTRODUCTION

European Union (EU decarbonization politics leads to a large development of renewable energy based decentralized power systems. The main goal is to reduce by 40% its gas emissions by 2030 and to reach 50% of renewable energy by 2050 [1]. Similarly, the increase of energy consumption and penetration of fluctuating decentralized power generation require the more intelligent management way, to mitigate induced variabilities and intermittentness in the power generation [2]. To compensate these negative effects on the power balance, it is required additional value maneuverability (flexibility) that never needed before. The actual conventional centralized, one direction DG with predictable generation can't anymore provide this flexibility.

The European internal electricity market rules, specifically Article 16, present a Local Energy Community (LEC) as one of the ways of efficient energy management at citizen level [3]. The LEC combines energy consumers, renewable energy generation and residential or centralized Battery Energy Storage Systems (BESSs). The BESSs integration is one of effective way of local self-consumption increase [4] related to the actual process of feed-in subsidies decrease [5]. Also, BESSs can be considered as a promising source of flexibility for DG through Ancillary Services (ASs) related to its higher-power ramp rate compared to conventional flexibility sources [6]. From one side, ASs participation allows consumers' faster payback investments [7] and the consumer becomes a prosumer [8]. From another side this allows supplying additional and local flexibility to DG [9].

Commonly, the electricity market has a regulation law with access threshold and participation of individual prosumers is not possible to a small capacity of residential BESSs. To provide ASs, a large number of prosumers need to be aggregated and operated by the aggregator. ASs could be associated to the energy pricing rules [10], and to the energy management services, according to the prosumer's local Energy Management System (EMS.

In [11], authors introduced the concept of up and down-regulation application to their study case. In this new paper, they completed the study by presenting the evaluation of real data collect from existing prosumer's apartment house in the Paris region, France. The evaluation takes care for one year of real data with corresponding real prices and ASs rules for France. It allows to simulate and to evaluate all different up and down ASs cases for all kinds of weather, seasons and consumer's consumption and followed by the large economical evaluation for this geographical zone. This allows more precisely assessing of advantages and disadvantages of this method on the real prosumer data case for real French operation conditions. For considered real prosumer and real economic conditions, this large real data simulation showed the economical attractiveness of the proposed method for end-prosumer also as for the flexibility of DG.

The overview about local flexibility in France, presented in this research, shows that for nowadays, already deployed French ASs are generally based on the load shedding (or generation grows). However, actual and future increase in RE generation requires the introduction in addition to these mechanisms, the mechanisms of local absorption of the excess of electricity generation. In this case, the proposed ancillary service of up and down regulation includes these mechanisms, with easy deployment and with a significant reducing of the prosumers electricity price, without degradation of battery lifetime.

II. LOCAL FLEXIBILITY IN FRANCE

In a context of energy transition and to respond to constantly changing production and consumption patterns, several adjustment mechanisms exist to make electricity grids smarter. In this case the local flexibility can serve as a new tool for optimizing the electricity distribution grid [12].

In France, on the supply side, non-centralized intermittent production has been growing strongly for several years. The electrical system must therefore integrate this production, which remains difficult to predict and highly variable. On the demand side, demographic changes as well as the rise of new uses (electric vehicles, self-consumption, etc.) make the management of grids and the electrical system even more difficult. Therefore, the exercise of the supply/demand balance becomes more and more complex. This complexity brings out new needs for flexibility of the means of generation, but also of consumption so that at all times, the balance between supply and demand is ensured. In France, flexibility has long existed at the national level on the Transmission Grid (TG), operated by electricity TG operator RTE, in particular via the industrial load shedding mechanism [13].

From the RTE point of view, French electricity consumption has stagnated. Except, during peak periods for the past ten years. On average, it takes about sixty gigawatts of electrical power (the equivalent of 60 nuclear reactors) to meet the usual needs of consumers. This power can exceed 100 GW in the coldest hours of winter. For this reason, electricity producers maintain in the state of power plants (hydraulic or thermal) that operate only a few tens of hours per year at most, if necessary [14]. Investing in such peak capacity is expensive and rarely profitable, under current electricity market conditions. However, due to the importance of French electric heating equipment and consumption habits, the power needed to "cover the peak" increases every year. In the short term, the electricity system may therefore no longer be able to guarantee the supply of all during times of high demand [15].

Firstly, it makes it possible to ensure that the capacities (production and load shedding) installed on the grid will make it possible to ensure balance during a ten-year peak, and, in the event of insufficient means, to ensure that the investments necessary to install new means can be profitable. The other objective is to encourage consumers, via their obligated player, to control peak consumption. This consumption, which will be referred to as the “obligation” in the rest of the document, is calculated by the grid managers then allocated to each of the obligated players, according to their scope of consumption sites. Each obligated player must then prove that they have sufficient capacity guarantees. For this aim, deployment of ASs can help to ensure the resiliency and flexibility of the DG [16].

In France, among classic centralized power grid regulation services (such as the primary and secondary frequency control, etc.) the capacity mechanism attracts attention in terms of flexibility (including local) of the electrical grid. It asks electricity suppliers for a contribution each year in order to guarantee security of supply, based on the consumed peak power. Each year, energy suppliers must have capacity guarantees corresponding to the annual obligation of their entire customer portfolio. These guarantees can be acquired from electricity producers or load shedding operators.

A French Certification Entity (CE), is an entity referenced by a certification contract for one or more demand response capacities or one or more generation capacities. It is RTE that references the CEs and draws up the certification contracts with the CE holders [17]. Fig. 1 shows the French TG compliance with potential site aggregation conditions. It can be seen that it is possible to aggregate sites with a capacity of less than 100 MW to form a CE. A site with a power of less than 1 MW is required to aggregate with other sites. The minimum value of a CE is 1 MW. In this case, local prosumers can be aggregated and presented as a one CE in the transmission grid level, thus to participate in ASM and to supply flexibility locally.

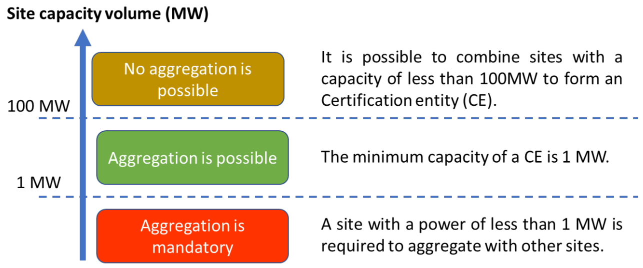

Fig. 1. Compliance with potential site aggregation conditions for French transmission grid capacity mechanism.

The capacity obligation of a site is calculated each year on the basis of its average electrical power during Peak Period 1 and 2 (PP1 and PP2 days) from 7 a.m. to 3 p.m. then 6 p.m. and 8 p.m. RTE determines them every year. PP1 days are based on weather forecasts (10 to 15 d/year, usually days with very low temperatures) and PP2 days on electrical system stress (10 to 25 d/year) [18]. The operating rules of the capacity mechanism were set by Decree 2012/1405 of 14 December 2012 [19], validated by the Ministerial Order of 29 November 2016 [20]. The decree of 29 November 2016 sets the maximum price that auctions can reach: €20,000/MW in 2017. Fig. 2 can show actual market evolution of the French price of capacity guarantees in €/MW. It can be seen that the capacity mechanism is very economically attractive due to its high retribution cost for MW, but it is applied only on the 15 25 maximum days of the year.

The cost of capacity represents an increasingly important part of the electricity bill of companies. Certifying its load shedding capacity allows industrial or tertiary companies to reduce or even eliminate this additional cost. Nonetheless, the electrical system will need much more flexibility and the focus must be shifted to the sources of local flexibility not only in TG, but also in DG.

Flexibility implementation has also started at the local level by the main French DG operator Enedis to meet the challenges of the territories in access of electricity. and to improve the management of the local grid. Concretely, it is a question of intervening locally on the distribution grid to modulate production or consumption ensuring the balance and thus avoiding infrastructure congestion [22]. But at present, in France, local flexibility mechanisms and their services for DG are still in the stage of discussion-deployment. Below will be presented the main axes of local flexibility, which Enedis plans to apply first.

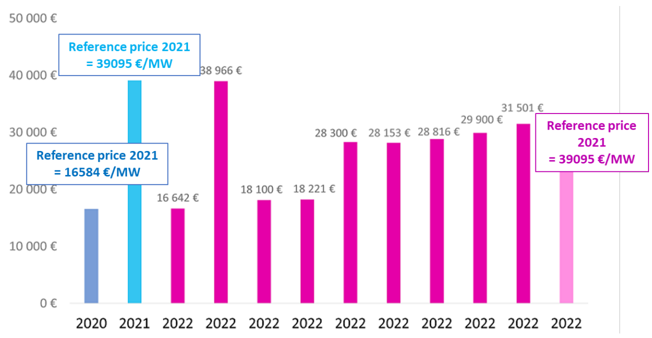

Fig. 2. Evolution of the French price of capacity guarantees for 2020-2022 in €/MW (source [21]) .

A. Intelligent Connection Offer

The grid manager has identified several types of local flexibility to be implemented. The first type concerns the production of renewable energies. By offering intelligent connection offers, new installations will be less expensive and commissioning will take less time. By agreeing to "flexibilize" its production, for example to stop it punctually in the event of congestion, the producer can benefit from a faster and cheaper connection because the distributor will avoid grid reinforcement works (arrangements to calibrate the voltage and current).

This offer may also be offered to consumers who agree, in this case, to temporarily suspend their consumption. The principle is the same: once the installation is in service, if the intensity or voltage on the local grid requires it, Enedis asks the customer to limit its consumption. The latter will be remunerated for the service rendered to the grid.

B. Electrical Resupply

To follow up on an incident or in anticipation of a one-time climate event, local flexibility can contribute to improve the system resiliency. For example, a customer cut off due to a storm will have visibility on the reduced power unavailability time thanks to local flexibility.

C. Better Plan Investments and Works

Depending on the nature of the scheduled work, the flexibility will make it possible to avoid power cuts to customers and therefore improve their satisfaction. Furthermore, the real-time management of the grid thanks to local flexibility could postpone investments that would otherwise have been necessary. For several years, ENEDIS has multiplied experiments and demonstrators on the subjects of flexibility (Nice Grid, Smart Occitania, Smart Grid Vendée, etc.) [23]. On the strength of these initial experiences, Enedis delivered, at the end of 2019, a map of local opportunities and a census of interest. The processing of responses, the competition and the management of contracts will occupy some time. A first activation of local flexibility is planned for early 2022 [24].

The above is showing that actual French regulation rules into effect for TG (RTE) and DG (Enedis) considers only the shedding load or increase generation capacities (Up-regulation) in the local flexibility processes. Notwithstanding, due to the energy transition, that the continuously growing part of RE cannot be consumed, transported, stored or exported at a given moment in time. And not to dissipate this energy senselessly, the local flexibility services based on the setting load or reducing of generation (Down-regulation) must also be applied. For this, the next chapter will present the up and down-regulation flexibility service as one of the keys to solve this problem which allows to combine the load shedding and load setting as well as to make more full use of local flexibility.

III. BESS Up and Down-Regulation Flexibility Service

The European Commission's defined the Regulatory Recommendations for Smart Grids deployment (EG3) dealing to the flexibility and regulation of electrical grid [25]. To respect the regulation (EU) 2019/943 considering the EU internal market for electricity, nowadays, majority of EU countries like Italy, Germany, Denmark, France, etc. is looking for new ways to improve access and financing mechanisms [26].

In the case of EU context, the increasing of a generation or the decreasing of consumption represents up-regulation flexibility [27]. Conversely, the decreasing of a generation or the increasing of demand represents the down-regulation flexibility [3]. Fig. 3 shows a common BESSs behaviour based on up and down-regulation algorithm, with the down-regulation for charging BESSs from the power system is red coloured [28], during low consumption periods in order to make better use of the released energy capacities. The up-regulation mode (Blue lines) occurs when discharging stored energy from the BESSs to the grid by reducing the consumption, Generally, during peak periods. Up and down-regulation have an influence on the energy and the operational prices of the system as a whole.

In the authors previous research [11], it was considered that each prosumer has one residential BESS. After the prosumer acceptance to participate in the AS and the validation of the bid by the system operator of ASM, the aggregator sends centralized signals to prosumers' local EMSs to manage the prosumer's BESS. In [11], all interactions between stakeholders (system operator, aggregator and prosumers providing flexibility service) were presented. It defines four possible managing strategies for the aggregator: not-accepted bid (mode of "Normal operation", that maximizes the self-consumption of each prosumer), accepted bid for only up-regulation, accepted bid for only down-regulation and accepted bid for up and down-regulation flexibility service. Also, the SO sends to the aggregator signal in case of flexibility requirement - a call signal. In total this represents 9 possible operation cases.

In its turn, the aggregator manages the local prosumers EMSs by sending them operation signals [11]. For down-regulation, to satisfy the minimum value of residential BESS, the "Preparation down call" operational mode is activated. It forbids charging of BESS some hours before ZC, and provide power to the local load.

For up-regulation, it is necessary to have the maximum level of stored energy in residential BESS. For this, there are "Preparation 1 up call" and "Preparation 2 up call" operation modes. First forbids the BESS discharge, and allow the charge by overgeneration of RE (if there is). "Preparation 2 up call" operation mode has the same rules as the previous mode, but in the case of insufficient level of residential BESS (less than 80% of SOC), it charges BESS by the energy from DG (till 80% of SOC).

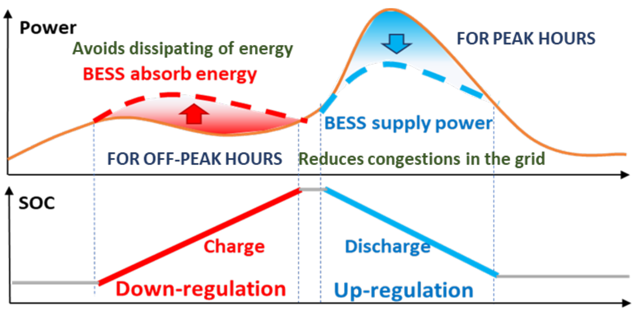

Fig. 3. BESS up and down-regulation flexibility service: energy (top chart) and the corresponding BESS State of Charge (SOC) evaluation (bottom chart) [11] .

This is done in order to ensure prosumer's participation in the up-regulation without fail and to not pay penalties (which are considered highly).

Considering to the availability of the residential BESS, the aggregator additionally sends the reference power rate of BESS charge $P_{down}^{callref^{ij}}$ or discharge $P_{up}^{callref^{ij}}$, calculated for each prosumer i and presented in (1) and (2).

$$P_{up}^{callref^{ij}} = \frac{\left(SOC_{max}{}^{ij} - SOC_t{}^{ij}\right) * C_{BESS}{}^{ij}}{TC_{up}} \quad (1)$$

where $SOC_t{}^{ij}$, $SOC_{max}{}^{ij}$ and $SOC_{min}{}^{ij}$ are the actual, the maximum and the minimum State of Charge (SOC) values for prosumer i related to local aggregator j, respectively, $C_{BESS}{}^{ij}$ is the reserved BESS capacity, TC_{up} is the call time for up-regulation (hours). Residential BESS is discharged by the local EMS by this power rate reference. After the end of the Time if Call (TC) or t^{ZC} period of time, the aggregator sends the operation signal of the "Normal operation" mode.

$$P_{DOWN}^{CALLref^{ij}} = \frac{\left(SOC_t{}^{ij} - SOC_{min}{}^{ij}\right) * C_{BESS}{}^{ij}}{TC_{DOWN}} \quad (2)$$

where, TC_{down} is the time of the call for down-regulation (hours).

This reference considers reserved residential BESS capacity, available energy and duration of TC. Also, it is considered that once the prosumer accepts participation in the AS, a failure to fulfill obligations leads to a significant penalty.

In this case, the prosumers daily benefit is calculated by (3).

$$B_{pross} = \sum_{t\epsilon T} \begin{bmatrix} C_{pv_{inj}}^t P_{pv_{inj}}^t + C_{ASpart}^t O_{ASpart}^t \\ + C_{Up}^t P_{Up}^t + C_{Down}^t P_{Down}^t \end{bmatrix} \quad (3)$$

where $C_{pv_{inj}}^t$ and $P_{pv_{inj}}^t$ are the cost function of active PV overgeneration energy injected into the grid and its amount of energy at the time t respectively, C_{ASpart}^t and O_{ASpart}^t are the cost function for AS participation availability and the state of prosumer's binary engagement in the period t (1 if the unit is online (available for AS), 0 offline), C_{Up}^t, C_{Down}^t, P_{Up}^t and P_{Down}^t are the cost functions for active energy injected, removed or extracted at the time t during participation in the up and down-regulation respectively.

The prosumers electrical average day price is estimated from (4).

$$C_{pross}^{kWh} = \frac{\sum_{t\epsilon T}\left[C_{grid}^t P_{grid}^t\right] - Bpross}{E_{cons}^{tot}} \quad (4)$$

where C_{grid}^t and P_{grid}^t are the functions of the cost of active energy and the power removed from the grid at the time t.

Therefore, the presented original methodology of up and down-regulation flexibility as well as economic calculations will be applied for actual research for one-year large-scale operational and economical evaluation based on the real French prosumer's data case.

IV. Experimental Evaluation of BESS Up and Down-Regulation Flexibility Services

As mentioned earlier, due to the small capacity of residential BESSs, the direct participation of individual households in the global electricity or flexibility market is not economically and technically feasible. The ASM usually has a minimum threshold of available energy. As was mentioned previously, in France a site with a power of less than 1 MW is required to aggregate with other sites and the minimum value of a CE is 1 MW [29]. To exceed it, a large number of small residential prosumers must be aggregated by the aggregator and as a whole (CE) will be presented in the ASM. The aim of actual experimental evaluation is to examine an individual prosumers' up and down-regulation participation as part of this common CE, its technical and economic feasibility for French climatic and economic realities, the impact of BESS lifetime and the possible benefits also as advantages for the DG and local flexibility supplying.

For the experimental evaluation was chosen a real existing prosumer's household, located in the urban community of Paris suburbs, France (94013) presented in Fig. 4. It can be seen that it represents a residential household with local installed PV panels of total capacity of 15 kWp and the local BESS with 10 kWh (the charge/discharge maximum power rate is 3.3 kWh).

According to Enedis "OPEN DATA" project [31], Fig. 5 presents the one-year household consumption profile and Fig. 6 presents its local PV generation profile for 2021.

Fig. 7 presents the 3D visualization of whole year daily energy consumption and local PV generation profiles. At the moment, the local BESS is used to grow the local self-consumption (store the excess of energy, to supply it when the PV generation is insufficient) due to the fact, that the ASs of local flexibility are not applied yet. However, this prosumer has already a contract with Enedis for sale the PV overgeneration to the DG by the price of 6 €c/kWh [32].

The aim of actual study is to evaluate the economic convenience, technical feasibility and impacts of possible residential prosumers participation in the up and down flexibility service based on the real one-year (365 days) data for different seasons, all possible operation and weather conditions of the considered regulation algorithm and system location. Daily, the prosumer will be managed by the aggregator's operation signals to its local EMS, according to developed methodology presented previously.

Fig. 4. 3D view of the considered real prosumer's apartment house in the Paris region (94013), France [30].

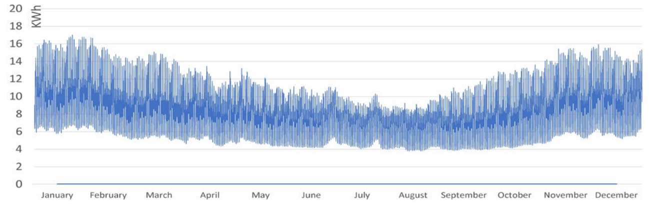

Fig. 5. One-year estimated prosumer's household electricity consumption (2021) [31].

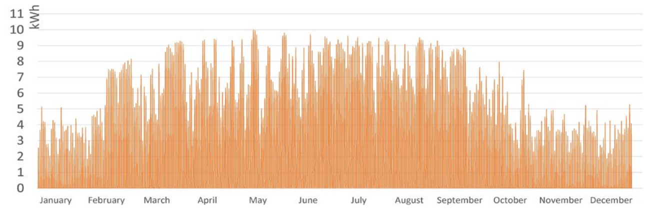

Fig. 6. One-year prosumer's residential PV generation (2021) [31].

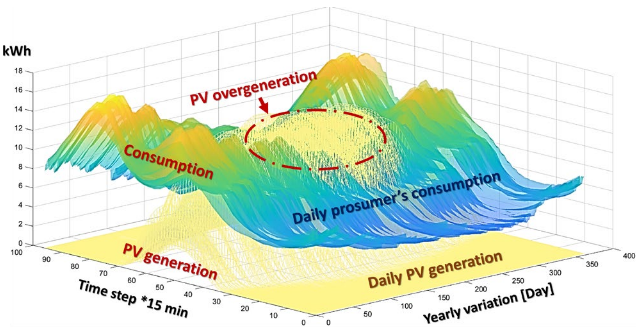

Fig. 7. 3D visualization of whole year daily energy consumption and local PV generation profiles (2021) [31].

The DG electricity tariff estimate is 15.97 €c/kWh, according to France residential EDF Blue tariff for base hours (<36kVa) [33]. In this paper, the up-regulation flexibility remuneration price per kWh of discharged energy (respectively, for down-regulation in charge mode) is 20 €c/kWh. This is done on the basis of the reports of the commission for the development and application of the local flexibility in France [34]. Taxes and AS participation availability are not considered.

Simulations were carried out using Matlab/Simulink with Stateflow Chart Programming. The Zone of Call (ZC), zone in which can be received, in the case of participation in AS, the signal to activate flexibility is considered from 6 a.m. until 10 a.m. for down-regulation and from 4 p.m. until 8 p.m. for the up-regulation (evening peak hours), the similar as in [11]. The TC is considered to be 2 hours for up and down-regulation flexibility services and the call appearance is distributed randomly in the ZC. During the evaluated year, the prosumer's EMS will be operated in all possible operation scenarios: not accepted bid ("Normal operation" mode), participation only in the up, down or up and down-regulation, with or without receiving a call signal for flexibility. The graphical representation of distribution of considered operation modes during the considered evaluation year is shown in Fig. 8. This allows evaluating all possible operation conditions for different seasons, weather and consumption, working days and weekends, etc for this real French prosumer.

Fig. 9 - Fig. 17 present SOCs of evaluation results for 9 considered cases (presented in Fig. 8) of prosumers' up and down-regulation participation in 2D (on the time axis) and 3D visualization (for group of days). Figures indicate the type of control, the number of days (on the horizontal axis), and the corresponding characteristic control zones if they are.

Generally, the day BESS's cycle starts by following. The already discharged BESS starts to be charged by the extra PV generation power (all cases, except Fig. 10, Fig. 14 and Fig. 16) if available, or by the down-regulation flexibility service (Fig. 10, Fig. 14 and Fig. 16 respectively). After the end of

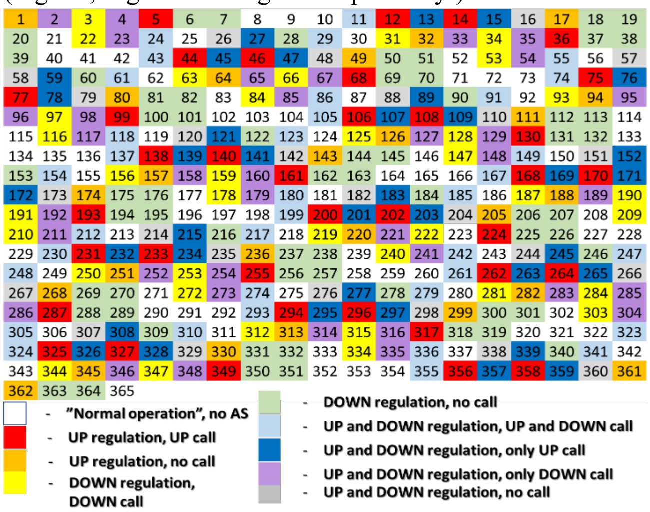

Fig. 8. One-year distribution of prosumer's operation modes considered for practical evaluation (2021).

down-regulation or its ZC , BESS is managed in the self-consumption mode till the end of the day, if there is no up-regulation participation (all cases, except Fig. 12, Fig. 14 and Fig. 15). If there's, the BESS will be prepared to the up-regulation, and in the zone of call will wait "Up call" signal.

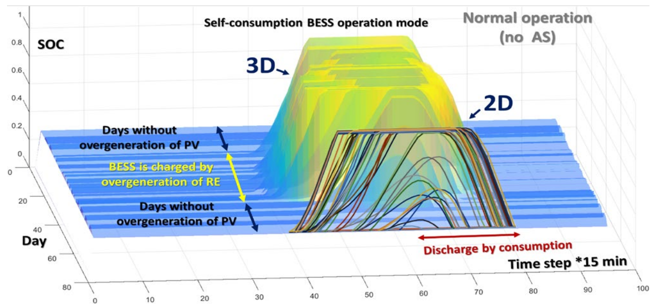

Fig. 9. 2D and 3D charts of SOC evaluation for considered days (72 days) under "Normal operation" (self-consumption) mode, no AS participation.

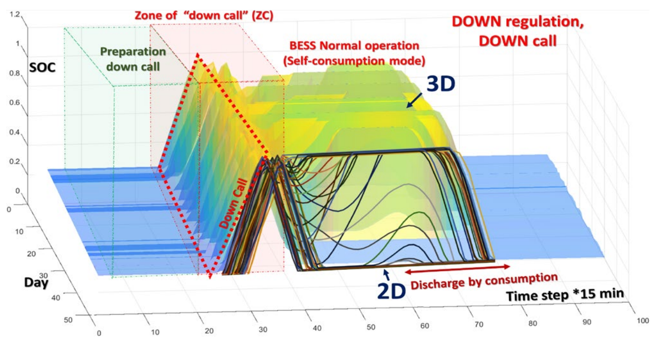

Fig. 10. 2D and 3D charts of SOC evaluation for considered days (48 days) under down-regulation mode with "Down call" appearance.

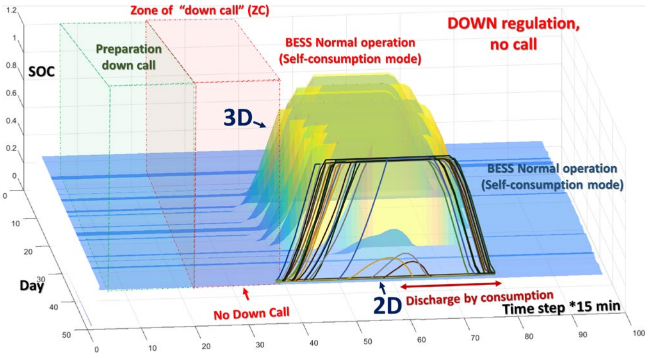

Fig. 11. 2D and 3D charts of SOC evaluation for considered days (49 days) under down-regulation mode, no call appearance.

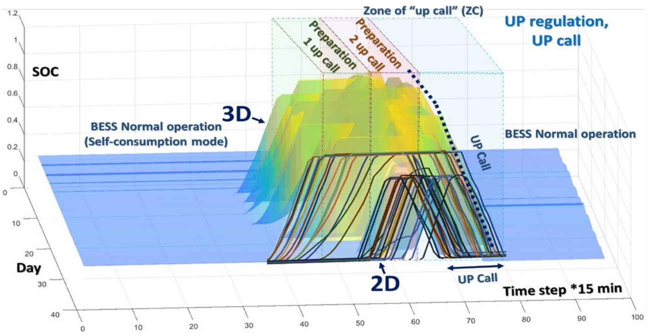

Fig. 12. 2D and 3D charts of SOC evaluation for considered days (37 days) under up regulation mode with "Up call" appearance.

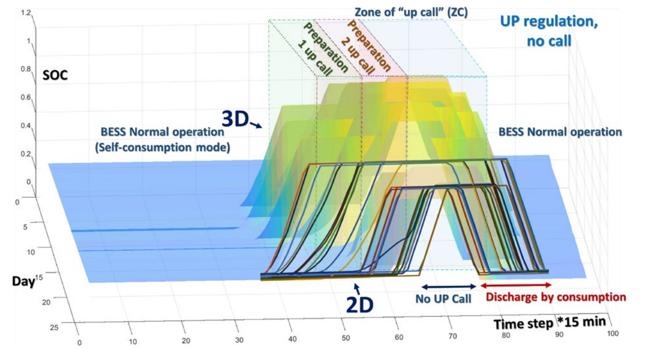

Fig. 13. 2D and 3D charts of SOC evaluation for considered days (25 days) under up regulation mode, no call appearance.

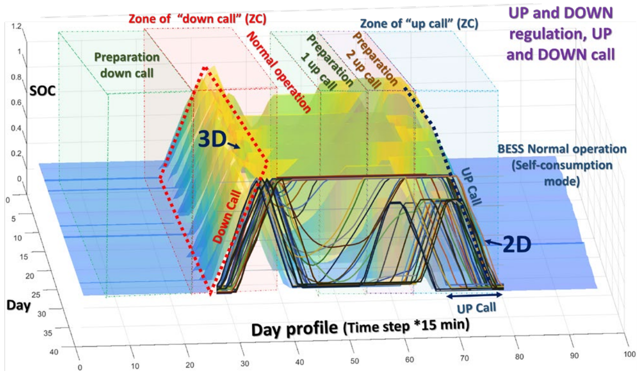

Fig. 14. 2D and 3D charts of SOC evaluation for considered days (36 days) under up and down-regulation mode, "Up call" and "Down call" appearance.

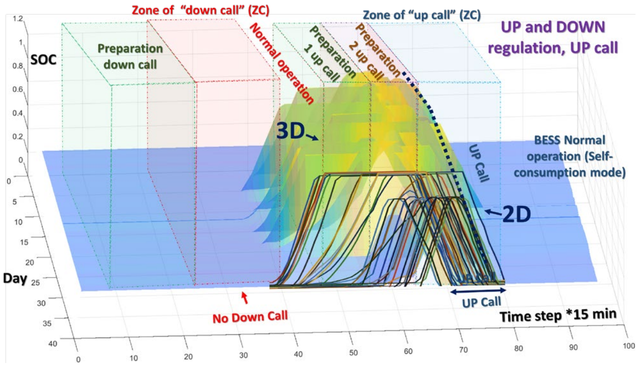

Fig. 15. 2D and 3D charts of SOC evaluation for considered days (36 days) under up and down-regulation mode with "Up call" appearance.

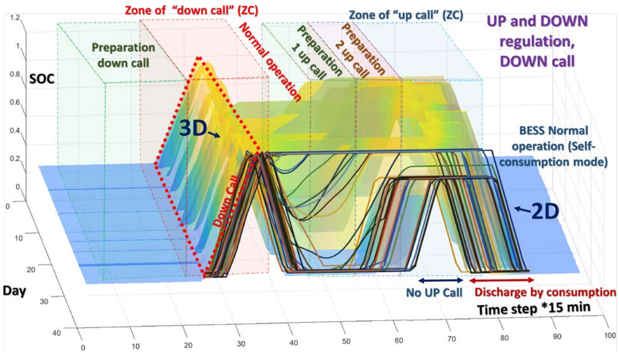

Fig. 16. 2D and 3D charts of SOC evaluation for considered days (38 days) under up and down-regulation mode with "Down call" appearance.

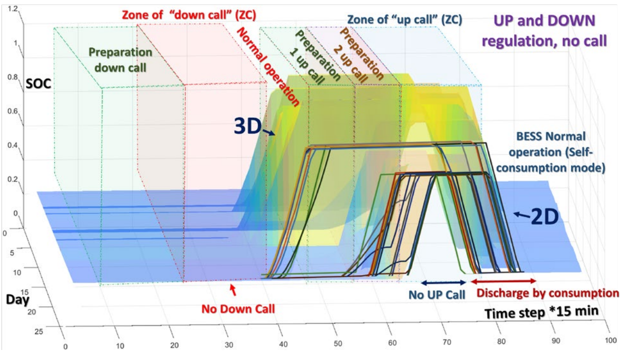

Fig. 17. 2D and 3D charts of SOC evaluation for considered days (24 days) under up and down-regulation mode, no call appearance.

Further, the BESS is discharged or during "Up call" signal if there is (Fig. 12, Fig. 14 and Fig. 15 respectively) or due to the supply of prosumer consumption.

TABLE I. presents one-year operation values of considered prosumer without AS participation and under-only "Normal operation" mode (increasing self-consumption) presented previously. These values will be the reference point for further economic evaluation of technical and economic profitability of prosumer's up and down AS participation.

TABLE II. shows operation values of considered and presented previously 9 evaluation cases. Since different days were used at different times of the year, the table presents the day-averaged values. The first colon presents the type of operation (SC is the self-consumption "Normal operation mode") and the presence or not of the call signal in the brackets. The second colon shows the number of days under this operation case (according to Fig. 13). The fifth colon indicates energy withdrawing and injecting into the DG. It can be seen that the major part of PV generation is self-consumed immediately, or stored and used afterwards. Only the small part (less than 12%) is sold into the grid.

TABLE III. and TABLE IV. present more precisely daily economic and flexibility evaluation of considered cases.

TABLE III. shows that for a group of days without AS participation, or with but without call signal presence, the average price of electrical energy is equal more or less to the average price under "Normal operation" mode (TABLE I. , raw 1). However, the prosumer's energy price is much lower for groups of days with ancillary services participation (and call signal presence), as shown in the rows 2, 4, 6, 7 and 8).

According to (4), for considered evaluation real participation case, the one-year average day electricity price is 10.34 c€/ kWh for cases of mixed participation in up and down-regulation, instead of 10.75 c€/ kWh for total non-participation. It is important to note that for the group of day

TABLE I. PROSUMER'S OPERATION UNDER THE "NORMAL OPERATION" MODE (WITHOUT AS PARTICIPATION).

	Days	Normal prosumers operation ("SC", no AS)			
		PV/ Consumption (kWh)	*To/from Grid (kWh)*	*PV sale (c€)*	*Price (c€/ kWh)*
Total	365	25076/ 71771.87	2624/ 49282	15748	
Average		**68.70/ 196.63**	**7.18/135**	**43.1**	**10.75**

TABLE II. PROSUMER'S OPERATION UNDER BESS UP AND DOWN-REGULATION FLEXIBILITY ANCILLARY SERVICE.

Regulation (UP CALL/ DOWN CALL)	Days	UP and DOWN capacity regulation AS (per day)		
		PV (kWh)	*Consumption (kWh)*	*To/from Grid (kWh)*
SC	72	67.21	195.55	5.85/ 132.9
Down (No/Yes)	48	69.64	200.15	9.78/ 139.9
Down (No/No)	49	68.83	196.76	8.29/ 134.2
Up (Yes/No)	37	69.3	196.09	9.68/ 135.2
Up (No/No)	25	66.67	196.08	6.38/ 135.73
Up + Down (Yes/Yes)	36	68.54	196.04	9.98/ 137.65
Up + Down (Yes/No)	36	71.94	196.59	9.33/ 133.3
Up + Down (No/Yes)	38	67.1	197.37	8.18/ 139
Up + Down (No/No)	24	70.25	195.67	8.77/ 134.2
Total	**365**	**25076**	**71771.87**	**3029/ 49460**
Average		**68.70**	**196.63**	**8.3/135.5**

with participation in the up and down-regulation, the average electrical price can go down to 9.55 c€/ kWh (from TABLE III. raw 6) what is significant due to the fact that the configuration of the system has remained the same and only the operation mode has changed.

TABLE IV. shows that for the considered year and considered evaluation cases (Fig. 13), the prosumer participates in 195 days of up and down-regulation and receives additional 29472 c€ of benefits (3), thus the average 150 c€ per day of participation. From another side, it supplies to DG about 2168.4 kWh of local flexibility to DG during these days of AS participation whether 11.12 kWh per day of

TABLE III. DAILY ECONOMICAL EVALUATION OF BESS UP AND DOWN-REGULATION FLEXIBILITY ANCILLARY SERVICE

Regulation (UP CALL/ DOWN CALL)	Days	UP and DOWN capacity regulation AS (per day)		
		Benefits (c€)		*Price (c€/ kWh)*
		PV sale	**UP/ DOWN**	
SC	72	35.13	-/ -	10.67
Down (No/Yes)	48	58.13	-/ 138.87	10.01
Down (No/No)	49	49.79	-/ -	10.63
Up (Yes/No)	37	58.13	119.4/ -	10.27
Up (No/No)	25	38.33	-/ -	10.85
Up + Down (Yes/Yes)	36	59.9	125.1/ 140.5	9.55
Up + Down (Yes/No)	36	56	128.7/ -	9.88
Up + Down (No/Yes)	38	55.2	-/ 110.4	10.44
Up + Down (No/No)	24	52.65	-/ -	10.69
Total	**365**	**18401.9**	**13533/ 15918.9**	**-**
			29259.4	
Average		**50.41**	**37.1/ 43.61**	**10.33**
		131.12		

TABLE IV. ECONOMICAL EVALUATION OF BESS UP AND DOWN-REGULATION FLEXIBILITY ANCILLARY SERVICE (IN TERMS OF FLEXIBILITY)

Regulation (UP CALL/ DOWN CALL)	Days	UP and DOWN capacity regulation AS		
		Supplied flexibility (kWh)		*AS benefits (c€)*
		UP	**DOWN**	
Down (No/Yes)	48	-	333.3	6665.76
Up (Yes/No)	37	220.8	-	4417.8
Up + Down (Yes/Yes)	36	225.1	252.98	9561
Up + Down (Yes/No)	36	231.6	-	4633.2
Up + Down (No/Yes)	38	-	209.8	4195
Total	**195**	**676.7**	**796.08**	**29 472.8**
		1472.78		
Average		**7.55**		**150**

participation. It can be seen that participation in the AS does not affect the prosumer's household consumption, brings it complementary benefits and most importantly additional flexibility to the DG and SO.

To analyse the impact of this AS on the battery lifetime, analysis of residential BESS charge-discharge cycles was made. The deeper data analysis shows that under "Normal operation" mode operation (TABLE I. , no AS case), residential BESS is used 208 times (208 days with PV overgeneration when the BESS makes cycles of charge-discharge from 365 considered days). Contrariwise, under up and down flexibility AS, the BESS is used 310 days per year: 234 days with the single charge-discharge cycle, 76 days with a double charge-discharge cycle. In total, BESS makes 386 charge-discharge cycles (Fig. 9 - Fig. 17).

For typical market residential BESS as AENTRON - A48100R [35], the cycle of life is approximately 3.000-4.000 cycles with 80 % discharge depth at +20 °C. In general cases, batteries lifetime is very limited in severe conditions of using [36][37][38][39]. We can see that for 10 years for actual prosumers' configuration and under "Normal operation" mode, this BESS will make only 2100 cycles. This is the case of an unsatisfactory use of equipment resources and investment as the battery will fail due to the end of its service life. For actual research case, the up and down-regulation make 3860 cycles during considered 10 years of life. For the studied case, it is the much more profitable option for BESS use and prosumers investments valuation. Participation in AS, and particularly in up and down-regulation allows to better payback prosumer's investments, to obtain additional economic benefits for prosumer from one side, and additional local flexibility for French DG from another.

V. Conclusion

The actual research aims to present the economic and technical interests of up and down-regulation of residential BESS for local DG flexibility in France. It presents the overview of the state of art of local flexibility in France. Then, the original operation methodology was presented and was applied for one-year large-scale operational and economical evaluation on the real French prosumers case. The technical and economic analysis shows the significant decrease of prosumer's electrical energy price due to mixed up and down participation for all considered possible operation cases. From another side, this AS is the promising and easy deploying source of additional and local flexibility for DG. Likewise, the technical analysis shows that for considered case the residential BESS is used more efficiently than for the conventional case of classical self-consumption, which additionally accelerates the prosumers investment valuation.

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