Title "*Demand-response load shaping and flexibility: the evolution of power grid into an adaptive model*"

Abstract

The energy transition implies a radical change of the electrical systems, characterized by an ever lower inertia of power grid system, an extreme variability of the power flows with a strong push from the static production areas and, at the same time, by an increase in the fault propagation due to the phase-out of conventional groups.

To achieve these objectives it is necessary to work on the coal phase-out processes by enabling the major development of renewables, guaranteeing production planning by introducing demand within the electricity system which, through its flexibility, makes the network evolve in an adaptive model various future needs (**adaptive grid**).

The power grid must evolve from a production-based system to one that integrates different types of consumption, transforming it from decentralized to adaptive to address new problems related to climate change, the introduction of non-programmable renewable energy and terrorist actions that can shatter the power grid system.

The aggregation of flexible resources (**Demand Side Management**) and the ability to comply with the electrical programs (*baseline*), introduce the definitive model of **Demand-Response Load Shaping**.

This paper presents the case study in Italy (North Italy electricity zone), in progress, where an industrial district has been created with virtual zones that are able to balance the power grid, providing services to the grid (Ancillary Service Market), through modulation of electricity consumption, in aggregate mode.

The goal of the project is to build clusters of flexible areas capable of reduce internal perturbance in the power grid (balancing/congestion) and external perturbance such as catastrophic meteorological events due to ongoing climate change or events attributable to cyber security.

Goal

The goal of the case study is to show how an aggregation, composed of different types of flexible resources:

- Electrical Vehicle Supply Equipment
- Energy Storage
- Modular loads (HVAC)
- Non-modular loads (furnace)

is comparable to a virtual power plant that feeds flexibility into the power grid, derived from the modulation of consumption, and replaces the physical input of energy to the network, in the Balance Market.

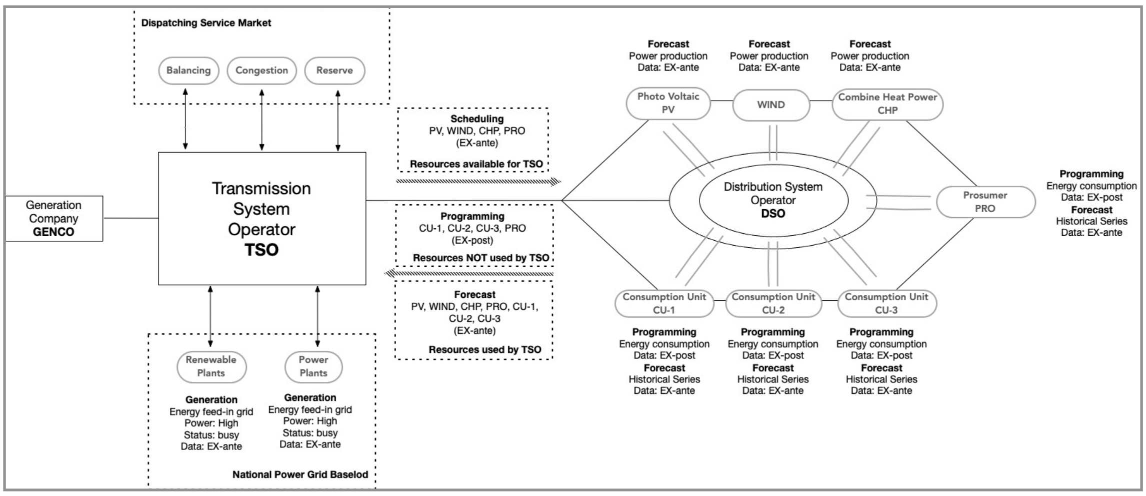
Different levels of flexibility are defined which are part of an optimization problem concerning the adaptive grid model which aims to preserve the basic principles[1] of the power grid system.

Problems

The power grid is focused on the planning of power generation only and provides the electricity service based on the forecast of demand. When the **Transmission System Operator (TSO)** requests to generation companies the resources that operate in ancillary services market for resolving the problems of the power grid (congestion resolution, balancing and reserve), they build their binding program identified as follows:

- Power generation program of programmable plants
- Forecast of renewables (Wind, PV)
- Consumption unit forecast (BEV, HVAC, …)

Starting from this phase (programming) known as **Ex-ante**, a series of errors are introduced in the construction constrained program, due to the forecast of the energy to be introduced from **Renewable Sources (RES).** Such errors are resolved in the **EX-pos**t phase of the **Balance Market Session.** [**FIG-1**]



[FIG-1]

[1] Energy Central post "Flexibility and Technology Transform the Power Grid in a Resilient Digital Infrastructure", May 26, 2021 (https://energycentral.com/c/gr/flexibility-and-technology-transform-power-grid-resilient-digital-infrastructure)

The currently power grid scheme presents this state of the art to be overcome, which manifests itself in the relationship between the **Transmission System Operator (TSO)** and **Distribution System Operator (DSO)**, both in the resource programming phase and in the program that resolves imbalances of the zones.

This model of interaction and operation between the TSO and DSO is at the basis of the systemic inconsistency that introduces the **first problem** of the integrity of the power grid: <u>instability of the electricity grid due to internal perturbations</u> (*zonal imbalances→propagation of zonal imbalances*), some examples :

- power peaks due to the random use of batteries for recharging mobility systems (unpredictable absorption program);
- energy from renewable sources not present or not dispatchable on the grid due to excessive production;
- concentration of localized consumption in an area or zone that cannot be predicted (ex. human behavior).

The **second problem** that the power grid must manage origin from the outside and is due to:

- extreme weather conditions;
- accidental environmental disasters (eg tree falls);
- conventional terrorism (damage to high voltage pylons);
- cyber-terrorism (modification of the set points of the consumption system or the program of the distributed power generation).

<u>The solution of the first problem allows to build the strategy to solve the second problem</u>.

Let's see how the strategy is created that manages to contain any perturbance up to the creation of power grid that preserves its integrity and safety in any scenario.

Solution

The consumption programming through digitalization allows the evolution of the system towards a more optimized model centered on the Demand-Response model.

The goals to achieve are:

- enhancement of renewable sources according to priorities linked to economic, physical and environmental aspects;
- reduction of the power grid imbalances through dynamic corrections of the consumption programs, without impacting operational processes;
- active participation of demand in the processes of flexibility and enhancement on the market.

The core of project is the consumption which becomes the resource available to the services of the dispatching instead of the power production, through its "*flexibility*" resource (ie the modulation of up and / or down consumption). The **Transmission System Operator (TSO)** "*views*" the aggregate as a virtual power plant and flexibility as "*energy*" to be introduced into power grid or reduced by power grid. The flexibility is not physical energy, but the electrical consumption programming (*baseline*) which is implemented through modulation of consumption (implementation of set points) "**UP**" (*reduction*) or "**DOWN**" (*increase*) of the Consumption Units. Below is the descriptive scheme. [**FIG-2**]

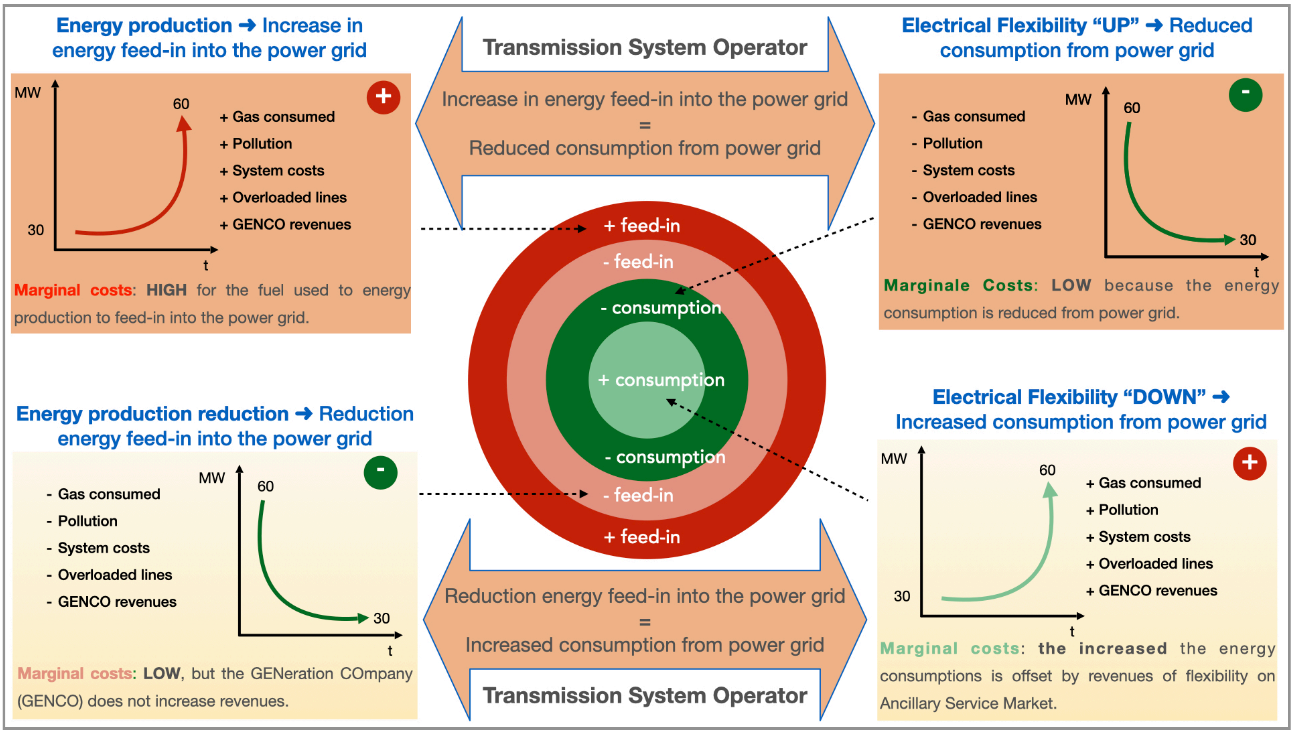


FIG-2

To make the power grid in a model that manifests itself to the outside as "*resilient*", two types of perturbations must be resolved.

The Adaptive network model is able to cope with two perturbations:

1. Zonal / nodal imbalances (**Inside Perturbance**)
2. Extraordinary Extreme Events (**Outside Perturbance**)

Project

The project shows the method that solves and/or contains the **Inside Perturbance (IP)** and builds the best conditions, to resolve any **Outside Perturbance (OP)**

The project, which is still active, plans to extract flexibility from the consumption systems present within the aggregated production sites in a Demand-Reponse type model, providing the **Transmission System Operator (TSO)** with flexibility as a resource for the balancing service.

The solution that is currently illustrated is being tested in Italy with an aggregate consisting of:

- Audi dealer (n.9 sites)
- Hospitals (n.3 sites)
- Thermoplastics Industry (n.2 sites)

The purpose of the experimentation is to "*identify*" for each Site (defined by meter number, location number and account number) the **VA (Virtual Area)** composed of **PN** (physical nodes that correspond to the consumption systems or systems for the input of electricity) monitored, manageable and modular to transfer their flexibility to the electricity grid by participating in the dispatching market.

The logical architecture of the industrial aggregation. [**Fig.3**]

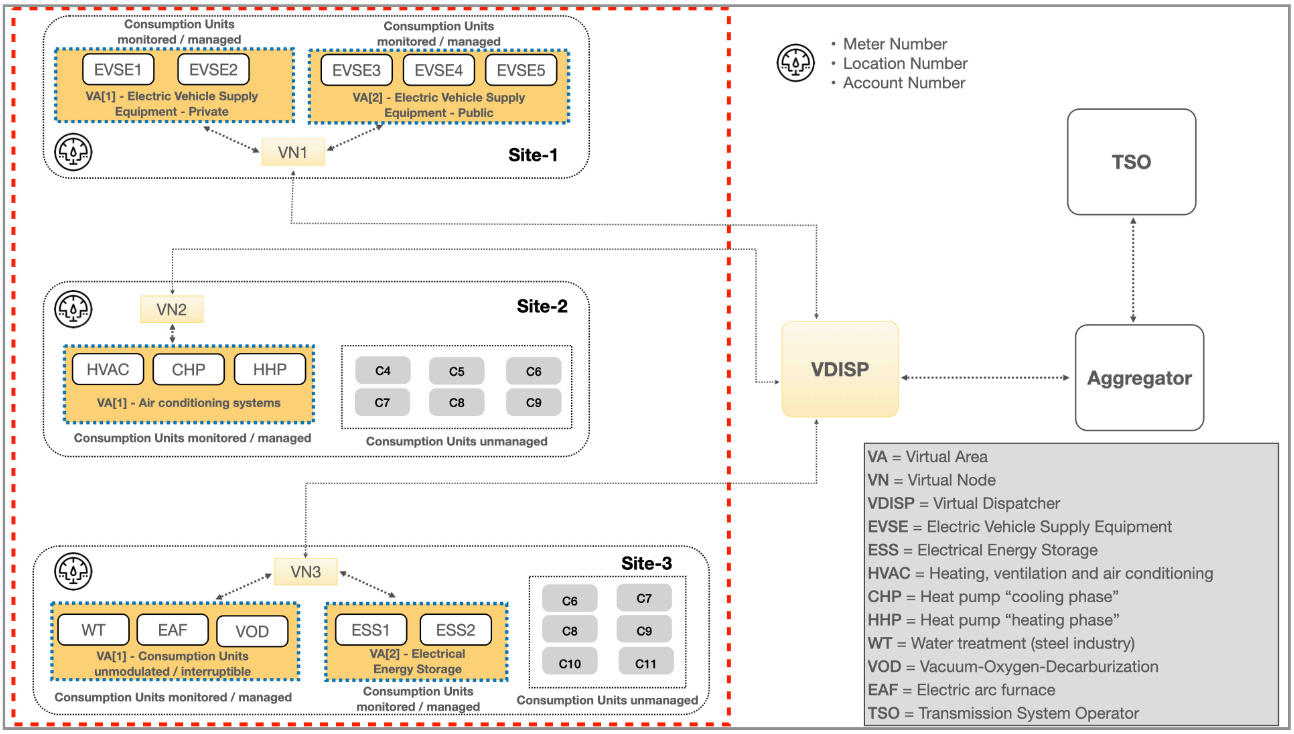


FIG-3

The list of CUs (*Consumption Units*) participating in the aggregation and defining the consumption program (*baseline*). [**TAB-1**]

Site-1			
Virtual Area	CU managed	Typology	Power [kW]
VN1	EVSE1	Electric Vehicle Supply equipment	180
	EVSE2	Electric Vehicle Supply equipment	180
VN2	EVSE3	Electric Vehicle Supply equipment	360
	EVSE4	Electric Vehicle Supply equipment	360
	EVSE5	Electric Vehicle Supply equipment	360
Site-2			
Virtual Area	CU managed	Typology	Power [kW]
VN1	HVAC	Air conditioning system	300
	CHP	Heat pump "cooling phase"	60
	HHP	Heat pump "heating phase"	40
Site-3			
Virtual Area	CU managed	Typology	Power [kW]
VN1	WT	Water treatment	200
	EAF	Furnace	60000
	VOD	Refining VOD	3000
VN2	EES1	Electrical Energy Storage	250
	ESS2	Electrical Energy Storage	250

TAB-1

In the example scenario, the baseline from 2 P.M. until 5.30 P.M., is communicated every 15 minutes (from Q (56) to Q (80), where Q = 15 minutes) to Transmission System Operator through the aggregatore operator. Below is the max power available for each sites.

- **Site-1** = 1.140 [kW]
- **Site-2** = 400 [kW]
- **Site-3** = 9.770 [kW]

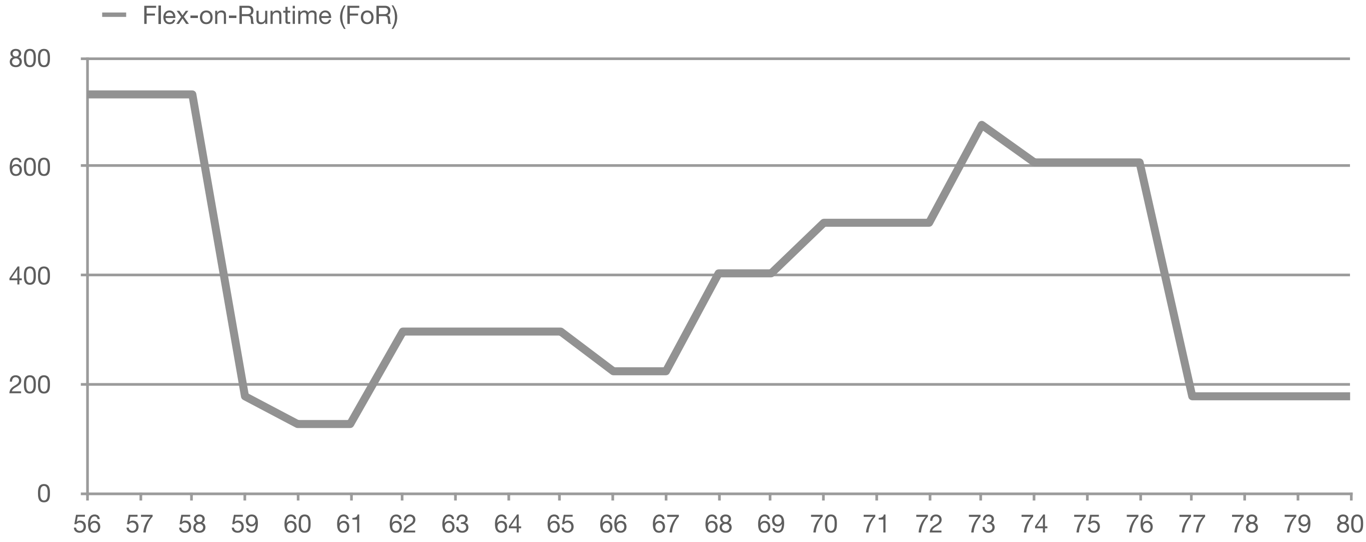
Baseline of the project [**TAB-2**]

Site-1		Site-2		Site-3		Sites aggregation	
Q(i)	Baseline [kW]	Q(i)	Baseline [kW]	Q(i)	Baseline [kW]	Q(i)	Baseline [kW]
56	1200	56	380	56	6000	56	7580
57	1200	57	380	57	6000	57	7580
58	1200	58	380	58	6000	58	7580
59	90	59	380	59	2880	59	3350
60	90	60	235	60	2880	60	3205
61	90	61	235	61	2880	61	3205
62	360	62	335	62	2880	62	3575
63	360	63	335	63	1575	63	2270
64	360	64	335	64	1575	64	2270
65	360	65	335	65	1700	65	2395
66	360	66	125	66	1700	66	2185
67	360	67	125	67	1700	67	2185
68	720	68	125	68	3225	68	4070
69	720	69	125	69	3225	69	4070
70	720	70	390	70	3225	70	4335
71	720	71	390	71	8710	71	9820
72	720	72	390	72	8710	72	9820
73	1080	73	390	73	8710	73	10180
74	1080	74	195	74	8900	74	10175
75	1080	75	195	75	8900	75	10175
76	1080	76	195	76	8900	76	10175
77	180	77	250	77	5660	77	6090
78	180	78	250	78	5660	78	6090
79	180	79	250	79	5660	79	6090
80	180	80	250	80	5660	80	6090

TAB-2

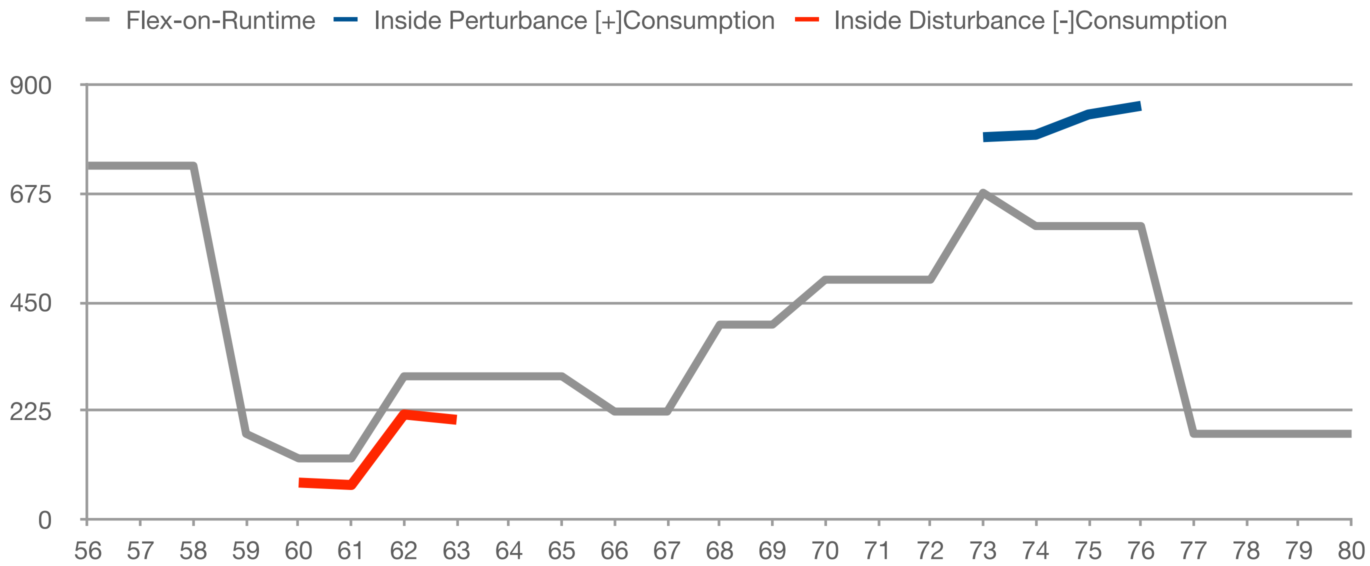
The electrical flexibility: the new resource for the Transmission System Operator

- The **Virtual Dispatcher (VDISP)**, which is a gateway connected directly **Virtual Node (VN)** via IEC protocol family, elaborates the flexibility profile **Flex-on-Runtime (FoR)** [**GRA-1**] to be submitted to the **Transmission System Operator (TSO)** as a flexibility resource in the Ancillary Session Market.
- The **VDISP** proposes the **FoR** to the **TSO**, giving the various **Virtual Nodes (VN)** the list of actions (setpoints) to be implemented on the relative CUs.
- The **TSO** *"sees"* its availability of energy increases or decreases, in the event that the **FoR** is called to operate towards the ancillary market in the "**UP**" or "**DOWN**" mode.



GRA-1

During the delivery of the **FoR** (modulation of consumption for the balancing service) at Q(60) and Q(73) as in the graph [**GRA-2**], **Internal Perturbance (IP)** occur for various reasons (electrical problems of the CU, breakage of the CU, industrial production, etc.). The system is able to include both types of perturbations as illustrated below.



GRA-2

Resolution of Inside Perturbance: Balancing Program

1. The **VDISP** receives the consumption and / or production measurements from the **VNs**, which monitor the CU (Consumption Units) / PU (Production Units) in the virtual areas, and verifies the presence of perturbances between **Flex-on-Running (FoR)** profile and the aggregate consumption measurement of the **VNs**. [**FIG-3**]
2. **Case Q(60)** - there is a lower absorption (**[-]Consumption**) from the power grid with respect to the **FoR** which must be corrected within Q(63) to avoid imbalance penalties, as required by the regulation of the network code.
3. **Case Q(73)** - there is a greater absorption (**[+]Consumption**) from the power gird with respect to the **FoR** which must be corrected within Q(76) to avoid imbalance penalties, as required by the regulation of the network code.
4. **At Q(60**) **VDISP** receives from **VN1** (Site-1) and from **VN2** (Site-2) an aggregate of measures that do not respect the **FoR** but which are less than 50 [kW] (**Delta Flex**):
   I. **VDISP** knowledges of the relative profiles of each CU, identifies the problem, which can refer to a single CU or to a combination of them (within the same virtual area or in different virtual areas within the same site or in different sites) .
   II. **VDISP** activates the **Balancing Program (BP)** which solves the anomaly with an appropriate scheduling that extracts the flexibility from the **Flex Recovery Runtime (FRR)** resolving the **Delta Flex (DF).** In this case, in the Q(60) from **FRR** 50 [kW] up to 90 [kW] are extracted at Q(63), increasing the consumptions from power grid with total of 274 [kW].
   III. The **BP** at Q(63) updates the **FRR** putting it in the state of **Flex Recovery Stand-by (FRSb)**, until the next Inside Perturbance where it enters into action with the next **FRR.** [**GRA-3**]
5. **At Q(73) VDISP** receives from **VN1** (Site-1) and from **VN2** (Site-2) an aggregate of measures that do not respect **FoR** but are greater than 115 [kW]:
   I. **VDISP** knowledges of the relative profiles of each CU, identifies the problem, which can refer to a single CU or to a combination of them (within the same virtual area or in different virtual areas within the same site or in different sites) .
   II. **VDISP** activates the **Balancing Program (BP)** which solves the anomaly with an appropriate scheduling that extracts the flexibility from the **Flex Recovery Runtime (FRR)** resolving from **Delta Flex (DF).** In this case, in the Q(73) from **FRR** 115 [kW] up to 249 [kW] are extracted at Q(73), reducing of the consumptions from the power grid by a total of 784 [kW].
   III. The **BP** at Q(76) updates the **FRR** putting it in the state of **FRSb**, until the next Inside Perturbance where it comes into action as **FRR**. [**GRA-3**]

Hour (PM)	Q(i)	Flex on Runtime (FoR) [kW]	Inside Perturbance (IP) [kW]	Delta Flex (DF) [kW]	Flex Recovery Runtime (FRR) [kW]	Flex Recovery Stand-by (FRSb) [kW]
2.00	56	733	733	0	100	100
2:15	57	733	733	0	100	100
2.30	58	733	733	0	100	100
2:45	59	178	178	0	100	100
3:00	**60**	127	**77**	**-50**	175	**125**
3:15	**61**	127	**72**	**-55**	175	**120**
3:30	**62**	297	**218**	**-79**	175	**96**
3:45	**63**	297	**207**	**-90**	175	**85**
4:00	64	297	297	0	175	175
4:15	65	297	297	0	175	175
4:30	66	224	224	0	220	220
4:45	67	224	224	0	220	220
5:00	68	404	404	0	220	220
5:15	69	404	404	0	220	220
5:30	70	497	497	0	220	220
5:45	71	497	497	0	375	375
6:00	72	497	497	0	375	375
6:15	**73**	677	**792**	**+115**	375	**260**
6:30	**74**	608	**797**	**+189**	375	**186**
6:45	**75**	608	**839**	**+231**	250	**19**
7:00	**76**	608	**857**	**+249**	250	**1**
7:15	77	178	304	0	200	200
7:30	78	178	112	0	235	235
7:45	79	178	123	0	235	235
8:00	80	178	150	0	235	235

GRA-3

Benefits

By reducing Inside Perturbance

- Flex "UP" which reduces the use of gas used by thermoelectric power plants to balance the grid;
- Aggregation reduces zonal and / or nodal imbalances;
- Introduction of electricity consumption within power grid system through Demad-Reponse Load Shaping model;
- The reduction of the effects caused by the Inside Perturbance allows the Transmission System Operator planning the strategy to resolve Outside Perturbance

Carbon footprint reduction by pilot project

Flex "UP"	[kWh]	CO_2 [tons/kWh]	CH_4 [tons/kWh]	NO_2 [tons/kWh]	GHG [tons/kWh]
Flexibility	5.881.200	1.625	4	9	1.638
Gas Reduction [Smc]	1.086.160				

Flex "DOWN"	[kWh]	CO_2 [tons/kWh]	CH_4 [tons/kWh]	NO_2 [tons/kWh]	GHG [tons/kWh]
Flexibility	588.120	162	0,38	0,88	163,70
Gas Reduction [Smc]	108.6161				

In the case of the pilot project if we extend the scenario from the industrial aggregate to the residential one, through the emerging energy communities, the power grid evolves into a model that manages to reduce Inside Perturbance by 50% using only consumption in "UP" modulation.

The contribution of the Demand-Response Load Shaping model to the power grid in terms of perturbance reduction is approximately **50%.**

The Inside of the Perturbance reduction is achieved by modulating consumption (flexibility) without using any production system.

All the results achieved by the pilot project will be announced in June 2023 (project closure)

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