FEDERAZIONE NAZIONALE IMPRESE ELETTROTECNICHE ED ELETTRONICHE

DAL 1945 IL VALORE DELL'INNOVAZIONE

Sistemi di automazione avanzata nelle stazioni di subtrasmissione per il dispacciamento decentralizzato

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Outline

- **Motivation and goal**
- **The voltage control function**
- **Congestion mitigation function**
- **Islanding function in subtransmission grid**

Motivation and goals

- **Currently, RES are characterized by:**
  - **are highly dispersed at the subtransmission and distribution levels**
  - **are highly intermittent and, as forecast techniques are not completely reliable, they are not fully exploited so far**
  - **individually, they have a reduced voltage control capability**
  - **they are often managed by DSOs, that have difficult coordination with the TSOs**
  - **they do not participate in active/reactive power regulation like conventional plants do**

Motivation and goals

- **Thus, as the RES penetration is continuously increasing (in particular, WFs in Italy), some issues arise:**
  - **undesirable voltage levels in the subtransmission system (e.g. high voltages in high generation – low load situations)**
  - **frequent congestions in the subtransmission system**
  - **the direction of power flows is more difficult to predict and control**

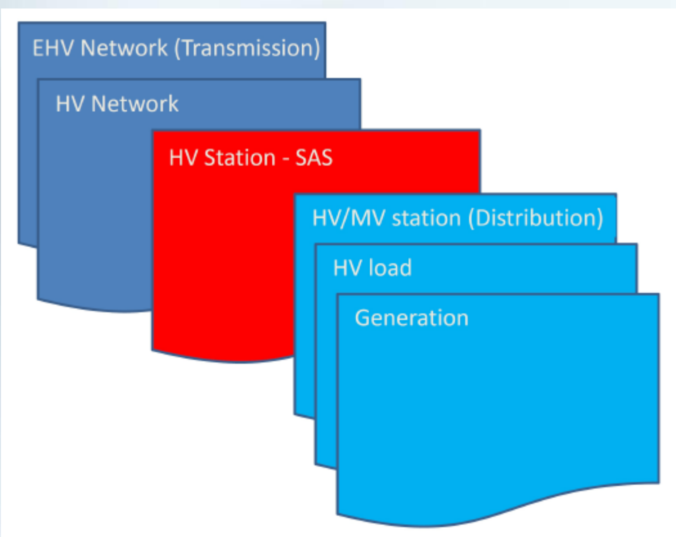
Motivation and goals

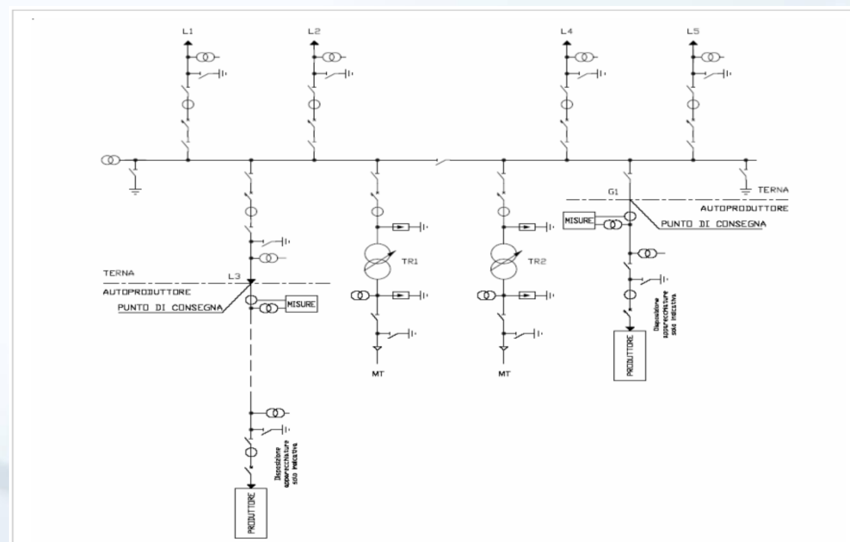
- **Under these circumstances, the project aims at investigating innovative approaches for the de-centralized network monitoring and control, focusing on the HV Substations, where RES converge**

- **The goal was to define an automation system in charge of:**
  - **control the substation voltage**
  - **control the real power, in order to solve possible congestions in the subtransmission feeder**
  - **prepare possible island conditions in case of major disturbance in the rest of the system**

SAS apparatus

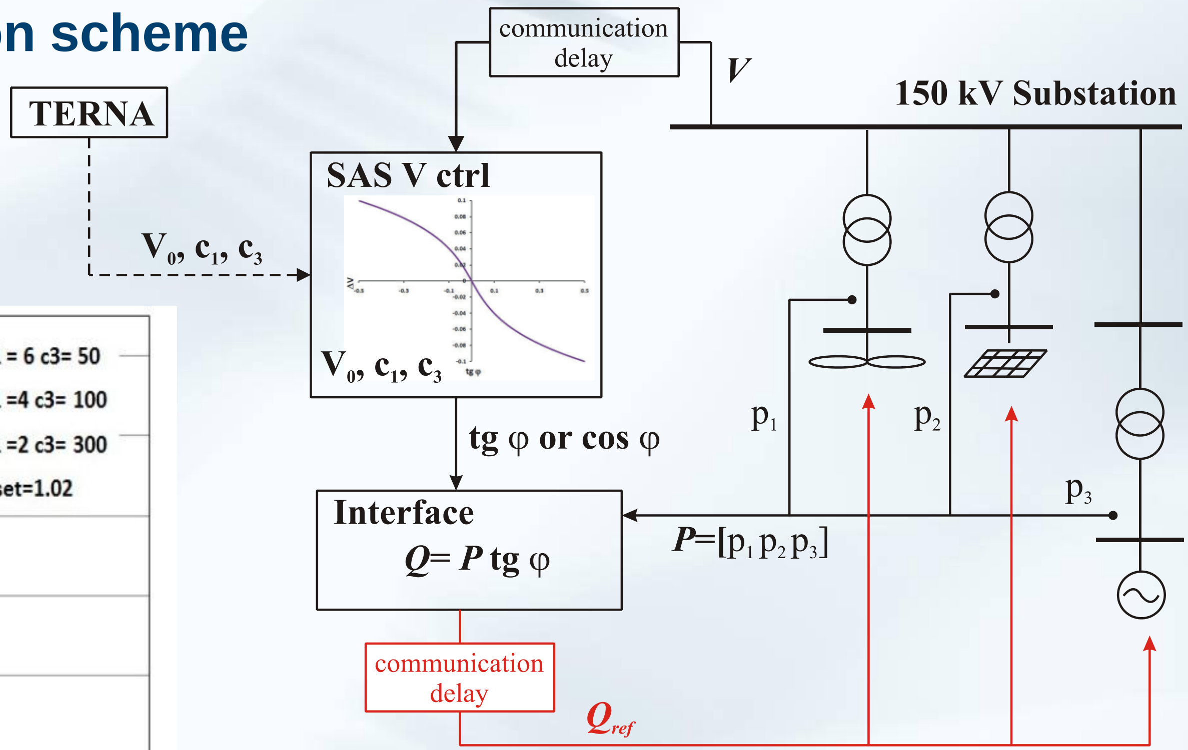
- **Layer representation of the electric grid**
- **SAS apparatus works on the interface between AAT and AT network**
- **SAS apparatus coordinates resources connected to the busbar:**
  - **Load (MV distribution network)**
  - **Load (directed connected on the HV busbar)**
  - **Generators (Directed connected to the HV busbar or on a tie-line)**

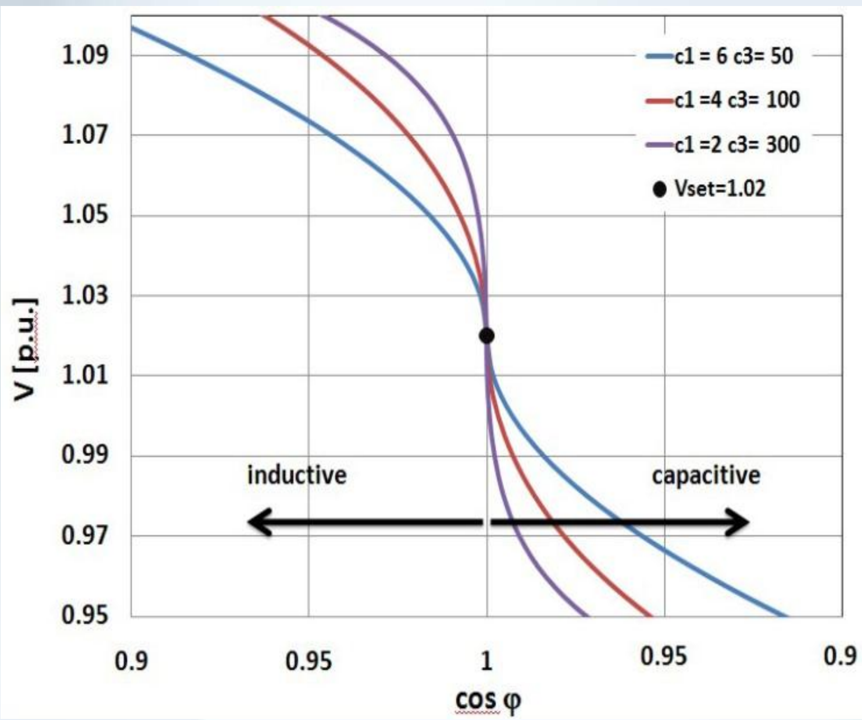




Voltage control function

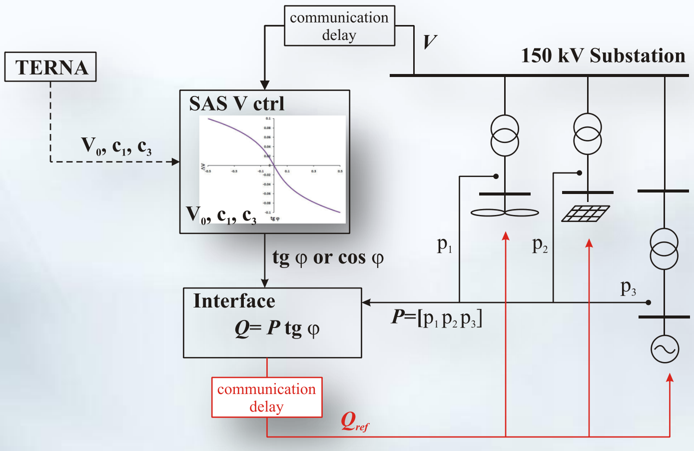
Proposed regulation scheme

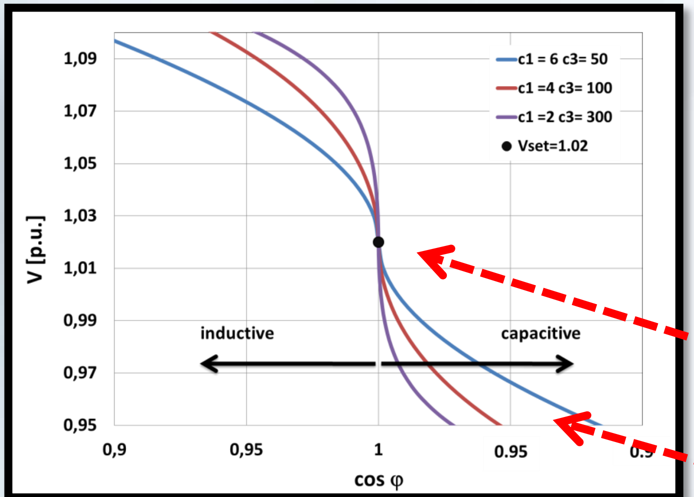




Proposed regulation law

Voltage control function





Different SAS can be coordinated/regulated, by TERNA, changing the parameters of the control laws

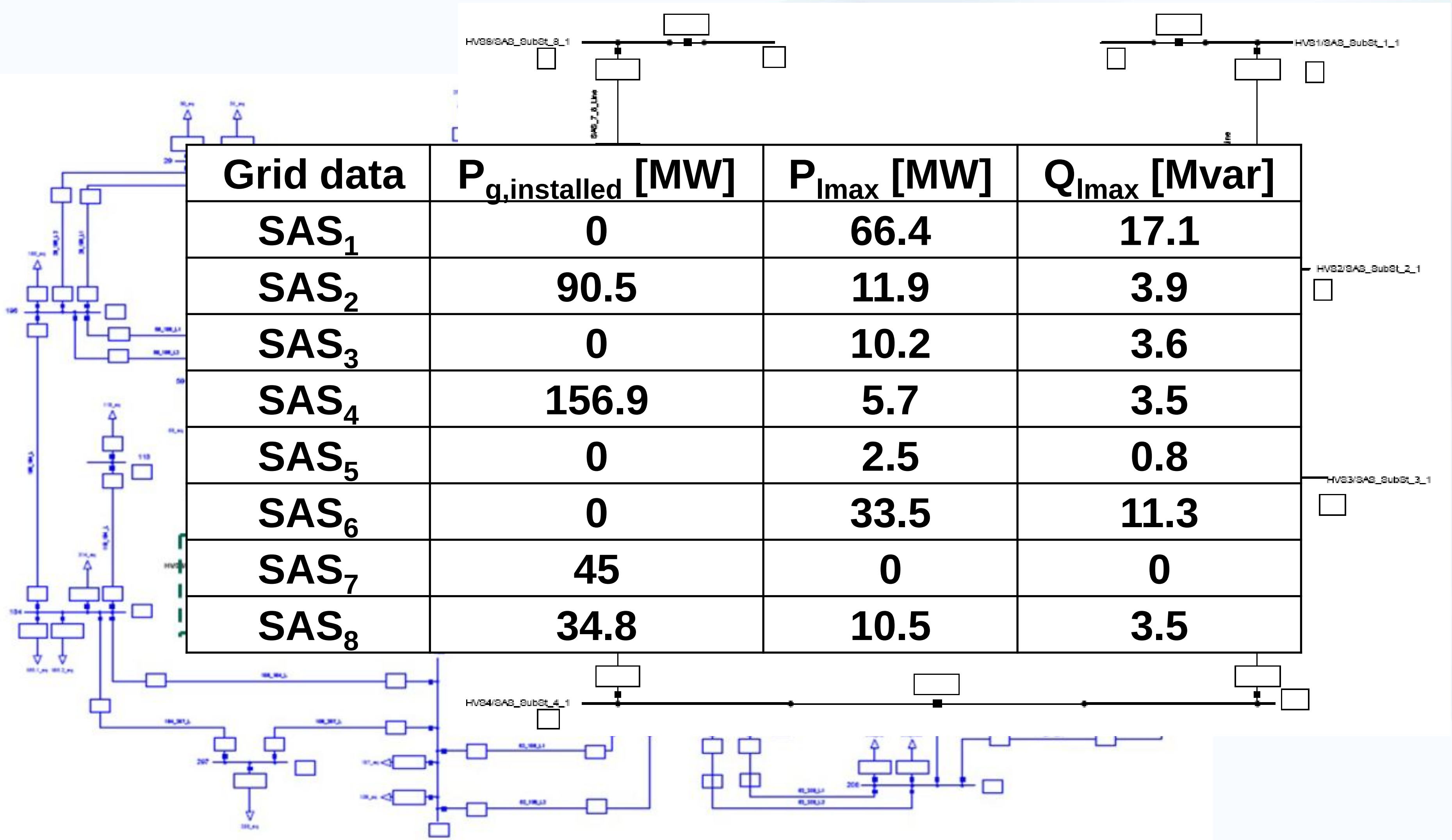
The RRR SAS regulator characteristic is defined such that it changes the reactive injection based on the locally measured voltage according to its characteristic defined in the figure

In particular is possible to operate on:

Center of the control laws

Sensitivity of the regulation (Q vs V)

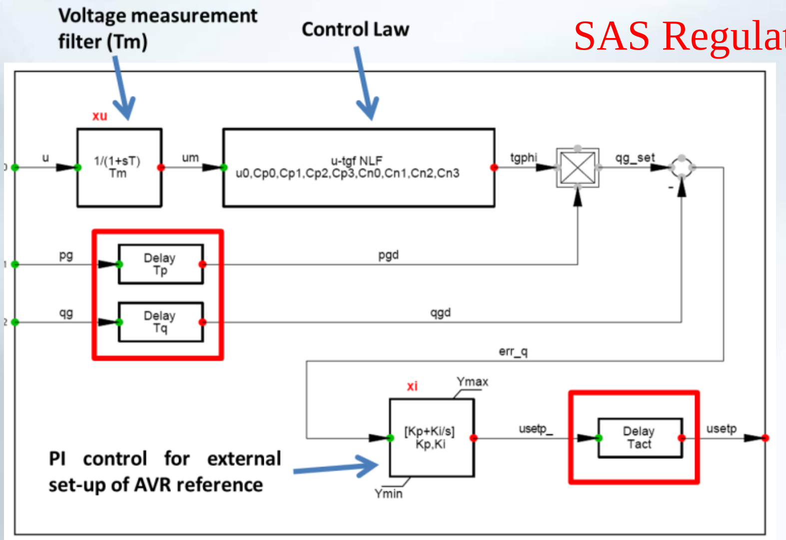
Voltage control function



Grid data	$P_{g,installed}$ [MW]	P_{lmax} [MW]	Q_{lmax} [Mvar]
SAS_1	0	66.4	17.1
SAS_2	90.5	11.9	3.9
SAS_3	0	10.2	3.6
SAS_4	156.9	5.7	3.5
SAS_5	0	2.5	0.8
SAS_6	0	33.5	11.3
SAS_7	45	0	0
SAS_8	34.8	10.5	3.5

Voltage control function

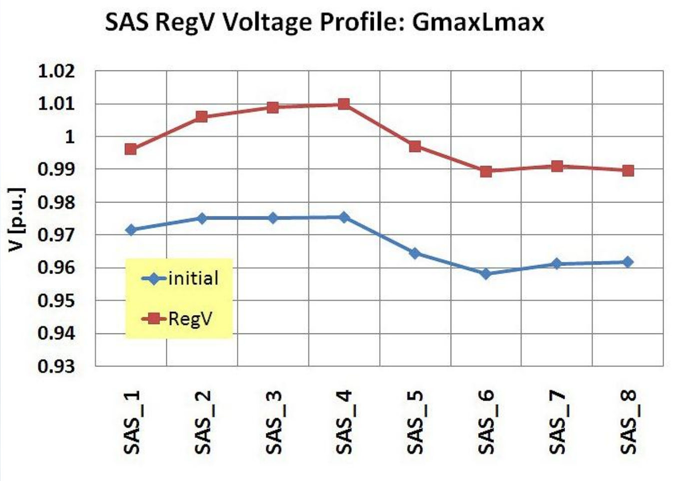
Detailed Models have been implemented and tested in a Steady State approach and in a Dynamic simulation

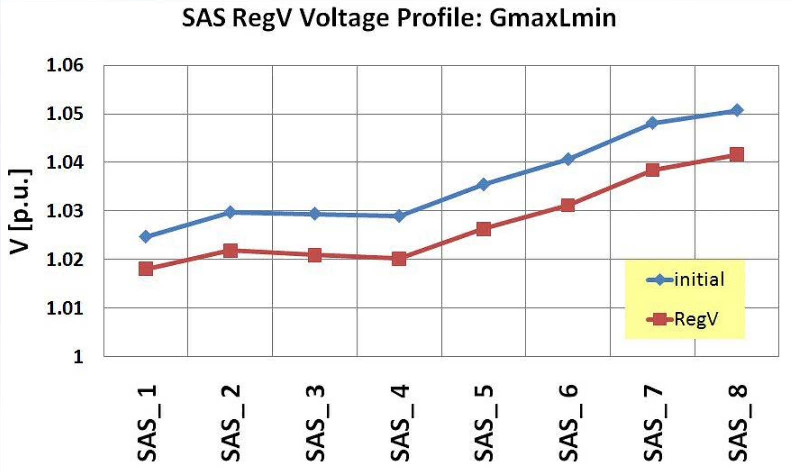


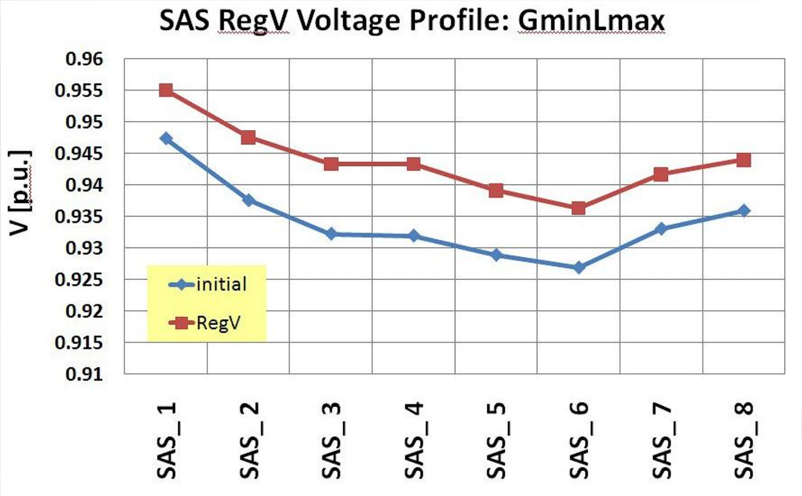
SAS Regulator:

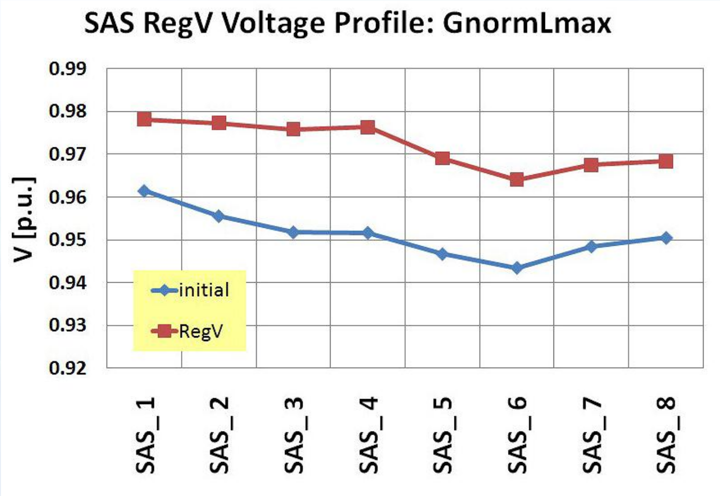
- **six different scenarios have been defined for:**
  - **maximum-medium-minimum generation levels: 80%, 25% and 20% of installed power, Gmax-Gnorm & Gmin**
  - **maximum-minimum load levels: 100% and 50% of the maximum load, Lmax-Lmin**

Voltage control function









Congestion Mitigation function

- One of the major problems raised by the increasing penetration of RES is the growth of electric lines overloading in the subtransmission system

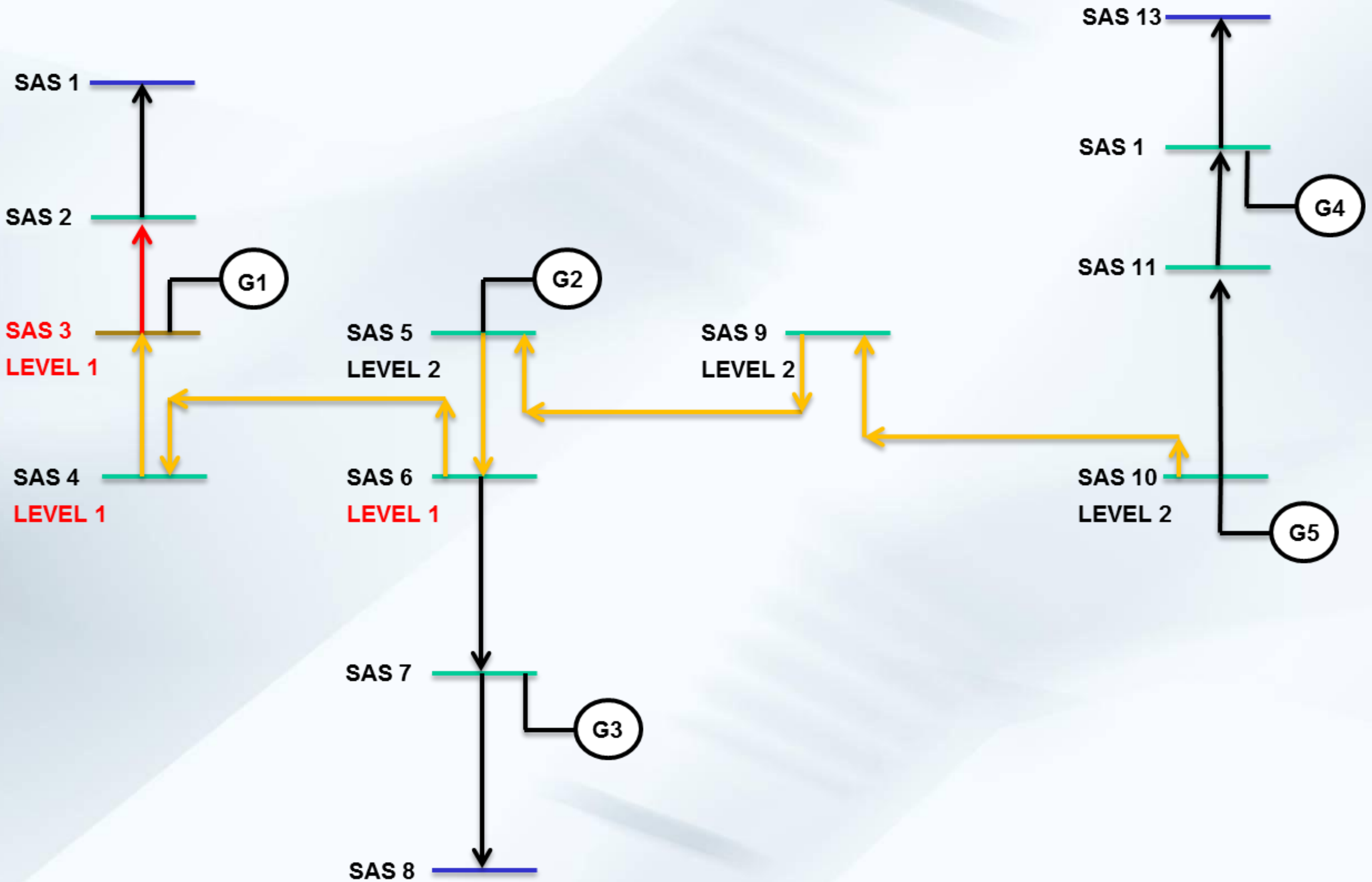
- The Congestion Mitigation function (CM) purpose is to mitigate the congestions locally, in a de-centralized manner.

- The goal is to define simple rules to identify generators responsible for a congestion

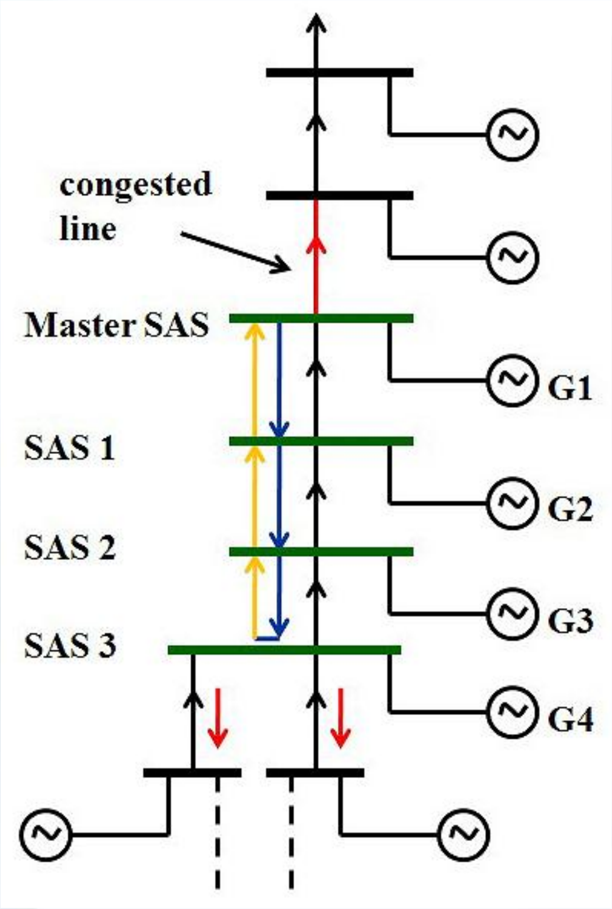
- Each SAS can participate to the relief of a congestion on each incoming line by dialoguing with the other SASs

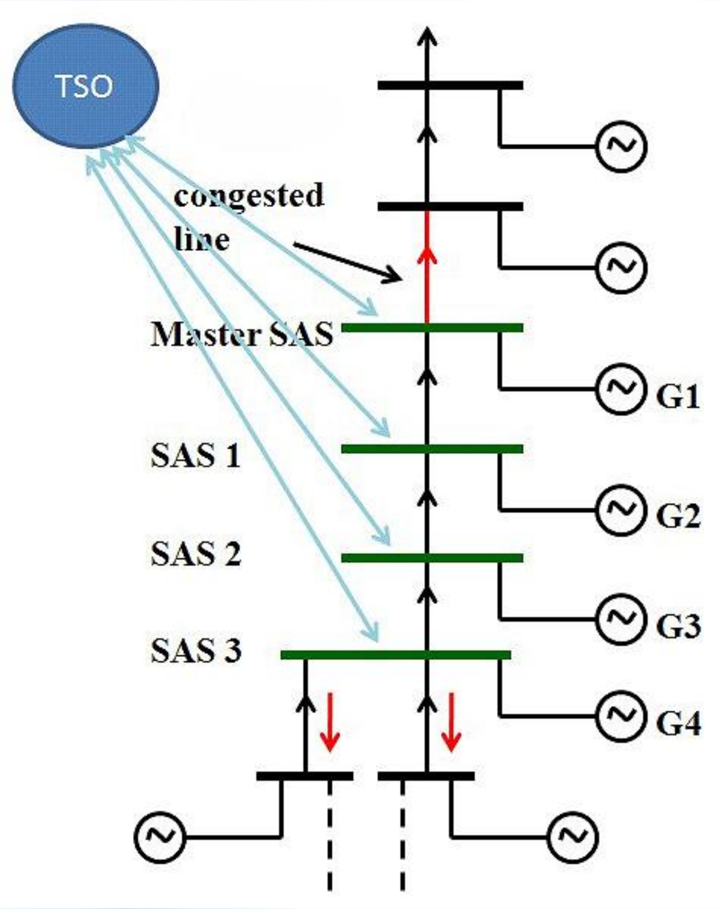
- It is not necessary to define a priori a controlled area

Congestion Mitigation function



Congestion Mitigation function





Congestion Mitigation function

- **A first step in designing the set of rules for the CM is to define two limits:**

the congestion limit, *LIM_{max}* – the maximum current/power limit above which the line is considered congested (in % with respect to the thermal limit of the line or another limit);

the minimum value, *LIM_{down}* in %, at which the congestion can be considered solved, allowing thus the line current to increase again by acting on the generators outputs, if possible

Congestion Mitigation function

- **first step: each SAS permanently monitors the current flows of the incoming lines. If a congestion is detected, the SAS at the "sending" end of the congested line will activate and become the Master SAS responsible for congestion mitigation:**

- **second step: the SAS Master will interrogate the SASs downstream the congested line, that directly inject power into the congestion, regarding the actual generation and control capability of each connected power plant**

!!!: the actual generation (MW) communicated to the SAS Master in the beginning of CM procedure (at t=0 s) will be considered as reference value during the entire CM procedure;

!!!: the generation steps will be given in % with respect to the communicated actual generation

Congestion Mitigation function

- third step: **the Master SAS will estimate the required real power generation reduction that can mitigate the congestion:**

$$\Delta P_{cong} = P_{cong}\left(1 - \frac{LIM_{down}}{LOD_{Line}}\right)$$

where ΔP_{cong} **- MW - is the estimated real power generation reduction necessary to mitigate the congestion; while** P_{cong} **- MW - is the measured real power flow in the congested line.**

Accelaration of the procedure using

$$\Delta P_{cong} = P_{cong}\left(1 - \frac{fact\_red}{LOD_{Line}}\right)$$

where $fact\_red < LIM_{down}$

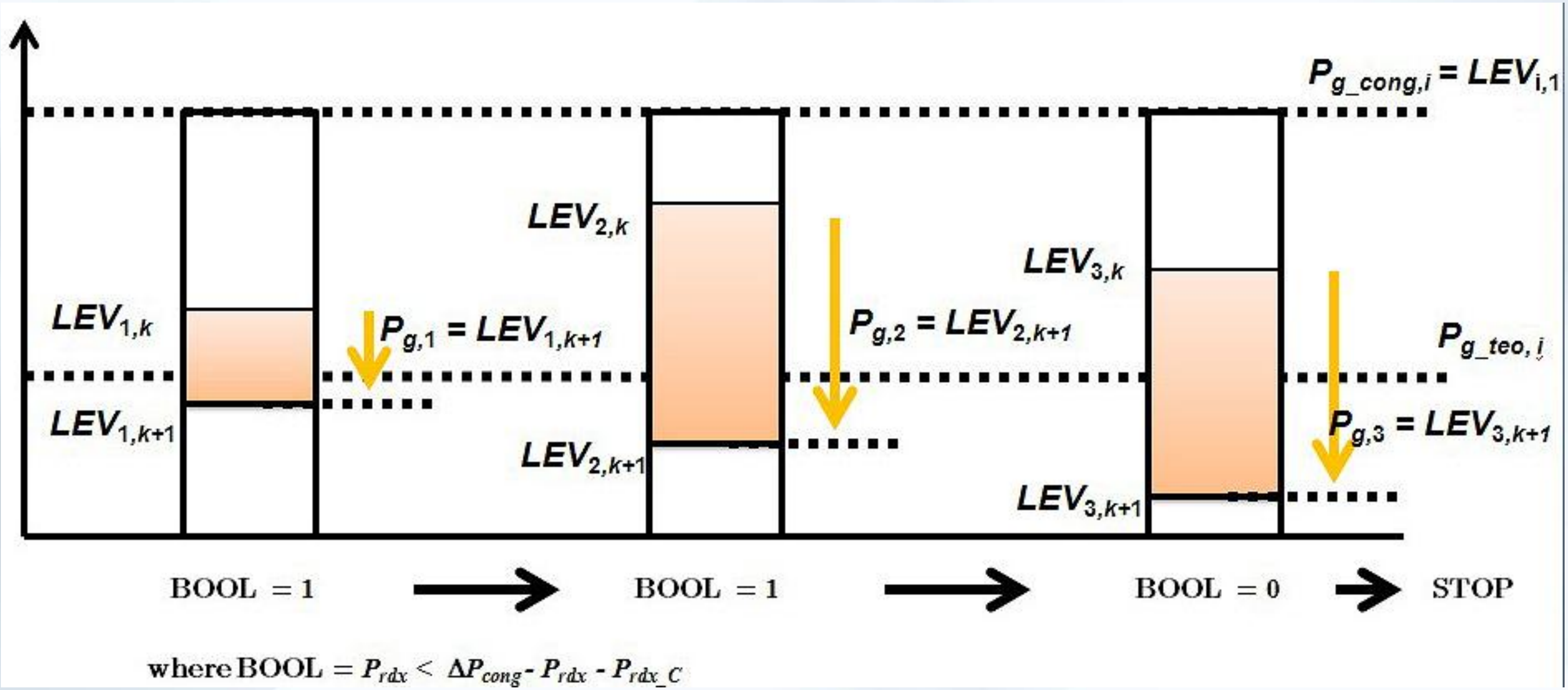
Congestion Mitigation function

- forth step: **the Master SAS will re-dispatch the real power generation such that the total reduction will be at least equal to DPcong. For this the "reduction steps" will be converted, only for computation reasons, into MW. The following procedure is applied:**

$$pg\_red = \frac{\Delta P_{cong}}{\sum_i P_{g,i}}$$

$$P_{g\_teo,i} = P_{g,i}\left(1 - pg\_red\right)$$

Congestion Mitigation function



Islanding grid function

The main idea of the research project is to give the possibility, for the sub-transmission network or a part of it, to survive to a disconnection from the bulk power system.

The goal of this function is to determine, for a given operating condition and a set of triggering events, the possibility for islanded operation.

The procedure can be mathematically expressed as a constrained integer programming problem that maximizes the load to be supplied after islanding.

Islanding grid function

Total number of SASs in the area

Total number of loads controlled by the i-th SAS

$$\max Load = \sum_{i=1}^{N_{SAS}} \sum_{j=1}^{N_{L_i}} \alpha_{ij} C_{ij}$$

model1

Binary variable (check feasibility)

Load j connected to the i-th SAS

Solving Model 1, due to the particular problem studied, multiple solutions can be found for the same load level

Islanding grid function

$$\max\left[Load + Generation\right] = \max\left(\sum_{i=1}^{N_{SAS}}\sum_{j=1}^{N_{L_i}}\alpha_{ij}C_{ij} + \sum_{i=1}^{N_{SAS}}\sum_{m=1}^{N_{E_i}}\gamma_{im}P_{im}^{E} + \sum_{i=1}^{N_{SAS}}\sum_{k=1}^{N_{D_i}}\beta_{ik}P_{ik}^{D}\right)$$

model2

$$\sum_{i=1}^{N_{SAS}}\sum_{k=1}^{N_{D_i}}\beta_{ik}D_{ik}^{+} = D_{tot}^{+} \geq \sigma\,\Delta I$$

$$\sum_{i=1}^{N_{SAS}}\sum_{k=1}^{N_{D_i}}\beta_{ik}D_{ik}^{-} = D_{tot}^{-} \leq \sigma\,\Delta I$$

$$\sum_{i=1}^{N_{SAS}}\sum_{k=1}^{N_{D_i}}\beta_{ik}D_{ik}^{+} - \sum_{i=1}^{N_{SAS}}\sum_{k=1}^{N_{D_i}}\beta_{ik}D_{ik}^{-} \geq \xi\,Load$$

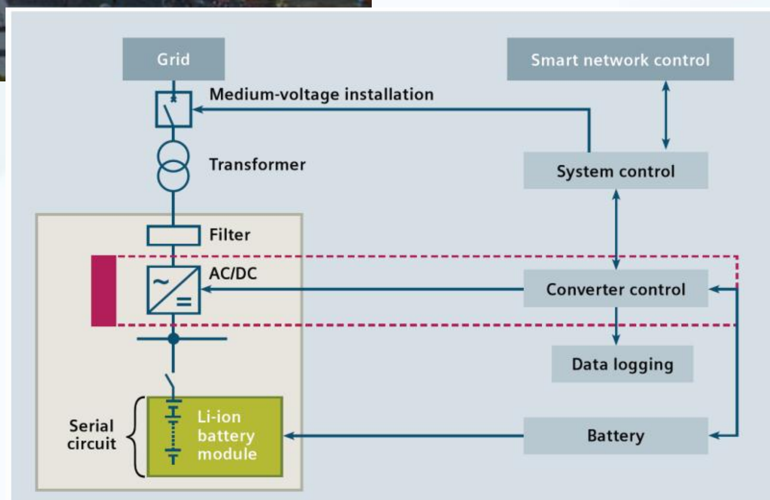
$$\Delta I = Load - Generation = \sum_{i=1}^{N_{SAS}}\sum_{j=1}^{N_{L_i}}\alpha_{ij}C_{ij} - \sum_{i=1}^{N_{SAS}}\sum_{m=1}^{N_{E_i}}\gamma_{im}P_{im}^{E} - \sum_{i=1}^{N_{SAS}}\sum_{k=1}^{N_{D_i}}\beta_{ik}P_{ik}^{D}$$

Islanding grid function

Case	ξ	σ	τ	ΔI	NCG	CG	TG	TL	f_{max}	f_{min}	f	V_{max}	V_{min}	OBNCG	OBCG	OBL
1	0,1	1,05	0,05	-18,26	44,65	59,7	104,35	86,09	51,428	49,814	50,401	1,088	0,86	3	1	0
2	0,2	1,05	0,05	-44,25	49,64	80,7	130,34	86,09	52,508	49,57	50,713	1,067	0,905	4	1	0
3	0,3	1,05	0,05	-13,21	39,6	59,7	99,3	86,09	50,98	49,93	50,323	1,112	0,81	3	1	0
4	0,4	1,05	0,05	-11,86	38,25	59,7	97,95	86,09	51,104	49,887	50,34	1,1094	0,835	4	1	0
5	0,1	1,05	0,1	-30,61	6,4	110,3	116,7	86,09	51,995	49,628	50,557	1,091	0,887	4	0	0
6	0,2	1,05	0,1	-30,61	6,4	110,3	116,7	86,09	51,995	49,628	50,556	1,091	0,887	4	0	0
7	0,3	1,05	0,1	-30,61	6,4	110,3	116,7	86,09	51,995	49,628	50,556	1,091	0,887	4	0	0
8	0,4	1,05	0,1	-30,61	6,4	110,3	116,7	86,09	51,995	49,628	50,556	1,091	0,887	4	0	0
9	0,1	1,05	0,15	-40,08	6,4	110,3	116,7	76,615	52,508	49,534	50,699	1,095	0,905	4	0	2
10	0,2	1,05	0,15	-34,14	0	110,3	110,3	76,955	52,286	49,597	50,646	1,104	0,887	5	0	5
11	0,3	1,05	0,15	-40,44	6,4	110,3	116,7	76,26	52,493	49,53	50,678	1,09	0,916	4	0	4
12	0,4	1,05	0,15	-40,26	6,4	110,3	116,7	76,44	52,523	49,53	50,706	1,09	0,894	4	0	2
13	0,1	1,15	0,05	-32,86	38,25	80,7	118,95	86,09	51,9	49,78	50,586	1,064	0,895	4	1	0
14	0,2	1,15	0,05	-20,55	56,04	50,6	106,64	86,09	51,76	49,57	50,448	1,03	0,908	3	2	0
15	0,3	1,15	0,05	-14,11	40,5	59,7	100,2	86,09	51,23	49,84	50,36	1,08	0,86	4	1	0
16	0,4	1,15	0,05	-32,86	38,25	80,7	118,95	86,09	51,9	49,79	50,586	1,06	0,894	4	1	0
17	0,1	1,15	0,1	-30,61	6,4	110,3	116,7	86,09	51,995	49,628	50,556	1,091	0,887	4	0	0
18	0,2	1,15	0,1	-30,61	6,4	110,3	116,7	86,09	51,995	49,628	50,556	1,091	0,887	4	0	0
19	0,3	1,15	0,1	-30,61	6,4	110,3	116,7	86,09	51,995	49,628	50,556	1,091	0,887	4	0	0
20	0,4	1,15	0,1	-30,61	6,4	110,3	116,7	86,09	51,995	49,628	50,556	1,091	0,887	4	0	0
21	0,1	1,15	0,15	-40,75	6,4	110,3	116,7	75,945	52,54	49,52	50,711	1,094	0,89	4	0	6
22	0,2	1,15	0,15	-40,16	6,4	110,3	116,7	76,54	52,52	49,52	50,696	1,092	0,905	4	0	3
23	0,3	1,15	0,15	-33,76	0	110,3	110,3	76,535	52,246	49,63	50,641	1,1	0,881	5	0	7
24	0,4	1,15	0,15	-33,65	0	110,3	110,3	76,65	52,23	49,63	50,636	1,094	0,89	5	0	2
25	0,1	1,25	0,05	-35,96	71,45	50,6	122,05	86,09	52	49,8	50,628	1,067	0,886	3	2	0
26	0,2	1,25	0,05	-6,81	33,2	59,7	92,9	86,09	50,98	49,95	50,238	1,14	0,773	4	1	0
27	0,3	1,25	0,05	-11,86	38,25	59,7	97,95	86,09	51,104	49,887	50,34	1,1094	0,835	4	1	0
28	0,4	1,25	0,05	-18,26	44,65	59,7	104,35	86,09	51,327	49,833	50,401	1,088	0,86	3	1	0
29	0,1	1,25	0,1	-30,61	6,4	110,3	116,7	86,09	51,995	49,628	50,556	1,091	0,887	4	0	0
30	0,2	1,25	0,1	-30,61	6,4	110,3	116,7	86,09	51,995	49,628	50,556	1,091	0,887	4	0	0
31	0,3	1,25	0,1	-30,61	6,4	110,3	116,7	86,09	51,995	49,628	50,556	1,091	0,887	4	0	0
32	0,4	1,25	0,1	-30,61	6,4	110,3	116,7	86,09	51,995	49,628	50,556	1,091	0,887	4	0	0
33	0,1	1,25	0,15	-40,12	6,4	110,3	116,7	76,575	52,538	49,523	50,705	1,096	0,895	4	0	6
34	0,2	1,25	0,15	-34,35	0	110,3	110,3	75,945	52,307	49,583	50,65	1,105	0,885	5	0	6
35	0,3	1,25	0,15	-40,4	6,4	110,3	116,7	76,295	52,526	49,5	50,705	1,094	0,895	4	0	7
36	0,4	1,25	0,15	-33,76	0	110,3	110,3	76,535	52,276	49,613	50,641	1,104	0,88	5	0	7

Future development

… in a nutshell: storage apparatus network integration …



Thanks for your attention