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RED ELÉCTRICA DE ESPAÑA

aDin

Simplified frequency stability tool for isolated systems

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aDin

What is it?

- "aDin" is a tool to perform fast dynamic simulations in the **frequency stability** scope in isolated and small systems.
- Developed as an **Excel function** and macro (Visual Basic) → no dedicated, technical and specialized software simulation is needed.
- It allows to obtain a huge number of results for **thousand of scenarios in a short time** (up to 250 simulations per minute).

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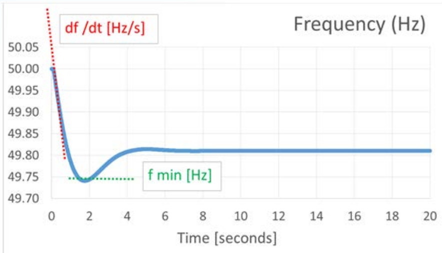
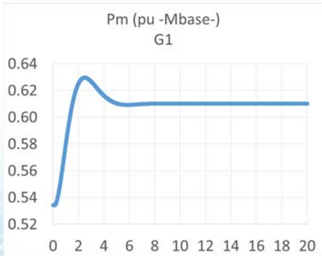
What results are obtained?

- Admissibility of the scenarios from the point of view of the **frequency stability** in the event of generation-demand unbalances.
- **Contingencies:**
  - o Generation and pump tripping (instantly or as a ramp)
  - o Demand variations
- **Results:**
  - o Maximum and minimum frequency
  - o Derivative of the frequency (RoCoF)
  - o Admissibility criteria fulfilment
  - o Graphics





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What are the input data?

- Generation dispatch (unit commitment)
- Generators structural data
  - o Max/min active power
  - o Synchronous: inertia, governors parameters (droop, time constant, dead band)
  - o Power electronics: synthetic inertia and primary regulation (optional)
  - o Frequency protections
- Load-shedding relays
- Batteries, ultracapacitors and synchronous compensators can be modeled
- User models

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Simplifying assumptions

- Reduction of the system to a **single node**

  In isolated and small systems active power losses and the disturbances propagation delays can be neglected.

- **First order** primary regulators
- Constant voltage modules

  The dynamics associated to the voltage modules are neglected

- Not valid for short-circuit simulations

  Although the tripping of generator without FRTC can be simulated

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Theoretical formulation

Equivalent synchronous generator

$$2H_{eq}\frac{dn}{dt} = P_m - P_e \qquad (1)$$

$$H_{eq} = \frac{\sum_i H_i S_i}{\sum_i S_i} \qquad (2)$$

H_{eq} : equivalent inertia constant [s]

n : frequency deviation [p.u.]

P_m : mechanical power [p.u.]

P_e: electrical power [p.u.]

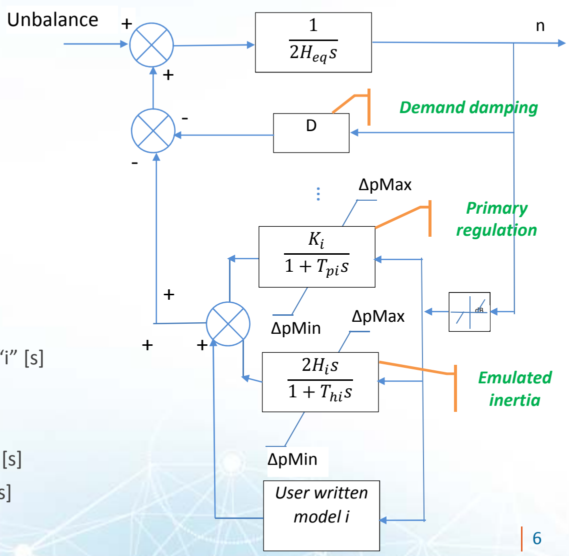
H_i : inertia constant of the generator "i" [s]

S_i : apparent power [MVA]

K_i : primary regulation gain [p.u.]

T_{pi} : primary regulation time constant [s]

T_{hi} : inertia emulation time constant [s]



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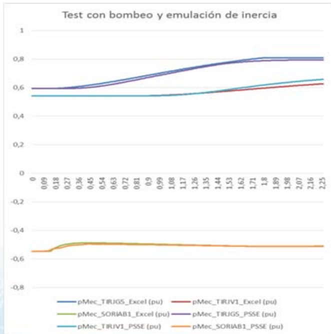
Validation "aDin" vs. "PSS/E"

- **Comparison between aDin simulation vs PSS/E simulation:**
  - Generation disconnection of 70 MW in a scenario of 560 MW of demand.
  - Several types of coupled technologies including 3 groups pumping through converters with inertia emulation enabled.

	"aDin"	PSS/E
Min. Freq.	49.17 Hz	49.20 Hz
Min. Freq. time	2.26 s	2.20 s



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Applications

- The most relevant applications are:
  - A simple Dynamic Stability Assessment (DSA) by the control center in real time constrained to the frequency stability scope.
  - As an analyzer of the unit commitment outputs in order to validate them in the frequency stability scope.
  - As a system planning tool: massive analysis of planning scenarios.
  - Synchronous must-run identification.
  - Disturbance analysis with large frequency excursion and load shedding.

"aDin" has been already used in these studies:

- Determination of stability requirements at Gran Canaria system in future scenarios with pumped hydro storage
- Analysis of minimum inertial requirements in El Hierro system

aDin – PRACTICAL EXAMPLE

1) Generation dispatch

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1		Simular	Group_E2	1			Group_D1	2			Group_D2	3			Group_D3	4			Group_TG1	5			Group_TG2	6
2	Dynamic Admissibility [Hz] or [Hz/s]	Contingency "id" for additional unbalance	N	I	P	C	N	I	P	C	N	I	P	C	N	I	P	C	N	I	P	C	N	I
3		0	Group_E2	1	10	1	Group_D1	2	13	0	Group_D2	3	13	0	Group_D3	4	13	0	Group_TG1	0	0	0	Group_TG2	0
4		0	Group_E2	1	20	1	Group_D1	2	13	1	Group_D2	3	13	0	Group_D3	4	13	0	Group_TG1	0	0	0	Group_TG2	0
5		0	Group_E2	1	30	1	Group_D1	2	13	0	Group_D2	3	13	0	Group_D3	4	13	0	Group_TG1	0	0	0	Group_TG2	0
6		0	Group_E2	1	40	1	Group_D1	2	13	0	Group_D2	3	13	0	Group_D3	4	13	0	Group_TG1	0	0	0	Group_TG2	0
7		0	Group_E2	1	50	1	Group_D1	2	13	0	Group_D2	3	13	0	Group_D3	4	12	0	Group_TG1	0	0	0	Group_TG2	0
8		0	Group_E2	1	50	6	Group_D1	2	13	0	Group_D2	3	13	0	Group_D3	4	12	0	Group_TG1	0	0	0	Group_TG2	0
9		0	Group_E2	1	60	1	Group_D1	2	12	0	Group_D2	3	12	0	Group_D3	4	12	0	Group_TG1	5	7	0	Group_TG2	0
10		0	Group_E2	1	70	1	Group_D1	2	9	0	Group_D2	3	9	0	Group_D3	4	8	0	Group_TG1	5	7	0	Group_TG2	0
11		0	Group_E2	1	80	1	Group_D1	2	7	0	Group_D2	3	7	0	Group_D3	4	7	0	Group_TG1	5	7	0	Group_TG2	0
12		0	Group_E2	1	90	1	Group_D1	2	7	0	Group_D2	3	7	0	Group_D3	4	7	0	Group_TG1	5	7	0	Group_TG2	0
13		9	Group_E2	1	10	0	Group_D1	2	13	0	Group_D2	3	13	0	Group_D3	4	13	0	Group_TG1	5	25	0	Group_TG2	0
14		0	Group_E2	1	20	1	Group_D1	2	13	0	Group_D2	3	13	0	Group_D3	4	13	0	Group_TG1	5	20	0	Group_TG2	0
15		0	Group_E2	1	30	1	Group_D1	2	13	0	Group_D2	3	13	0	Group_D3	4	13	0	Group_TG1	5	10	0	Group_TG2	0
16		0	Group_E2	1	40	1	Group_D1	2	11	0	Group_D2	3	11	0	Group_D3	4	11	0	Group_TG1	5	7	0	Group_TG2	0

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2) Contingencies

	A	B	C	D	E
1	Id	Contingency type	Value	Instant of ocurrence [s]	Ramp duration [s]
2	**1**	**Instant tripping**	**-1**	**0.1**	**0**
3	2	Instant increment: 100%	1	0.1	0
4	3	Instant decrement: 15%	-0.15	0.1	0
5	4	Instant increment: 15%	0.15	0.1	0
6	5	Ramp. Decrement. 40% in 3 seconds	-0.4	0.1	3
7	**6**	**Ramp. Decrement. 50% in 3 seconds**	**-0.5**	**0.1**	**3**
8	7	Instant generation-demand unbalance	20	1.0	0
9	8	Instant generation-demand unbalance	30	0.1	0
10	**9**	**Instant generation-demand unbalance**	**40**	**0.1**	**0**
11	10	Ramp of generation-demand unbalance	-0.2	0.1	2
12	11	Ramp of generation-demand unbalance	0.15	0.1	2
13	12	...			

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3) Generators structural data

Id	Name	Mode	FRTC (1: yes, 0: no)	Pnom [MW]	Mbase [MVA]	PmaxT [MW]	PminT [MW]	PmaxB [MW]	PminB [MW]	Upwards reserve capability (1: yes, 0: no)	dB+ [p.u]	dB- [p.u]	H [s]	Power capacity for synthetic inertia [p.u.]	Kp [p.u.]	Tp [s]	Inst min freq protection [Hz]	Temp min freq protection [Hz]	Temp min freq protection [s]	Inst max freq protection [Hz]	Te[illegible] max prote[illegible] [H[illegible]
1	Group_ENL_2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2	Group_D1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
3	Group_D2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
4	Group_D3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5	Group_TG1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6	Group_TG2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7	Group_TG3_a_b	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8	Group_TG3_b	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9	Group_TG4_a_b	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10	Group_TG4_b	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11	Group_TG5_a_b	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
12	Group_TG5_b	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
13	EOL_S	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	FTV_N	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
15	FTV_O	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

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4) Simulation parameters

	A	B
1	Damping demand coefficient (pu system demand)	1
2	**Minimum frequency (pu 50 Hz)**	**47.5**
3	Maximum frequency (pu 50 Hz)	52
4	**Minimum frequency derivative (Hz/s)**	**-2**
5	Maximum frequency derivative (Hz/s)	4
6	Integration step (s) (less than 1/4 the smaller constant time)	0.01
7	Level of information to generate (only from macro)	3
8	Stop with the first change of sign of df/dt	0
9	Apply load shedding	1
10	Apply generators relays performance	1
11	Maximum simulation time (s)	30
12	Time constant of the filter of the synthetic inertia (s)	0.1
13	Breakers opening time (s)	0.05
14		
15		

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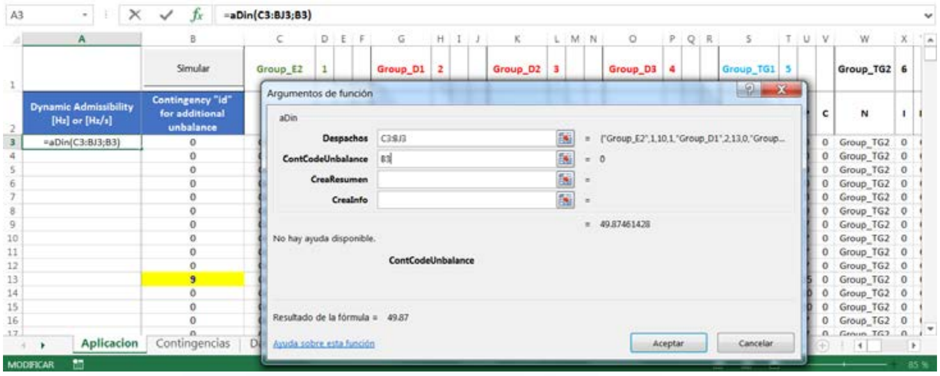
5.a) Results. Excel function



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5.b) Results. Thousands of scenarios in minutes

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1		Simular	Group_E2	1			Group_D1	2			Group_D2	3			Group_D3	4			Group_TG1	5			Group_TG2	6
2	Dynamic Admissibility [Hz] or [Hz/s]	Contingency "id" for additional unbalance	N	I	P	C	N	I	P	C	N	I	P	C	N	I	P	C	N	I	P	C	N	I
3	49.87	0	Group_E2	1	10	1	Group_D1	2	13	0	Group_D2	3	13	0	Group_D3	4	13	0	Group_TG1	0	0	0	Group_TG2	0
4	49.57	0	Group_E2	1	20	1	Group_D1	2	13	1	Group_D2	3	13	0	Group_D3	4	13	0	Group_TG1	0	0	0	Group_TG2	0
5	49.49	0	Group_E2	1	30	1	Group_D1	2	13	0	Group_D2	3	13	0	Group_D3	4	13	0	Group_TG1	0	0	0	Group_TG2	0
6	49.31	0	Group_E2	1	40	1	Group_D1	2	13	0	Group_D2	3	13	0	Group_D3	4	13	0	Group_TG1	0	0	0	Group_TG2	0
7	-2.82	0	Group_E2	1	50	1	Group_D1	2	13	0	Group_D2	3	13	0	Group_D3	4	12	0	Group_TG1	0	0	0	Group_TG2	0
8	49.47	0	Group_E2	1	50	6	Group_D1	2	13	0	Group_D2	3	13	0	Group_D3	4	12	0	Group_TG1	0	0	0	Group_TG2	0
9	48.94	0	Group_E2	1	60	1	Group_D1	2	12	0	Group_D2	3	12	0	Group_D3	4	12	0	Group_TG1	5	7	0	Group_TG2	0
10	48.81	0	Group_E2	1	70	1	Group_D1	2	9	0	Group_D2	3	9	0	Group_D3	4	8	0	Group_TG1	5	7	0	Group_TG2	0
11	48.70	0	Group_E2	1	80	1	Group_D1	2	7	0	Group_D2	3	7	0	Group_D3	4	7	0	Group_TG1	5	7	0	Group_TG2	0
12	-2.12	0	Group_E2	1	90	1	Group_D1	2	7	0	Group_D2	3	7	0	Group_D3	4	7	0	Group_TG1	5	7	0	Group_TG2	0
13	50.82	9	Group_E2	1	10	0	Group_D1	2	13	0	Group_D2	3	13	0	Group_D3	4	13	0	Group_TG1	5	25	0	Group_TG2	0
14	49.48	0	Group_E2	1	20	1	Group_D1	2	13	0	Group_D2	3	13	0	Group_D3	4	13	0	Group_TG1	5	20	0	Group_TG2	0
15	49.22	0	Group_E2	1	30	1	Group_D1	2	13	0	Group_D2	3	13	0	Group_D3	4	13	0	Group_TG1	5	10	0	Group_TG2	0
16	48.97	0	Group_E2	1	40	1	Group_D1	2	11	0	Group_D2	3	11	0	Group_D3	4	11	0	Group_TG1	5	7	0	Group_TG2	0

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5.c) Results. Detailed output

Scenario	Demanda [MW]	Synchronous base [MVA]	Inertia [s]	Ec [MJ]	Unbalance [MW]	Unbalance / Synchronous base [%]	min freq [Hz]	t min freq [s]	max freq [Hz]	t max freq [s]	max negative df/dt [Hz/s]	t max negative df/dt [s]	max positive df/dt [Hz/s]	t max positive df/dt [s]
3	133	405.1	3.46	1400.26	-10.00	-2.47	49.87	0.95	50.00	0.00	-0.27	0.11	0.05	1.42
4	133	405.1	3.46	1400.26	-33.00	-8.15	49.57	0.91	50.00	0.00	-0.96	0.11	0.15	1.38
5	133	340.3	2.97	1011.46	-30.00	-8.82	49.49	0.76	50.00	0.00	-1.39	0.11	0.29	1.17
6	133	340.3	2.97	1011.46	-40.00	-11.76	49.31	0.76	50.00	0.00	-1.85	0.11	0.34	1.22
7	138	340.3	2.97	1011.46	-50.00	-14.69	49.98	0.11	50.00	0.00	-2.32	0.11	0.00	0.00
8	138	340.3	2.97	1011.46	-50.00	-14.69	49.47	3.51	50.00	0.00	-0.22	1.12	0.07	4.15
9	133	370.7	4.13	1532.07	-51.16	-13.80	48.94	1.56	50.00	0.00	-1.41	0.11	0.17	2.75
10	133	370.7	4.13	1532.07	-52.74	-14.22	48.81	1.35	50.00	0.00	-1.65	0.11	0.19	2.66
11	138	370.7	4.13	1532.07	-53.87	-14.53	48.70	1.25	50.00	0.00	-1.89	0.11	0.22	2.56
12	138	370.7	4.13	1532.07	-90.00	-24.28	49.98	0.11	50.00	0.00	-2.12	0.11	0.00	0.00
13	100	289.6	4.46	1292.74	40.00	13.81	50.00	0.00	50.82	2.11	-0.11	3.28	0.77	0.11
14	100	289.6	4.46	1292.74	-20.00	-6.91	49.48	1.75	50.00	0.00	-0.61	0.11	0.08	2.44
15	100	289.6	4.46	1292.74	-30.00	-10.36	49.22	1.76	50.00	0.00	-0.91	0.11	0.10	2.52
16	100	289.6	4.46	1292.74	-33.36	-11.52	48.97	1.64	50.00	0.00	-1.22	0.11	0.25	2.41
17	100	289.6	4.46	1292.74	-37.02	-12.78	48.80	1.30	50.00	0.00	-1.52	0.11	0.25	2.43
18	101	269.6	4.52	1219.74	-60.00	-22.26	49.98	0.11	50.00	0.00	-2.01	0.11	0.00	0.00

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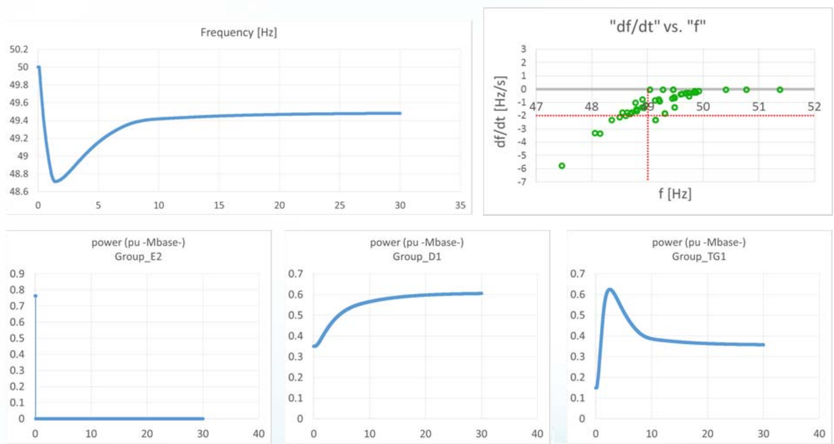
5.d) Results. Graphical output



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