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AGC Modifications for Coal Plant Performance Improvement

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Global Power Grids Energy Mix - Summary Comparison

Share of electricity production by source (2022)					Source: ourworldindata.org/energy				
	(TWh)		(Slow Support)	(Fast Support)		(Fixed)	(Varying)		Frequency Control
Power Grid	Energy Demand (2022)	% of India	Coal %	Gas %	Hydro %	Nuclear %	Solar %	Wind %	with RE Penetration
India	1837.95	100.0	74.16	2.71	9.5	2.52	5.18	3.81	Highly Challenging (Coal)
China	8839.13	480.9	61.33	3.13	14.91	4.72	4.76	9.06	Challenging (Coal)
USA	4296.88	233.8	19.29	39.32	5.96	17.96	4.75	10.12	Very Comfortable (Gas)
EU(27)	2812	153.0	16.4	19.78	9.85	21.64	7.37	14.95	Comfortable (Gas)
Russia	1114.93	60.7	17.64	42.96	17.54	20.31	0.24	0.5	Very Comfortable (Gas)
Japan	966.72	52.6	32.93	34.17	7.63	5.36	10.21	0.95	Comfortable (Gas)
Brazil	680.88	37.0	2.3	7.18	62.87	2.14	3.89	11.75	Very Comfortable (Hydro)
Canada	638.42	34.7	6.38	10.51	61.48	12.89	0.87	5.97	Very Comfortable (Hydro)
South Korea	606.51	33.0	33.93	28.09	0.59	27.8	4.8	0.56	Comfortable (Gas)
UK (GBR)	324.89	17.7	1.61	39.26	1.76	14.82	4.28	24.62	Comfortable (Gas)
Australia	251.68	13.7	47.25	18.73	6.19	0	13.31	11.59	Comfortable (Gas)

Indian grid energy mix is unique, and highly challenging from frequency control perspective.

Global Power Grids Frequency Stats - Summary Comparison

Summary of grid frequency statistics Power Grid	Avg.Freq Hz	Max.Freq Hz	Min.Freq Hz	FVI Hz	Std.Dev Hz	49.97-50.03 %	49.95-50.05 %	49.90-50.05 %	*GFPi* %	*AGCi* %
EU(27) : 9 months, 1s	50.0001	50.18	49.758	0.0055	0.0234	83.02	96.38	98.18	287.57	150.32
Australia Mainland : 6 months, 4s	50	50.201	49.771	0.0064	0.0252	76.94	97.47	99.29	243.64	30.67
UK (GBR) : 9 months, 1s	50	50.26	49.631	0.0471	0.0686	27.79	49.1	67.73	24.01	-32.9
India (Jan23-Jun23) : 6 months, 1s	49.998	50.492	49.415	0.0696	0.0834	31.76	51.18	66.34	20.76	2.36
India (Jul23-Oct23) : 4 months, 1s	49.974	50.399	49.44	0.0518	0.067	44.27	63.97	82.33	37.28	34.99

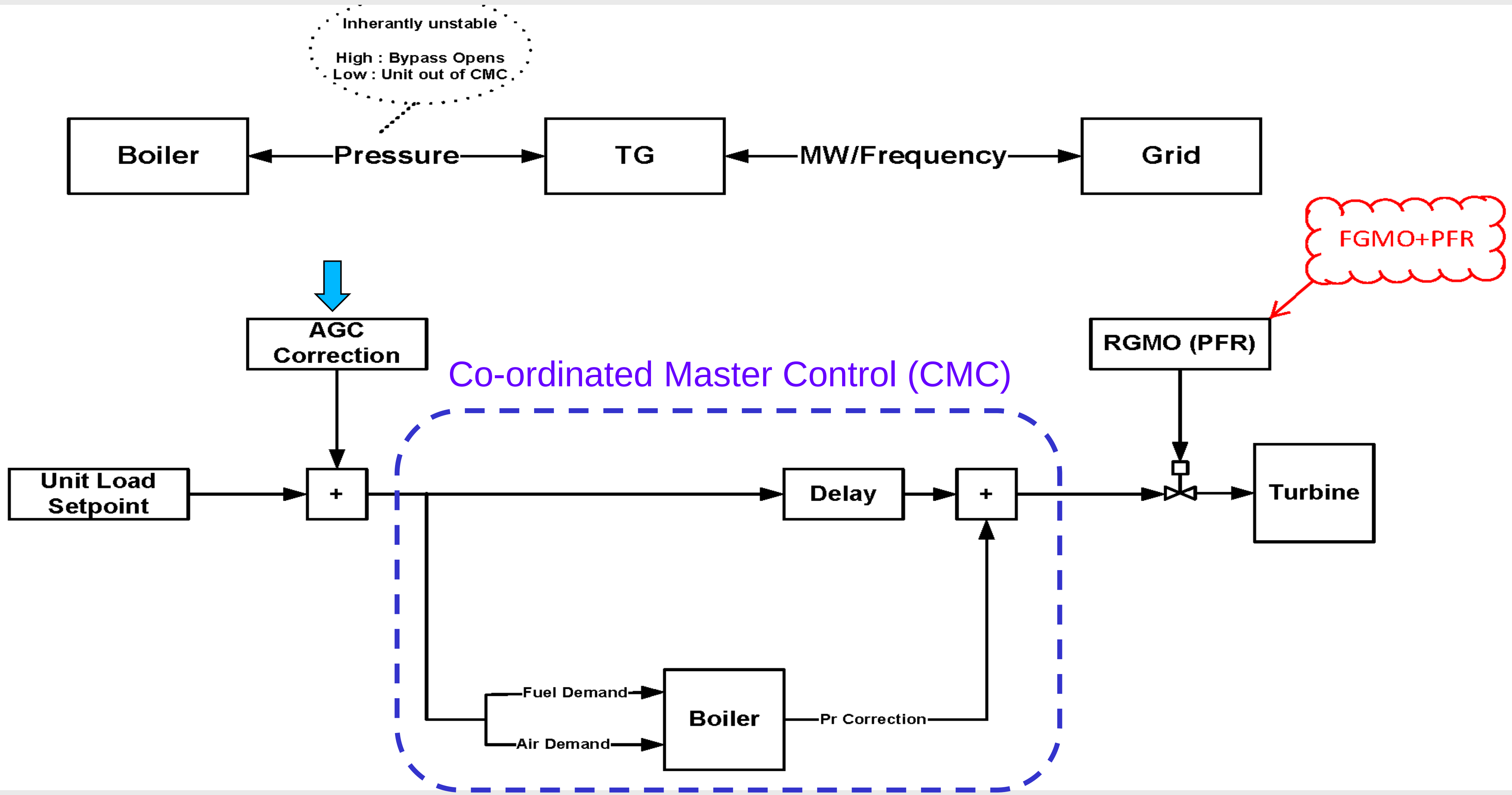
* Grid Frequency Performance Index GFPi
= (0.1(49.97-50.03 %)/(FVI + Std.Dev)*
Higher the better from pure statistics point of view.

** AGC Index AGCi
= (100(DayCount>50.00 + DayCount<50.00)/(DayCount>50.03 + DayCount< 49.97)) – 100*
Higher the better from cyclic variation point of view

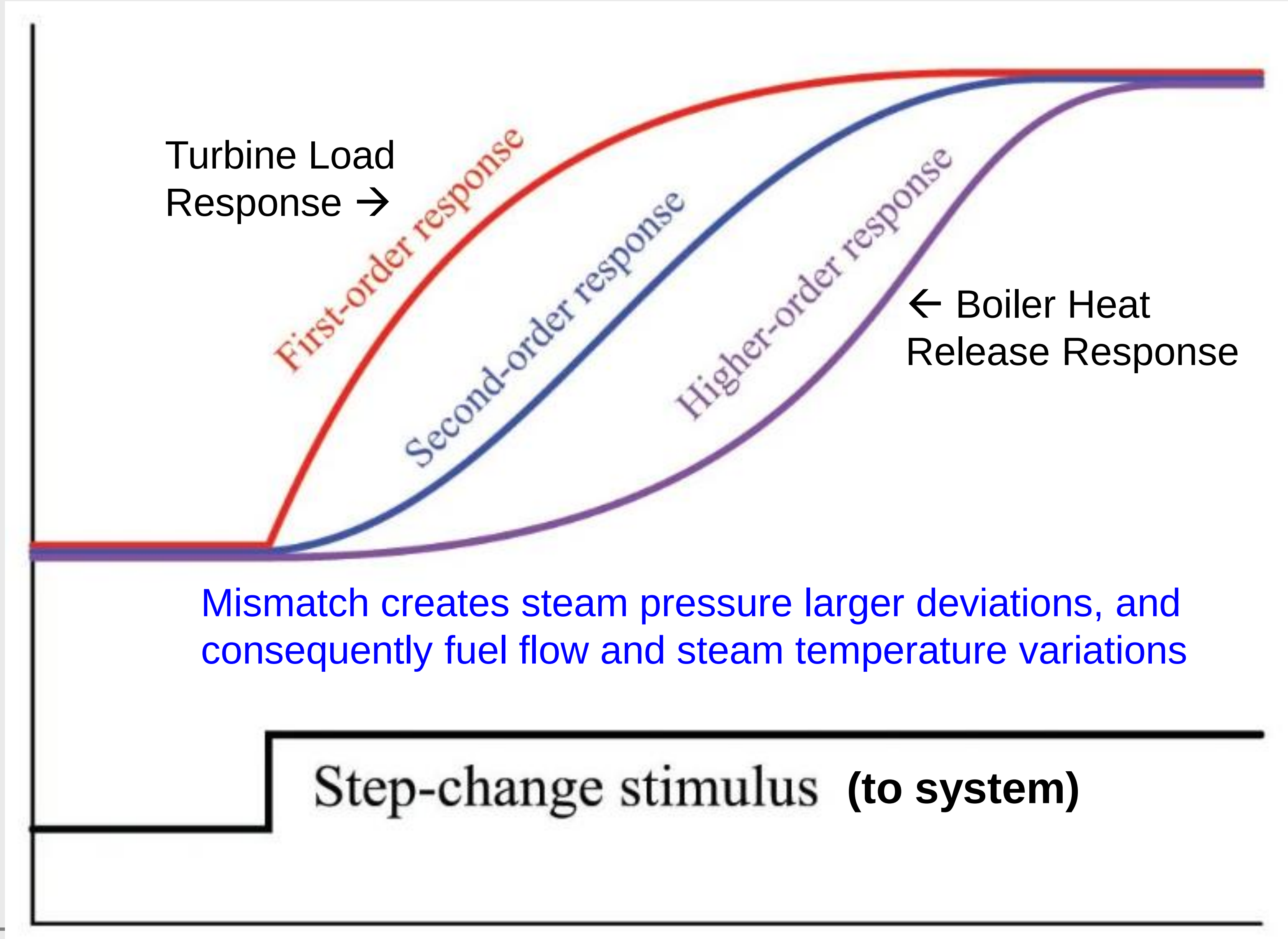
Due to unique energy mix, Frequency stats cannot be benchmarked with best performing grids.

Moreover, solutions from other grids need careful customization.

Automatic Generation Control (AGC) : Coal Thermal unit scheme



CMC of Coal Thermal Unit : Process Characterization



Typical initial delay (dead-time) :
1 to 1.5 minutes

Typical interim delay (response time) :
5 to 7 minutes

Model approximation :

Second Order Plus Time Delay (**SOPDT**)

CMC of Coal Thermal Unit : Integrating Process

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Any mismatch between boiler heat release (energy output of fuel input to boiler) and turbine energy demand (governor modulation) will result in a ramping deviation of throttle pressure, ***deteriorating over time.***

Conclusion

Although most pressure control loops contain self-regulating processes, throttle pressure is an exception being an integrating process when the unit runs in boiler-following mode. This requires special tuning considerations to ensure throttle pressure and fuel flow remain stable. Incorrect tuning of the throttle pressure controller can cause oscillations in all critical control loops around the boiler.

*Source: https://www.opticontrols.com/files/documents/throttle_pressure.pdf

Issue No.1 : Parametric Variation due to AGC Micro-Cycling

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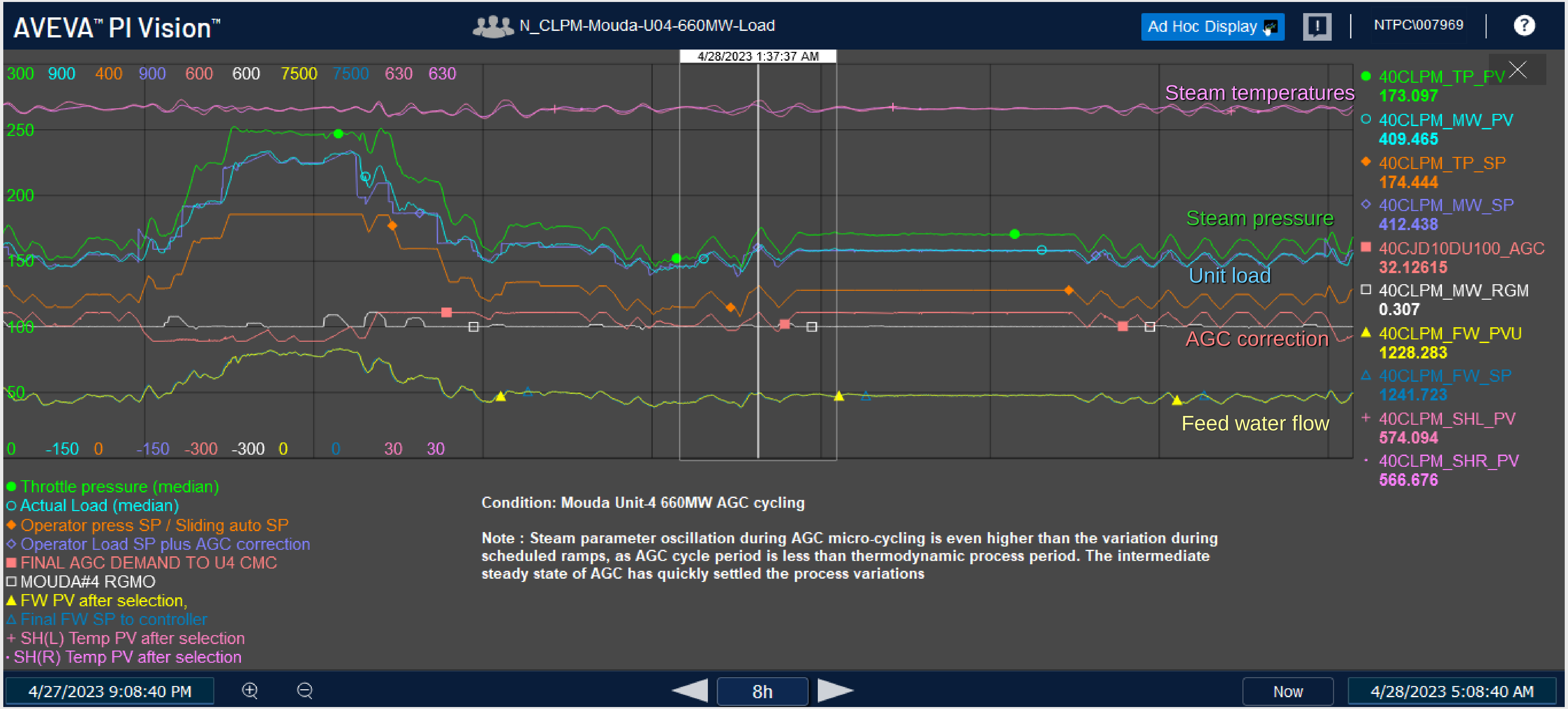


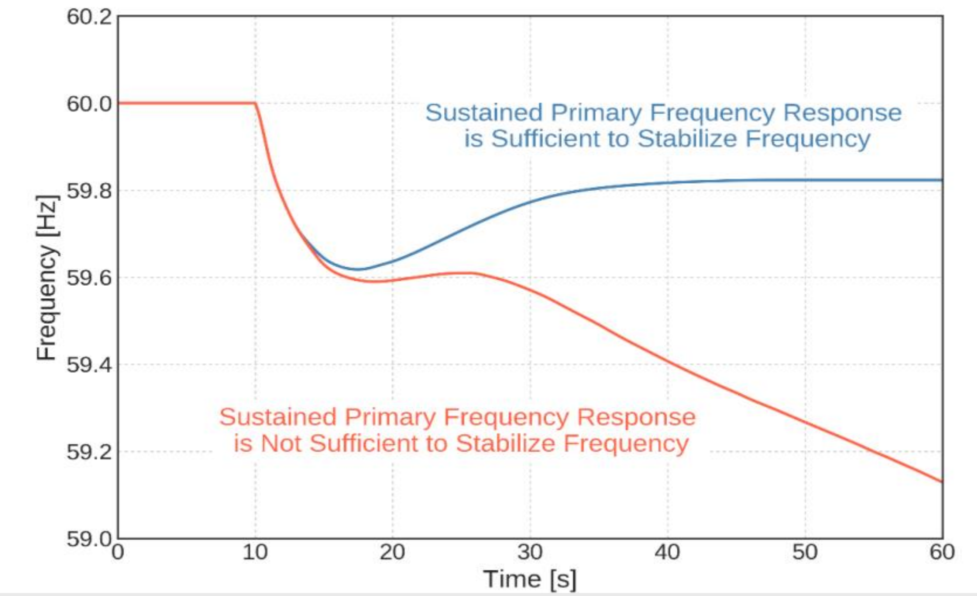
Solution : Joint AGC retuning exercise

Grid Frequency Control : Also Integrating Process

Integrating processes ***inherently drift away*** from desired operating point if left in open loop over time, or alternately if the actual response from controlled element is saturated or gets inhibited by any restriction.

Allocation and Distribution of Frequency Responsive Reserve for Sustained Primary Frequency Response

The sudden loss of a generating resource will cause frequency to decline. Loss of generation events are fairly common. For this reason, each Interconnection should be designed and operated to withstand the sudden loss of a certain amount of generation without jeopardizing reliability. BAs are required to meet a frequency response obligation for their areas. Providing frequency response in such events is accomplished by maintaining frequency responsive reserve (FRR) capacity that is adequate to arrest and stabilize the decline in frequency and to reserve additional headroom that is adequate to restore frequency to its scheduled value. In a scenario where the reserved capacity of generation providing frequency response and secondary response is lower than the loss of generation, frequency would continue to decline and could potentially lead to the loss of load through the triggering of UFLS. The aggregate performance of the units supplying the reserve capacities can vary based on the number of generators and the generation mix of the fleet. Overall, the expectation is that the reserved capacity exceeds its largest expected generation loss with margin in order to account for uncertainty in the actual performance of the fleet. The NERC OC-approved operating reserve management guideline[4] provides additional details on the recommended methods to determine FRR needs.



*Source: https://www.nerc.com/comm/OC/RS_GOP_Survey_DL/PFC_Reliability_Guideline_rev20190501_v2_final.pdf

Issue No.2 : AGC Correction Opposing SG ramp (at FL or TML)

Reason : Constrained margins getting released when RULSP moved away from the telemetered plant maximum/minimum limits

Solution : Restrict AGC rate to 0.5% per min in the opposite direction to SG ramp

Implementation (DCS of individual coal thermal unit):

a) If ULSP>(RULSP+0.5) and RULSP<95%, AGC down rate = 0.5% per min.
Else AGC down rate = declared rate (1.5 or 2% per min)

b) If ULSP<(RULSP-0.5) and RULSP>60%, AGC up rate = 0.5% per min.
Else AGC up rate = declared rate (1.5 or 2% per min)

Progress : Discussed with NLDC for clearance, implemented in 30 units with higher AGC rate. Will be done in more units during opportunity

Down Ramp Illustration : Schedule Ramp with 1% Block Average

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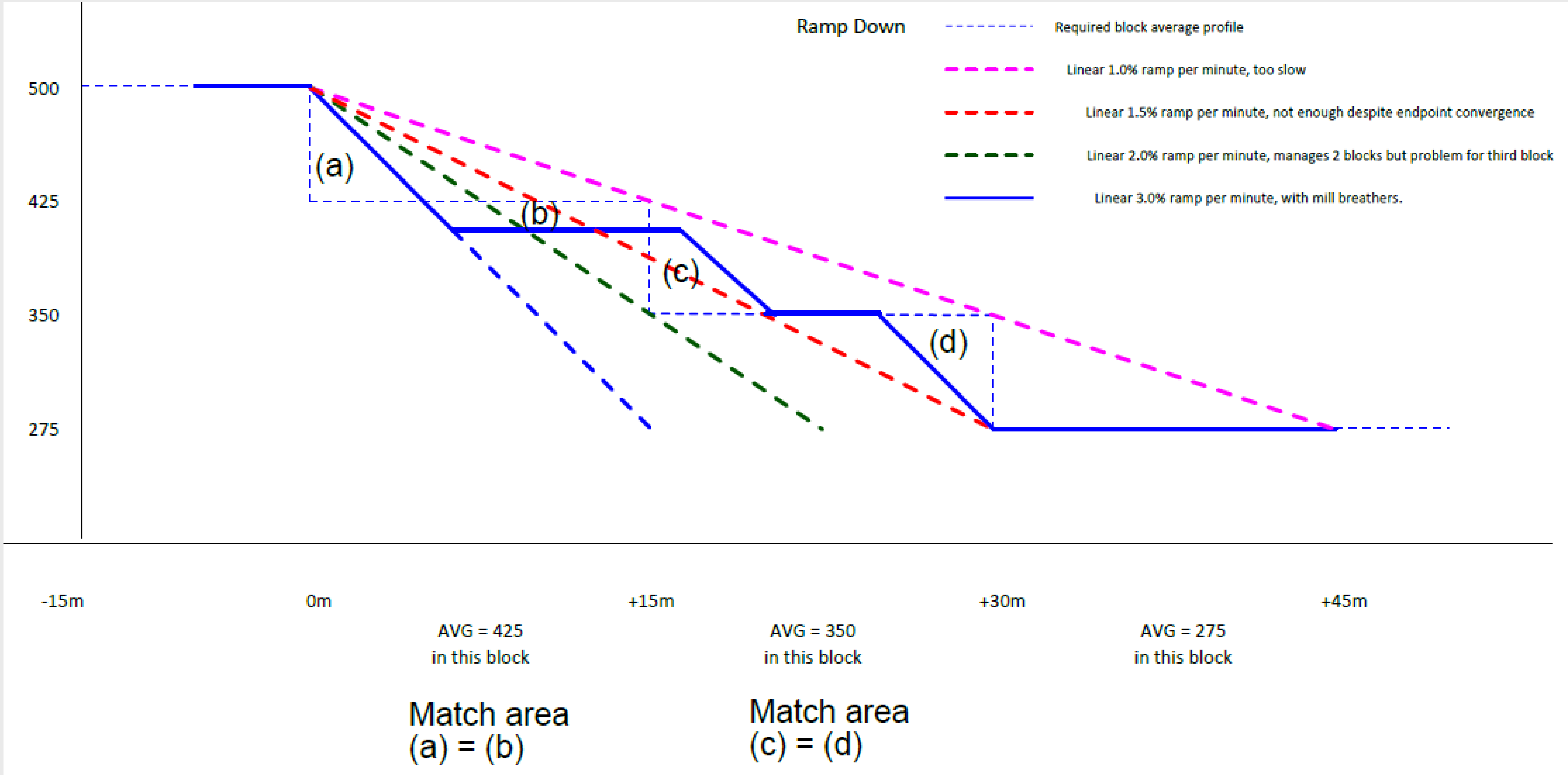
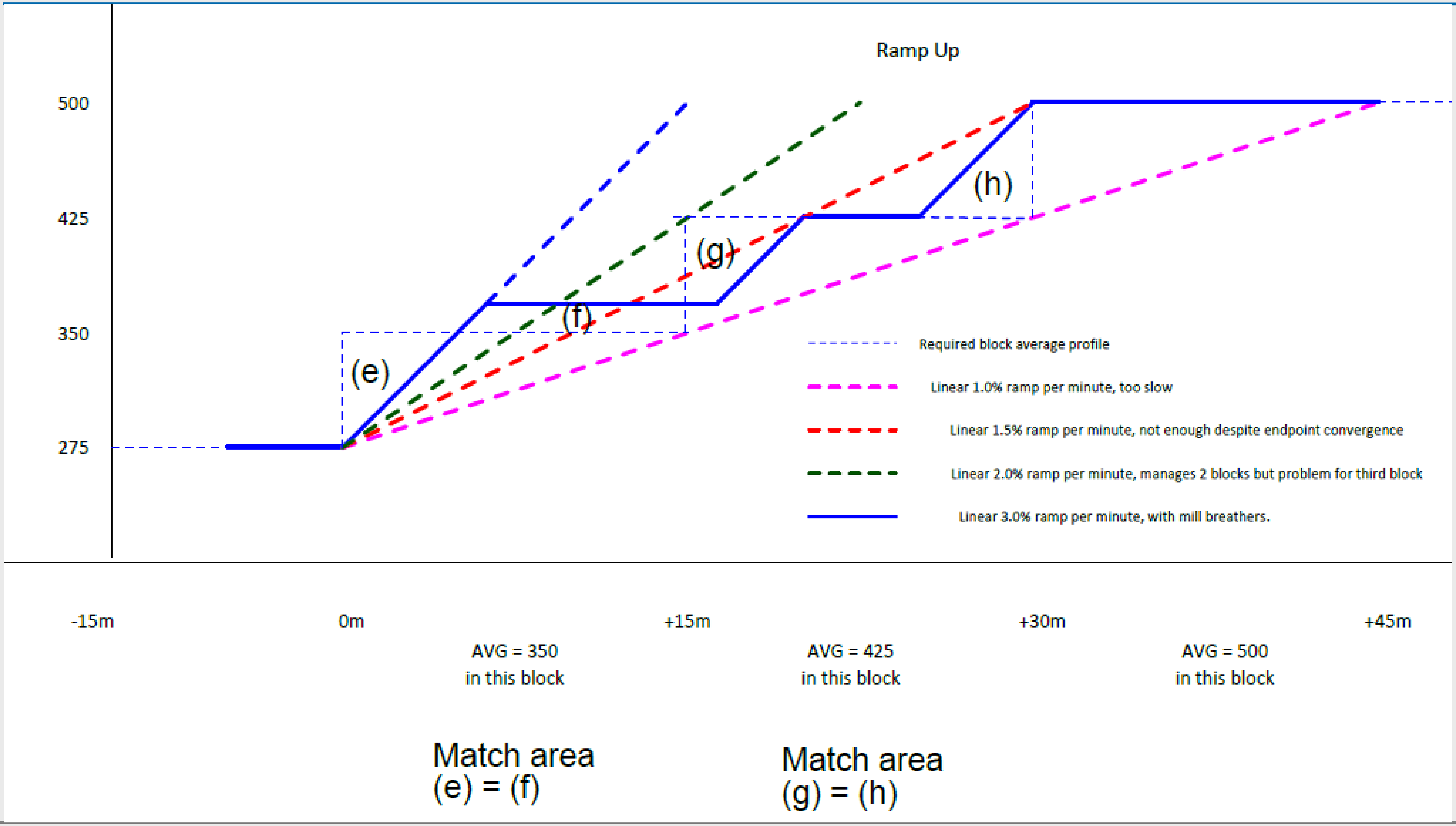


Up Ramp Illustration : Schedule Ramp with 1% Block Average



3%/min actual Load slope is Practically Required for Fully complying with 1% block Average criterion

Assumptions for illustration:

1) Freq = 50 Hz
i.e. no DSM. SG to be followed

2) Load change linear profile

AGC Retuning exercise : Key Objectives

Better grid frequency control : Evaluated through statistical parameters of grid frequency data as per NLDC website daily reports, as well as NTPC internal PI data analysis

Reduced parametric cycling : Evaluated through AGC demand movement patterns, correlated with SD data

AGC Retuning exercise Chronological Progress:

07.07.2023 : AGC controller integration time increased at NLDC end. Gain increased by 10%

10.07.2023 : 20 units of NTPC enabled for higher AGC participation ramp rate

02.08.2023 : AGC controller integration time further increased at NLDC end

10.08.2023 : Further 12 units of NTPC enabled for higher AGC participation ramp rate, total 32

11.08.2023 : Further 8 units of NTPC enabled for higher AGC participation ramp rate, total 40

18.08.2023 : AGC controller integration time further increased at NLDC end

29.08.2023 : AGC controller integration time further increased at NLDC end

11.10.2023 : AGC controller integration time further increased at NLDC end

09.11.2023 : AGC controller integration time further increased at NLDC end

22.11.2023 : Further 20 units of NTPC enabled for higher AGC participation ramp rate, total 60

AGC Incremental Response : Impact to Grid

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Note:

AGC Rate as added to CMC increased from 1 → 1.5% in Supercritical, 1 → 2% in sub-critical

Deviations from given normative calculation:

1) Units off bar

2) Units at FL have no +ve AGC margin

3) Units at TML have No AGC –ve margin

4) AGC performance as per SRAS evaluation

Expected actual rate-extra

= 271.7 * 0.75 * 0.5 * 0.75

~ 76 MW/min

Sl no	Commercial Stage	No.of Units	AGC Rate MW/min	Station Load	AGC quantum (MW)	AGC rate new	AGC rate prev	Rate-extra (MW/min)
1	Comm.Stg-01	3	2%	1500	75	30	15	15
2	Comm.Stg-02	2	2%	1000	50	20	10	10
3	Comm.Stg-03	1	2%	500	25	10	5	5
4	Comm.Stg-04	2	2%	1000	50	20	10	10
5	Comm.Stg-05	3	2%	1500	75	30	15	15
6	Comm.Stg-06	3	1.50%	2400	120	36	24	12
7	Comm.Stg-07	2	1.50%	1320	66	19.8	13.2	6.6
8	Comm.Stg-08	2	1.50%	1320	66	19.8	13.2	6.6
9	Comm.Stg-09	2	1.50%	1600	80	24	16	8
10	Comm.Stg-10	2	2%	1000	50	20	10	10
11	Comm.Stg-11	2	2%	1000	50	20	10	10
12	Comm.Stg-12	2	2%	1000	50	20	10	10
13	Comm.Stg-13	3	2%	1500	75	30	15	15
14	Comm.Stg-14	2	2%	1000	50	20	10	10
15	Comm.Stg-15	2	1.50%	1600	80	24	16	8
16	Comm.Stg-16	3	1.50%	1980	99	29.7	19.8	9.9
17	Comm.Stg-17	3	2%	1500	75	30	15	15
18	Comm.Stg-18	1	2%	500	25	10	5	5
19	Comm.Stg-19	2	2%	1000	50	20	10	10
20	Comm.Stg-20	2	2%	1000	50	20	10	10
21	Comm.Stg-21	1	2%	500	25	10	5	5
22	Comm.Stg-22	1	2%	500	25	10	5	5
23	Comm.Stg-23	2	2%	1000	50	20	10	10
24	Comm.Stg-24	2	1.50%	1000	50	15	10	5
25	Comm.Stg-25	2	2%	1000	50	20	10	10
26	Comm.Stg-26	1	2%	500	25	10	5	5
27	Comm.Stg-27	1	1.50%	800	40	12	8	4
28	Comm.Stg-28	1	1.50%	660	33	9.9	6.6	3.3
29	Comm.Stg-29	2	2%	1000	50	20	10	10
30	Comm.Stg-30	1	2%	500	25	10	5	5
31	Comm.Stg-31	1	2%	500	25	10	5	5
32	Comm.Stg-32	1	1.50%	660	33	9.9	6.6	3.3
		60		33840	1692	610.1	338.4	271.7

500MW AGC Demands – Before retuning : Apr ‘23 to Jul ‘23

500MW AGC Demands – During retuning : Aug ‘23 to Nov ‘23

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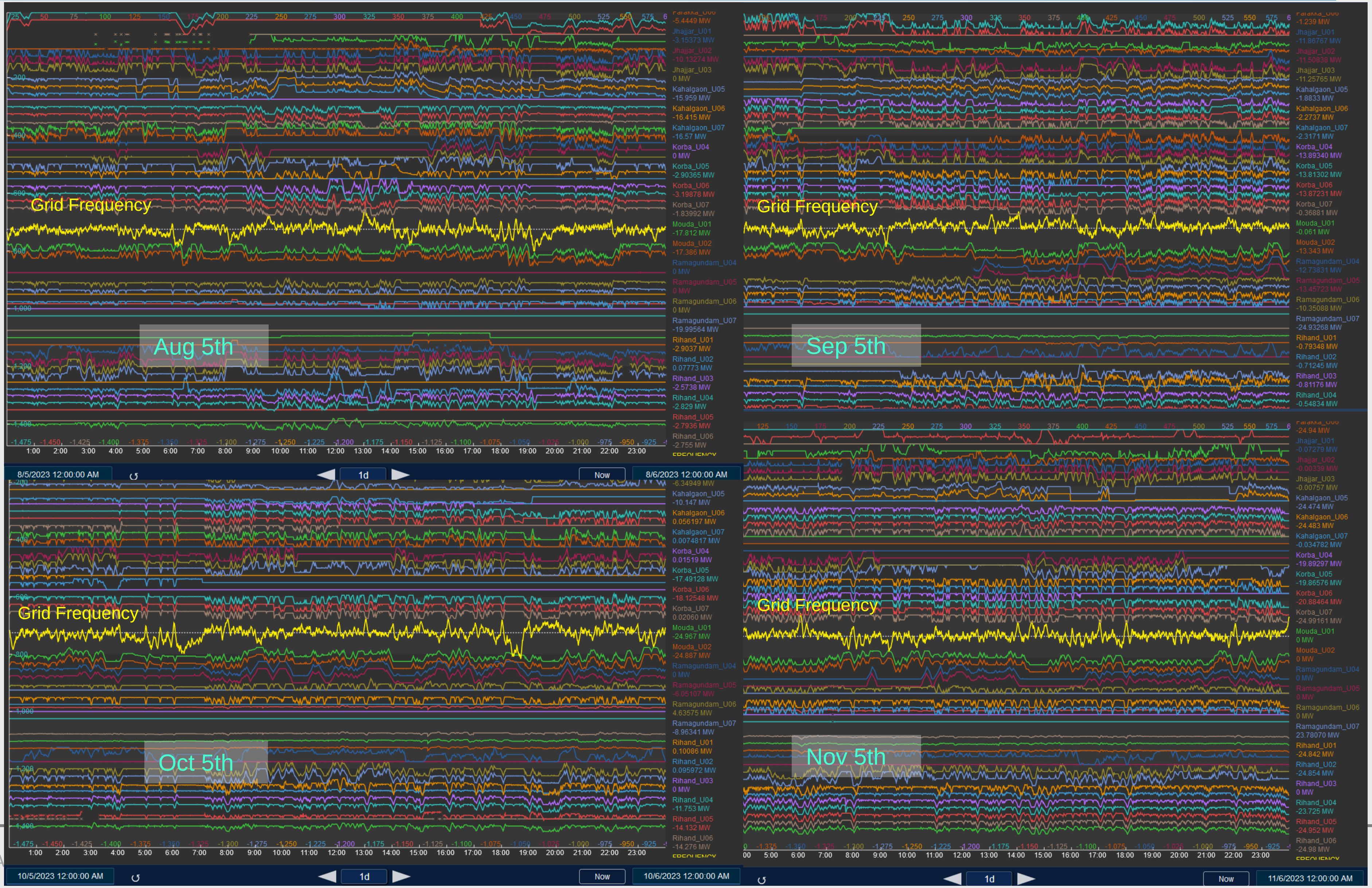

AGC Grid Response Illustration

MS temperature SD 2023-24 data : Units with higher AGC rate

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NTPC COS - Control System Tuner Group : SH temperatures standard deviation (2023 : units with higher AGC rate)

Sl No	Unit	Rating	AGC rate	SH-Right std.dev. for one week in month									SH-Left std.dev. for one week in month									Remark
		MW	%/min	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	
1	Unit-A	500	1->2% on 10.07.23	5.9	4.64	5.84	4.85	4.82	5.01	5.04	4.42	4.15	6.26	5.27	6.55	5.08	6.4	5.04	5.3	4.26	5.32	*Cyclic load*
2	Unit-B	500	1->2% on 10.07.23	3.39	4.79	3.31	3.5	3.8	3.74	4.14	3.85	6.37	3.63	3.33	3.54	3.82	4.09	3.95	4	4.05	4.5	*Cyclic load*
3	Unit-C	500	1->2% on 10.07.23	5.42	3.91	4.31	4.66	4.68	4.59	5.78	4.6	5.58	6.15	3.84	4.48	4.89	5.5	5.24	6.56	5.22	5.84	*Cyclic load*
4	Unit-D	500	1->2% on 10.07.23	3.14	3.11		3.85	5.45	4.16	3.07	3.66	2.81	5.46	6.32		4.67	5.14	4.48	5.02	4.42	5.35	*Cyclic load*
5	Unit-E	500	1->2% on 10.07.23	3.81	3.18	2.85	3.82	3.53	3.18	3.09	2.86	3.71	5.18	4.4	4.72	5.14	5.84	6.41	6.84	6.29	5.52	*Cyclic load*
6	Unit-F	800	1->1.5% on 10.07.23	3.44	4.3	3.41	4.01	4.05	2.79	3.67	4.62	4.58	3.45	3.68	3.38	3.5	4.12	2.69	4.51	3.64	3.78	*Base load*
7	Unit-G	660	1->1.5% on 10.07.23	6.38		4.35	4.24	4.82	4.87	4.77	5.62	6.29	5.92		4.63	4.19	4.88	4.56	4.86	5.08	6.16	*Cyclic load*
8	Unit-H	660	1->1.5% on 10.07.23	5.4	5.81	4.63	4.58	4.47	4.4	4.78	4.9	5.29	6.8	5.81	5.83	5.58	5.84	5.56	6.24	6.46	6.58	*Cyclic load*
9	Unit-I	660	1->1.5% on 10.07.23	4.32	4.23	4.35	3.99	4.62	4.47	3.09	5.13	2.64	5.56	5.09	4.23	4.49	4.89	4.42	3.4	4.17	2.81	*Base load*
10	Unit-J	500	1->2% on 10.08.23	5.23	6.42	5.71	6.08	5.37	2.25		3.56	3.08	4.05	5.37	4.55	4.43	5.25	3.81		6.41	5.37	*Cyclic load*
11	Unit-K	500	1->2% on 10.08.23	3.71	3.59	4.04	4.24	3.65	3.79	3.71	4.38	3.37	6.87	6.92	4.82	5.88	6.25	5.03	5.01	4.55	3.92	*Cyclic load*
12	Unit-L	500	1->2% on 10.08.23	6.21	4.3	3.87	5.44	5.69	5.34	4.29	4.49	5.01	4.22	4.12	3.68	5.01	4.31	4.28	3.94	5.34	5.77	*Cyclic load*
13	Unit-M	660	1->1.5% on 10.08.23	3.98	3.56	4.63	3.79	2.72	3.59	2.23	2.66	2.76	4.55	3.57	5.26	4.19	3.09	3.89	2.76	3.09	2.69	*Base load*
14	Unit-N	800	1->1.5% on 11.08.23	4.32	3.96	3.36	3.53	2.71	3.26	2.9	2.86	2.95	3.87	3.36	3.37	3.32	2.75	3.35	2.97	2.79	3.12	*Base load*
15	Unit-O	500	1->2% on 11.08.23	2.62	3.14	3.1	2.94	2.93	2.39	2.84	2.98	2.65	3.49	3.61	3.23	3.07	3.97	3.87	4.16	4.18	3.7	*Base load*
	Average			**4.48**	**4.21**	**4.13**	**4.23**	**4.22**	**3.86**	**3.81**	**4.04**	**4.08**	**5.03**	**4.62**	**4.45**	**4.48**	**4.82**	**4.44**	**4.68**	**4.66**	**4.70**	

(Grey cell) Data error / 1 week running NA

Time period for data is by default from 23rd 12 AM to 30th 12 AM of month

If unit has not stopped in between (as per pressure/load) and temperature max/min values are correct (no PI signal exchange abnormality), standard deviations are recorded. Else data is captured for previous week etc.

Despite higher AGC rates enabled, almost all units are able to ***sustain or improve up on*** respective steam temperature standard deviations (last week data in each month).

Indian Power Grid – Before AGC retuning : Jan '23 to Jun '23

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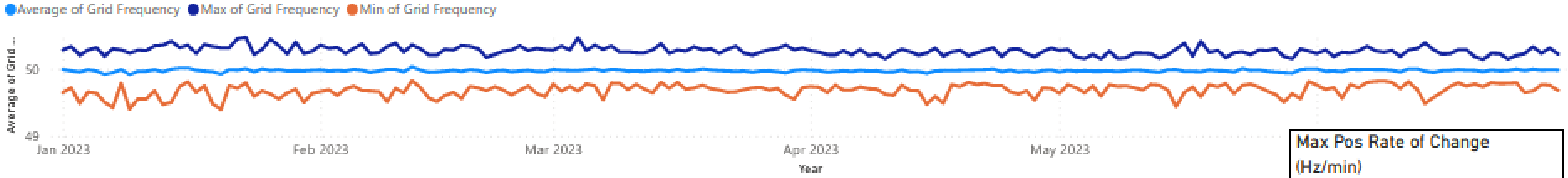
Indian Grid - 2023

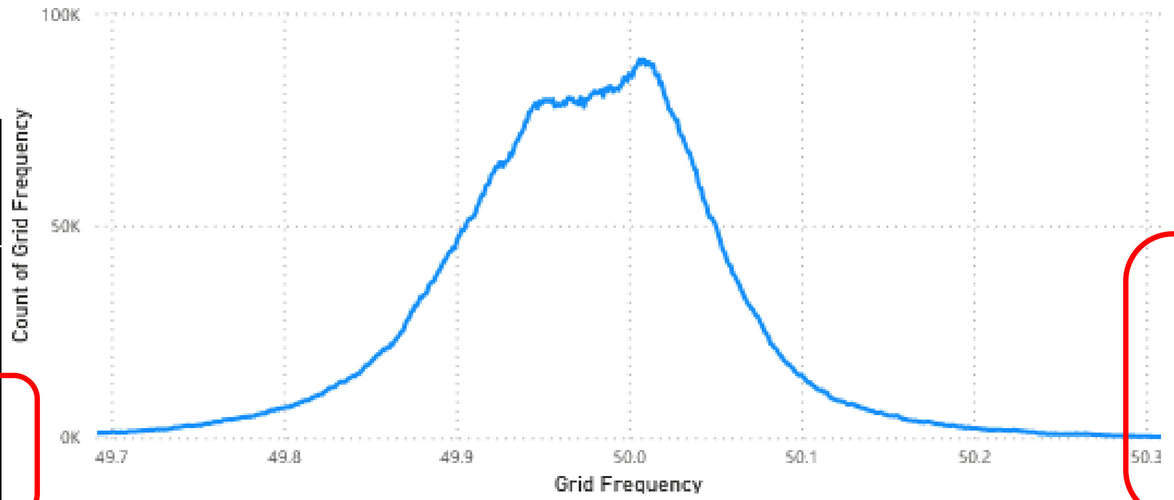
COS-CST
Corporate OS - Control Systems Tuners Group

Date
1/1/2023 – 6/30/2023

Click here for report of year 2022



49.973	Average of Grid Frequency
50.467	Max of Grid Frequency
49.390	Min of Grid Frequency
0.0838	Standard deviation of Grid Fr...



Day Count of Freq fall to below 49.97 Hz	151
Day Count of Freq rise to above 50.03 Hz	120
Day Count of Freq fall to below 50.00 Hz	154
Day Count of Freq rise to above 50.00 Hz	154

Max Pos Rate of Change (Hz/min)	0.697
Max Neg. Rate of Change (Hz/min)	-2.317
Avg Pos Rate of Change (Hz/min)	0.015
Avg Neg. Rate of Change (Hz/min)	-0.015

$$GFPi_{\%} = 0.1 * \frac{\%0.03DB}{STDEV + FVI}$$

19.89	0.0882	0.0777	13.71
GFPi %	StdDev50	FVI	AGCi_%

32.13	49.96	70.19
%<0.03DB	%<0.05DB	%Time(49.90-50.05)

$$FVI = 10 * \frac{1}{N}\sum_{n=1}^{N}(50.00 - f_n)^2$$

$$AGCi\,(\%) = 100 * \frac{count(f \downarrow 50.00) + count(f \uparrow 50.00)}{count(f \uparrow 50.03) + count(f \downarrow 49.97)} - 100$$

87.06
%Time(49.875-50.125)

Data Source : NTPC Corporate PI Server

Data Scan rate : 1 second

Indian Power Grid – During AGC retuning : Jul '23 to Dec '23

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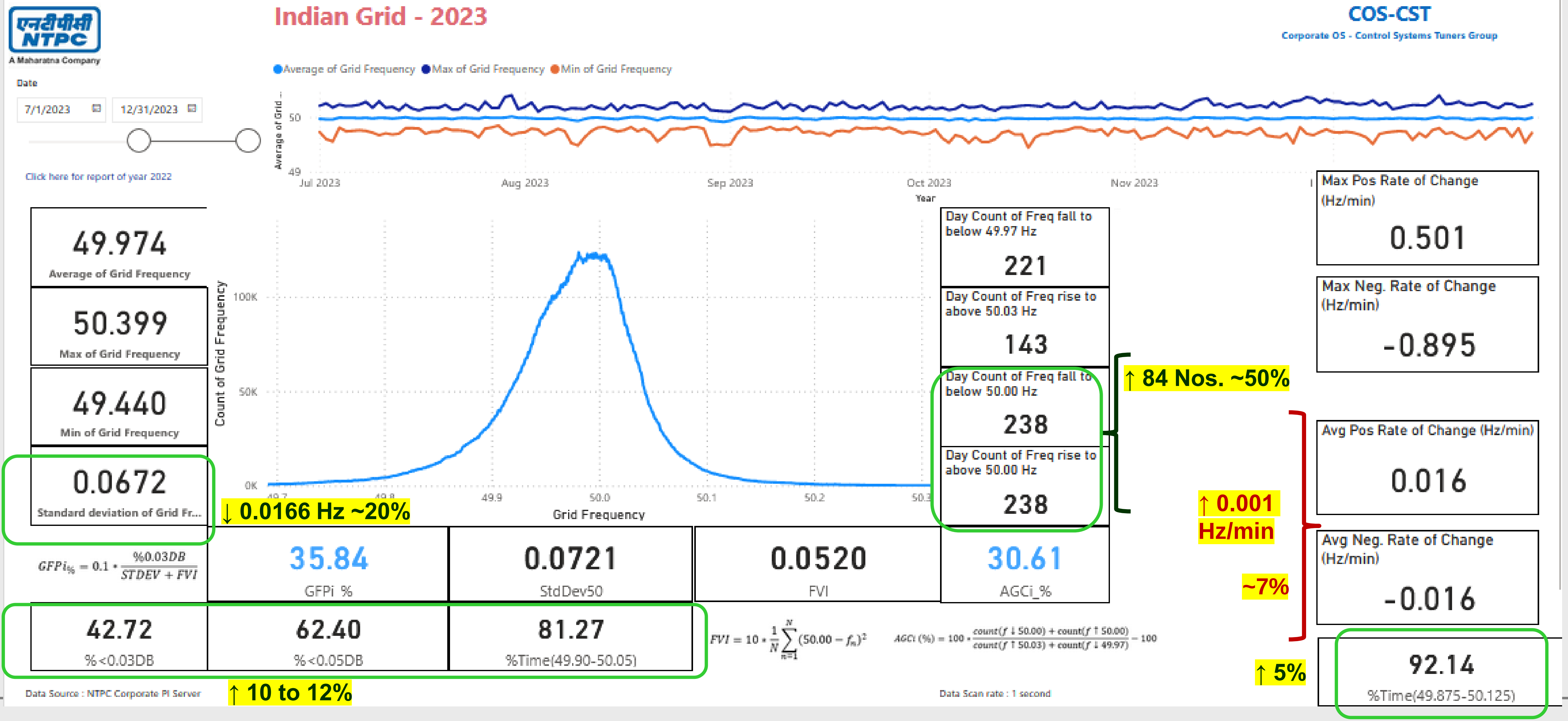

Conclusion

- Due to the unique characteristics of Indian coal-centric power grid, ***customized control solutions*** are required for improved grid frequency control ***protecting long-term reliability of coal thermal units*** also.

- AGC as secondary frequency control mechanism needs to ***evolve continuously*** as the prime stabilizing factor, with exponential growth of ***renewables penetration*** round the corner.

- ***Wider participation*** in AGC from all generating utilities – Central/State or Public/Private Sector, is the need of the hour for creating the ***required ±5% AGC reserves*** available at all times on grid.

- The ***fine balance*** between control objective (target frequency performance) and controlled element reliability (thermal fatigue tolerance) is essential to be maintained continuously for ***energy security that is sustainable and affordable***.

Acknowledgements

Special gratitude is hereby expressed towards the Technical Team and Management of National Load Dispatch Center (NLDC), Grid Controller of India Limited (Grid-India), for their close co-ordination and extensive technical deliberations during the ongoing joint AGC retuning exercise, targeting improvement on both grid frequency and power plant metrics front.

Thank You for Participation. Questions Please …