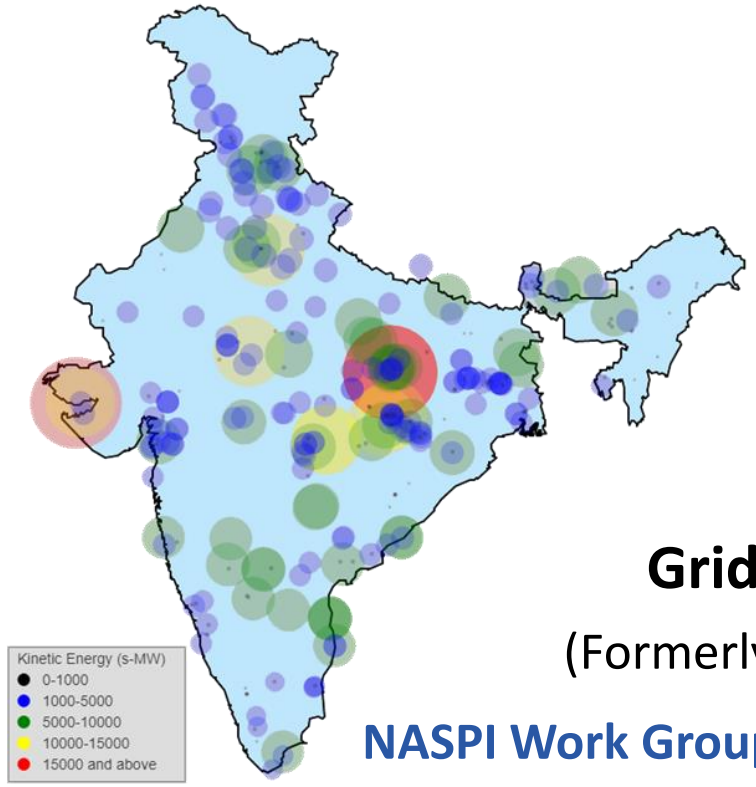
Assessment of Inertia Using PMU Data for Indian Power System



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(Formerly Power System Operation Corporation Limited, India)

NASPI Work Group Meeting and Vendor Show, April 4-5, 2023 (Tempe, AZ, USA)

Indian Grid…One of the World's Largest

Source: GO15

1 National Synchronous Grid

electricity generation

3 electricity consumption

installed generation capacity

transmission system

4 Wind Generation

solar generation

6 Hydro generation

9 Pumped storage installed capacity

Source: IEA Key World Energy Statistics 2021 & IHA 2021 Hydro Status Report (2019 data, 2019 provisional data)

Dimensions of Indian Power System

~412 GW
generation capacity

210 GW+
peak demand

> 4.5 TWh
daily energy met

468,000 ckm+
EHV transmission

~169 GW
renewables
(including large Hydro)

14+
HVDCs

~ 120 GW
inter-regional capacity

3.2 million km²
area footprint

1.3 Billion+
people served

4 GW+
international exchanges

120 TWh+
annual market trades

3
power exchanges

6000+
market participants

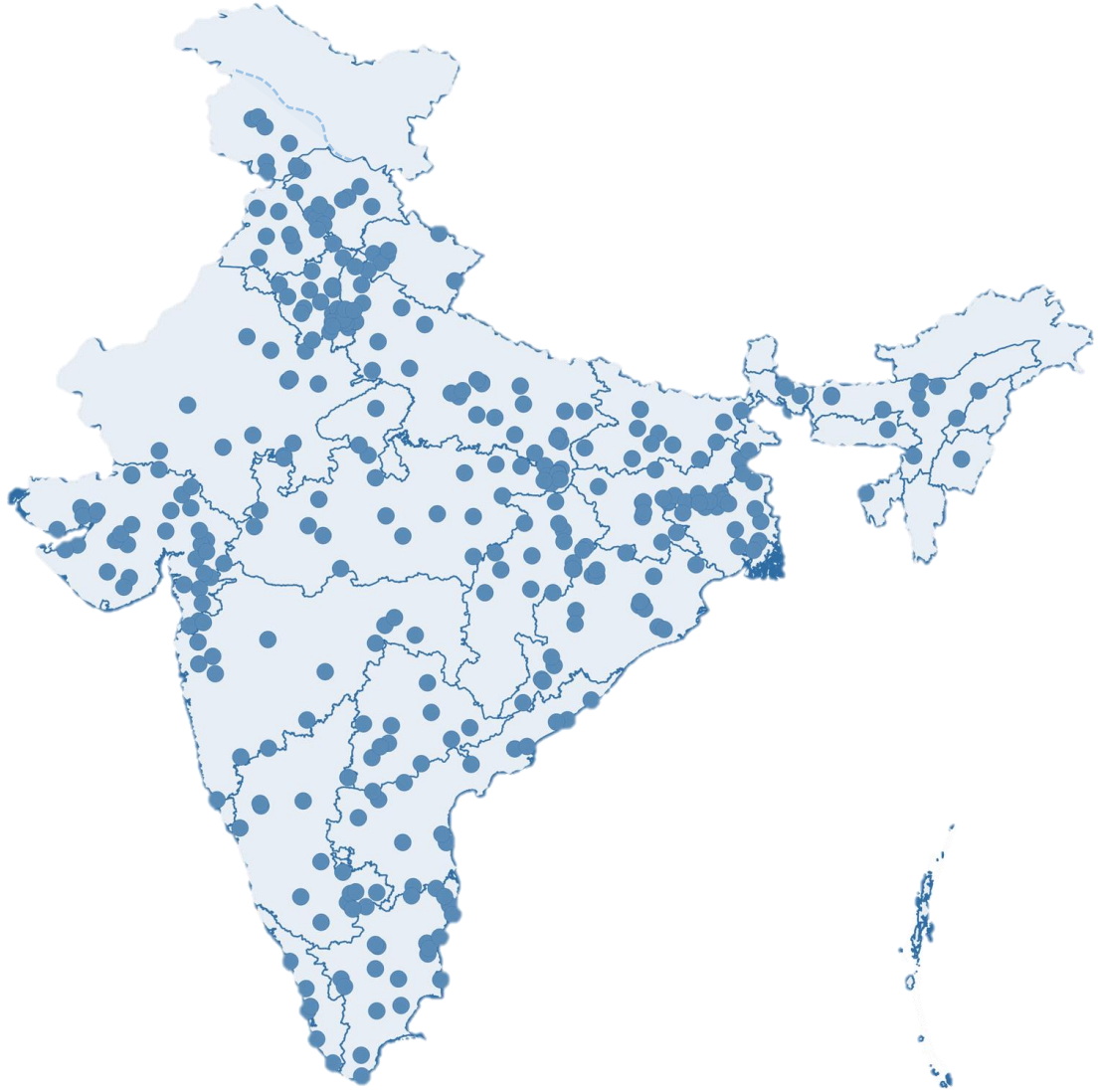
50,000+
market transactions

Indian Grid: Salient Features

Typical parameters in Indian power system	
Highest capacity of single synchronous generating unit (nuclear)	1000 MW
Highest capacity of generating station (thermal)	4760 MW
Highest solar capacity integrated at single pooling station	2430 MW
Highest wind capacity integrated at single pooling station	2305 MW
System inertia (assessed from historical data of 2014-2022)	5 - 9 seconds
Average Power number (assessed from 2014-2021 historical data)	10000 MW/Hz
Median value of Frequency Response Characteristics	15000 MW/Hz
Time to reach Nadir/Zenith frequency	9-14 seconds
Observed load damping of frequency sensitive load	2-5%

Operating standards	
Operating frequency band as per Indian Electricity Grid Code	49.90 - 50.05 Hz
Reference contingency (IEGC 2020 expert committee report) for defense plans	Loss of 4500 MW
Nadir frequency for reference contingency (as per simulations)	49.55 Hz
Quasi steady state frequency for reference contingency (as per simulations, assuming FRC = 15500 MW/Hz)	49.71 Hz
Setting of 1st stage Automatic Under frequency-based Load shedding Scheme	49.4 Hz
Setting of 1st Stage of df/dt (Rate of change of frequency-based) load shedding	- 0.1 Hz / sec , 49.9 Hz

Synchro phasors in India



Present visibility of Indian Grid with Synchro phasors

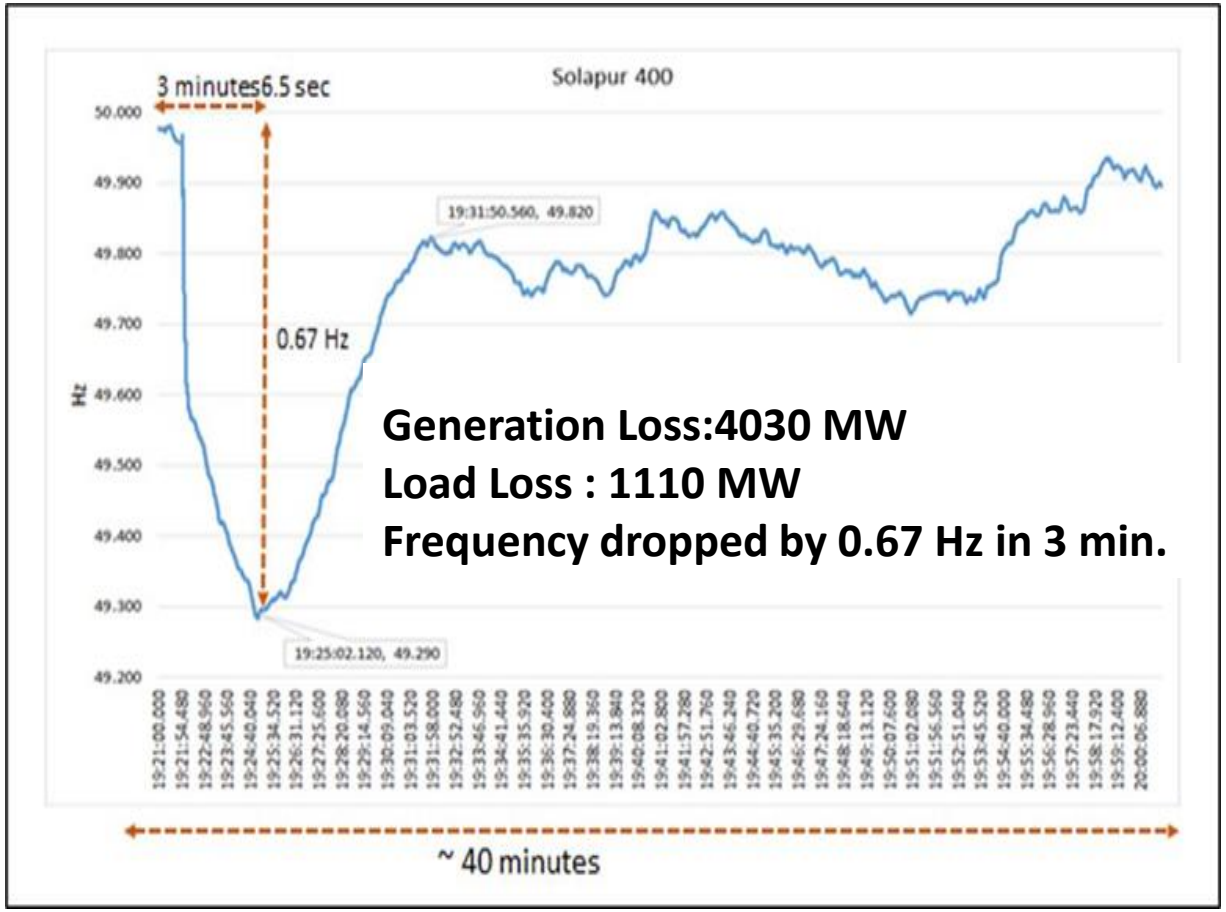
PMUs in URTDSM phase-I

- Total locations – 351
- Total transmission lines – 2274
- Number of PMUs – 1186

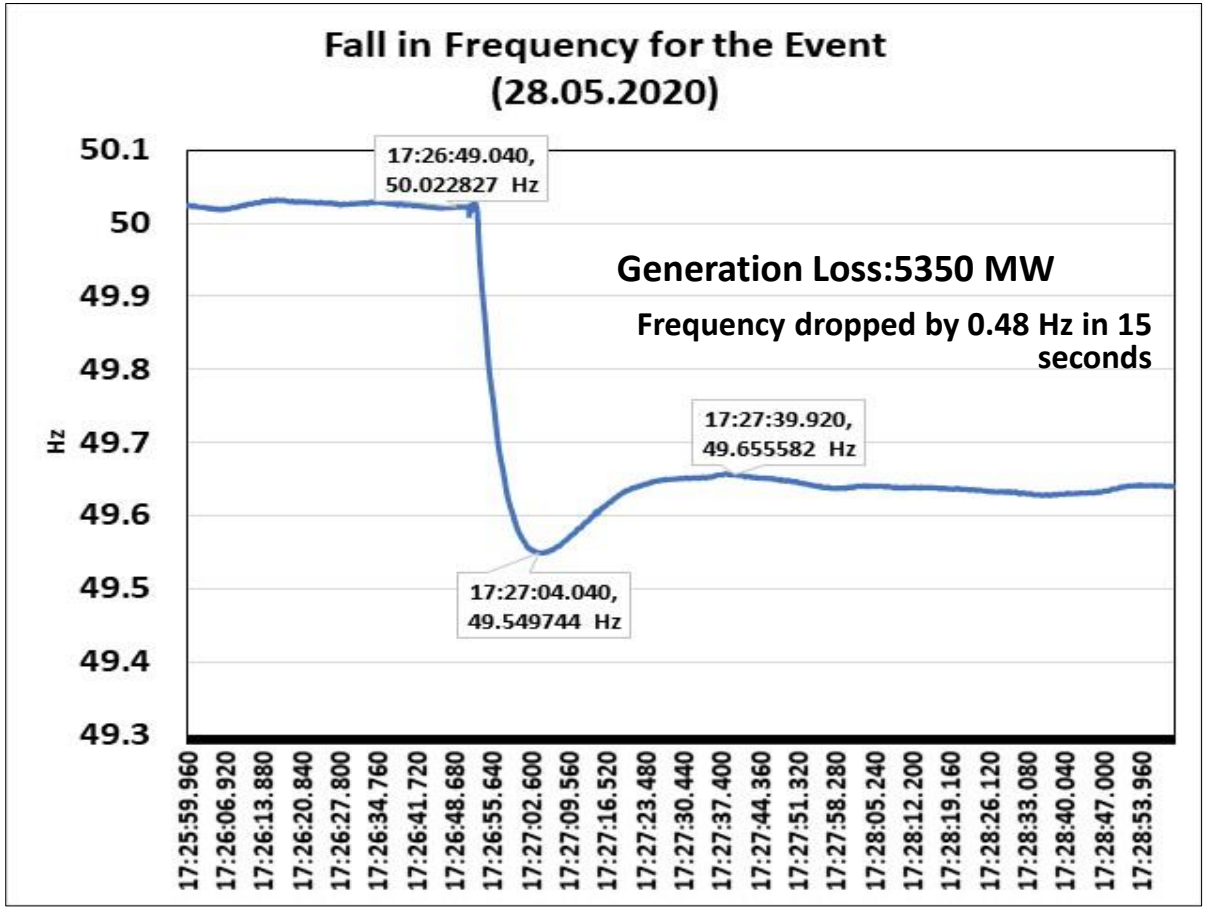
Upcoming (under URTDSM phase-II)

- Locations identified – 230
- Total transmission lines – 925
- Total number of PMUs – 483

Frequency Profile during major imbalance events (PMU based data resolution 40 msec)

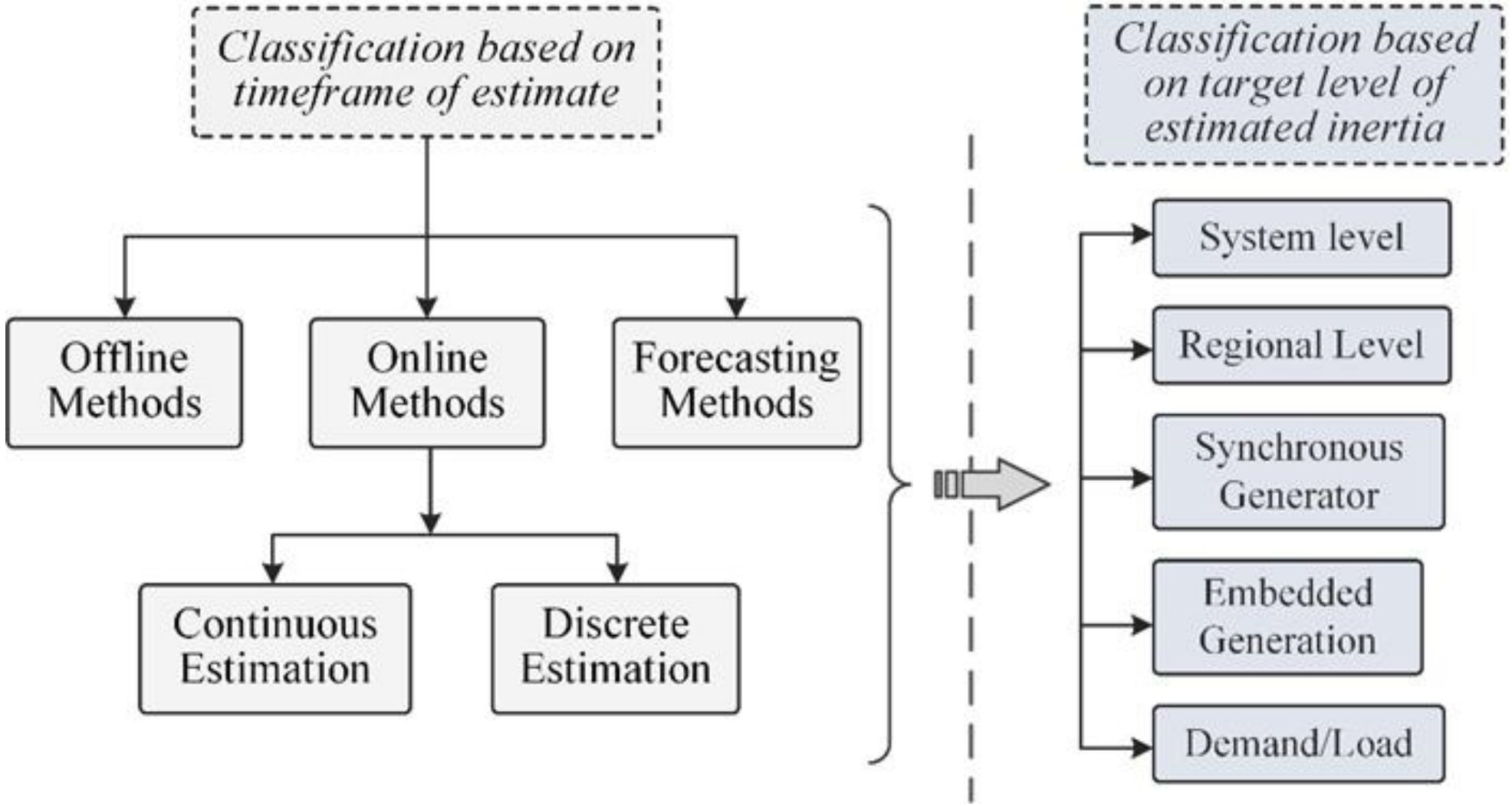


1st stage of under frequency load shedding was triggered



Cascading Effect resulted in Tripping at Multiple Stations

Inertia Estimation Methods

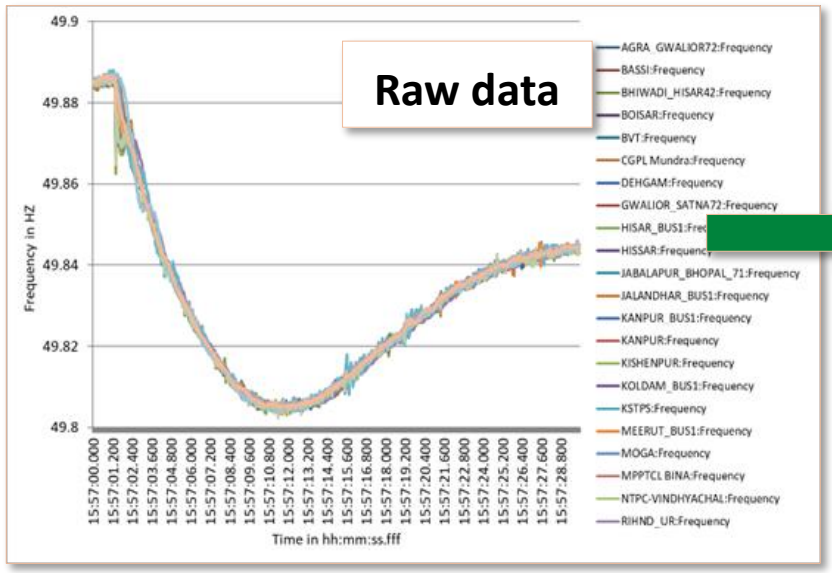


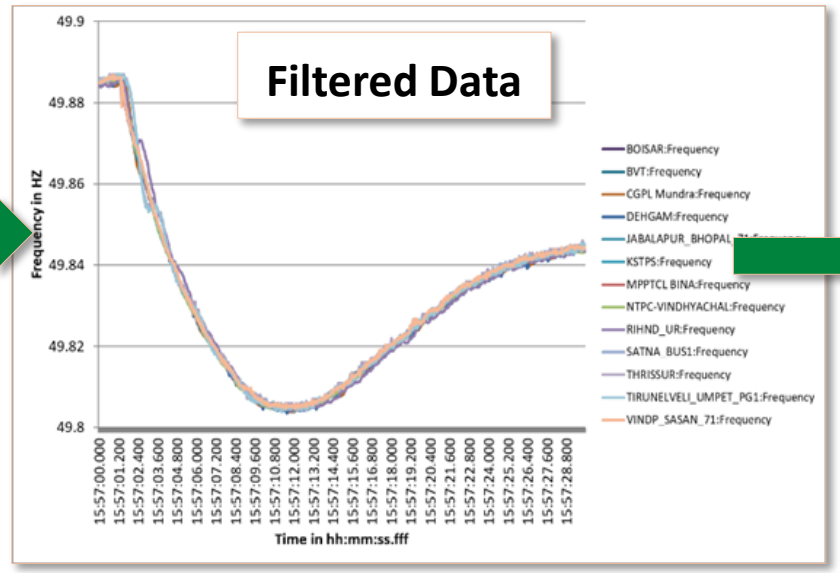
Estimation of inertia : Offline

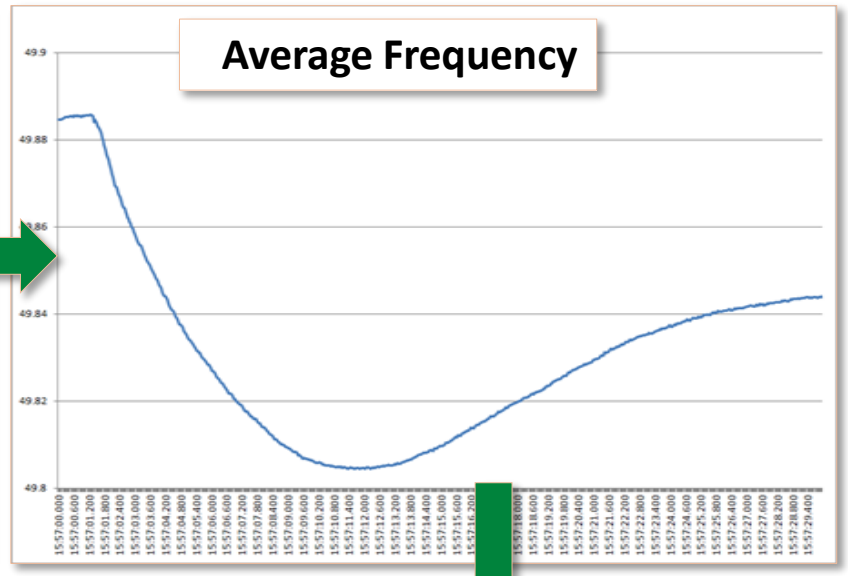
Key Features

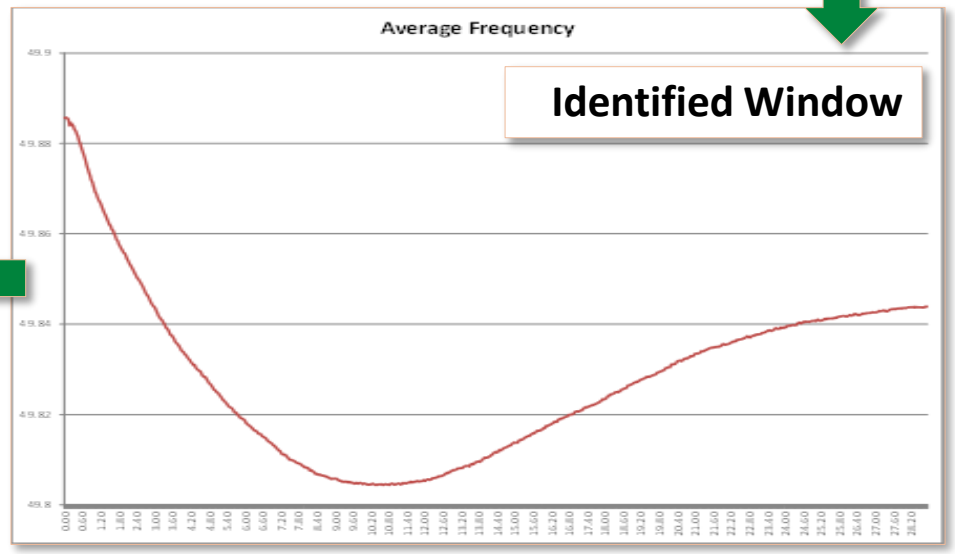
Assumption	System Base	Staggered or Aggregate event	Input Data
PMU data	Event Start Identification	Curve Fit	ROCOF Calculation

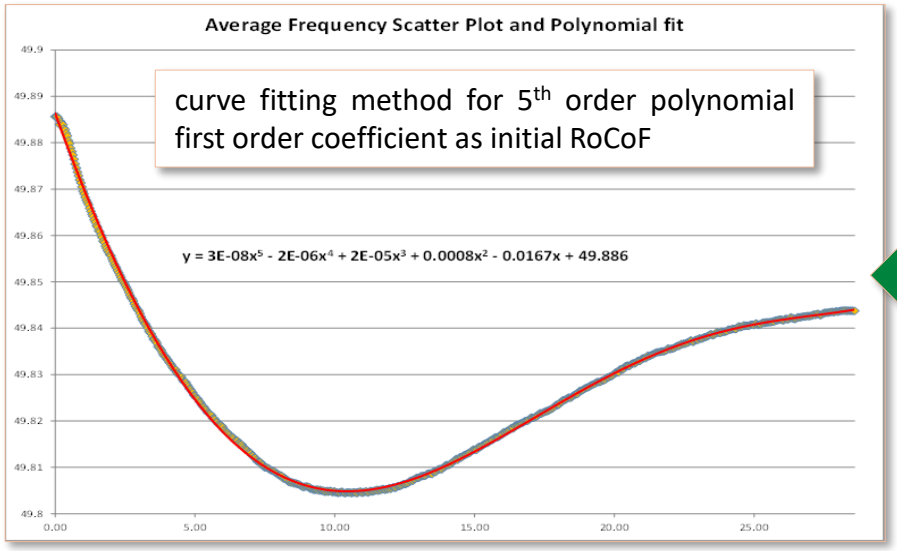
Approach for inertia estimation











Calculations for a sample event

Initial Frequency (Hz)	**49.885**
All India Generation (From NLDC SCADA) (MW)	144482
Actual Generation Loss (SCADA) (MW)	780
Calculated ROCOF from Avg Frequency (Hz/s) *	0.0167
Estimated inertia (sec)	8.06
Nadir Frequency (Hz)	49.804
Time to Reach Nadir Frequency (sec)	10.6
Frequency Drop (Hz)	0.0810
Power Number =$\Delta P/\Delta f$ (MW/Hz)	9626.65

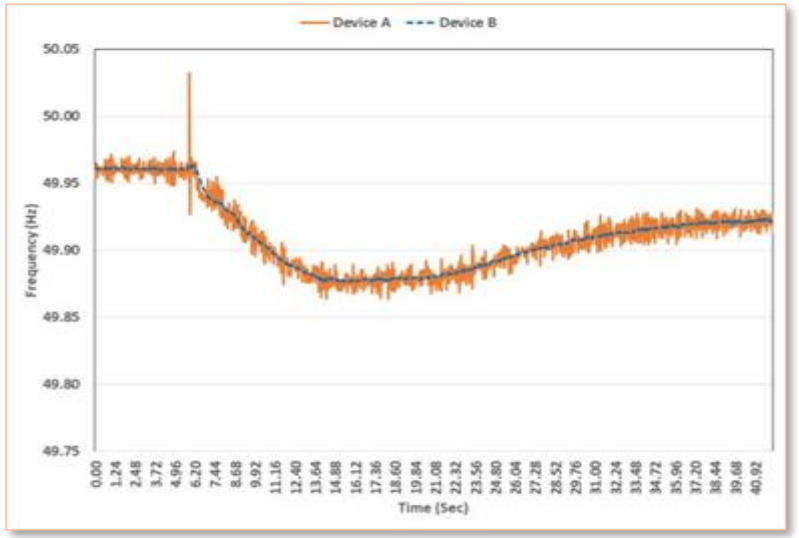
$$\frac{2H}{f_0}\frac{df}{dt} = \frac{P_m - P_e}{S}$$

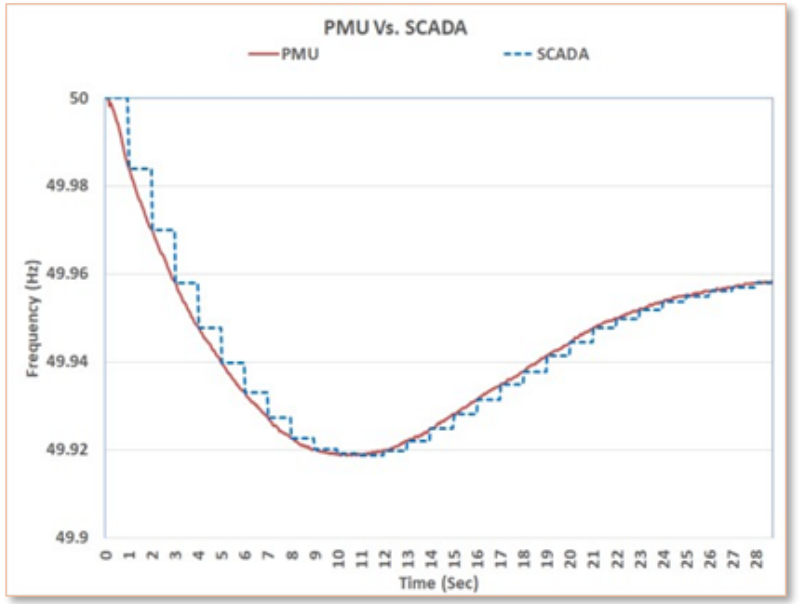
**Captive power generation is not under monitoring in India at National/Regional Control centre which ranges from 10-15 % of total generation.*

**Utilisation of monitored MW in place of MVA base in calculation of inertia.*

Challenges in measurement based inertia estimation

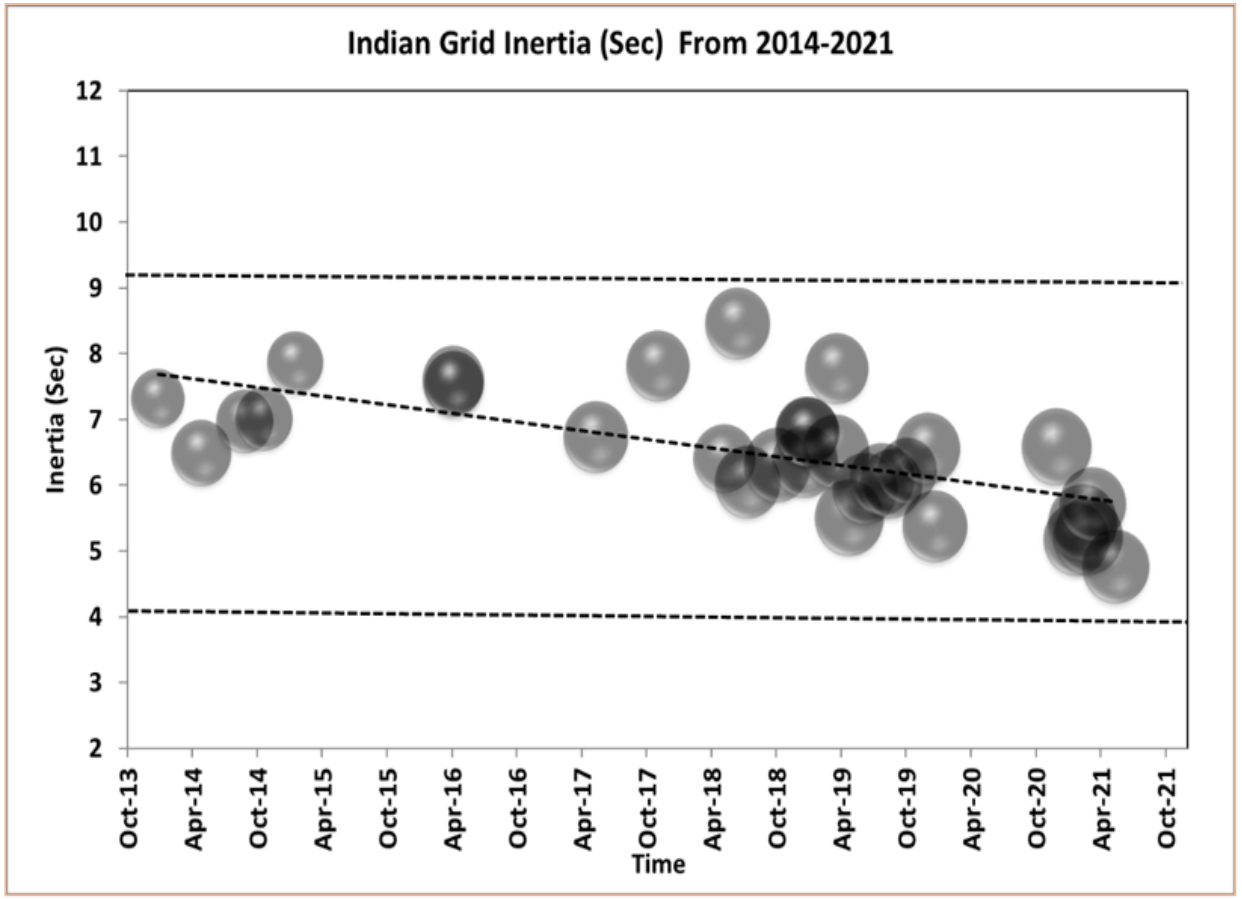
- RoCoF values reported by PMU not suitable
- Important to avoid initial transient phase in calculations
- RoCoF values required at t=0+
- Identification of suitable moving average window
- Assigning proper weightage to respective location frequency
- Identifying appropriate event for inertia estimation (sequential or aggregate)
- Factoring Primary response

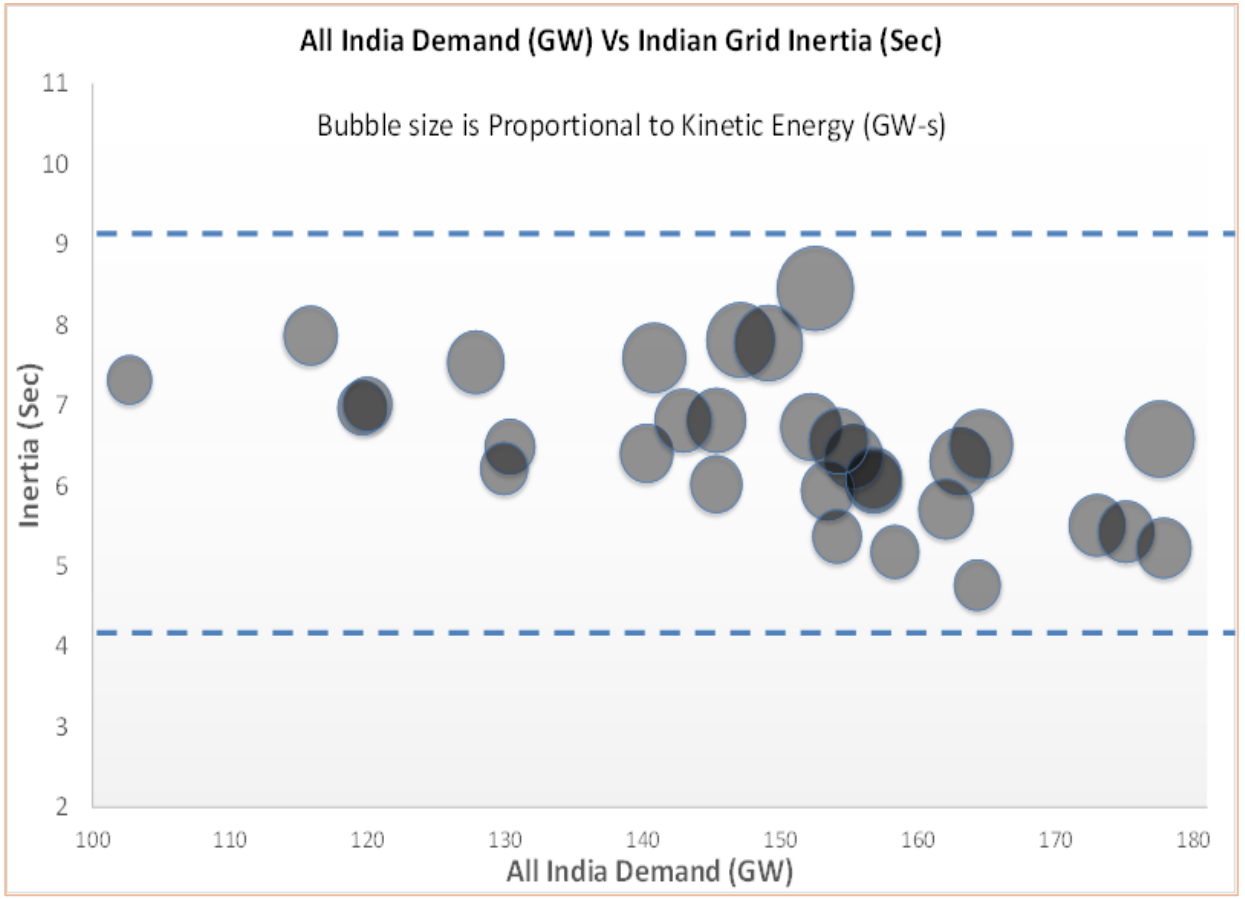




Results on estimation of inertia (29 events)

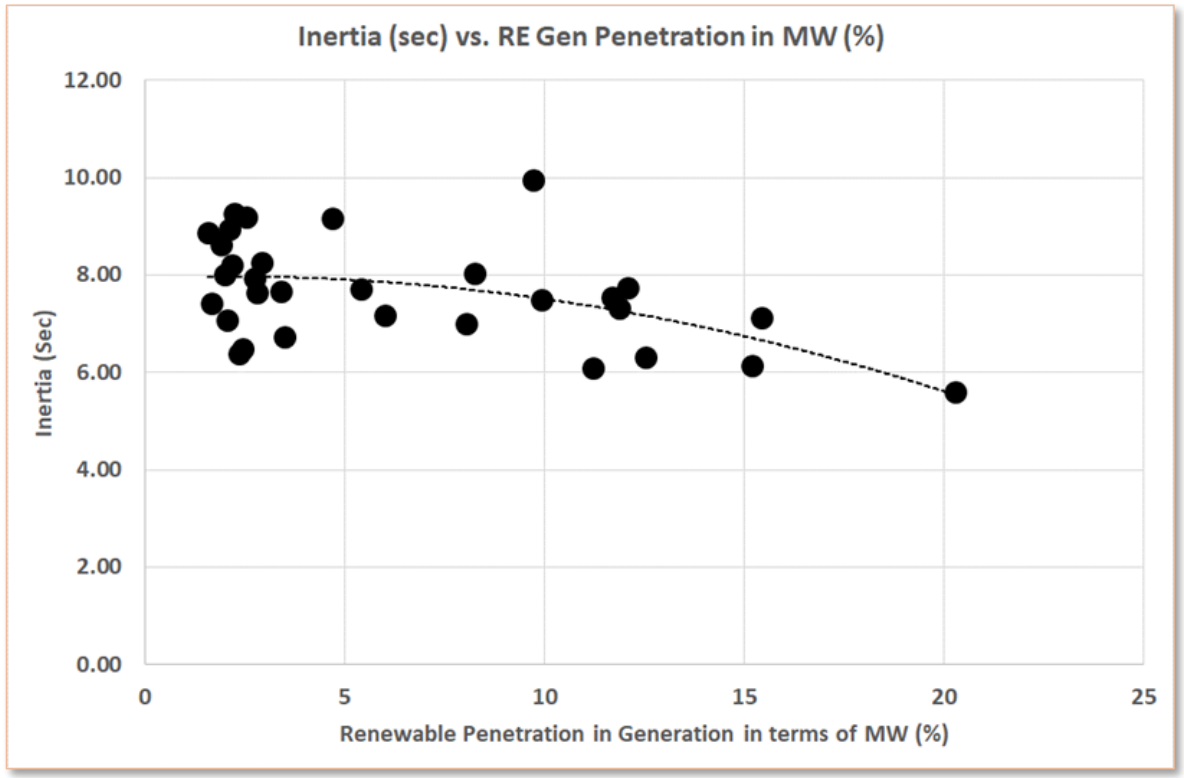
Inertia Estimation Results

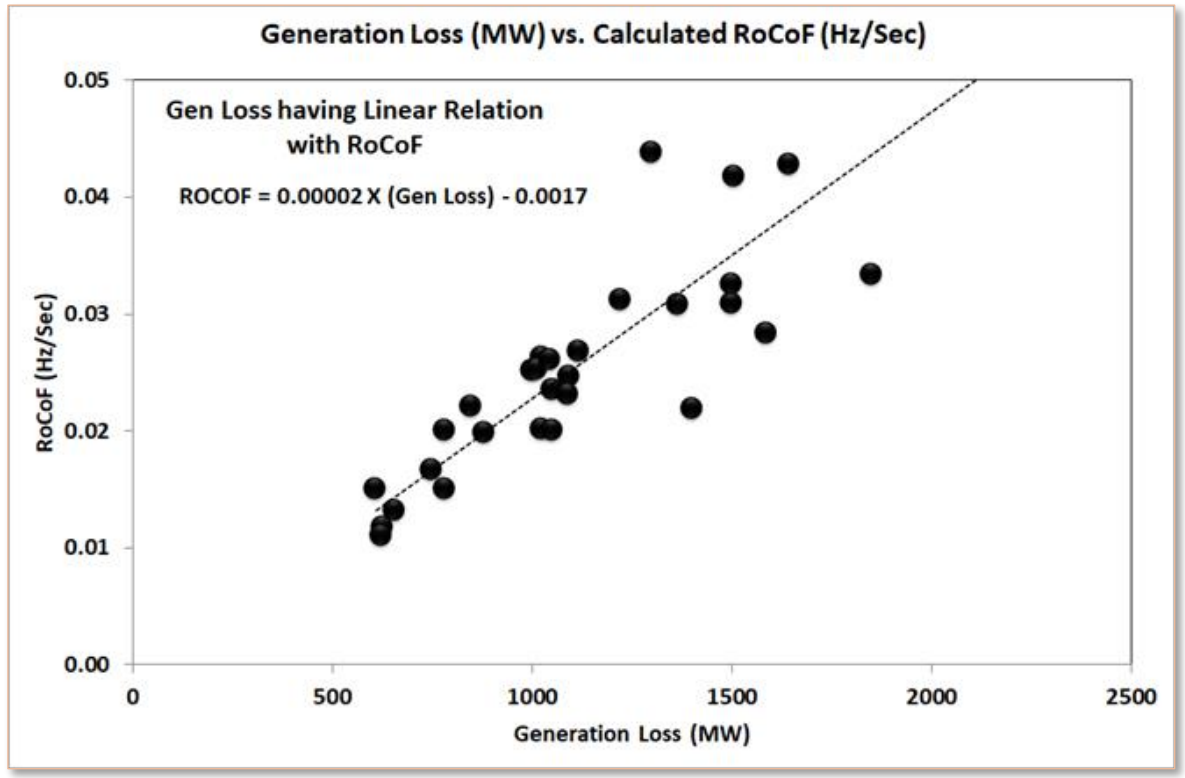




The Indian power system inertia has varied between 5 to 9 Seconds between Jan 2014-June 2021. The mean value of inertia is 6.5 seconds.

Inertia with RE penetration and Generation Loss vs calculated RoCoF



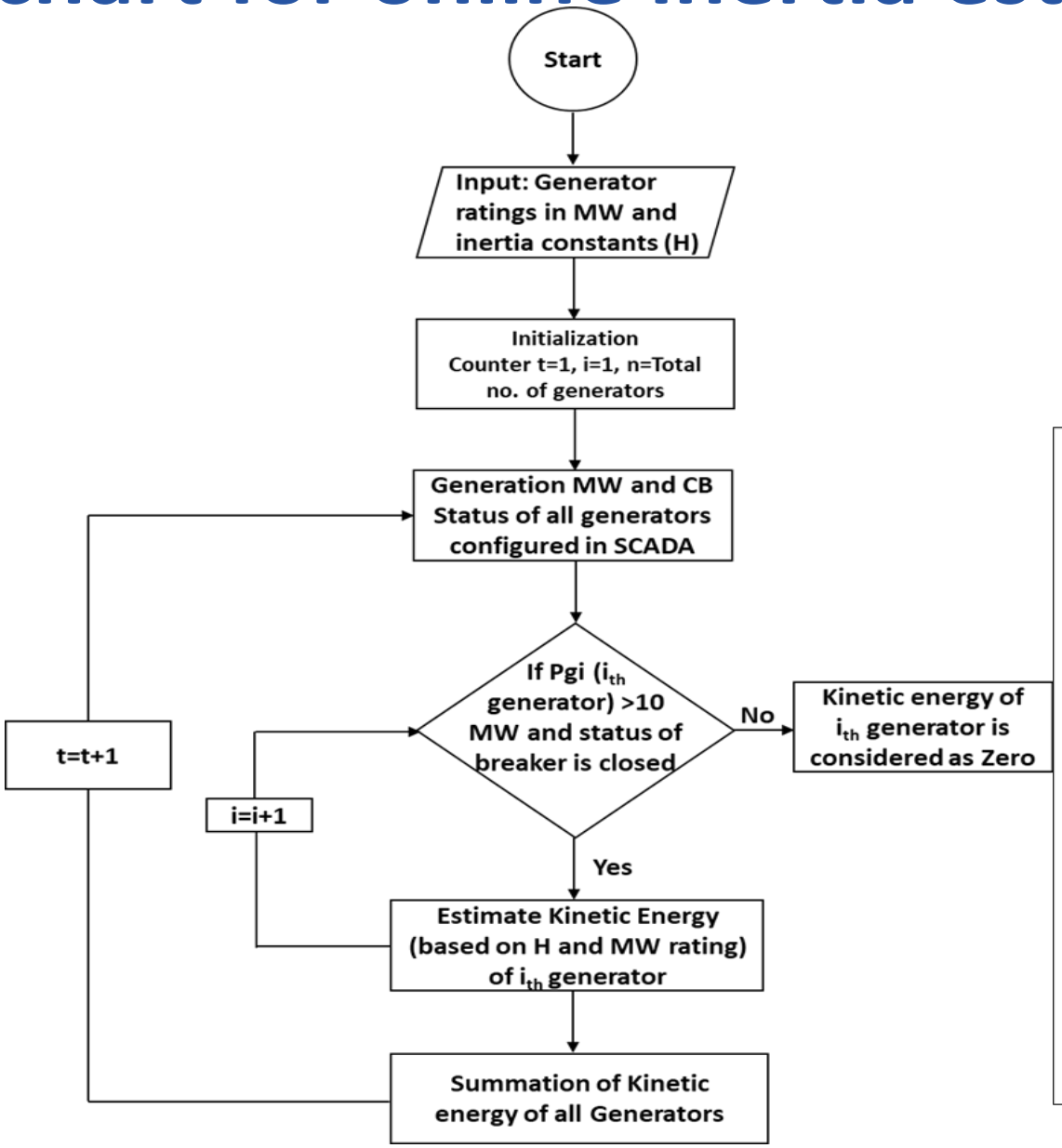


System is becoming lighter with the increase in RE penetration

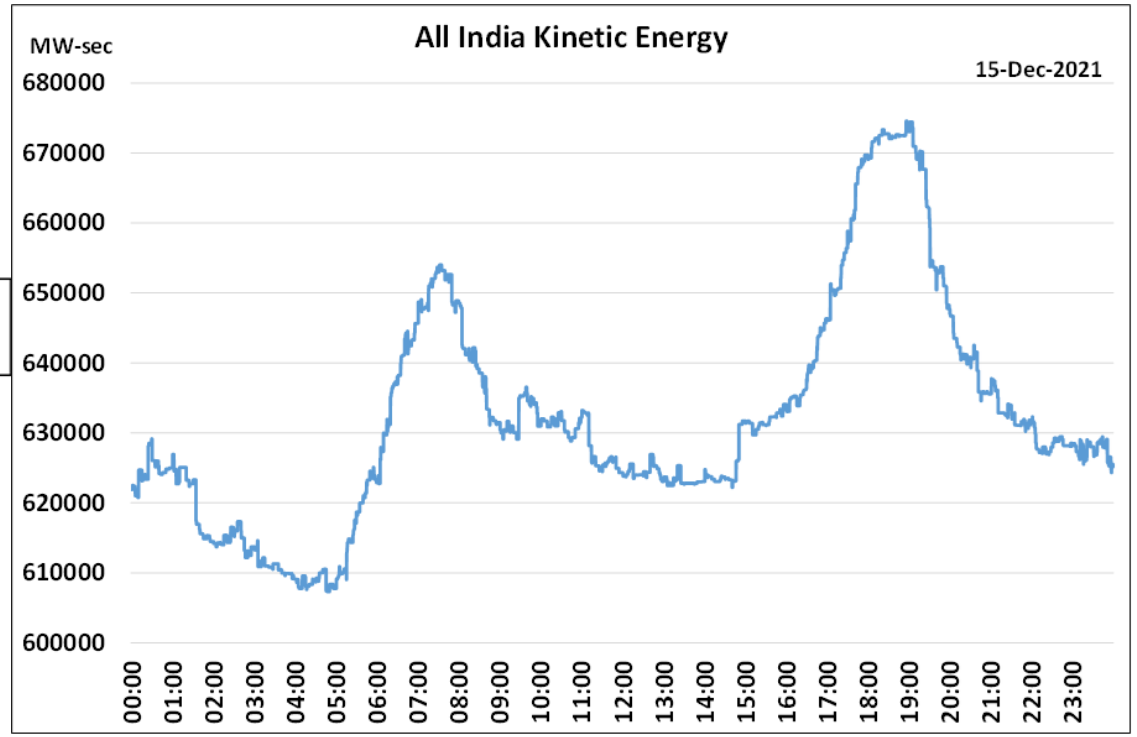
Slope is likely to decrease in case of improvement in governor response

Online inertia monitoring using SCADA

Flow chart for online inertia estimation



$$H_{sys} = \frac{\sum_{i=1}^{n} S_i * H_i}{\sum_{i=1}^{n} S_i}$$



Inertia Monitoring at National level

All India Power System Inertia				
Region	As per SCADA Data			Derived Value
	No of Units On Bar	Capacity on Bar (MVA)	Actual Generation (MW)	Kinetic Energy (Sec-MW)
Northern Region	108	34736	29695	113328
Western Region	191	69654	57479	234004
Southern Region	166	38679	37921	166010
Eastern Region	162	41900	21893	151763
North Eastern Region	50	3092	2197	9376
All India	677	188062	149185	674482

Inertia Monitoring at Regional level

System Inertia of Northern Region	
No of Units on Bar	108
Capacity on Bar (MVA)	39828
Actual Generation (MW)	28237
Kinetic Energy (MW-sec)	109391

System Inertia of Western Region	
No of Units on Bar	183
Capacity on Bar (MVA)	78648
Actual Generation (MW)	54076
Kinetic Energy (MW-sec)	222935

System Inertia of Southern Region	
No of Units on Bar	165
Capacity on Bar (MVA)	43088
Actual Generation (MW)	36731
Kinetic Energy (MW-sec)	157260

System Inertia of Eastern Region	
No of Units on Bar	92
Capacity on Bar (MVA)	29077
Actual Generation (MW)	13966
Kinetic Energy (MW-sec)	100168

System Inertia of North Eastern Region	
No of Units on Bar	65
Capacity on Bar (MVA)	4322
Actual Generation (MW)	3247
Kinetic Energy (MW-sec)	11659

Technical Recommendations

- Maintaining of power system inertia adequacy in the overall planning of system security
- Inertia Estimation/ Measurement/ Forecasting tools
- Load Composition Understanding and variation in load composition over different time scales
- Standardising RoCoF Calculation
- Periodically review of RoCoF and Frequency nadir based protection schemes
- Identifying Minimum Inertia for secure and stable grid operation
- Spatial Distribution of Inertia
- Synchronous as one of the constraints in the future security constrained unit commitment scheme


धन्यवाद ☺
Thank you !
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