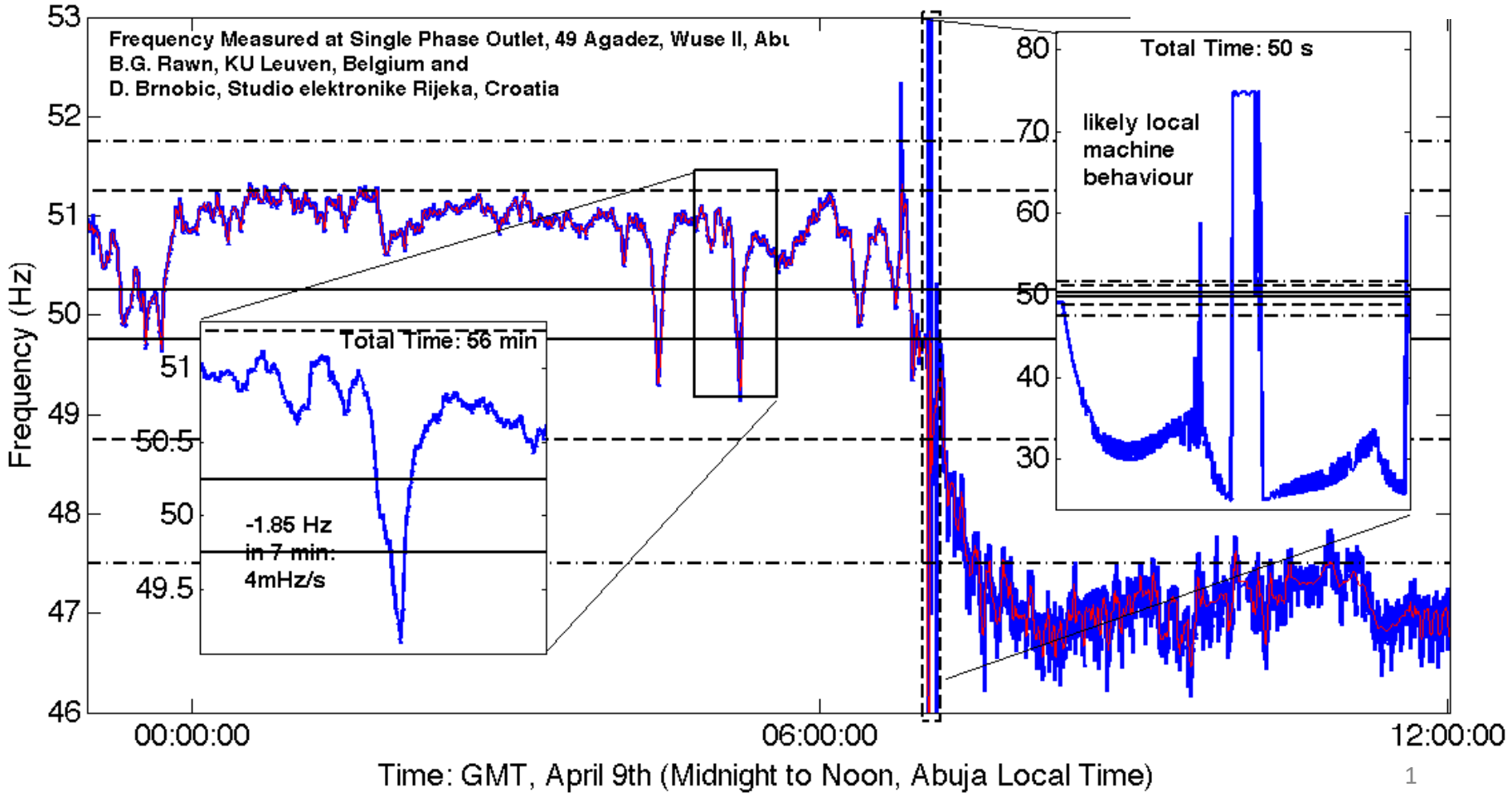
Making Do with That PMU

Processing Techniques and Purposes

Presented Feb 15 2018 by Dr Barry Rawn to NASPI DisTT

Brunel University London



Making Do with That PMU

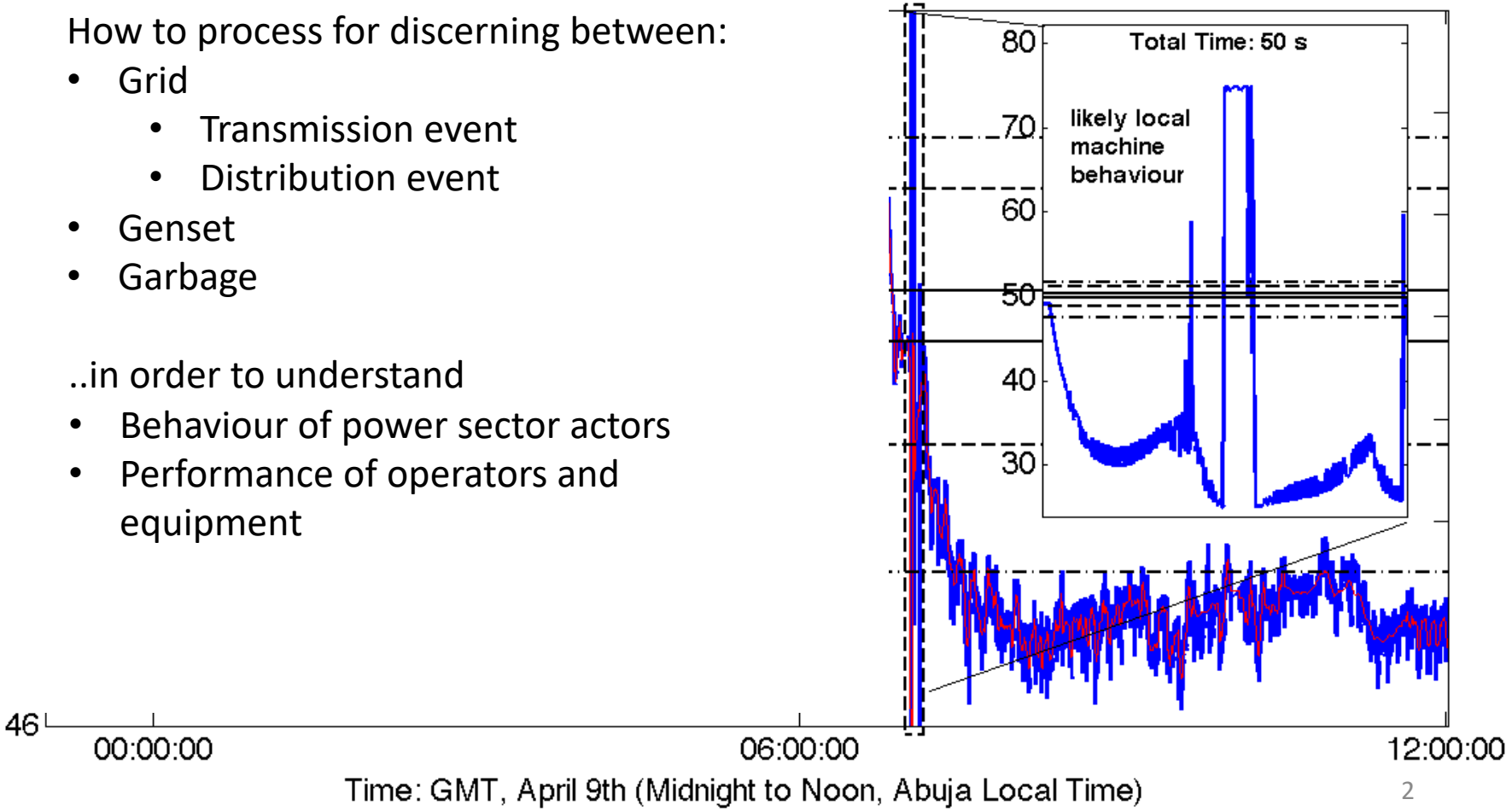
Processing Techniques and Purposes

How to process for discerning between:

- Grid
  - Transmission event
  - Distribution event
- Genset
- Garbage

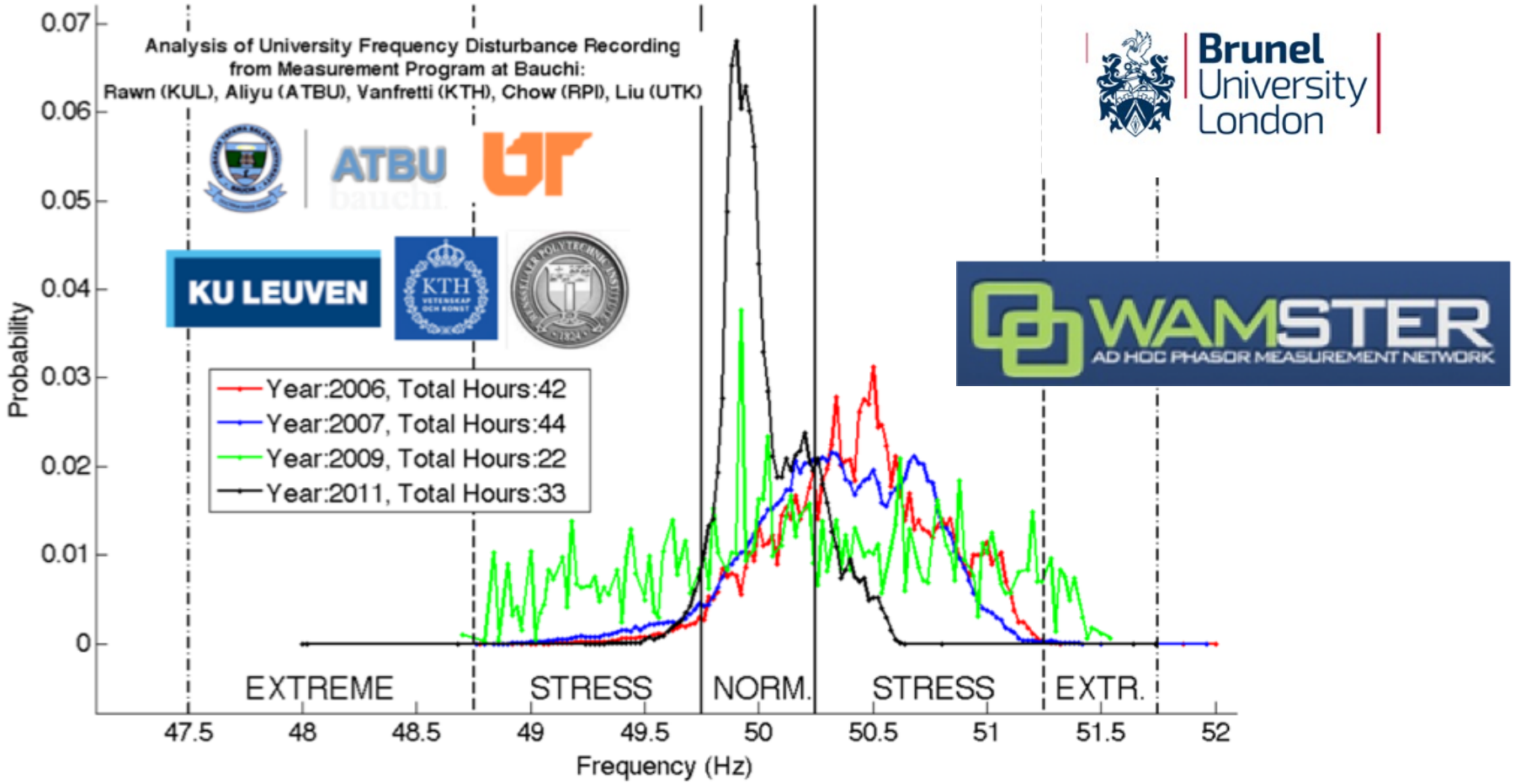
..in order to understand

- Behaviour of power sector actors
- Performance of operators and equipment



Making Do with That PMU

Acknowledgements



The STudio Elektronike Rijeka (STER) PMU: Portable and Accessible Through Mobile Network

Features:

•Continually broadcasts at 1-10 FPS ***(frames per second)*** for archiving in database

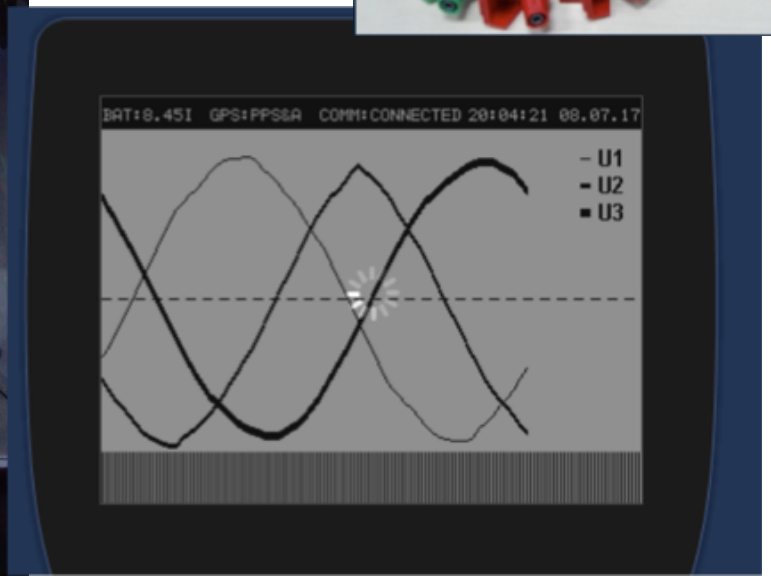
•Also locally stores data at highest resolution

•can be remotely commanded to send detailed (50 FPS) event records or automatically does so on desired triggers

•Also waveforms, harmonics

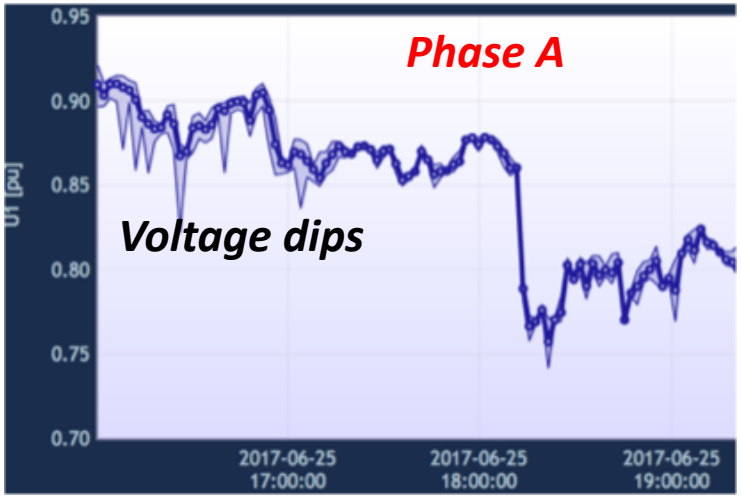
WAMSTER
AD HOC PHASOR MEASUREMENT NETWORK

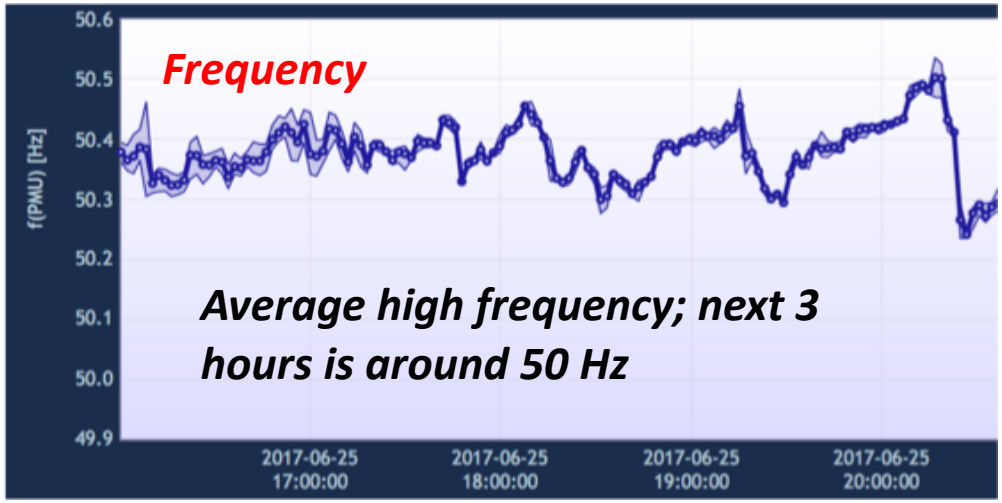
Distribution Board Recordings



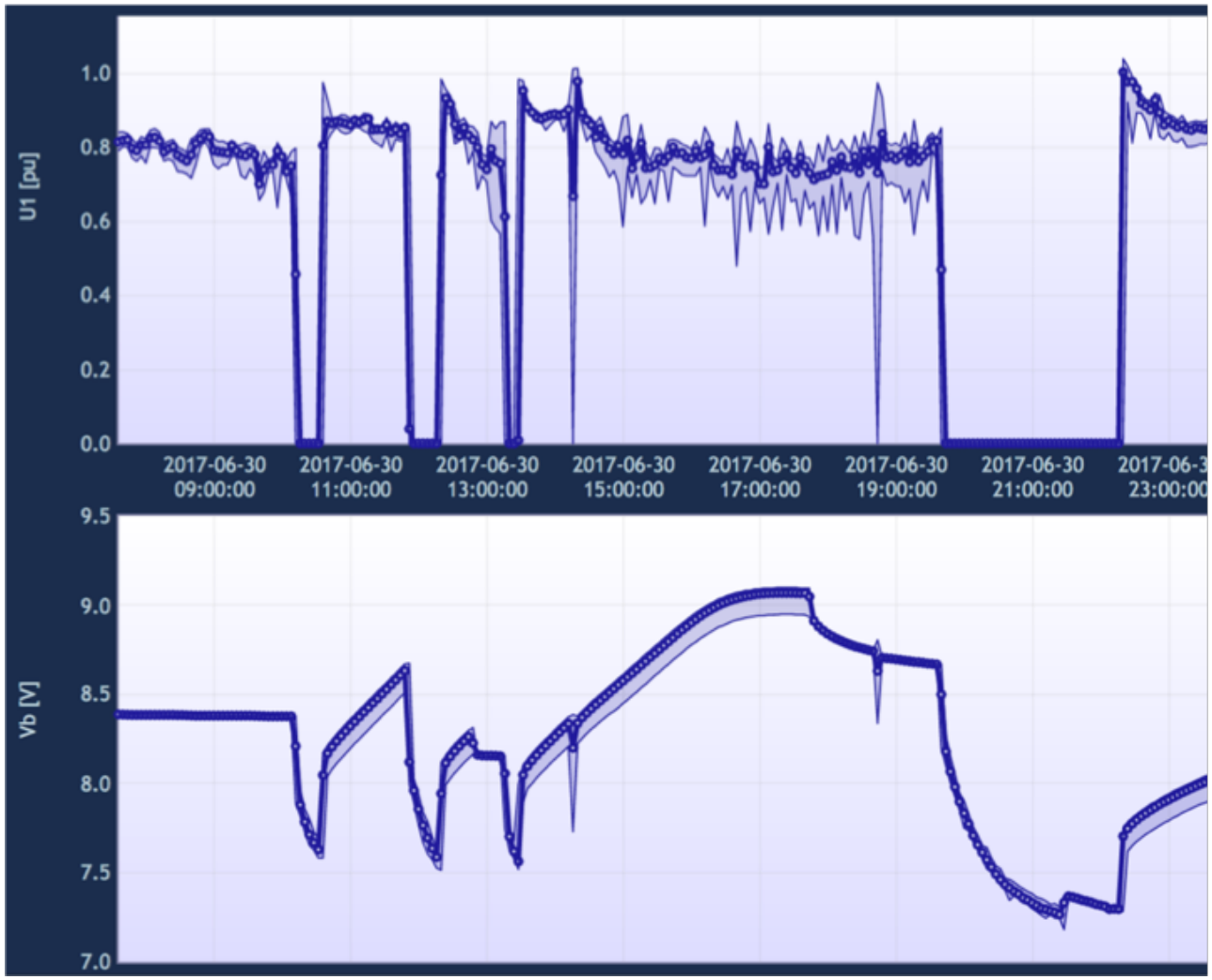
Distribution Board Recordings

June 2017, Victoria Island, Lagos, ~3 hours





Distribution Board Recordings

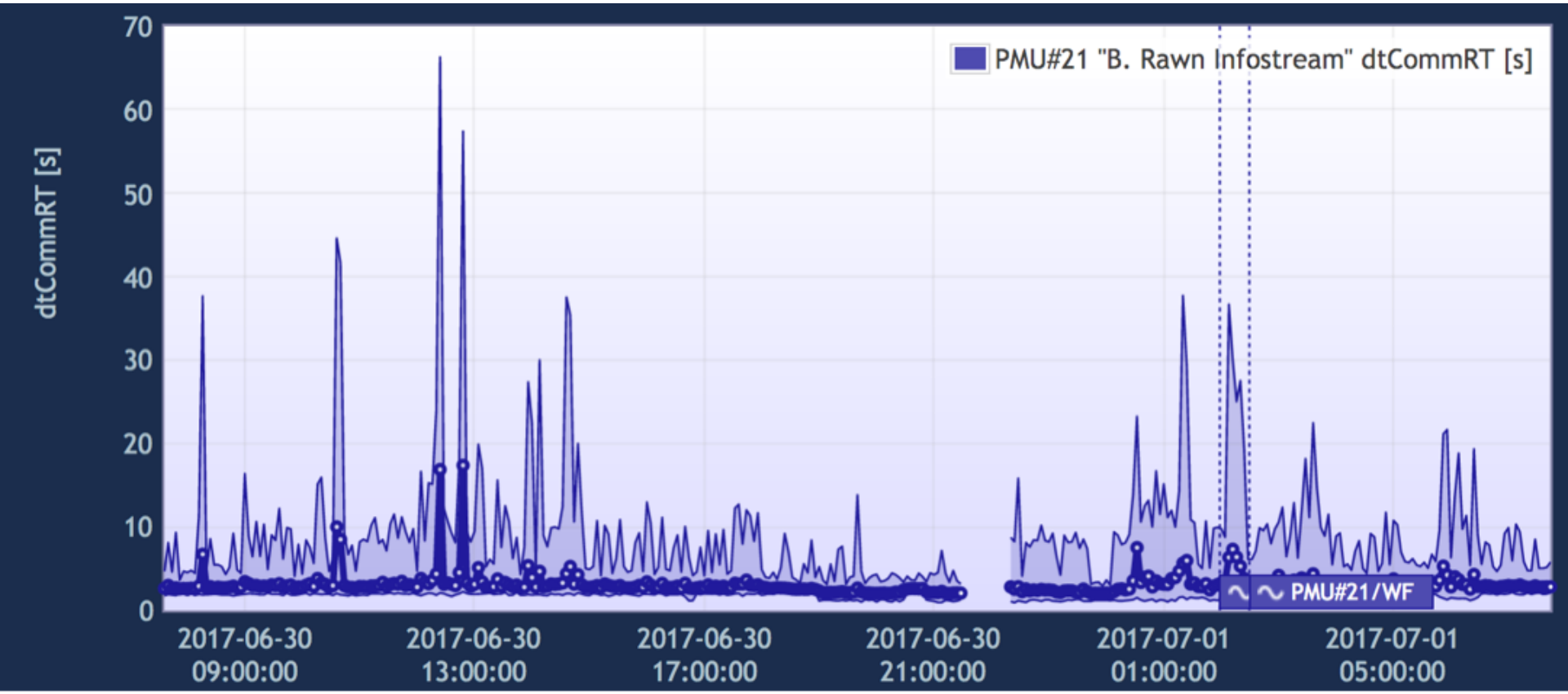


Not missing data, but load shedding

(note unit battery draining, charging, in lower trace)

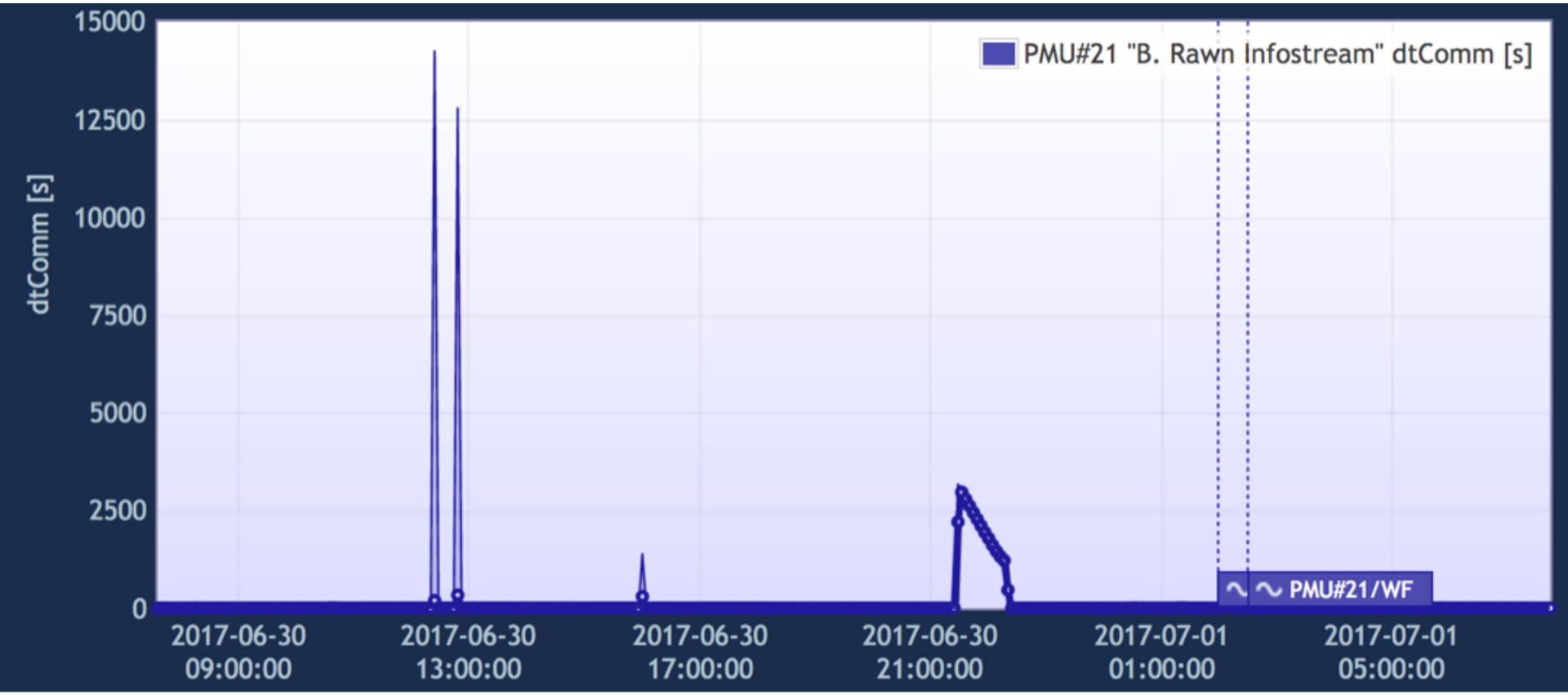
Distribution Board Recordings

Communication Delay: Real Time Readout

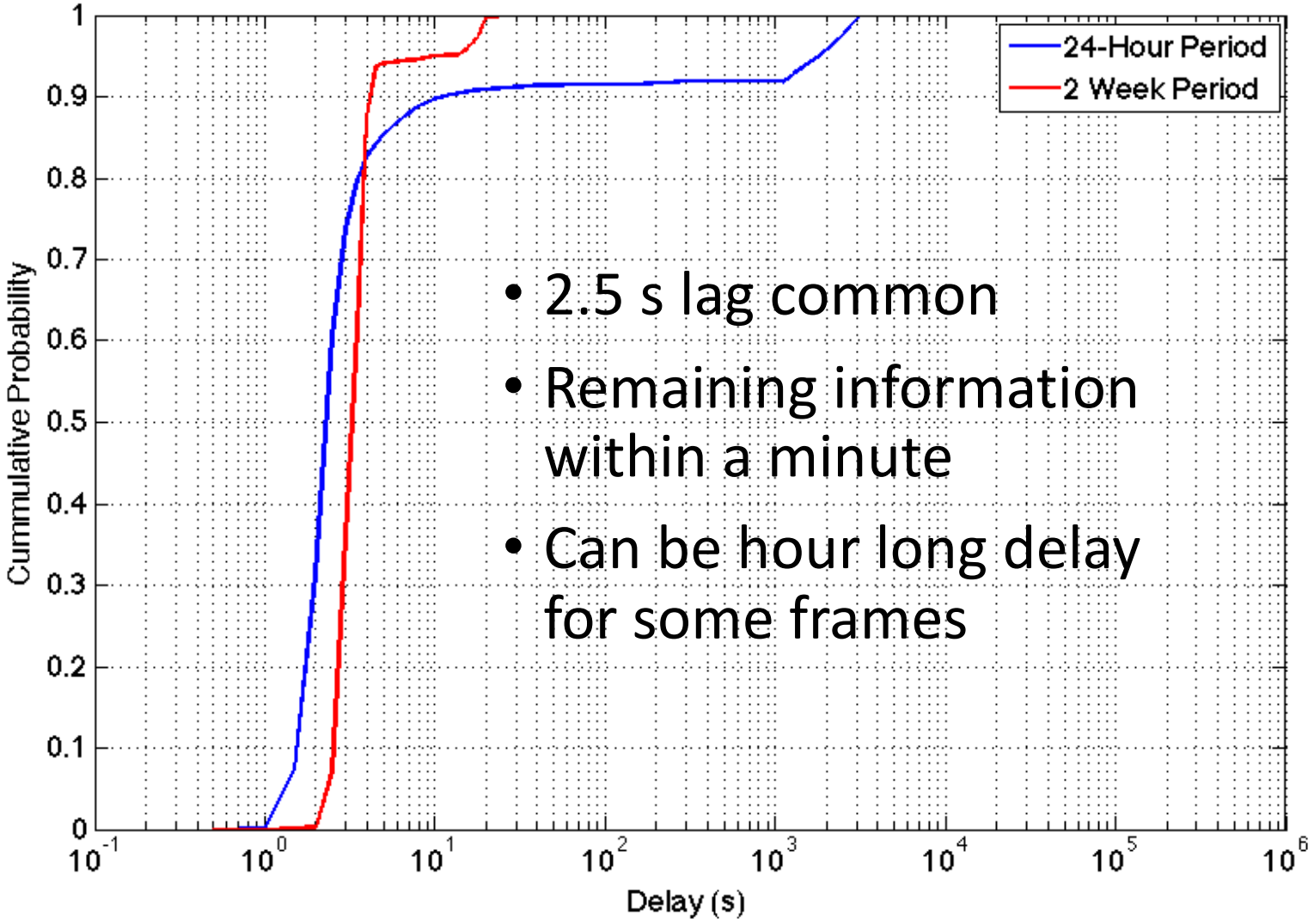


Distribution Board Recordings

Communication Delay: All Frames



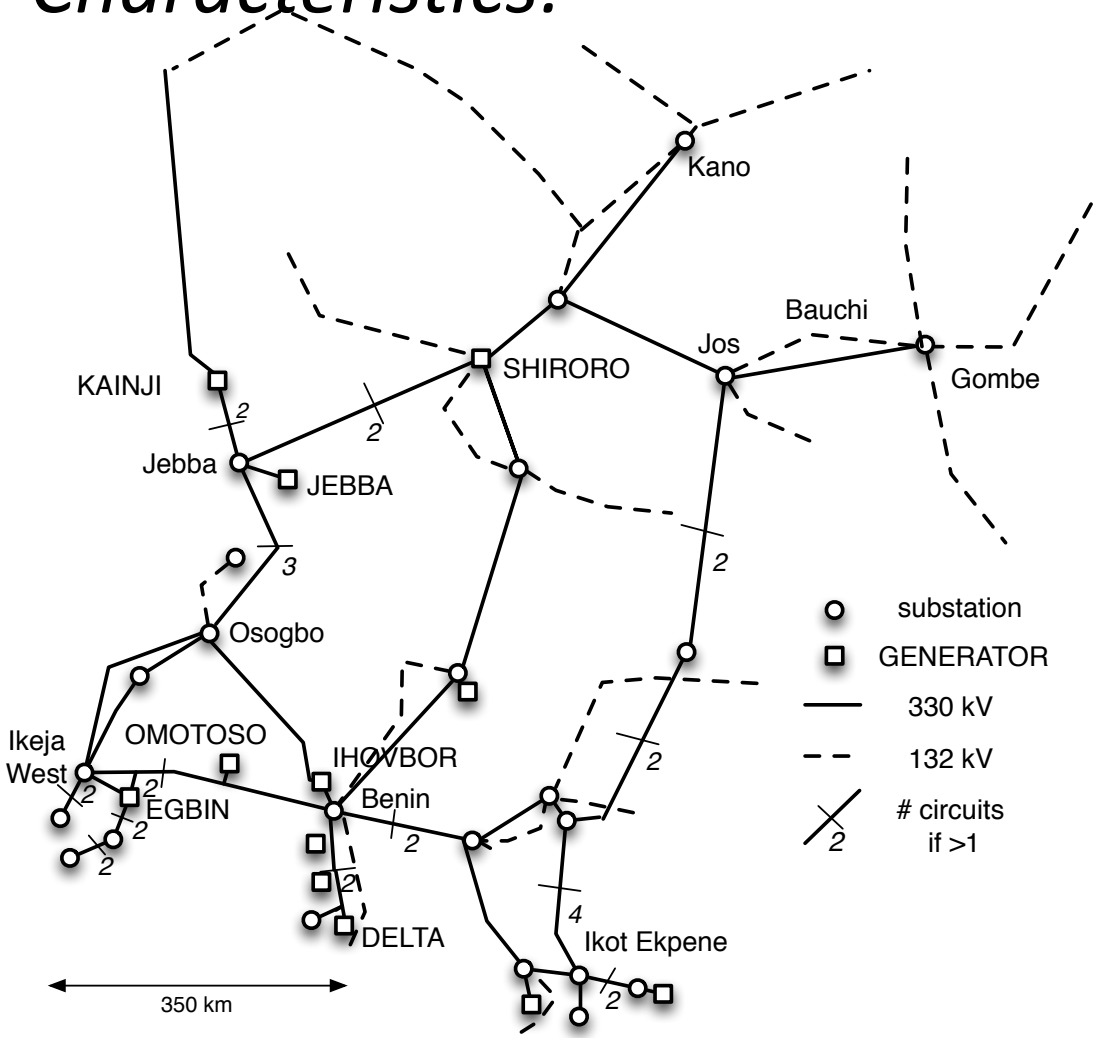
Distribution Board Recordings



- 2.5 s lag common
- Remaining information within a minute
- Can be hour long delay for some frames

Nigerian High Voltage System

Characteristics:



~180 million people:

- 50% no access;
- 30% DG
- 20% on-grid

~1GW per million people in industrialised country, but..

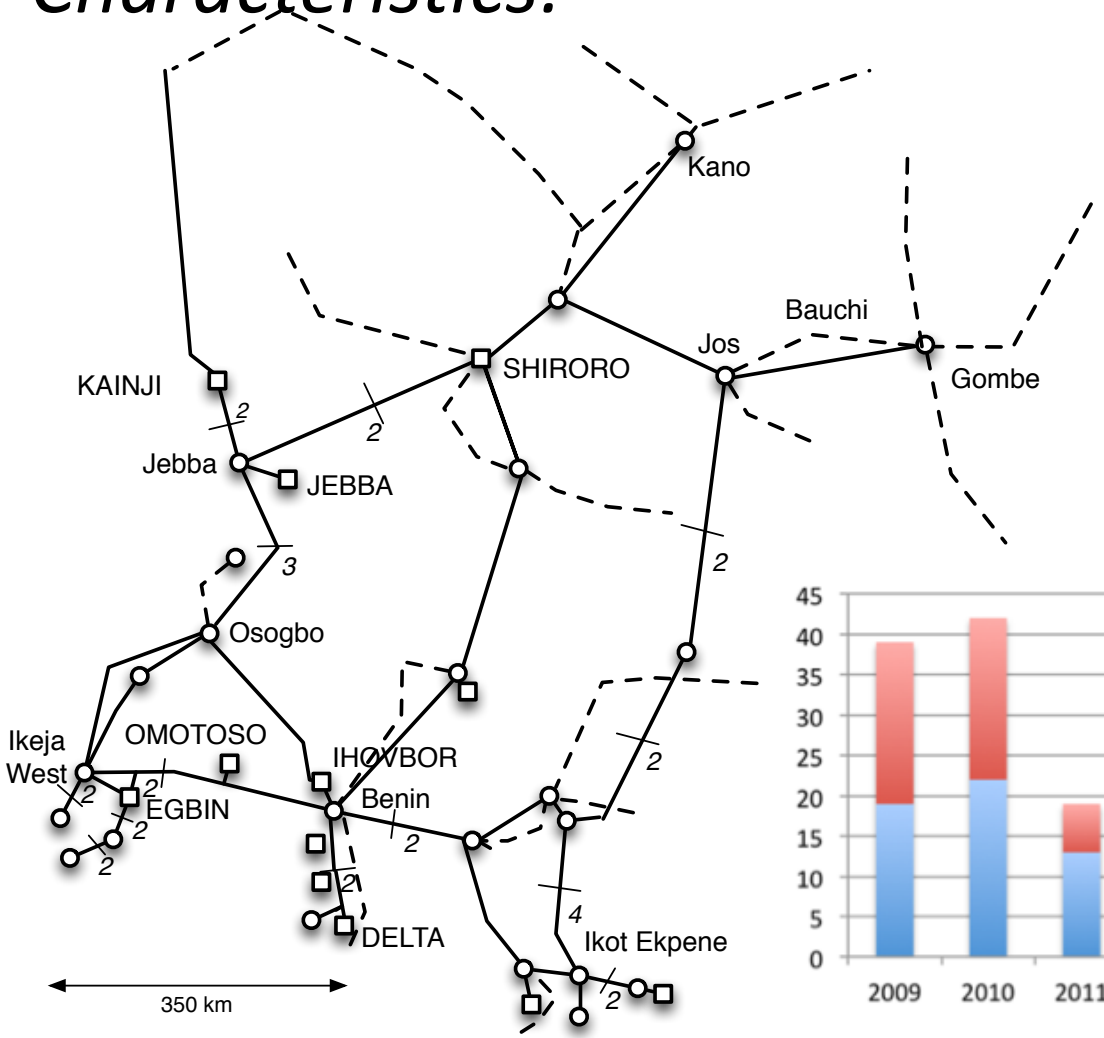
Peak load about 4.8 GW:

- Banks, hotels, small industry left grid due to intermittency, power quality

12 % Hydro, rest is gas power plants in South

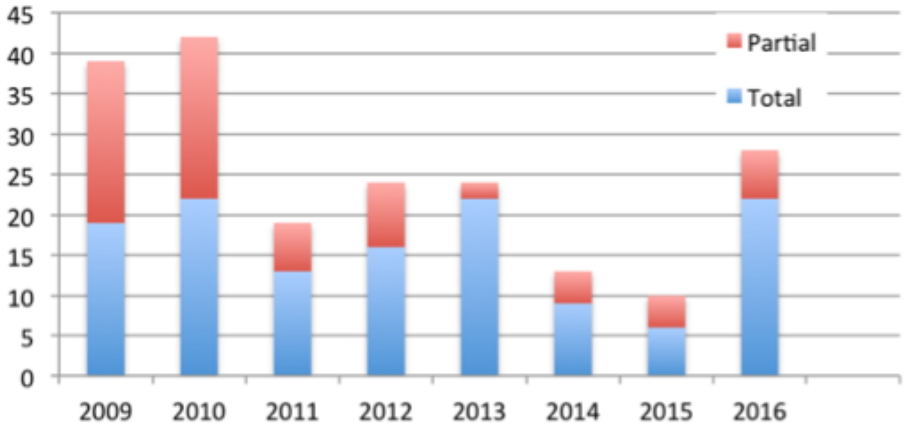
Nigerian High Voltage System

Characteristics:

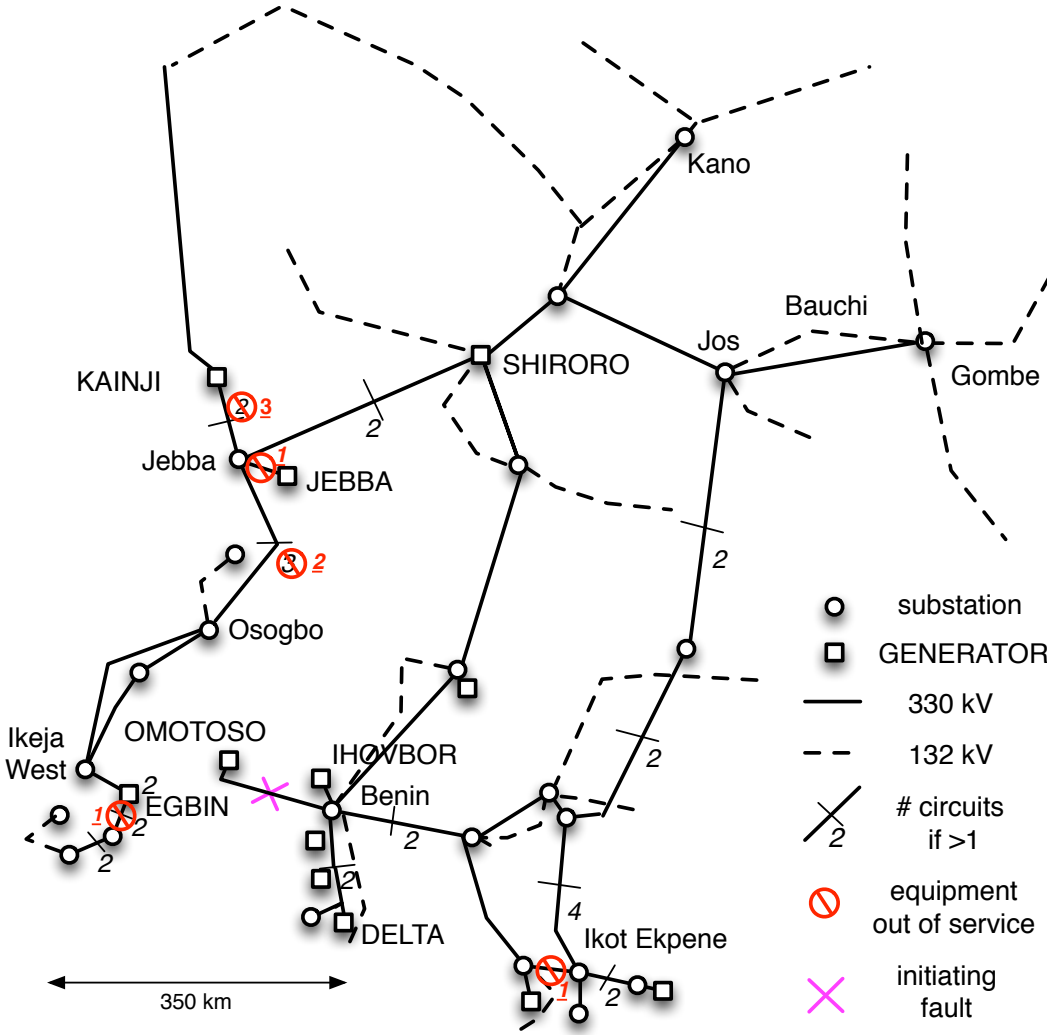


Frequent System Collapses:

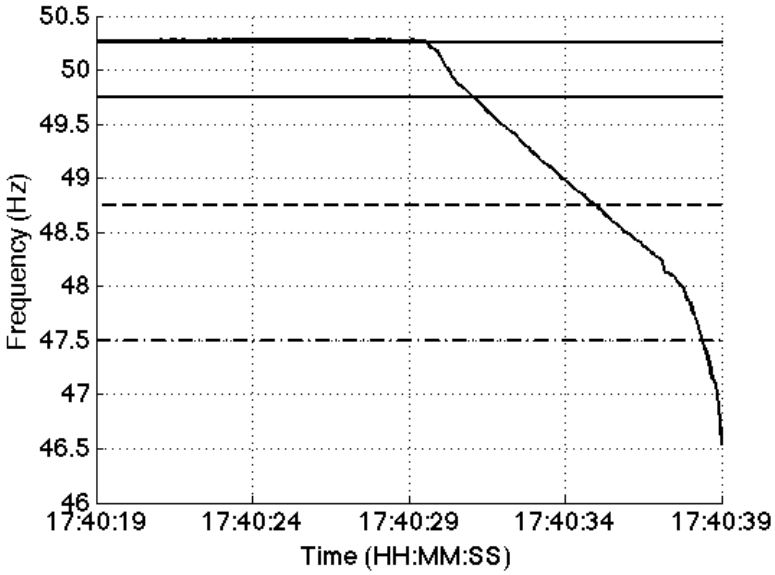
- Underinvestment
- Vulnerable network
- Equipment maloperation
- Limited situational awareness
- Monthly restoration from complete blackout



Nigerian High Voltage System:



System Collapse: June 27th, 2017

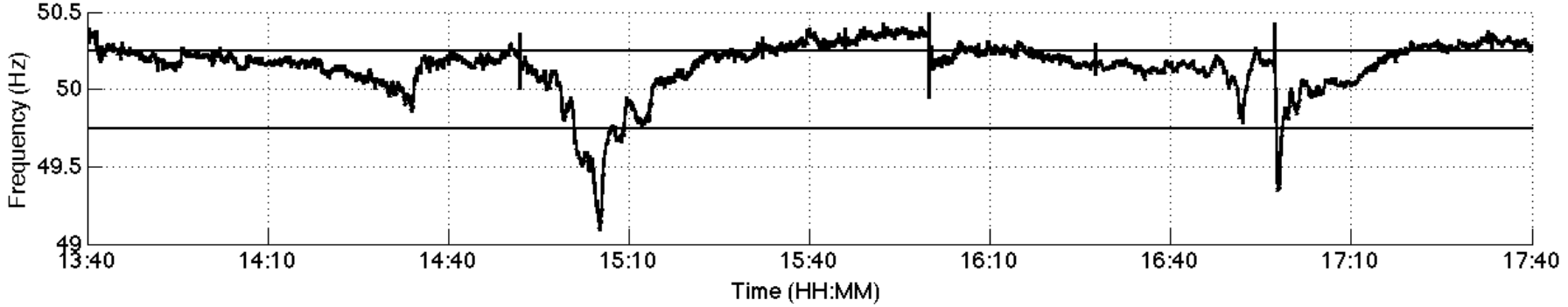


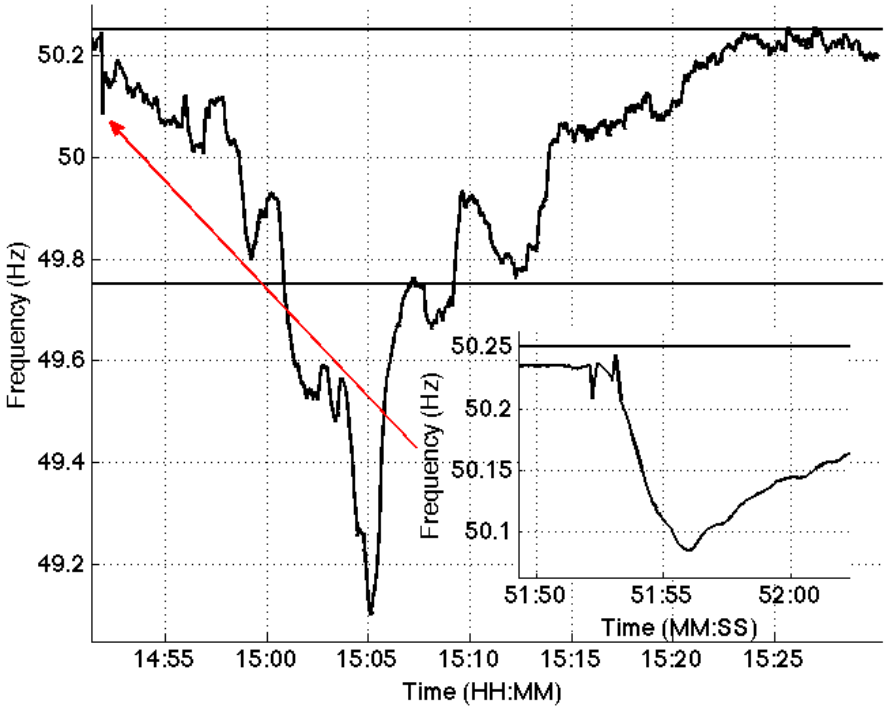
Loss of Omotoso:

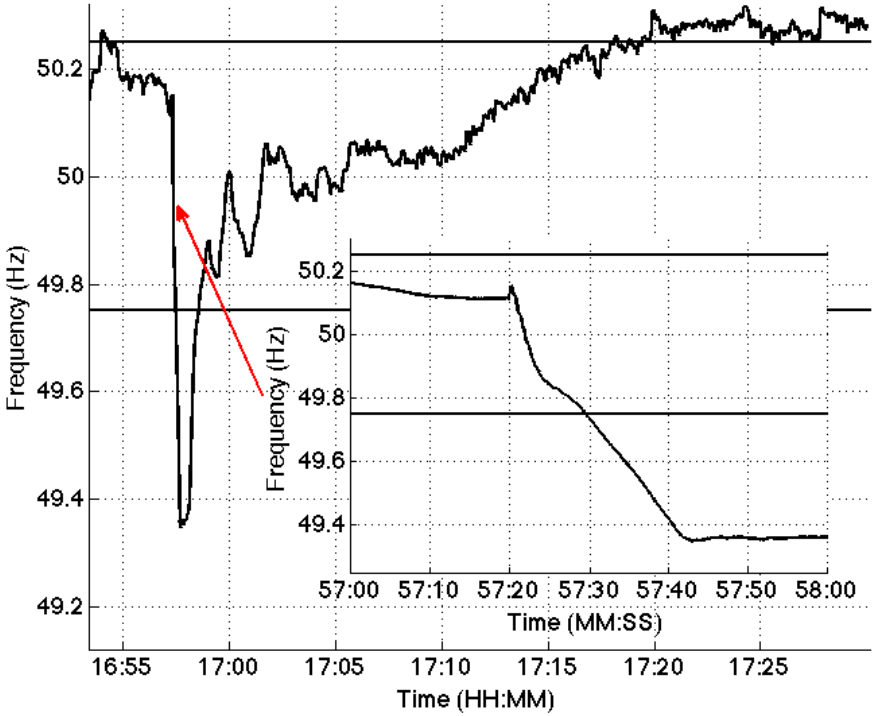
Not survivable event for full operation, too fast for operator reaction.

Nigerian High Voltage System:

Successful Defences: Generator droop, Operator

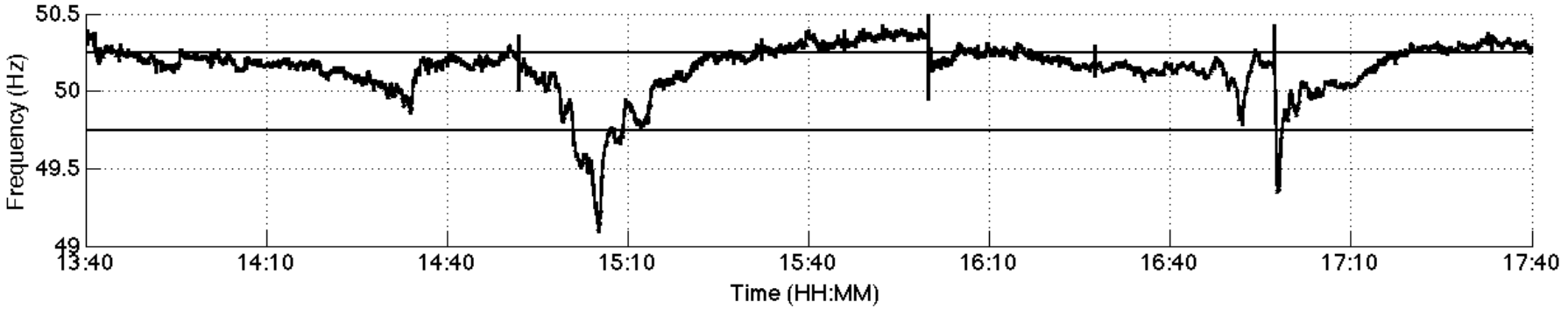




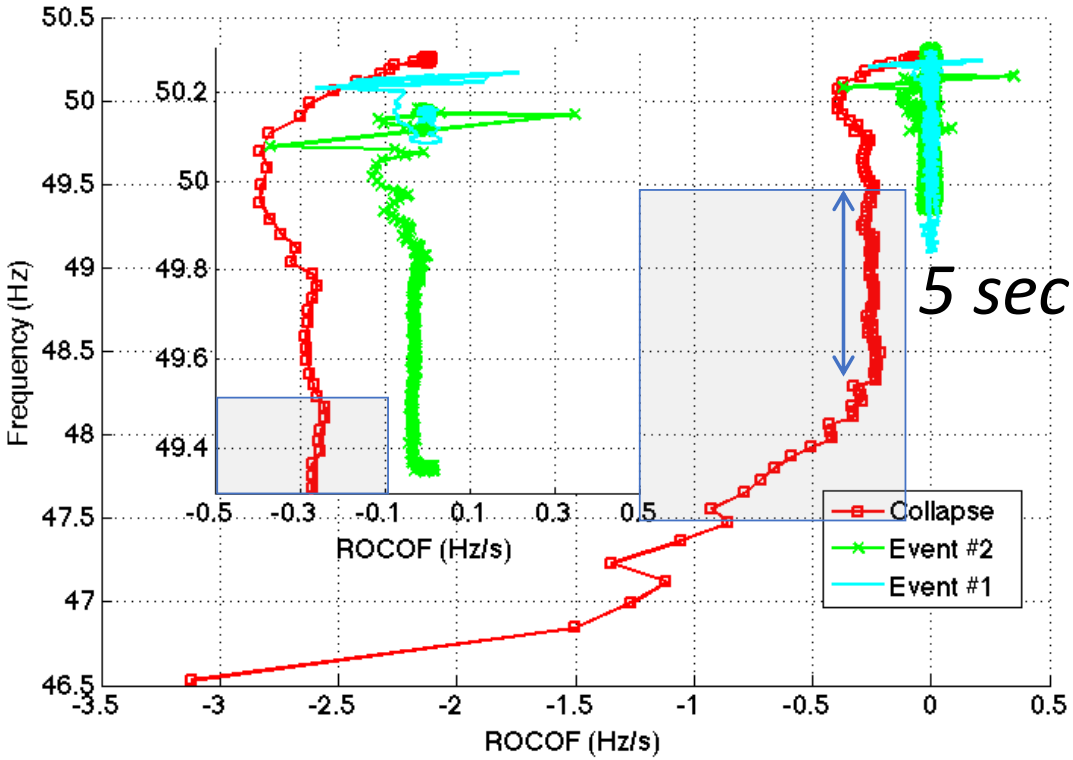


Nigerian High Voltage System:

Failed defence: Under-Frequency Load Shedding (UFLS)



Grey box: Designed Activation Zone of UFLS



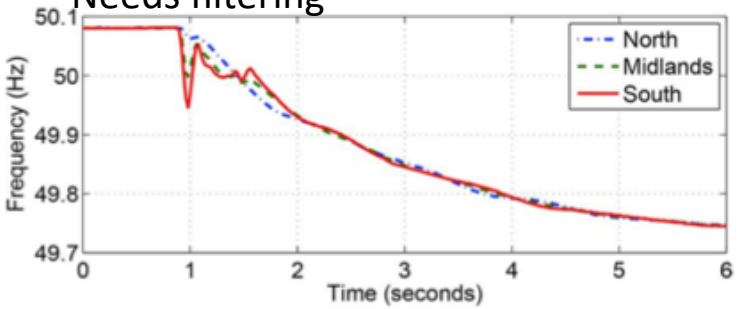
5 sec to react..

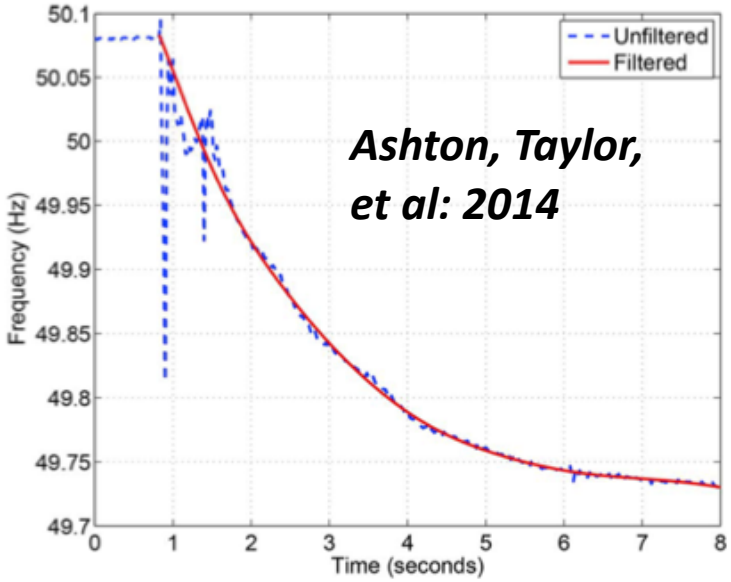
But didn't: disabled.

Distribution Board: "Goldilocks" location?

Proximity at transmission to bus:

Needs filtering





- Some natural filtering of frequency, as bus is deep among local motor loads?
- Witnessed whole event..

Distribution Board: "Goldilocks" location?

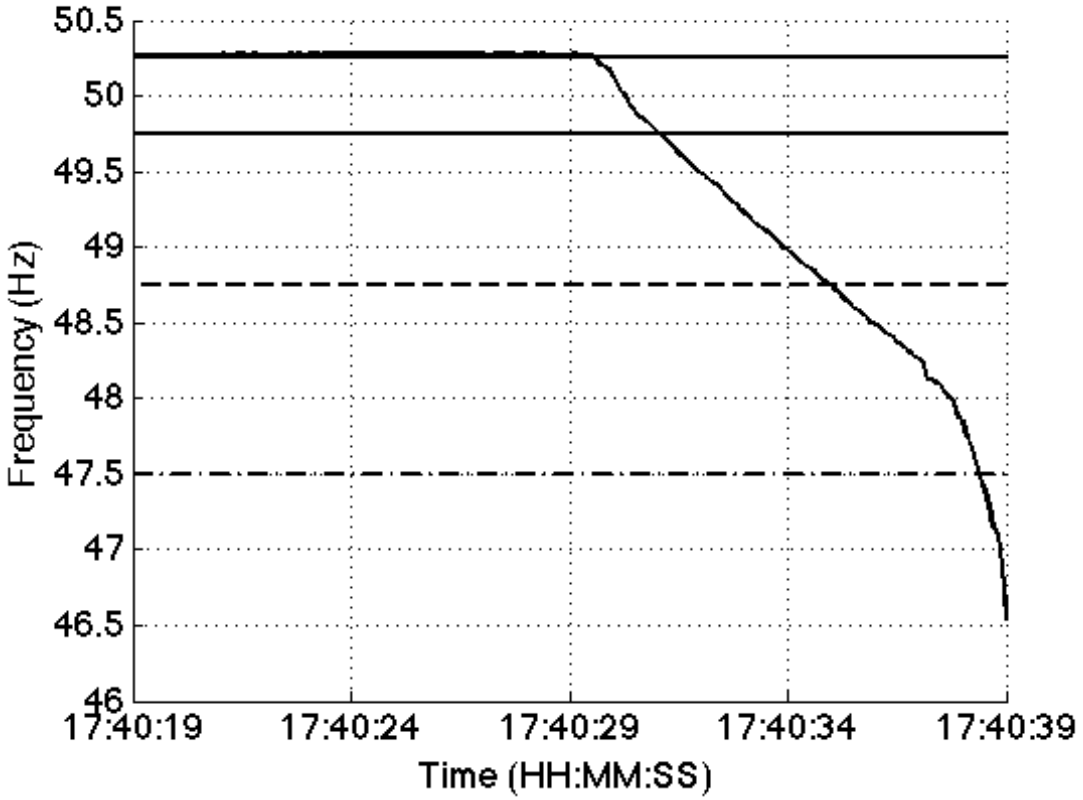
		Synchrophasor record?	Daily Operations	Collapse Report
28/09/2017	20:03	No	?	Yes
20/09/2017	15:17	No	?	Yes
18/09/2017	15:02	No	?	Yes
27/06/2017	17:40	Yes	Yes	Yes
08/05/2017	?	No	Yes	No
26/04/2017	05:32	No	No	Yes
04/12/2016	16:45	Low resolution, half day up to 6 min	Yes	Yes
24/11/2016	13:17	Yes	Yes	Yes
17/11/2016	19:19	Very poor record, 1 min before collapse	Yes	Yes
28/10/2016	17:04	No	Yes	Yes
10/07/2016	13:02	No	Yes	Yes
28/06/2016	13:49	No, load shed	Yes	Yes
23/06/2016	09:52	No, no record on day, begins after	Yes	Yes
22/06/2016	14:53	No, 3 hour record ends 9:32, begins after restoration	Yes	Yes

- Some natural filtering of frequency, as bus is deep among local motor loads?
- Witnessed whole event..
- ….. but missed many others

Making do with: being load shed

Making do with: local behaviour

System Collapse:
June 27th, 2017

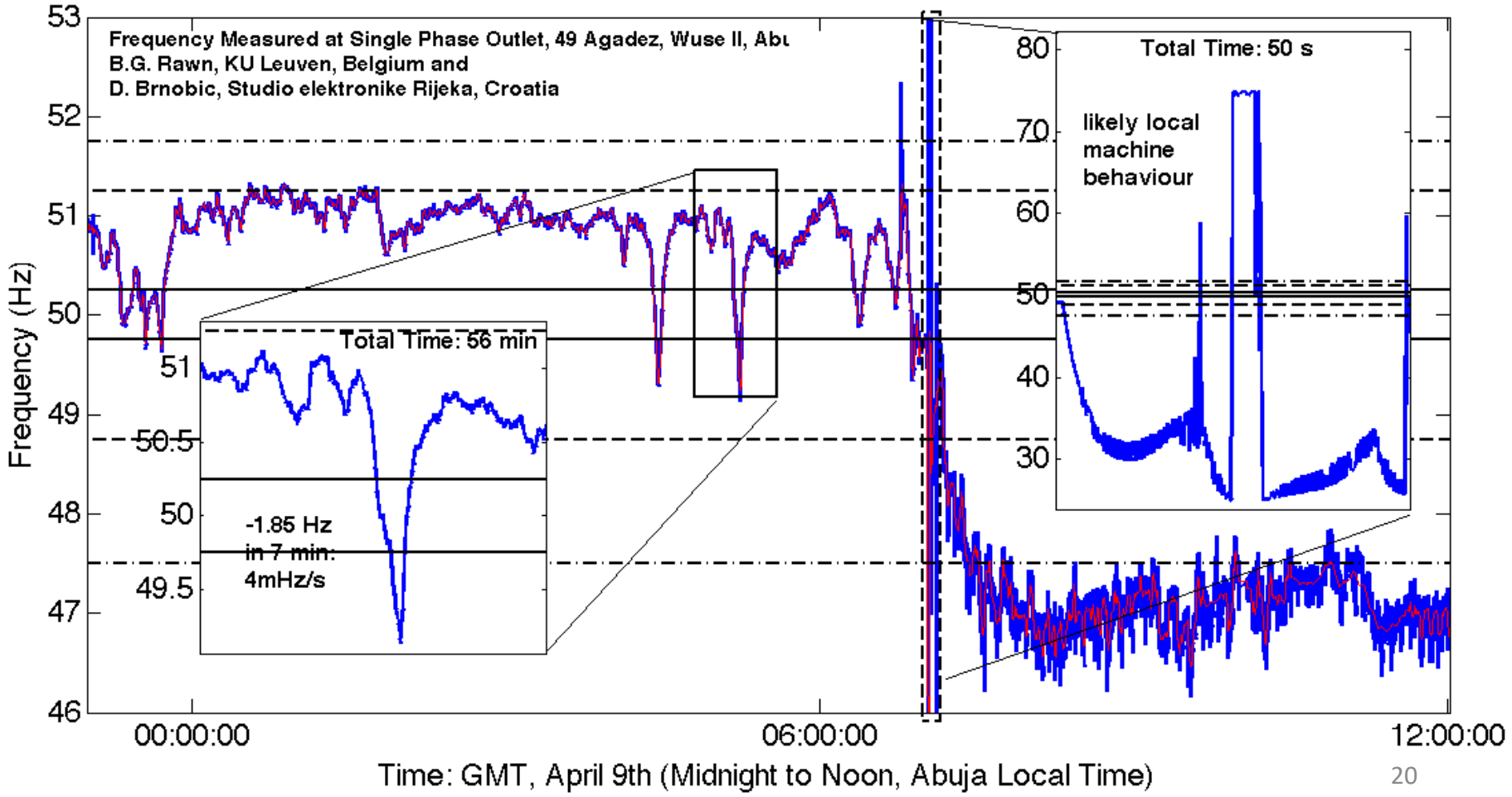


Credible transmission system behaviour

Making do with: local behaviour

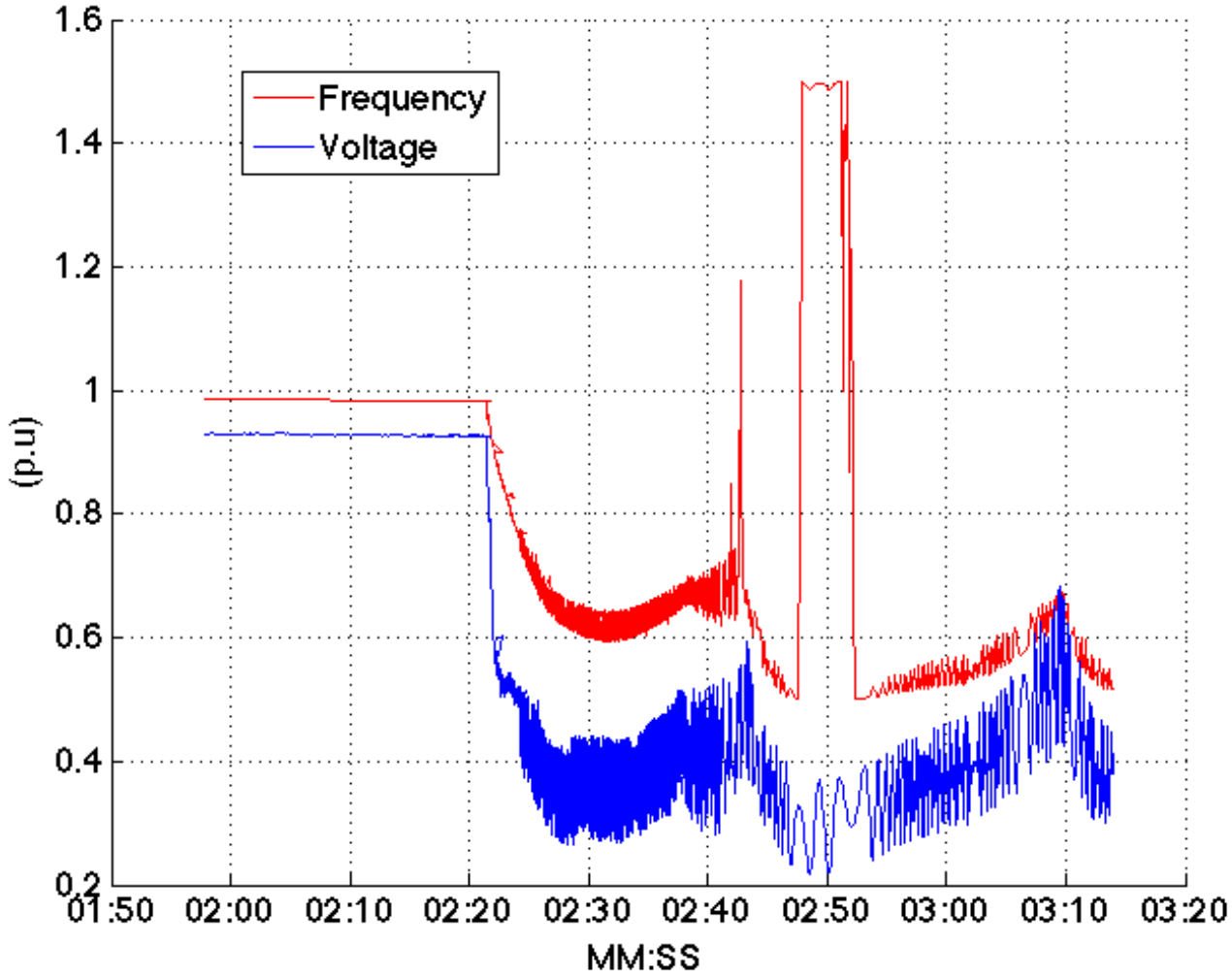
Making do with: local behaviour

-example of common midday transient: separation?
-grid connected, then 1-2 minutes of odd local behaviour, then diesel genset for remainder of day.



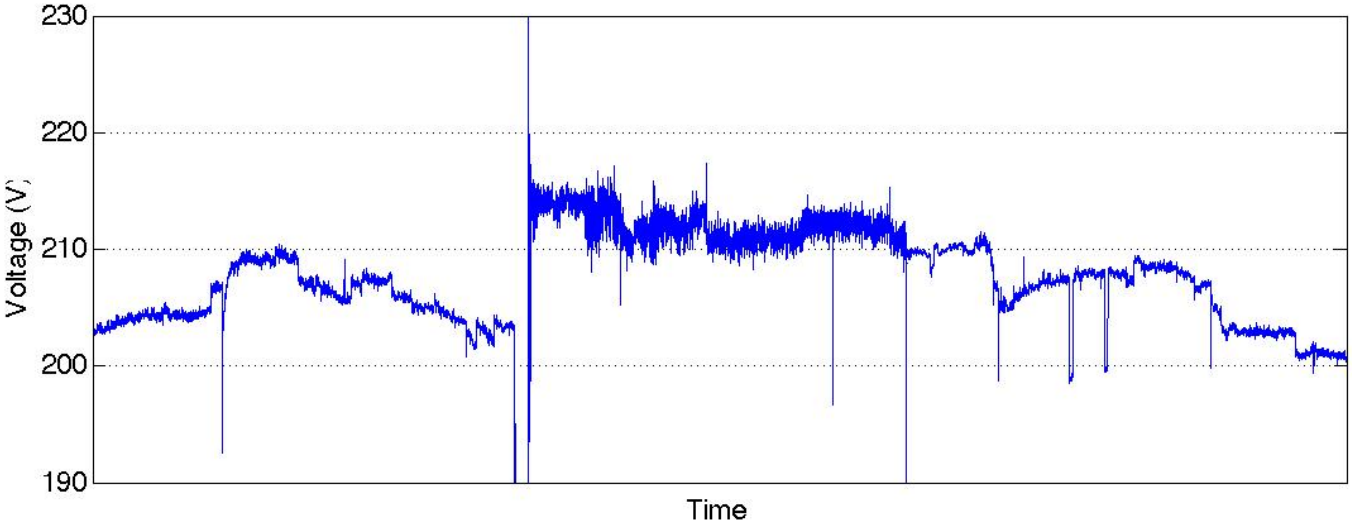
Making do with: local behaviour

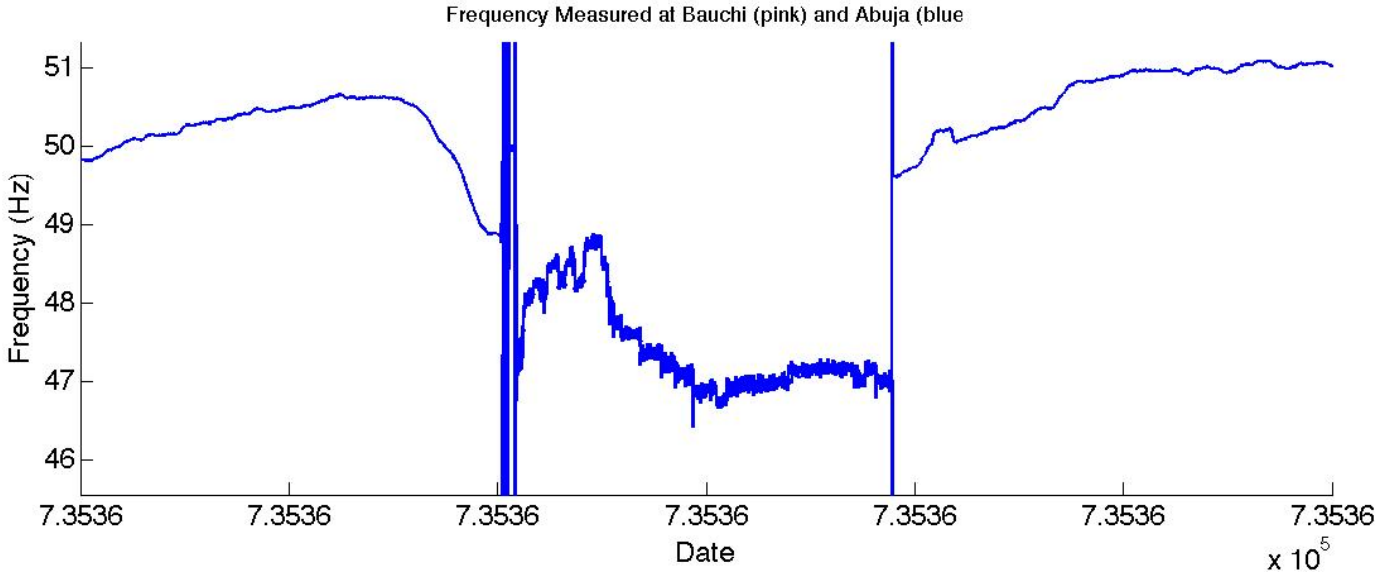
Sample Transient: 1.5 minutes



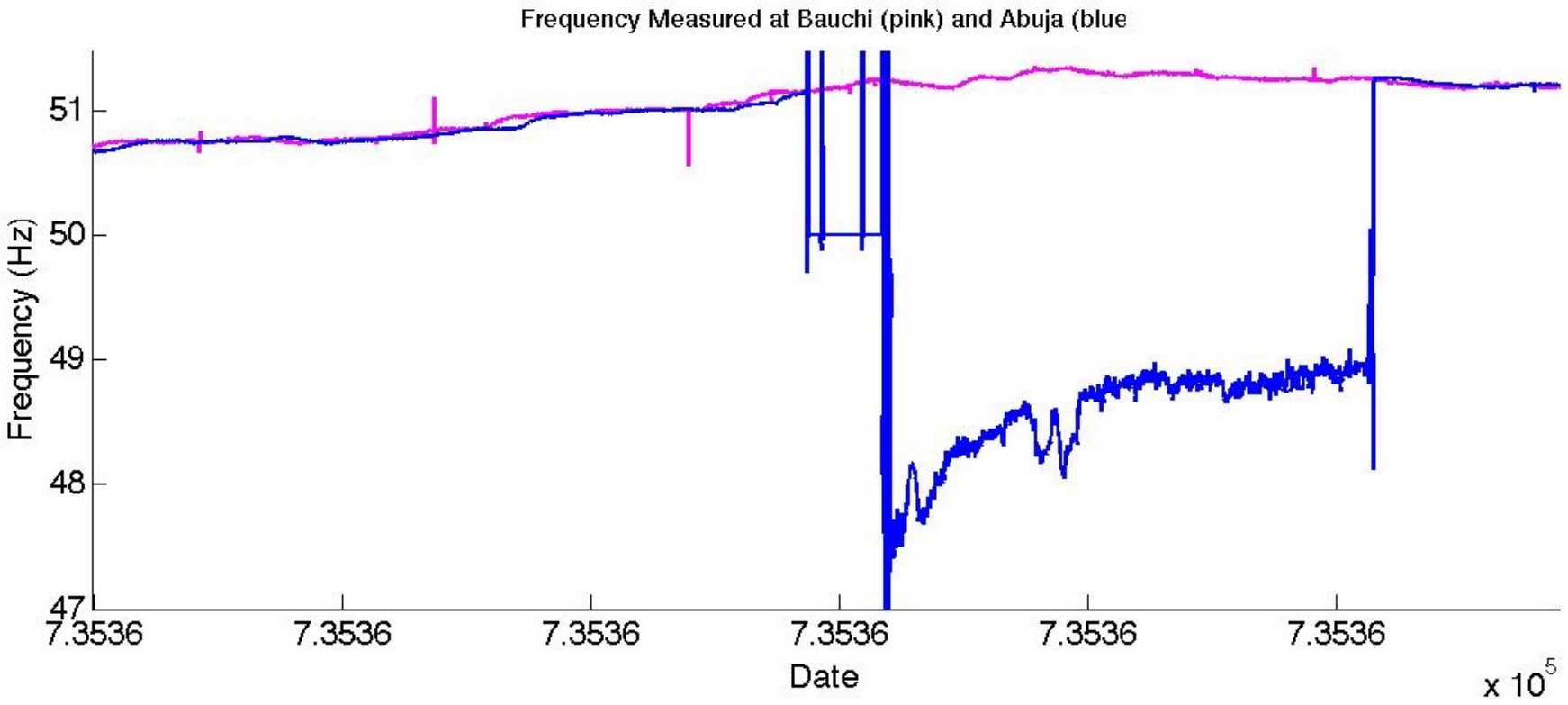
Is this
-a local motor load,
-some DG,
-a generator not tripped out on underfrequency?
-garbage?

Question: Backup-Gen or Separation?





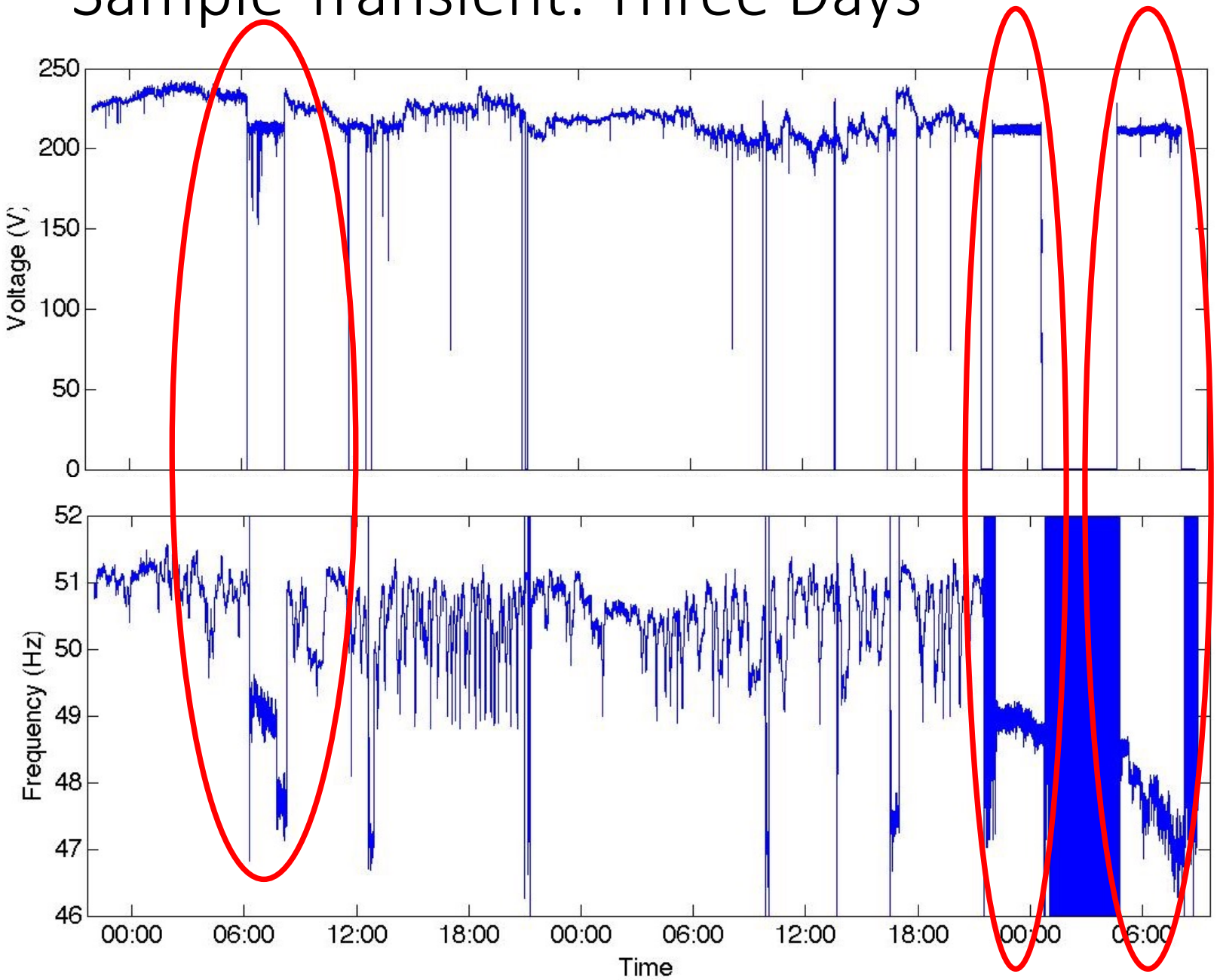
Question: Backup-Gen or Separation?



-Two measurements: FDR Abuja (residential), and 400 km away in Bauchi (substation); appears to be 12 s timestamp shift

-Clearly not synchronous: looks like 50Hz startup, followed by loading

Sample Transient: Three Days



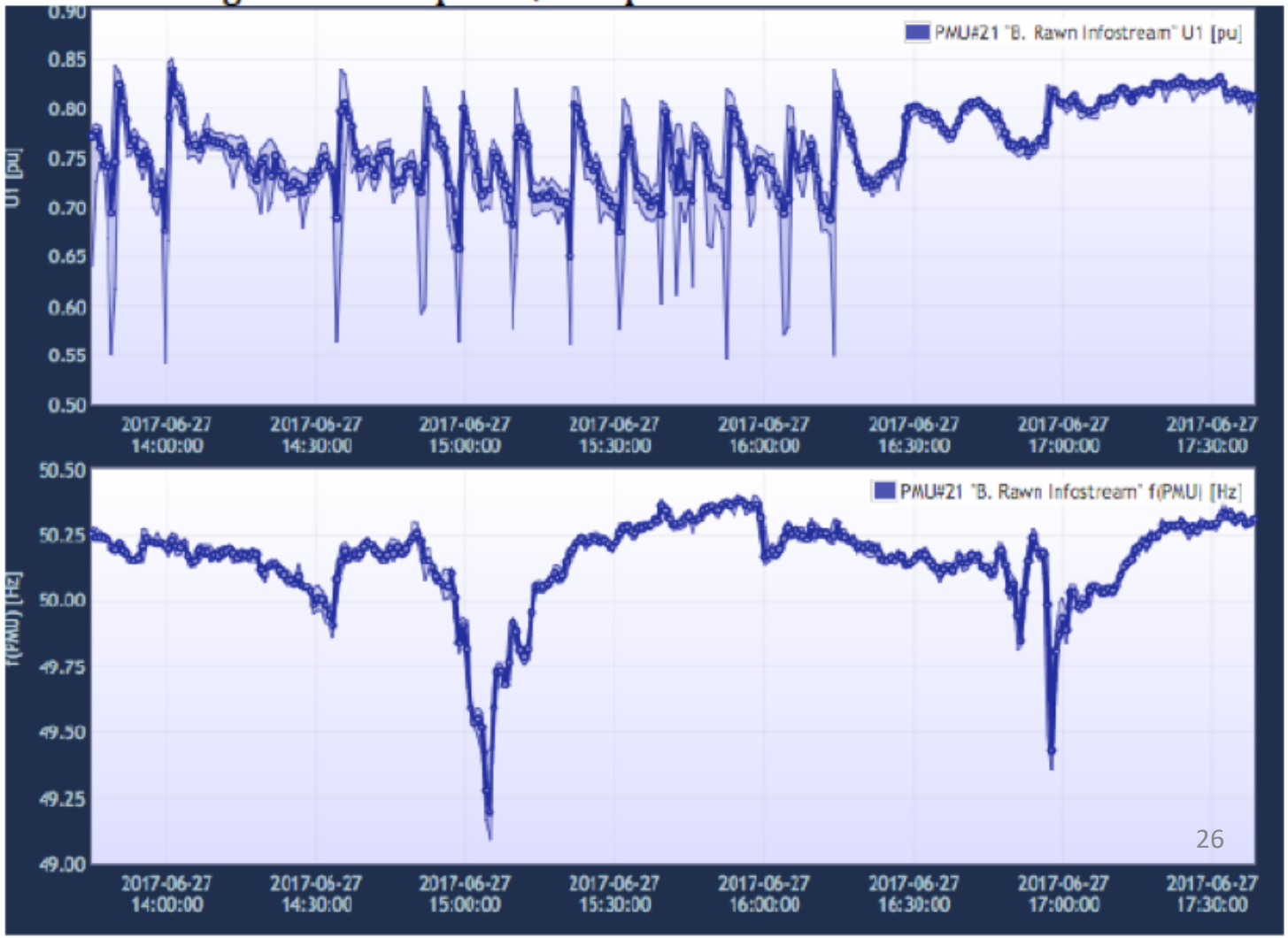
Interpretation

- Concepts
  - Local loads: mostly affect voltage, suspiciously fast frequency changes
  - Line switching, trips: mostly appear in voltage, but if significant, also frequency
  - Generation/load trips: mostly affect frequency
  - System in trouble: increasing correlation between voltage and frequency
- Crude metrics
  - Step detection using numerical derivative
  - Standard deviation
  - Covariance

Nigerian High Voltage System:

Example: independence of frequency, voltage; local trends

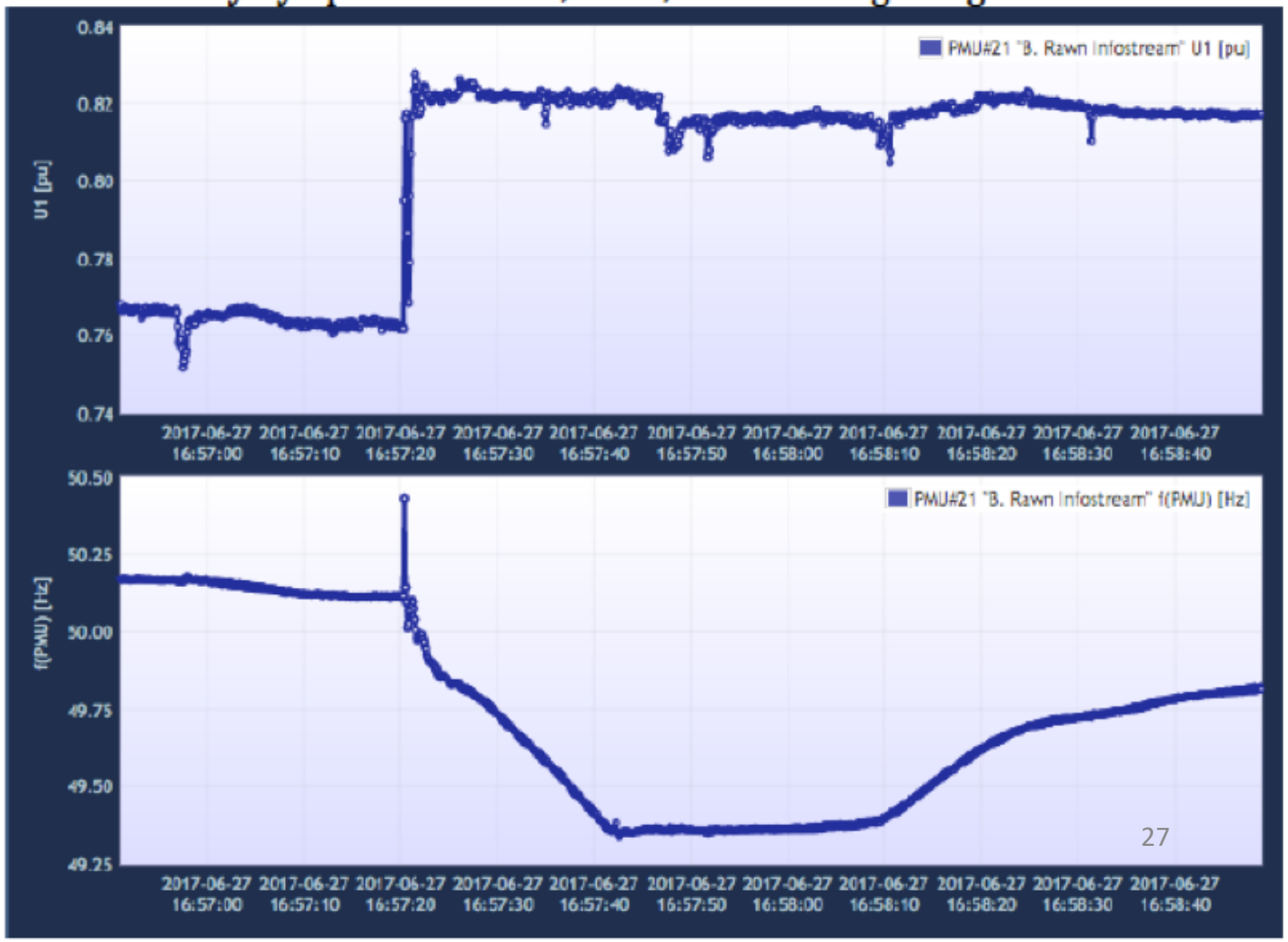
Three and a half hours preceding collapse: frequency regulation was good due to units on free governor response, except for two disturbances at 3PM and 5PM:



Nigerian High Voltage System:

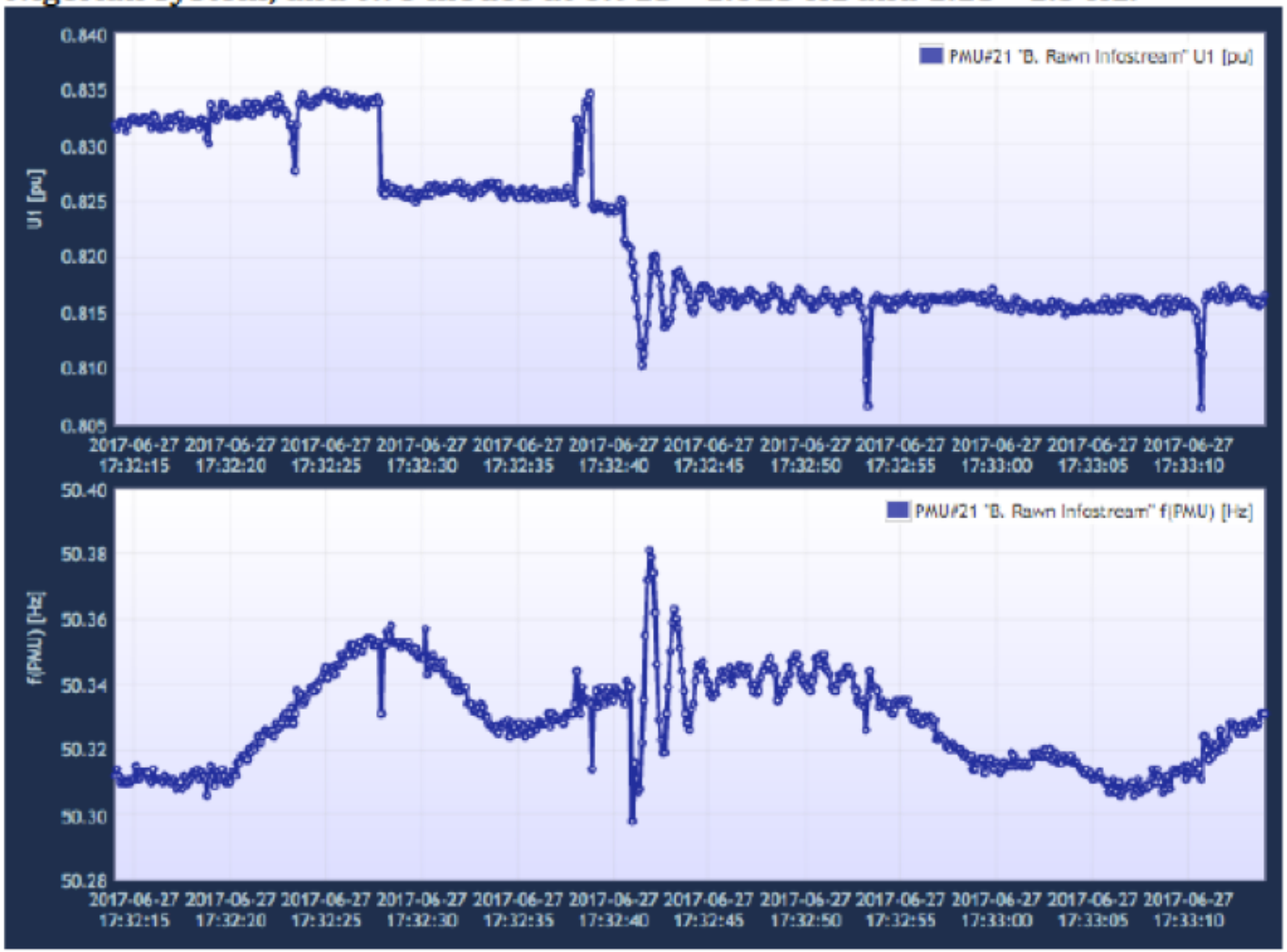
Examples: significant system event involves co-varying

2 minute period focusing on 16:57:20 event: at 16:57:40, the fall of frequency is arrested stiffly by operator action, UFLS, or exceeding of a governor deadband.



Nigerian High Voltage System:

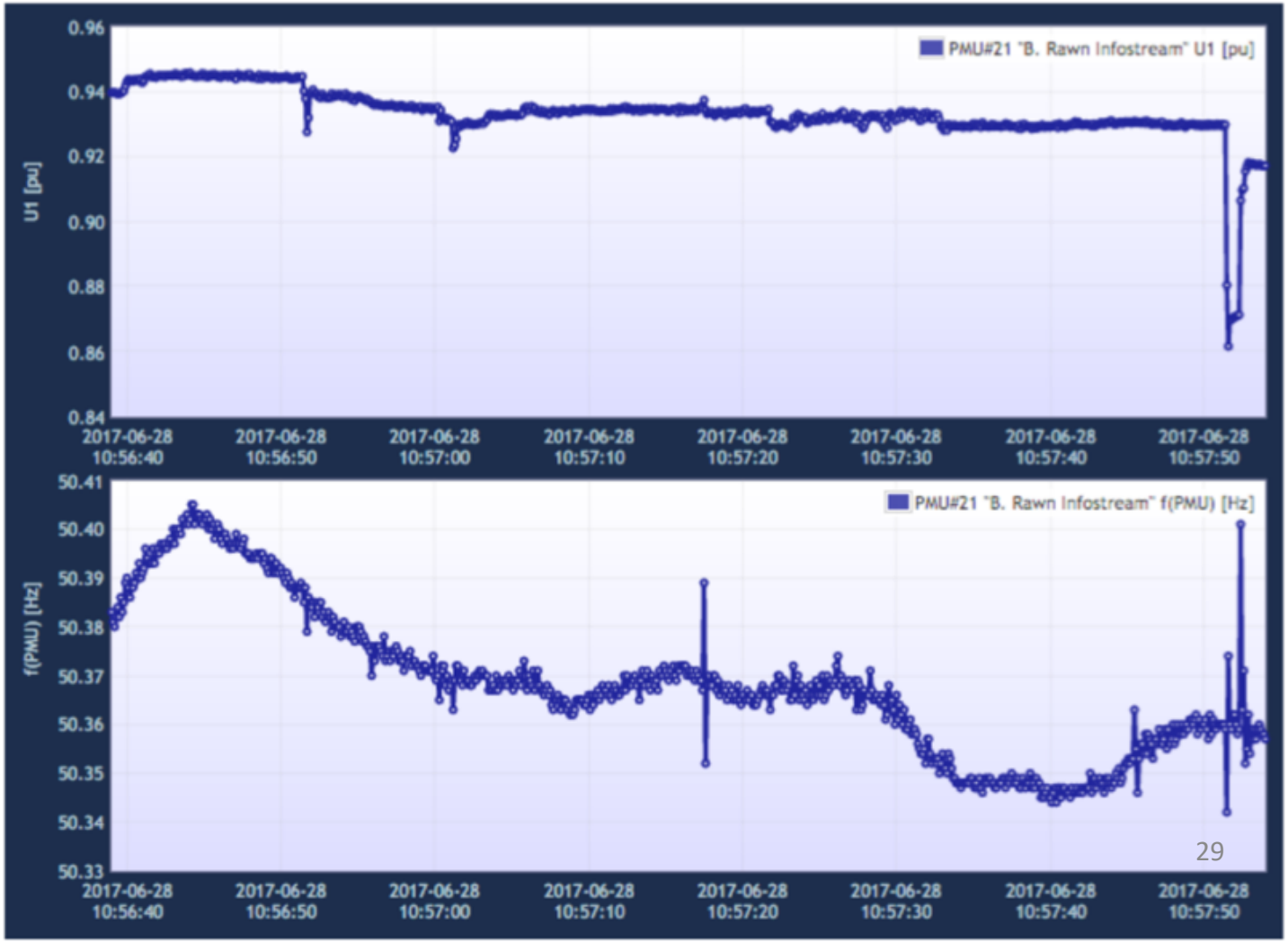
Significant oscillations appear in both local voltage and local frequency, with a frequency slightly less than 1 Hz, which could be a local mode of a generator against the system. Note that a 2010 conference paper detected a 0.2 Hz inter-area mode in the Nigerian system, and two modes at 0.915 - 1.025 Hz and 1.15 - 1.3 Hz.



Nigerian High Voltage System:

Monitoring and confirming events

10: 10:55Hrs, Geregu P/S was instructed to reduce generation by 50MW. Frequency was 50.40Hz.



Nigerian High Voltage System:

Monitoring and confirming events

11. 11:17Hrs, Jebba P/S 2G2 was shut down for frequency management. Frequency was 50.38Hz. Load loss = 88MW.

No comment is made about this otherwise significant event at 3:06AM

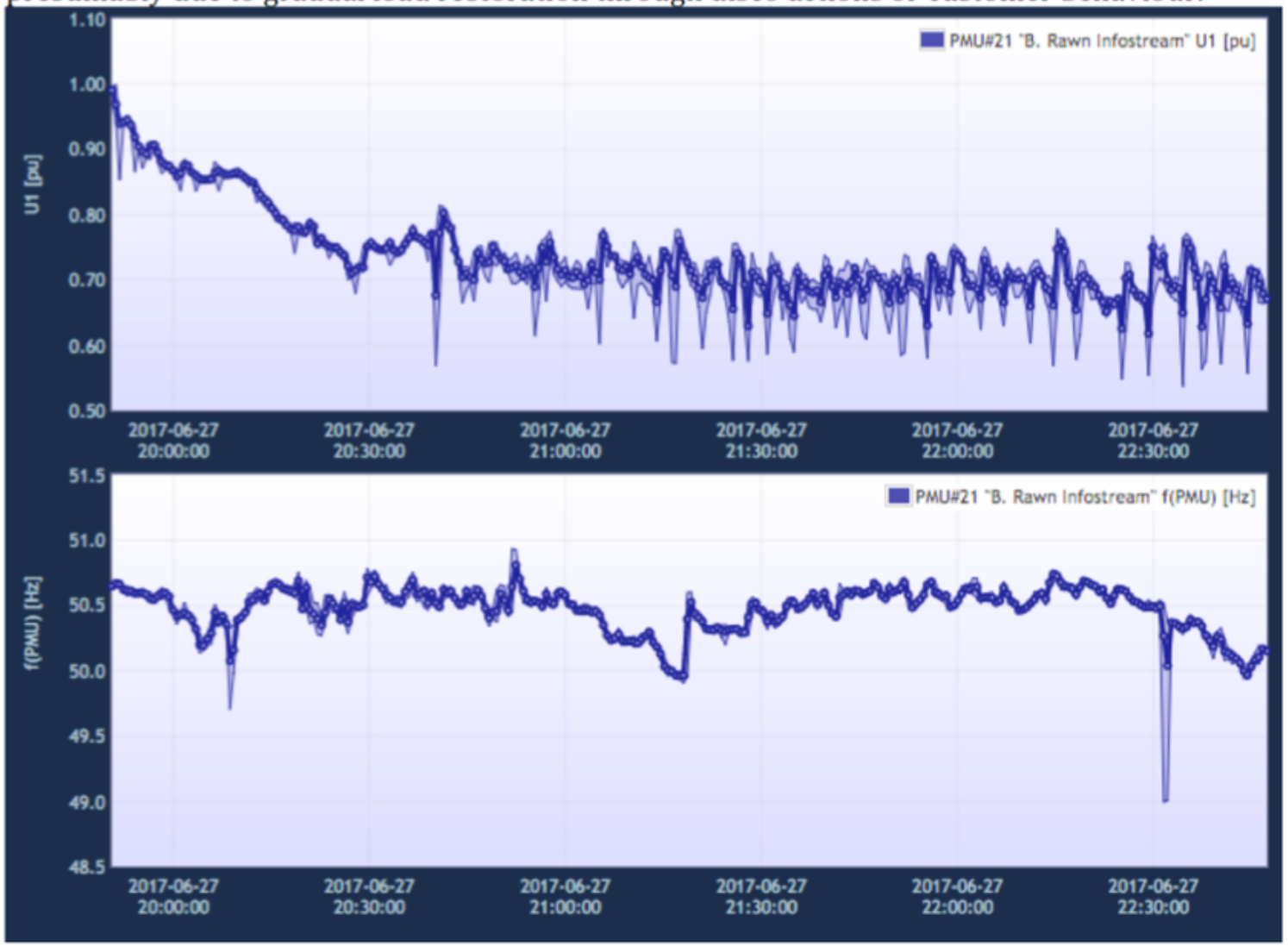
but it may be related to the following miscellaneous event noted in the NOR.

6. 03:30 – 09:25Hrs, Kainji P/S 1G5 was shut down for frequency management. Load loss = 72MW. Frequency was 50.45Hz.

Nigerian High Voltage System:

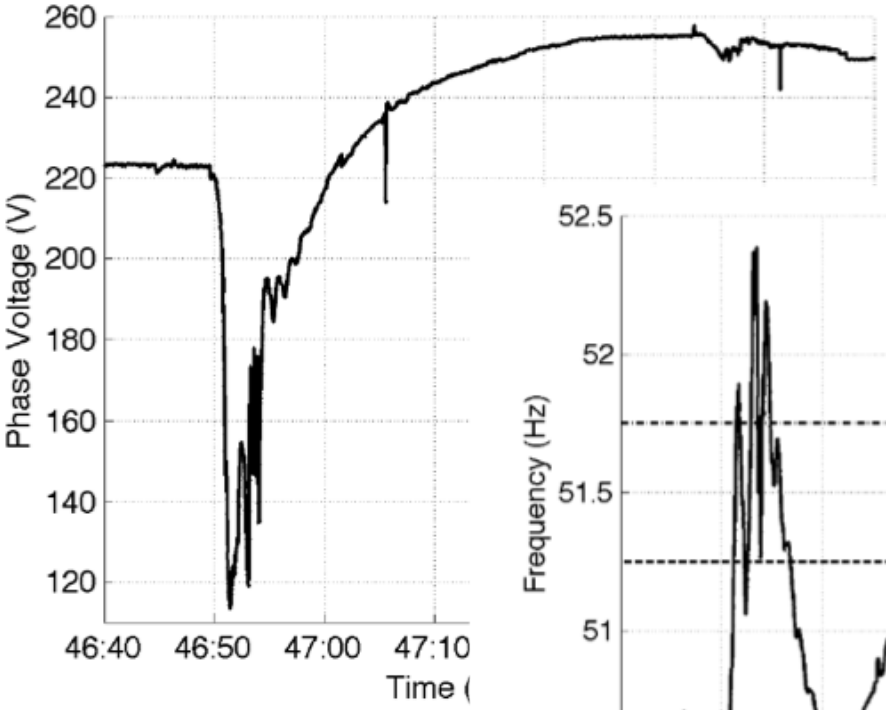
Habitual &recurring events

This particular part of Victoria Island receives NEPA again between 7PM and 8PM, until 22:50. An 80 minute interruption occurs, after which power is present into the next day starting from 00:10:00. Each time power is restored, a 10-30 minute lowering of voltage seems to occur, presumably due to gradual load restoration through disco actions or customer behaviour.



Nigerian High Voltage System:

Forensics, Precursors



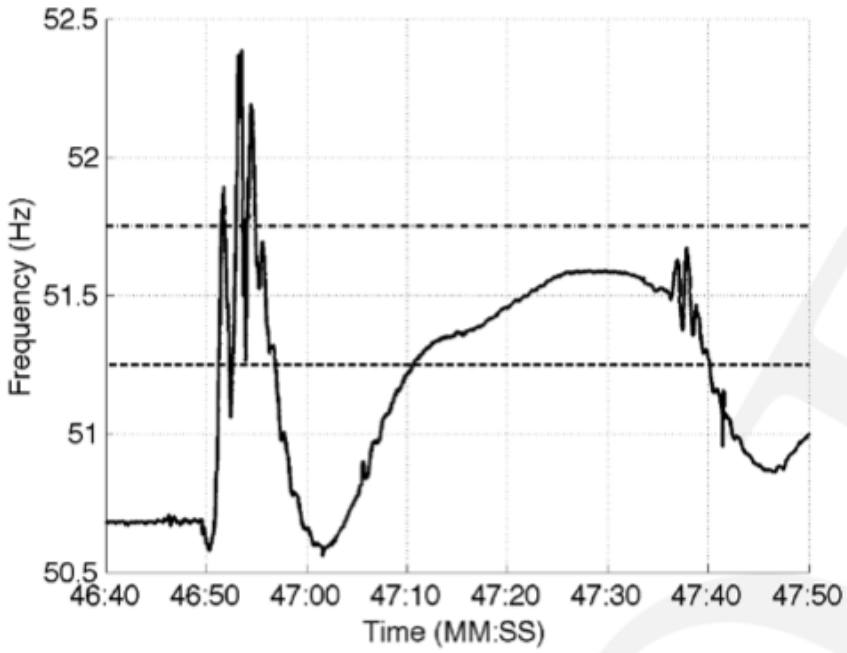
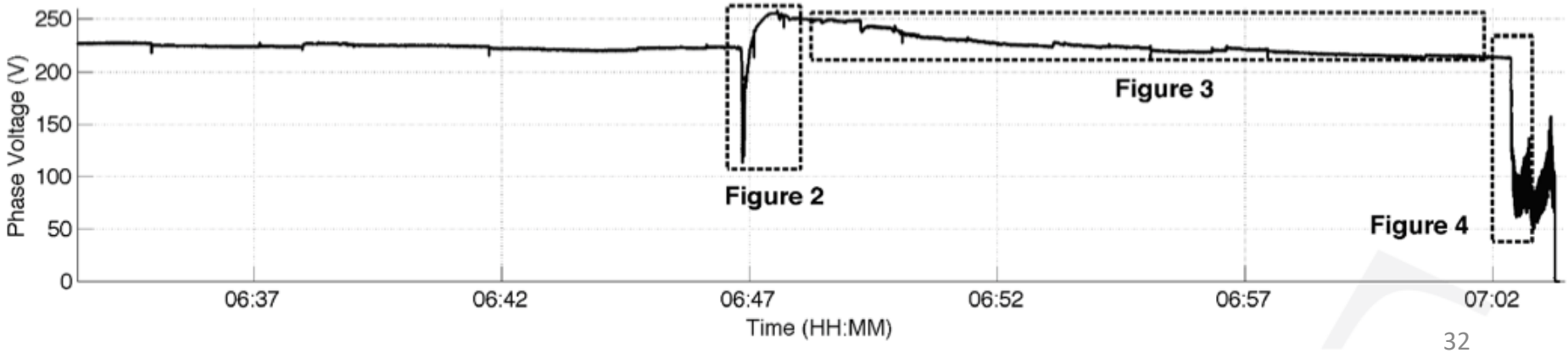


Figure 2: Details of disturbance.



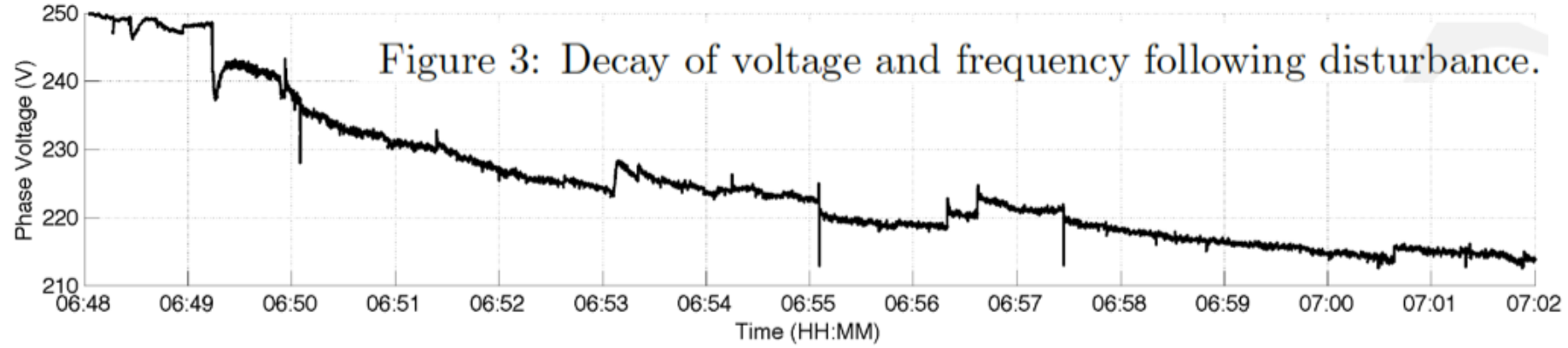
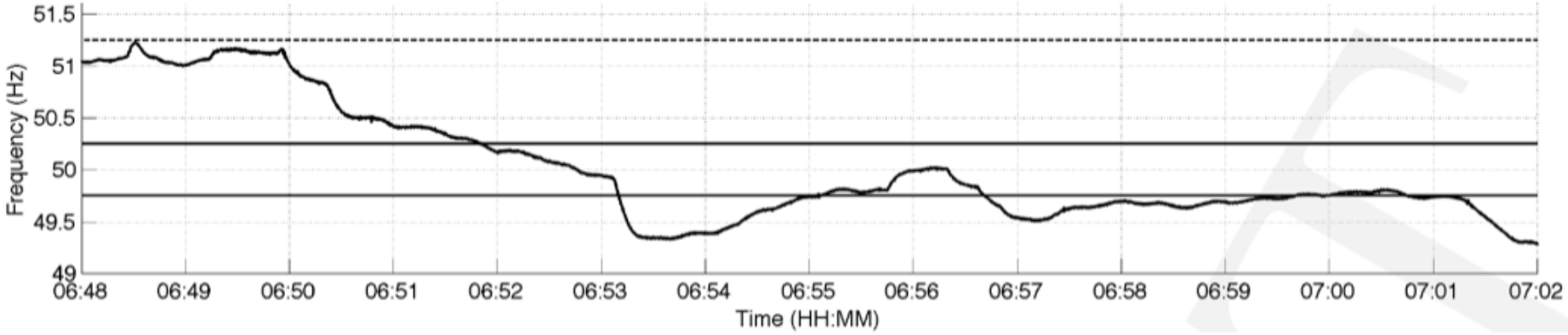
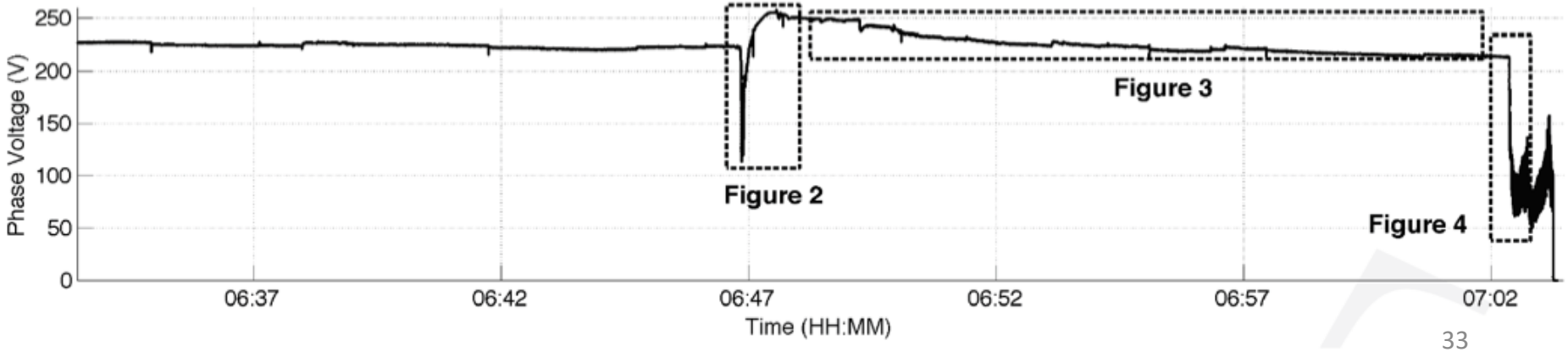


Figure 3: Decay of voltage and frequency following disturbance.

(a)





Speculation and Applications

Speculation and Applications

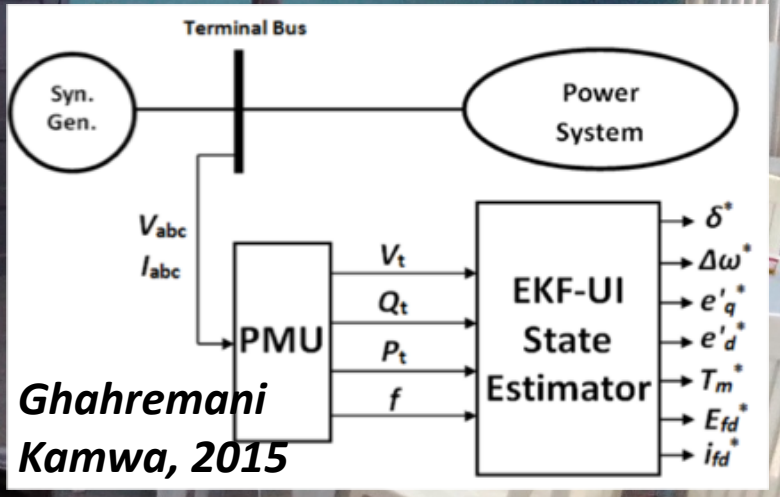
- Analysis methods
  - Cross-spectral density between voltage and frequency
  - Automatic event detection
  - Removal of habitual events; phase issues make strict hourly binning ineffective

- “Killer Apps”

Synchrophasor Analytics: for Auditing

Killer App #1: Online Compliance Monitoring

Confirm unit availability , contributions to droop, inertial response



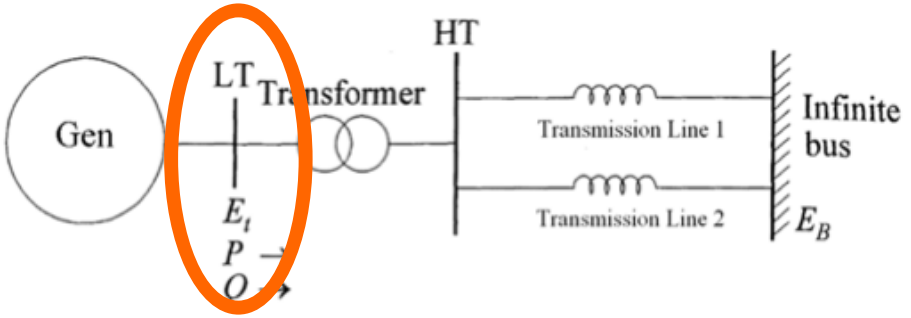
Ghahremani Kamwa, 2015

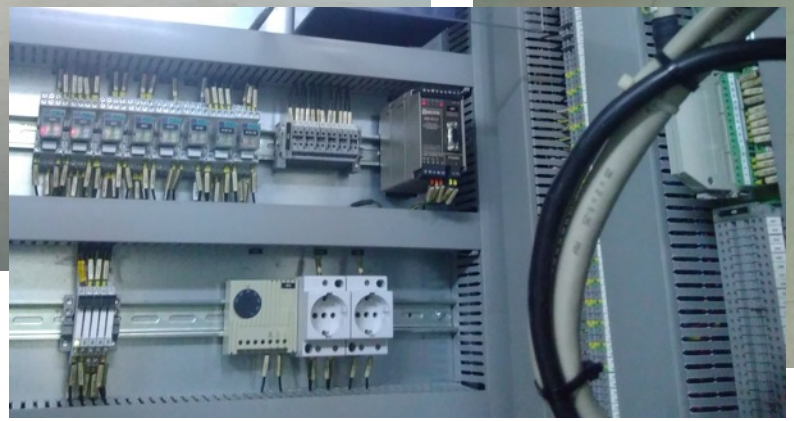
Tochi Nwachukwu SA to President on Power Privatisation

Maintain incentives and penalties for automatic control

Odukpani Generating Station Project

Phase 1: Direct Generator Monitoring, STER PMU



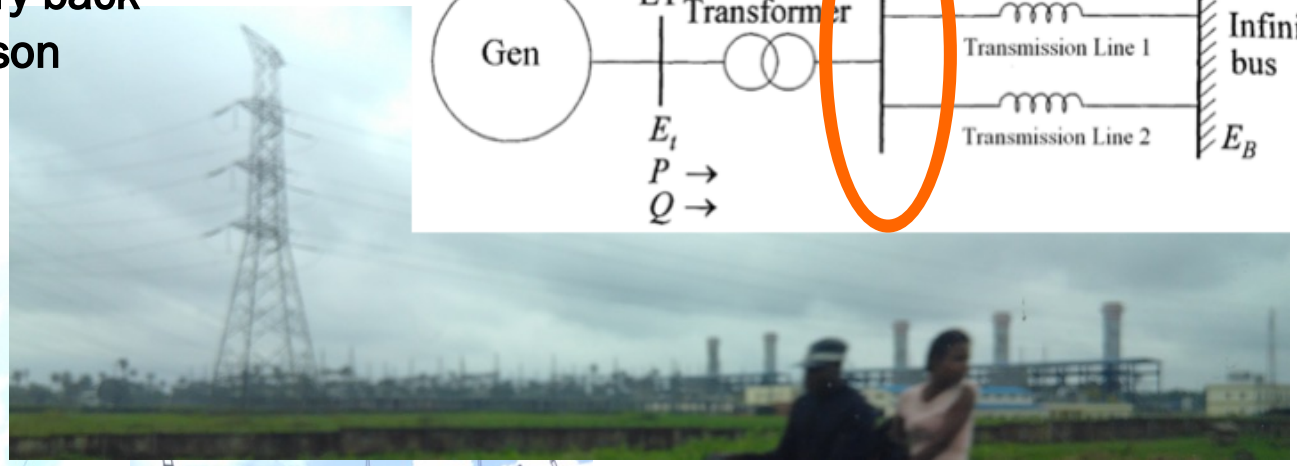


Verify parameter estimation algorithms for simplest case; Validate part of dynamic model

Odukpani Generating Station Project

Phase 2: Whole Facility Monitoring, OpenPMU

Safe enclosure with battery back up being designed by Nelson Carsane, Level 3 Student



Confirm monitoring can monitor unit status from TCN property

Speculation and Applications

- Recommended analysis methods to explore
  - Cross-spectral density between voltage and frequency
  - Automatic event detection
  - Removal of habitual events; phase issues make strict hourly binning ineffective

- “Killer Apps”
  - An actual need for PMUs
  - Enabling new behaviour in the sector
  - Examples include
    - Collapse forensics: continuing analysis of blackout events with PhD student, and transmission company staff
    - Compliance monitoring: detection of number of generators running, implied reserve levels, and governor response.

- Not just making do: Investigations of DisCo Power Quality, Interventions