Panel Session:
Synchro-Waveforms: Principles, Data-Analytics, and Applications

Synchronized waveform data: the next advancement in power apparatus and system monitoring

Presented by
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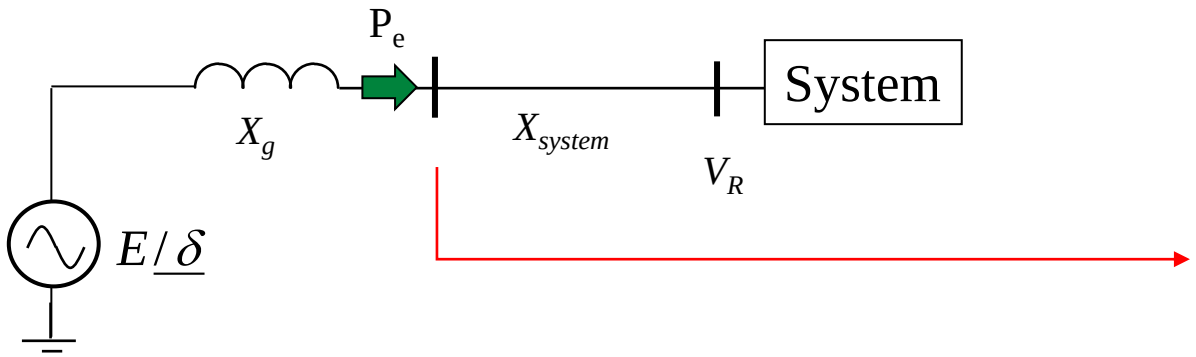
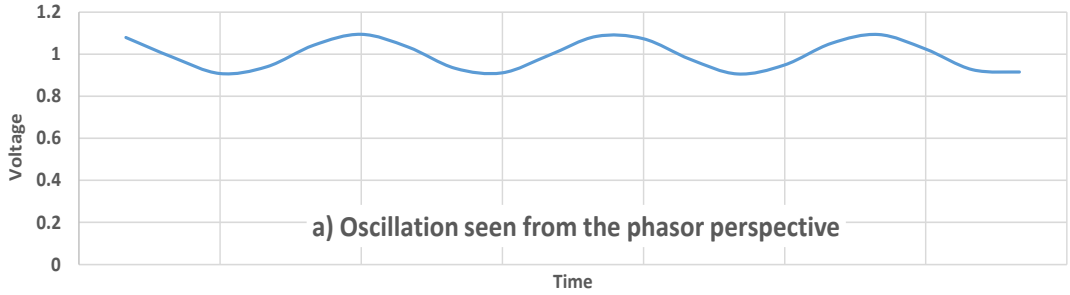
Outline

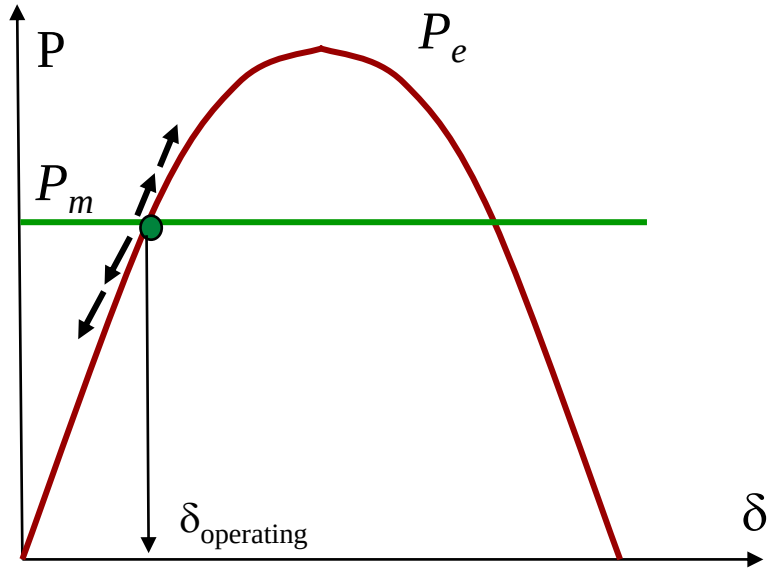
1. **Insights from waveform data – an example**
2. **Status of synchronized waveform data**
3. **How to move forward**
   - Three application platforms
   - Five application development strategies
4. **Conclusions and takeaways**

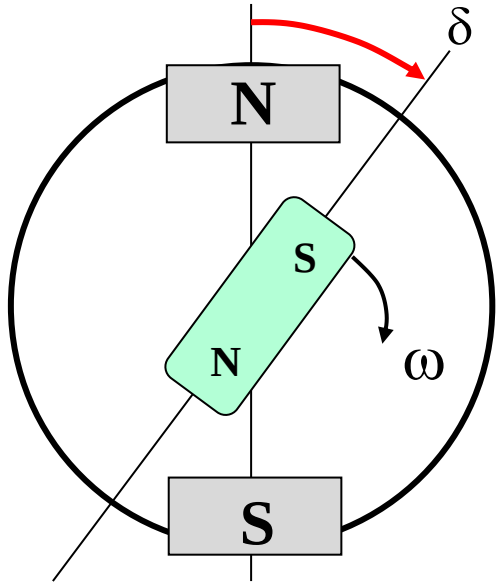
1. Insights from waveforms – an example

The phenomenon of generator oscillations: phasor perspective





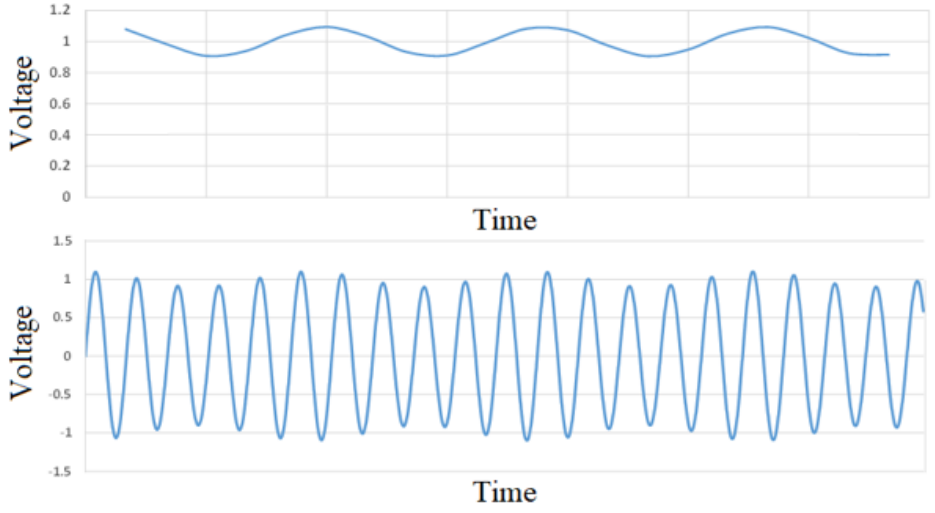


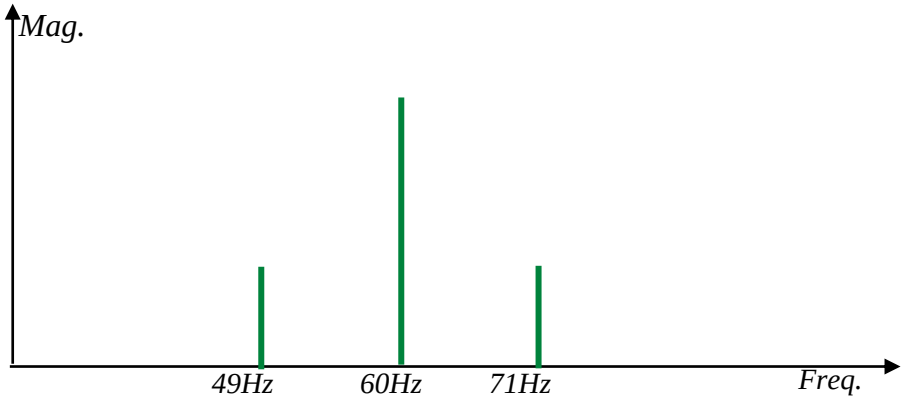


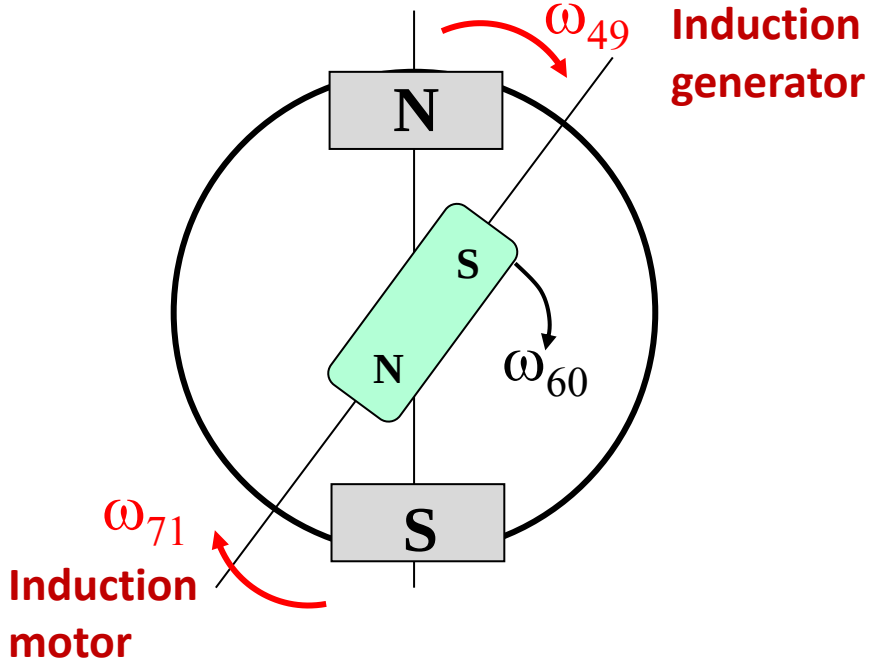
Why rotor oscillates when the stator field is just a pulsating field?

1. Insights from waveforms – an example

The phenomenon of generators oscillations: waveform perspective





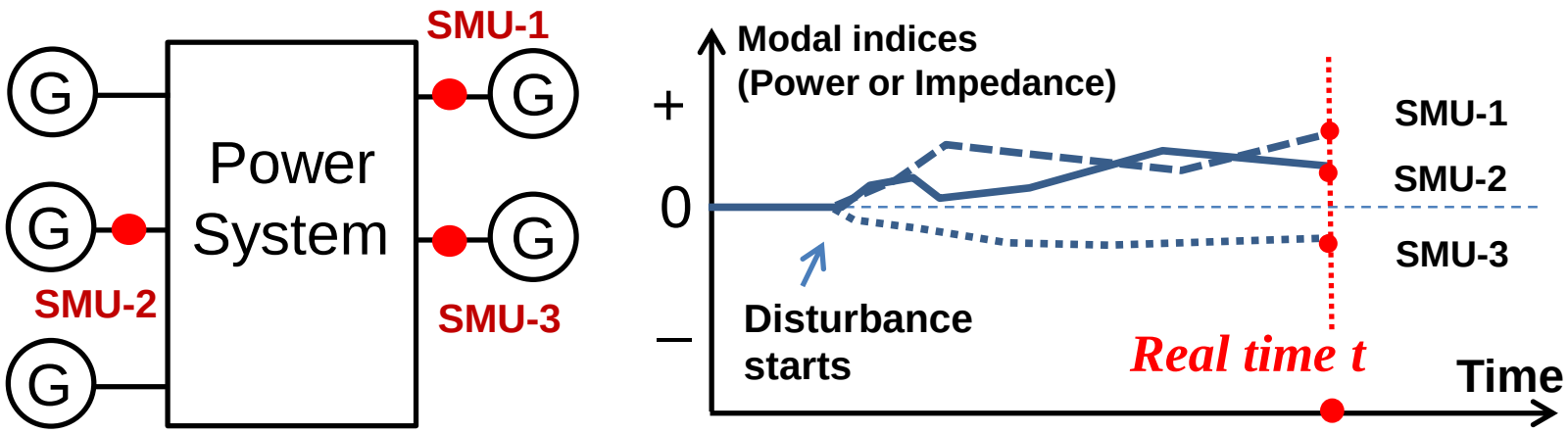


There are two additional rotating fields of 49Hz and 71Hz. Both produce torques on the rotor, leading to rotor oscillation!

1. Insights from waveforms – an example

The phenomenon of generator oscillations: the insights

- It seems that the cause of power system oscillation is the result of power exchange at the non-60Hz frequencies
- By monitoring the power flows at such frequencies, we can detect the contributors or participants of such oscillations
- Waveform data is essential for applying this idea. The data needs to be synchronized



2. Status of synchro-waveform data

Devices capable of measuring such data is already available

Portable PQ monitor

Relay-based SMU

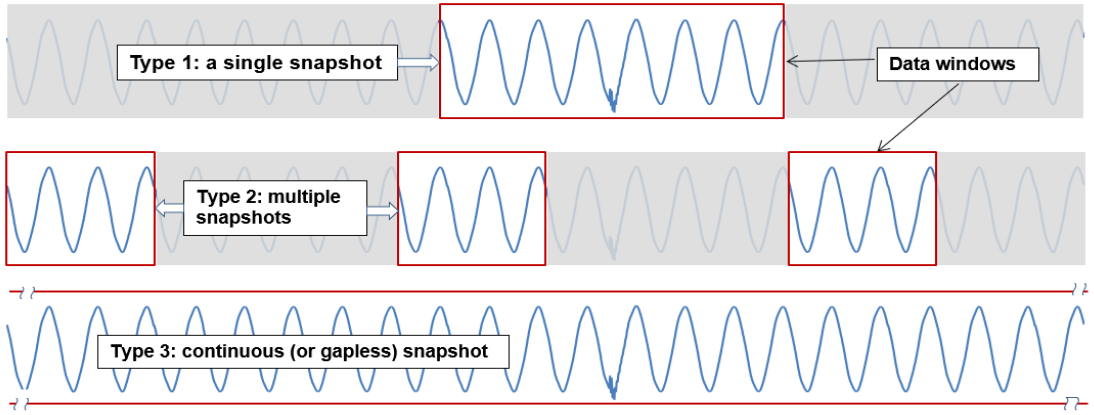
Stationary PQ monitor

Merging Unit

Gapless SMU

SMU
– synchronized waveform measurement unit (also called WMU)

- **Types of data**



- **Forms of data sent to the center**
  - Raw waveform data
  - Derived data (i.e. indices)

- **Central location for synchronized analysis:**
  - It does not mean control center only
  - It can be a substation or even an engineering office

2. Status of synchro-waveform data

Scheme of data collection and transfer

- On-demand such as download
- Event driven
- Real-time streaming

Differentiate
three concepts about the data:

- data with precision time information,
- synchronized recording of data,
- synchronous transfer of (real-time) data.

This is what we are talking about here

How synchro-waveform data is used is highly dependent on the type of applications. Real-time streaming of the data to control center (the most demanding one) is only one of the possible approaches

Three types of applications

- **Offline analysis, such as**
  - Troubleshooting
  - Model parameter estimation
- **Online monitoring (no automatic action)**
  - Incipient fault detection
  - Equipment condition monitoring
- **Real-time P&C (protection & control)**
  - Generator trip
  - Differential line protection

3. Moving forward: A) Three application platforms

Platform No.1: Special purpose sync-wave platforms

- For protection & control applications, which is the real-time application type
- Extremely high reliability requirement due to automatic control actions
- Customized, dedicated SMU network is the acceptable approach
- Consistent with current industry practice

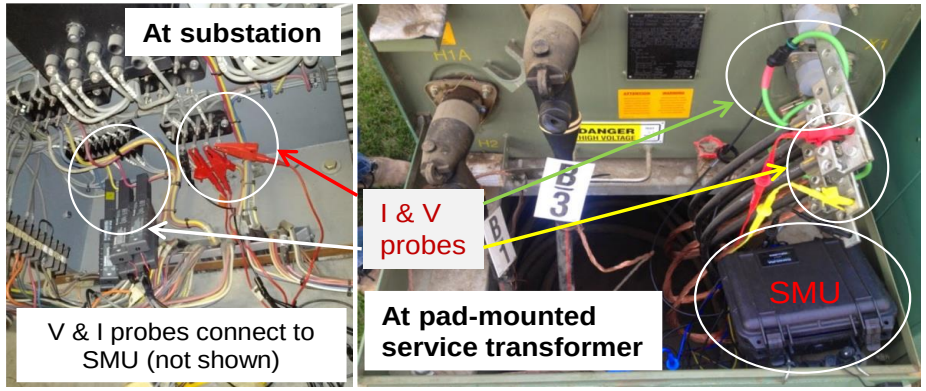
  Note: dedicated network does not mean dedicated infrastructure

Platform No.2: Multi-Use Sync-wave Platforms

- For online monitoring and offline analysis applications
- Real-time streaming of data is NOT necessary
- Thus a lot more options are available to construct such a network

Platform No.3: Mobile Sync-wave Platforms Using Portable SMUs

- For offline analysis, e.g. troubleshooting, model validation, etc.
- Can be deployed at almost any locations with little infrastructure support
- A very important tool to support university research including emulating PMUs

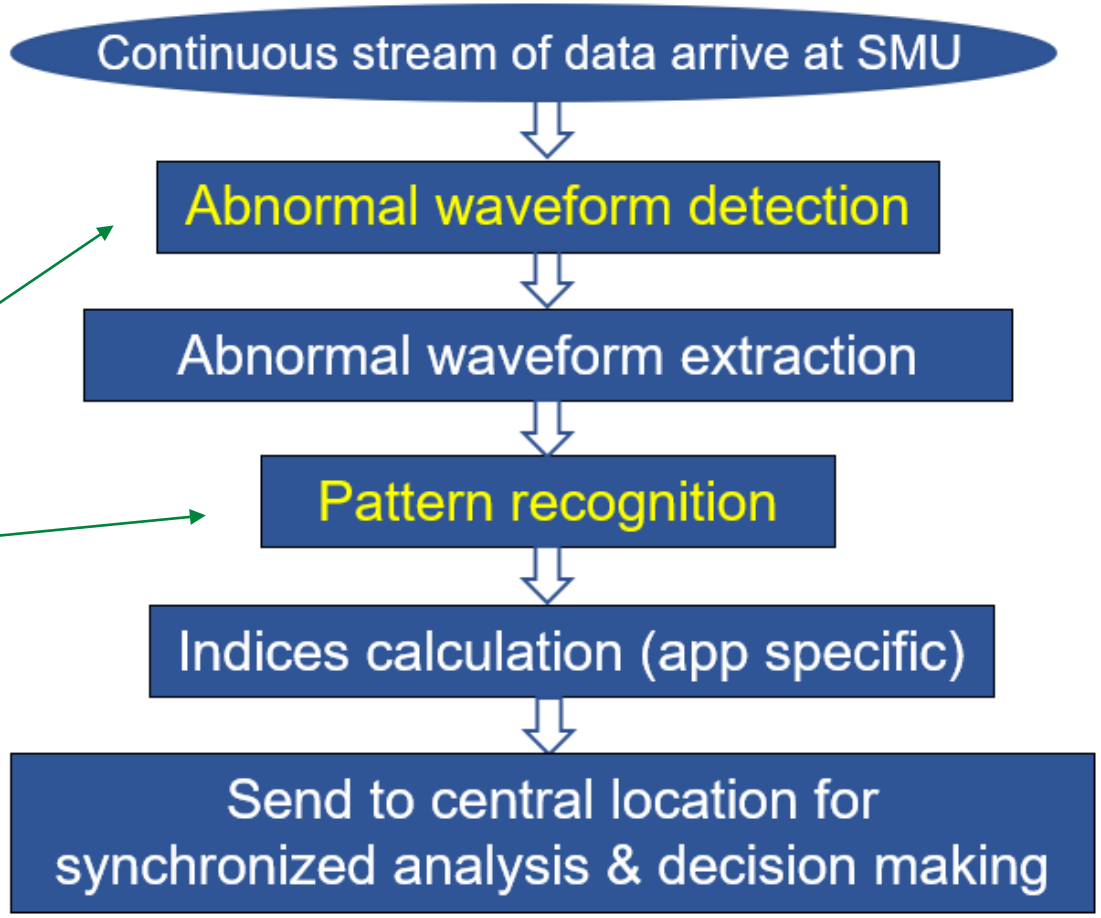


Example of platform No 3: Installation of two SMUs (Portable PQ monitors)

3. Moving forward: A) Three application platforms

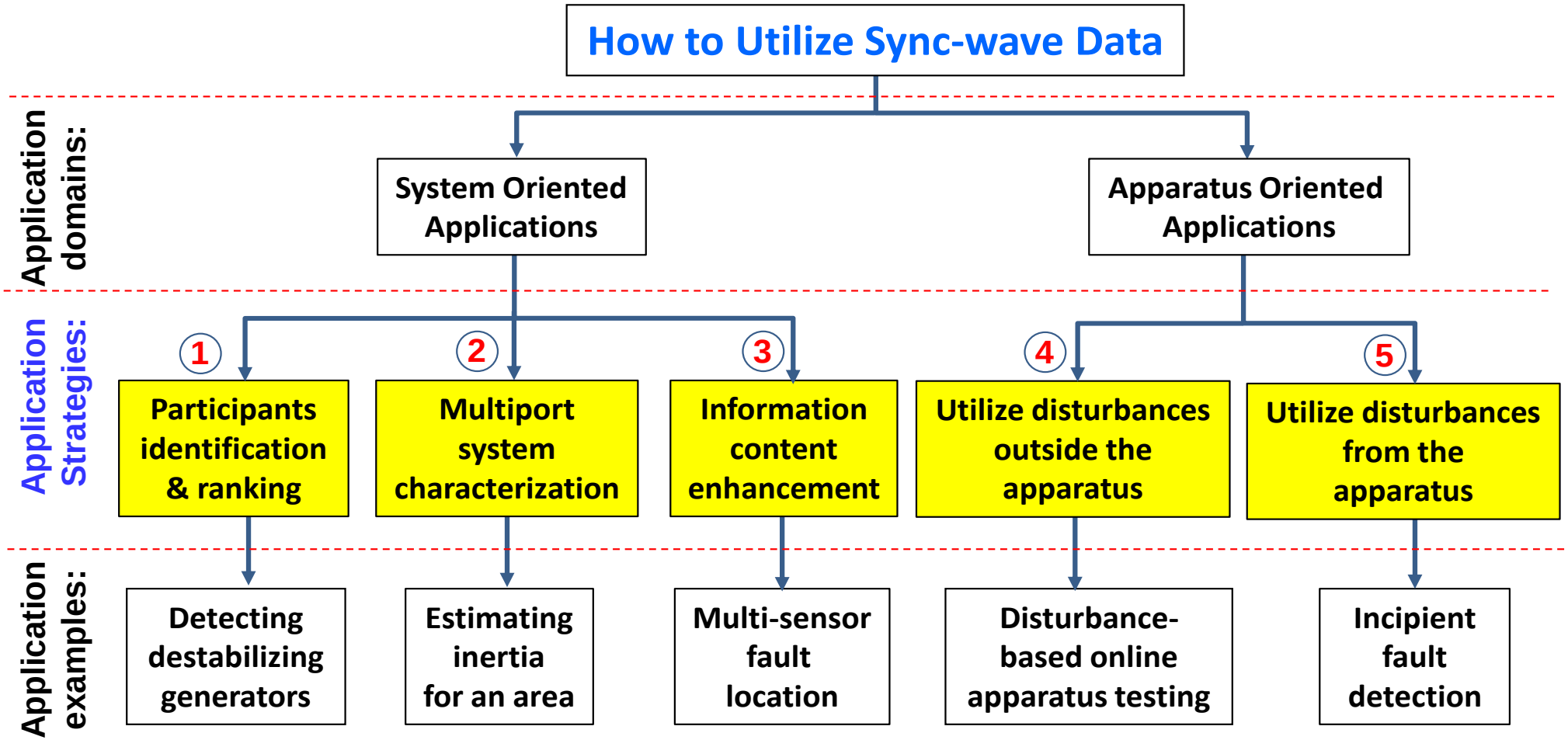
Need to research and develop general-purpose data analytics algorithms

- Most useful sync-waves are those that contain changes or disturbances (called abnormal waveforms here)
- Focusing on abnormal data reduce capacity requirements on infrastructures
- Need to develop general-purpose abnormality detection & pattern recognition algorithms
- Application specific data processing algorithms are then developed and applied (e.g. extracting SSR indices)



SMU seems to be the best location to perform the above analysis

3. Moving forward: B) Strategies of app development



More details can be found from W. Xu, H. Huang, X. Xie & C. Li "Synchronized Waveforms – A Frontier of Data-Based Power System and Apparatus Monitoring, Protection, and Control", IEEE Transactions on Power Delivery, vol. 37, no. 1, pp. 3-17, Feb. 2022, doi: 10.1109/TPWRD.2021.3072889.

4. Conclusions and takeaways

- **Waveforms are the most authentic and granular data revealing power system behaviors. They provide much more information than the phasor data**
- **The main strength of synchronized data is to enable integrated analysis of multi-location data, thus synchro-waveform is especially useful to solve problems involving:**
  - Interactions of multiple components (e.g. ranking, contributor identification)
  - Multiport systems or subsystems (e.g. characterizing an area instead of a component)
  - Cross-referenced information extraction (e.g. difference analysis)
- **Real-time streaming of synchro-waveform data is not necessary for many applications. It is needed mainly for a dedicated platform serving a specific control function**
- **Two other platforms, multi-use (on-demand access) platform and mobile platform are likely to be more useful, at least at the early stage of sync-wave adoption**
- **Synchro-waveform data can support both system- and apparatus-oriented applications**