PQStream: A Data Stream Architecture for Electrical Power Quality

Dilek Küçük, Tolga İnan, Burak Boyrazoğlu, Serkan Buhan, Özgül Salor, Işık Çadırcı, and Muammer Ermiş

TÜBİTAK – Uzay, Power Quality Group
Ankara, Turkey
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Introduction [1]

- Considerable research have been carried out on data streams including the studies on
  - data stream management systems such as STREAM [1]
  - tracking cross-correlation in data streams [2, 3]
  - mining data streams such as StreamCube [4]
  - real world applications of data streams such as GigaScope [5].
Introduction [2]

- In this study, a data stream architecture, called \textit{PQStream}, is presented for processing and managing electrical power quality (PQ) data.

- The feasibility and effectiveness of \textit{PQStream} is demonstrated on the PQ data obtained by a mobile PQ measurement system monitoring the transformer substations of the Turkish Electricity Transmission System [6].

  - This measurement system is also part of the PQStream architecture.
Electrical Power Quality Parameters [1]

- Electrical power is one of the most essential items used by commerce and industry today.

- It is an unusual commodity because
  - it is required as a continuous flow – it cannot be conveniently stored in quantity –
  - it cannot be subject to quality assurance checks before it is used [7].

- *Power Quality (PQ)* corresponds to the characteristics of the electricity at a given point on an electrical system, evaluated against a set of reference technical parameters [10].
Electrical Power Quality Parameters [2]

- **Power**
  - *Electric power* is defined as the amount of work done by an electric current, or, the rate at which electrical energy is transferred.
  - In alternating current circuits, energy storage elements such as inductance and capacitance may result in periodic reversals of the direction of energy flow:
    - The portion of power flow that averaged over a complete cycle of the AC waveform, which results in net transfer of energy in one direction is known as *real power*.
    - That portion of power flow due to stored energy that returns to the source in each cycle is known as *reactive power*. 
Electrical Power Quality Parameters [3]

- Power (cont’d):
  - The relationship between real power, reactive power and apparent power can be expressed by representing the quantities as vectors.

Relation between Real, Reactive, and Apparent Powers
Electrical Power Quality Parameters [4]

- **Demand**
  - Electric power demand is directly proportional to the current demand of consumer.
  - Hence consumer’s power demand profile may obtained by sampling the current demand values.
Electrical Power Quality Parameters [5]

- Voltage and Current RMS
  - *RMS (Root-Mean-Square)* value is defined to be square root of the arithmetic mean of the squares of the instantaneous values of a quantity taken over a specified time interval.
  - The average power consumed by a sinusoidally driven electrical device is a function of the RMS values of the voltage across the terminals and the current passing through the device, and of the phase angle between the voltage and current sinusoids.
Electrical Power Quality Parameters [6]

• **Frequency**

  • *The mains frequency* is the frequency at which alternating current is transmitted from a power plant to the end user.
  • In most parts of the world, it is typically 50 or 60 Hz.
  • Mains frequency is fixed to 50 Hz for the Turkish Electricity Transmission System.

• Mains frequency turns out to be an important PQ parameter indicating the frequency stability of the particular utility grid.
Electrical Power Quality Parameters [7]

- **Harmonics**
  - Ideally, voltage and current waveforms are perfect sinusoids.
    - However, because of the increased popularity of electronic and other non-linear loads, these waveforms often become distorted [8].
  - Deviation from a perfect sine wave can be represented by *harmonics*—sinusoidal components having a frequency that is an integral multiple of the fundamental frequency.
    - A pure voltage or current sine wave has no distortion and no harmonics, and a non-sinusoidal wave has distortion and harmonics.
  - To quantify the distortion, the term *total harmonic distortion (THD)* is used.
    - The term expresses the distortion as a percentage of the fundamental (pure sine) of voltage and current waveforms.
Electrical Power Quality Parameters [8]

- Harmonics (cont’d):

*Distorted Waveform Composed of Fundamental and 3rd Harmonic*
Electrical Power Quality Parameters [9]

• Flicker
  - The power supply network voltage varies over time due to perturbations that occur in the processes of electricity generation, transmission and distribution.
  - Interaction of electrical loads with the network causes further deterioration of the electrical PQ.
  - Flickering of light sources which can cause significant physiological discomfort, physical and psychological tiredness, and even pathological effects for human beings.
  - *Flicker* is quantified based on models of light sources and human sensation [9].
Electrical Power Quality Parameters [10]

- **Events**
  - *Voltage Sag*: Temporary reduction of the voltage at a point in the electrical system below a threshold.
  - *Voltage Swell*: Temporary increase of the voltage at a point in the electrical system above a threshold [10].
Events (cont’d):

- **Unbalance**: Balanced three-phase systems should have the same amplitude on all phases. Unbalance is a measure which indicates how much the amplitude of the phases differ from each other.

- **Interruption**: Reduction of the voltage at a point in the electrical system below the interruption threshold [10].
PQStream Architecture

Abstract Representation of PQStream Architecture
PQ Data Measurement Module [1]

- Mobile PQ measurements in the Turkish Electricity Transmission System are carried out for a period of seven consecutive days for each measurement point [6].
- The sampling frequency of the program is 3200 Hz, that is, it acquires 3200 raw samples per second for each PQ parameter.
- The program calculates and outputs the averages corresponding to the PQ parameters according the PQ standards [10] in an online fashion. It outputs raw PQ data as well in case of events.
PQ Data Measurement Module [2]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Precision</th>
<th>Update Rate (Averaging Interval)</th>
<th>Three Phase</th>
<th>Average PQ Data Bit Rate (bps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Power</td>
<td>Double</td>
<td>every second</td>
<td>Yes</td>
<td>192</td>
</tr>
<tr>
<td>Reactive Power</td>
<td>Double</td>
<td>every second</td>
<td>Yes</td>
<td>192</td>
</tr>
<tr>
<td>Apparent Power</td>
<td>Double</td>
<td>every second</td>
<td>Yes</td>
<td>192</td>
</tr>
<tr>
<td>Power Factor</td>
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<td>every second</td>
<td>Yes</td>
<td>192</td>
</tr>
<tr>
<td>33 Voltage Harmonics</td>
<td>Double</td>
<td>every 3 secs</td>
<td>Yes</td>
<td>2.112</td>
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<tr>
<td>33 Current Harmonics</td>
<td>Double</td>
<td>every 3 secs</td>
<td>Yes</td>
<td>2.112</td>
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<tr>
<td>RMS Current and Voltage</td>
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<td>every 0.2 secs</td>
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<td>1.920</td>
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<tr>
<td>Event Length</td>
<td>Integer</td>
<td>variable</td>
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<td>4</td>
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<td>Event Type</td>
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<td>10</td>
</tr>
<tr>
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<td>variable</td>
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<td>every 15 mins</td>
<td>Yes</td>
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<td>Frequency</td>
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<td>every second</td>
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<td>64</td>
</tr>
<tr>
<td>Total (with Events)</td>
<td></td>
<td></td>
<td></td>
<td>1,235,790,533</td>
</tr>
<tr>
<td>Total (without Events)</td>
<td></td>
<td></td>
<td></td>
<td>6,990,533</td>
</tr>
</tbody>
</table>

Outgoing Data Traffic of PQStream Measurement Module
PQ Data Measurement Module [3]

Directory Structure of Mobile PQ Measurements
Data Model for PQ Data [1]

Conceptual Data Model for PQ Data Represented with a UML Class Diagram
Data Model for PQ Data [2]

- *Measurement_Point* class holds information about the busbars or feeders (measurement points) where PQ measurements take place.

- *Transfer_File* class is for holding information related to the transfer file and actual data transfer time.

- *Event* class is used to model an entry for each and every event that occurred during the entire measurement period.

- *Event_Stat* is a class introduced for efficiency reasons. It is used to model a summary of the events occurred in a measurement point.
Data Model for PQ Data [3]

- Among the remaining classes, `Flicker_PST` models short term, and `Flicker_PLT` models long term flicker measurements.
  - Long term flicker (Plt) is calculated from short term flicker (Pst) with the following formula taking $N=12$ where $P_{sti}$ ($i=1..N$) are consecutive values of Pst.

\[
P_{lt} = 3 \sqrt{\frac{\sum_{i=1}^{N} P_{sti}^3}{N}}
\]

- As their names imply, the classes `Demand`, `Frequency`, `RMS` and `Power` are for modeling respective PQ parameters.
PQStream Graphical User Interface [1]

- A GUI for PQStream has been developed using Java programming language, with its Swing Application Programming Interface (API), in Eclipse development environment.

- It enables its users to query each of the PQ parameters and results can be represented using different visualization options such as tables, bar/pie charts, or time-series graphics.
  - Graphics facilities are implemented using the open-source JFreeChart API.
PQStream Graphical User Interface [2]

PQStream GUI (with Flicker Query Panel)
PQStream Graphical User Interface [3]
Conclusion [1]

- In this study, we have described a data stream architecture for electrical PQ data.

- The main modules of PQStream architecture are:
  - a measurement module which processes continuous PQ data and computes averages according PQ standards,
  - a database for storing the averages that the measurement module computed, and finally
  - a GUI for retrospective analysis and visualization of the stored PQ data.
Conclusion [2]

- PQStream chooses not to store raw PQ data to lower the storage requirements of the acquired PQ data.

- Its proprietary GUI it enables users to access summaries of PQ data with relevant visualization facilities such as bar/pie charts and time-series graphs which are typical ways of presenting PQ data.
Conclusion [3]

- As further studies,
  - Data mining techniques can be applied on PQStream database such as
    - classification and clustering algorithms in order to group those measurement points from which PQ data are acquired
    - sequence mining techniques to determine the time-evolution of PQ problems.
  - With the results of these data mining attempts on PQStream,
    - experts of PQ domain will be able to take the necessary measures to detect and reduce PQ problems in electricity transmission systems.
References

Thank you