Intelligent PMU

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Viktor Litvinov
Design, Develop and Deploy - digital transformation solutions for an Interconnected World.

- Power system and industrial automation
- Business Analytics, Data Warehousing and Big Data
- Information Security and Compliance
There will be 50 billion things connected to the internet by 2020,
From Consumer to Control Center

- **EMS**
- **DMS**
- **SCADA etc.**

**PowerLink**
- Data acquisition/storage/analytics
- Distributed Historian
- In-Memory Grid analytics
- Advanced visualization

**IloT Intelligent Controllers**
- Real-Time
- Private
- Location aware

**Data sources and/or control devices**
- (power plants, substations, consumers)
- Relay protection and automatic emergency control
- New and existing

- Control centers
- Control systems for renewables, DER, conventional generation, transmission and distribution grids, micro-grids, consumers

Bi-Directional Data exchange
PowerLink – Logical Architecture

**Visualization**
- Mobile-Enabled Web Applications
- Strategic Decision Making
- Client-Facing Applications
- Advanced Analytics
- Reporting/Dashboarding

**Components**
- Map, Charts, Offline Browsing, Mobile-Ready Navigation

**Data Access Layer**
- Big Data Integration, Caching for Responsive Applications, Relational Access

**Data Processing**
- Rules Execution
  - Alerts Definition, Data Transformation Rules, DQ Rules
- Stream Processing Layer
- Messaging Bus & Distributed Cache
- Sensor Data Ingestion
- Database Adapters
- Distributed Data Storage
- Streams and Files Adapters
- Model Management
- Model Import
- Custom Adapter to Client’s Systems

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PowerLink – Node Structure

PROCESSING (MULTI NODES): Hazelcast Jet

LOAD BALANCER AND FAULT TOLERANCE CLUSTERING (TWO NODES)

GLOBAL STORAGE AND ANALYTICS
MULTI NODES CLUSTER

CQL

Cassandra

PMU, DFR, other IEDs

PDC
SCADA
RTU
PLC

IEC 104, C37, OPC etc.

IEC 104, C37, OPC etc.

Vert.x Data adapters

Vert.x Data adapters

Vert.x Type A processing
Memory Cache

Vert.x Type B processing
Memory Cache

Vert.x Type C processing
Memory Cache

Local Storage

Local Storage

Local Storage

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**PowerLink – Distributed Multi-node**

- **Regional Control Center A**
  - Processing
  - Data Intake
  - Load balancer
  - Storage and Analytics
    - Stores only data required for this region and aggregated global data
    - Region-level analytics
  - Global Storage and Analytics
    - Stores and analyses all available data in batch mode

- **Regional Control Center B**
  - Processing
  - Data Intake
  - Load balancer
  - Storage and Analytics
    - Stores only data required for this region and aggregated global data
    - Region-level analytics

- **ISO Level Control Center A**
  - Processing
  - Data Intake
  - Load balancer

- **Substation Level**
  - Processing
  - Data Intake
  - Load balancer
  - Storage
    - Local storage for local decision integrated with global cache

- **Device Level**
  - Processing
  - Data Intake
  - Load balancer
  - Storage
    - Local decision integrated with global cache

**Global Memory Cache**

- Using new techniques of data exchange, optimized data flows
- Combining **JSON API** (web-services), **MQZero messaging middleware** and **Hazelcast in-memory-grid** for online and off-line data exchange between the network nodes
Intelligent PMU based on IIoT Intelligent Controller

- Object control and sensors/actuators data acquisition/transmission
- Connection with an upper-level data acquisition and control system (e.g. PowerLink cloud platform)
- Advanced networking: interconnects with other ICs to form an IC network for load balancing and fault tolerance
- Enhanced built-in analytics
Direct measurements of the synchronous generator load angle

Secondary data-stamp time source capability

Excitation parameters and rotor angular position measurement subsystem

Current transformer
Voltage transformer
Generator

Intelligent PMU

GPS/GLONASS
Secondary (network) time source

PDC
Network
System Operator Control center

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\[ x(t) = a_0 + a_1 \cdot \sin(\omega t) + b_1 \cdot \cos(\omega t) \]

\[ X_m = a_0 + \sqrt{a_1^2 + b_1^2} \]

\[ \varphi = \arctan \frac{a_1}{b_1} \]
Express evaluation technique vs Modified Hilbert transform

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Magnitude</th>
<th>Frequency</th>
<th>Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Express evaluation</td>
<td>Modified HT</td>
<td>Express evaluation</td>
</tr>
<tr>
<td>Average deviation</td>
<td>0,04 %</td>
<td>-0,01 %</td>
<td>0,01 %</td>
</tr>
<tr>
<td>RMS</td>
<td>0,87 %</td>
<td>0,95 %</td>
<td>0,11 %</td>
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<tr>
<td>Maximum deviation</td>
<td>2,81 %</td>
<td>5,37 %</td>
<td>0,49 %</td>
</tr>
</tbody>
</table>
Express evaluation technique

Computation window – 10 ms, filtering window – 5 ms
Computation delay – down to 5 ms
Intelligent PMU capabilities

- accelerated disturbance detection and analysis by instantaneous measurements processing;
- forming local control actions or adjusting local protection and automatic control systems on a 100 ms cycle basis;
- power quality monitoring on an object or an interconnection level: computation and analysis of power quality indicators inside the device with the sampling rate corresponding to the initial measurements (10 kHz or over) with the subsequent aggregation and transmission at the rated sampling frequency (60 Hz);
- data validation – platform for the 3-level data validation (1st level – an object, 2nd level – adjacent objects, 3rd level – interconnections);
- error detection and correction in energy metering;
- extended generating equipment monitoring, including excitation system parameters acquisition;
- proactive equipment condition monitoring with the maintenance/repair recommendations;
- advanced networking capabilities.
Conclusion

- Intelligent PMU network brings an extra layer to the cloud where sensor data can be stored, analyzed and act upon instantaneously.

- Intelligent PMU will become a backbone of DER systems due to
  - growing demand for Intelligent Grid from producers/consumers
  - increased interest from heat, water, utility gas, etc. providers
  - development of adaptive models for equipment and power system

- Foundation for the Demand Response and Demand Side Management approaches in the corresponding fields
Q&A

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Thank You

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