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HEAVY-DUTY DATA ACQUISITION SYSTEM FOR SMART ENERGY MANAGEMENT ALGORITHMS

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AGENDA

1. The center of digital solutions for smart grid
2. Ideas of the experimental area of the CDSSM
3. Data acquisition system architecture
4. Datasets and open access
5. Implementation challenges
6. Research projects

THE CENTER OF DIGITAL SOLUTIONS FOR SMART GRID

Created on Sep 7, 2018 by the order of the director of ICS RAS

- The Center is an out-of-the structure division of ICS RAS, not a legal entity
- The Center aims at coordination and collaboration of laboratories of ICS RAS and of third parties to conduct joint basic and applied research
- “Virtual laboratories” consolidates Institute’s staff and the researchers of the third parties working on the joint research project
- The research infrastructure of the Center is the Experimental area of digital solutions for smart grid.

EXPERIMENTAL AREA: THE MAIN IDEA

- Not a testbed, not a laboratory installation, but rather a information collection system for real-world data.
- Because datasets are needed to implement data-driven approach to control
- Main requirements/features
    - Large scale (not a single lab),
    - Real-life object (Research institute)
    - Maximum use of new metering technologies (real-time collection, robust wireless, etc.)
    - Integral information from engineering networks (electrical, heat, climate, weather, motion/occupation, events)
    - Economy (reasonably cheap meters and non-intrusive installation, maximum use of the existing IT and engineering infrastructure)
    - Reproducibility (minimize use of unique or proprietary solutions)

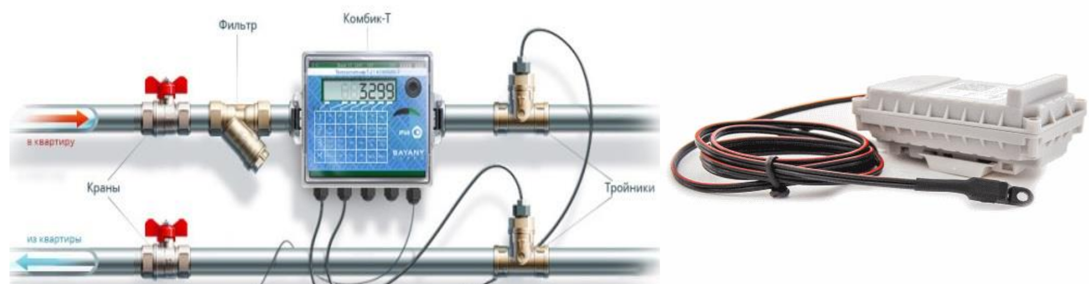
SUBSYSTEMS OF EXPERIMENTAL AREA

1. Electrical subsystem – total monitoring of power distribution system of ICS RAS

2. Climate subsystem – indoor microclimate monitoring in halls and lecture rooms of ICS RAS

3. Heat subsystem – temperature of radiators

4. External site (solar/wind generation and complex loads at partner's site – School 29, Podolsk)



EXPERIMENTAL AREA: KEY FEATURES

- Real-time (1-5 sec) measurements of instant active and reactive power at every of 100+ feeders (consumer groups)

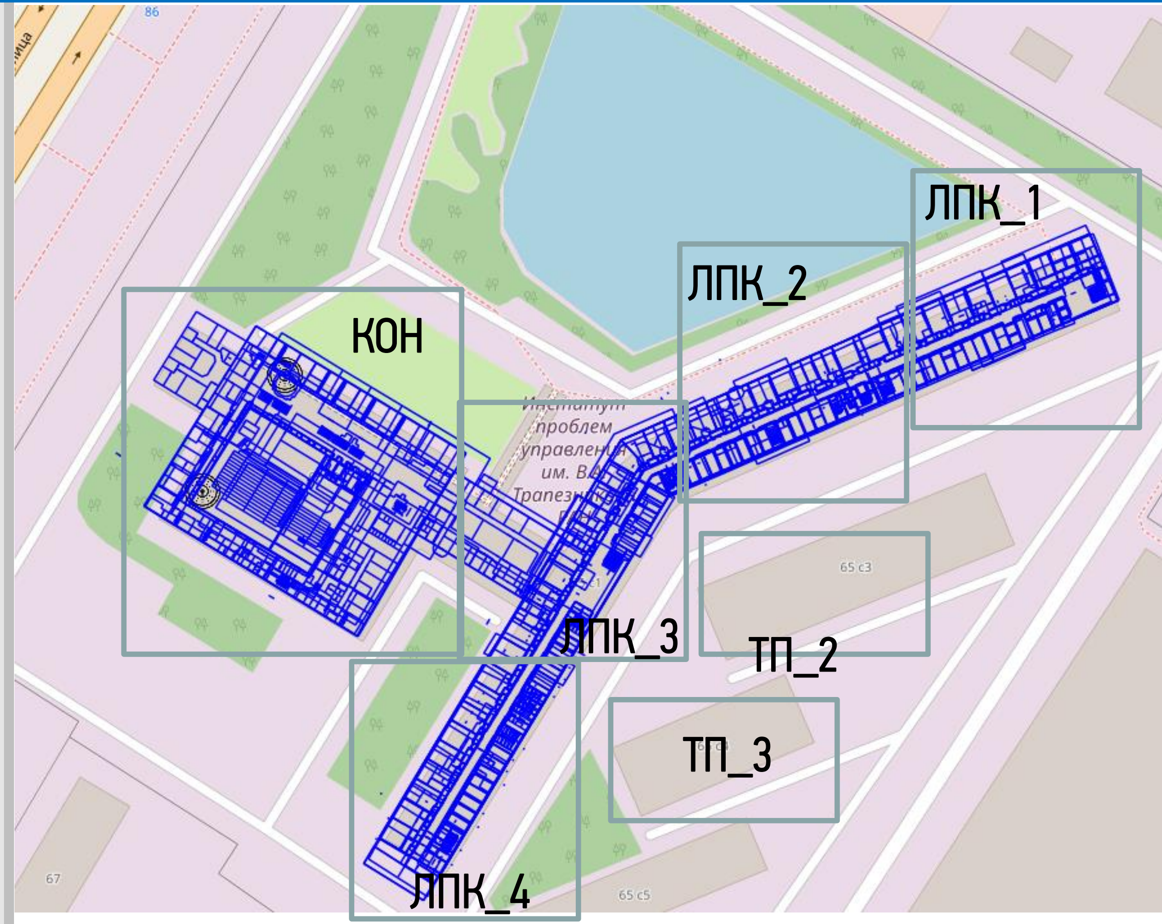
1. High load granularity is a challenge for forecasting
2. Lots of information typically lost, which can be a valuable predictor of load (e.g., the fine pattern of energy use by a laptop can be a feature connected to room occupation)
3. Measurements can be used for online operation (our duty staff looks at the dashboard with active loads, switch states, neutral line breaking detection)

- Active and reactive power make 2 dimensions instead of one for forecasting and energy disaggregation.

ELECTRICAL SUBSYSTEM: FINE GRANULARITY 100+ 3-PHASE FEEDERS

1. КОН –32 smart meters
2. ЛПК _1 – 23 smart meters
3. ЛПК _2 - 26 smart meters
4. ЛПК _3 - 20 smart meters
5. ЛПК _4 – 20 smart meters
6. ТП 2 – 16 smart meters
7. ТП 3 – 15 smart meters (in progress)

Cover 100% of consumption



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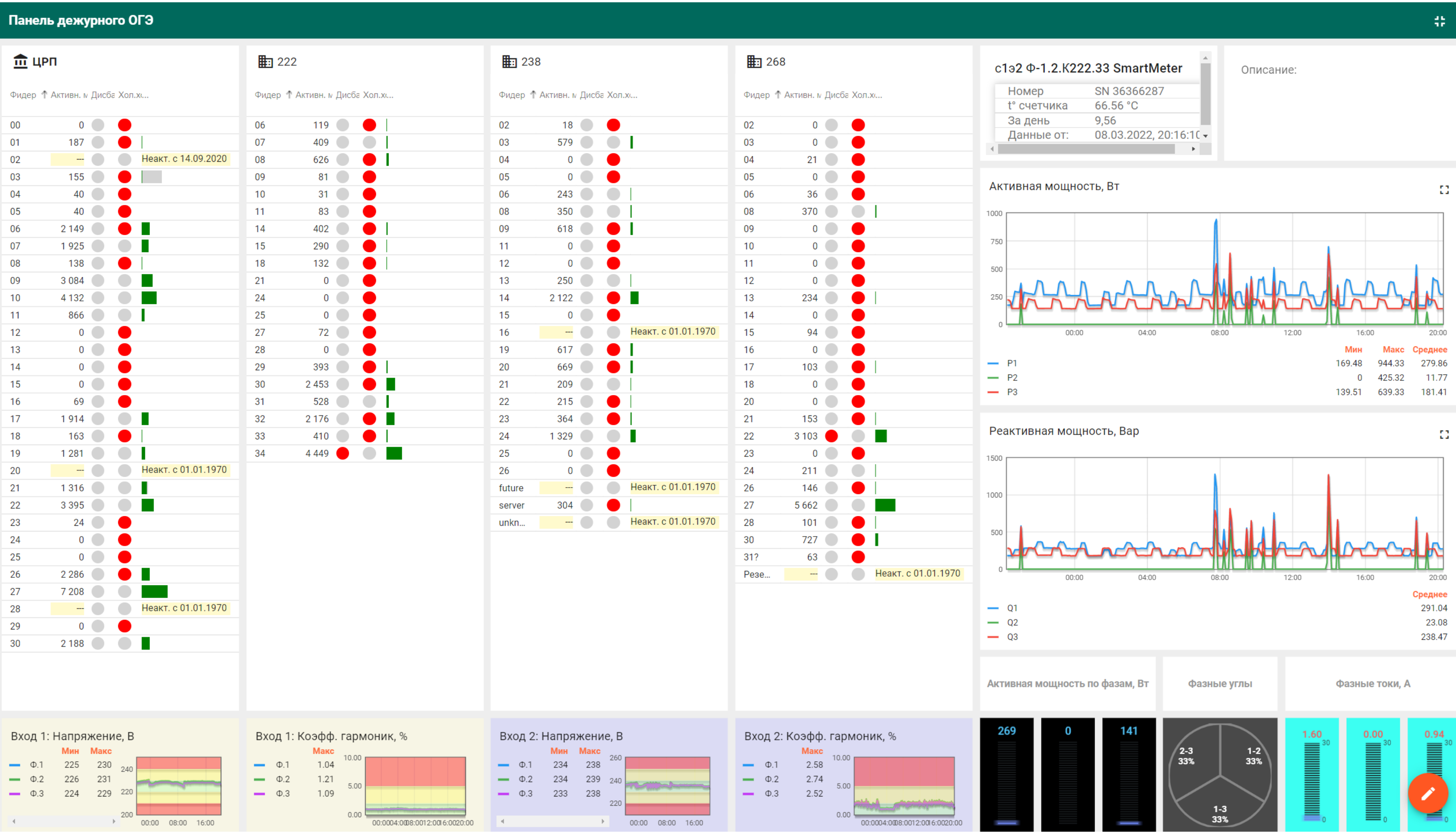
ONLINE MONITORING DASHBOARD FOR DUTY STAFF OF POWER ENGINEER DEPARTMENT

Online monitoring of the state of ICS RAS electric grid (loads, line breaking, zero line breaking, energy quality)



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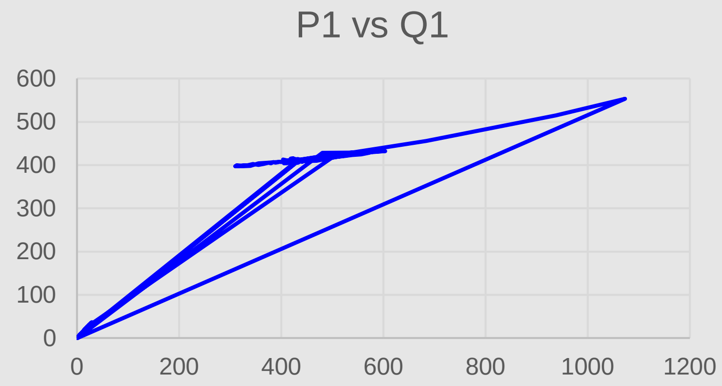
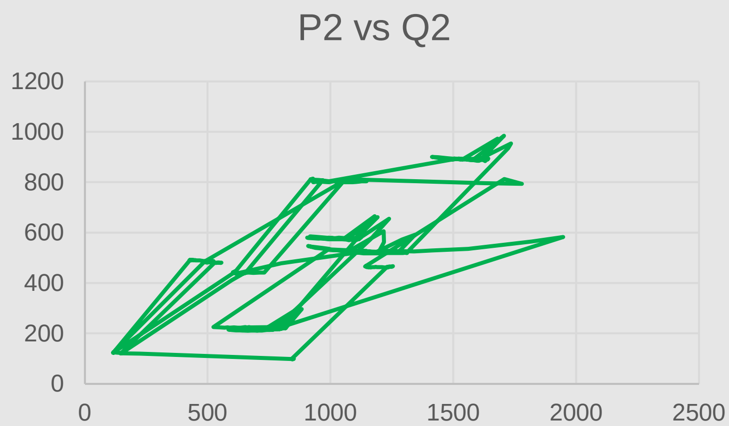
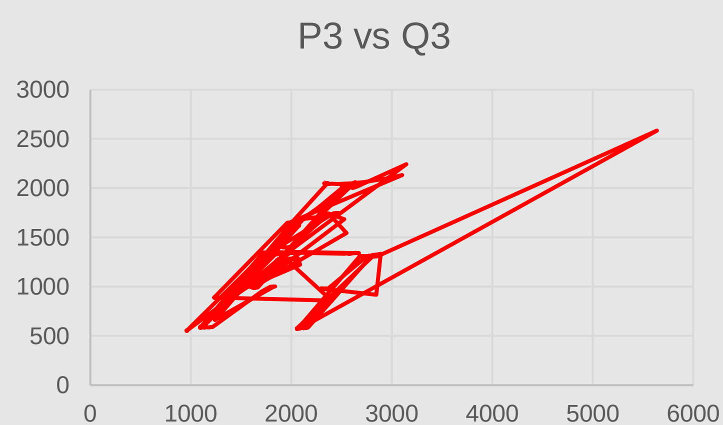
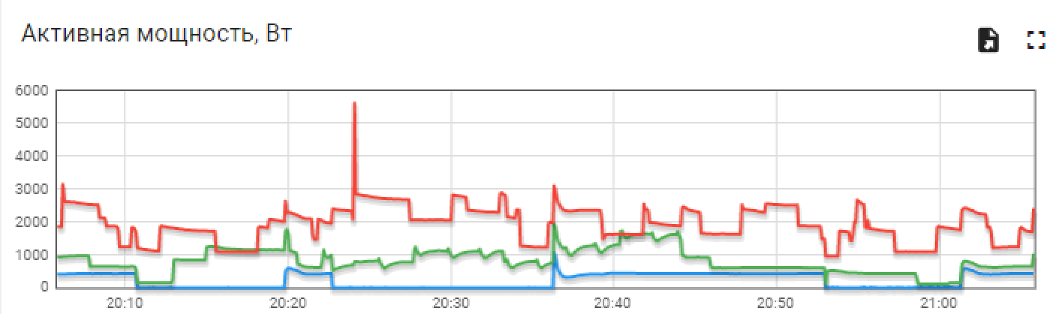
REACTIVE POWER: VALUABLE INFORMATION FOR FORECASTING AND DISAGGREGATION



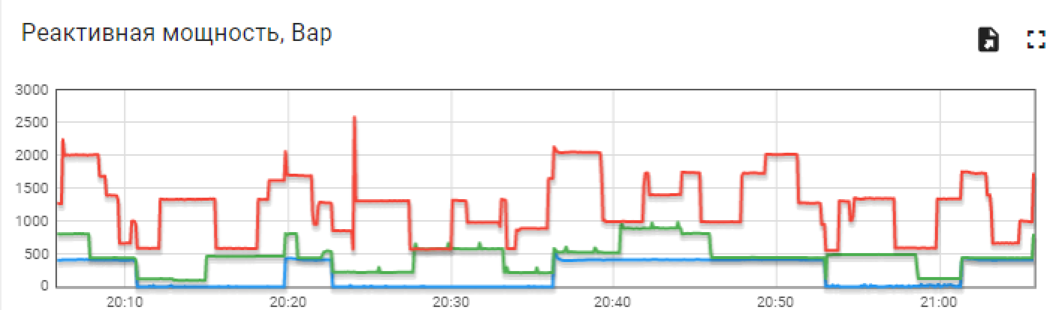




Example: industrial refrigerators (canteen)



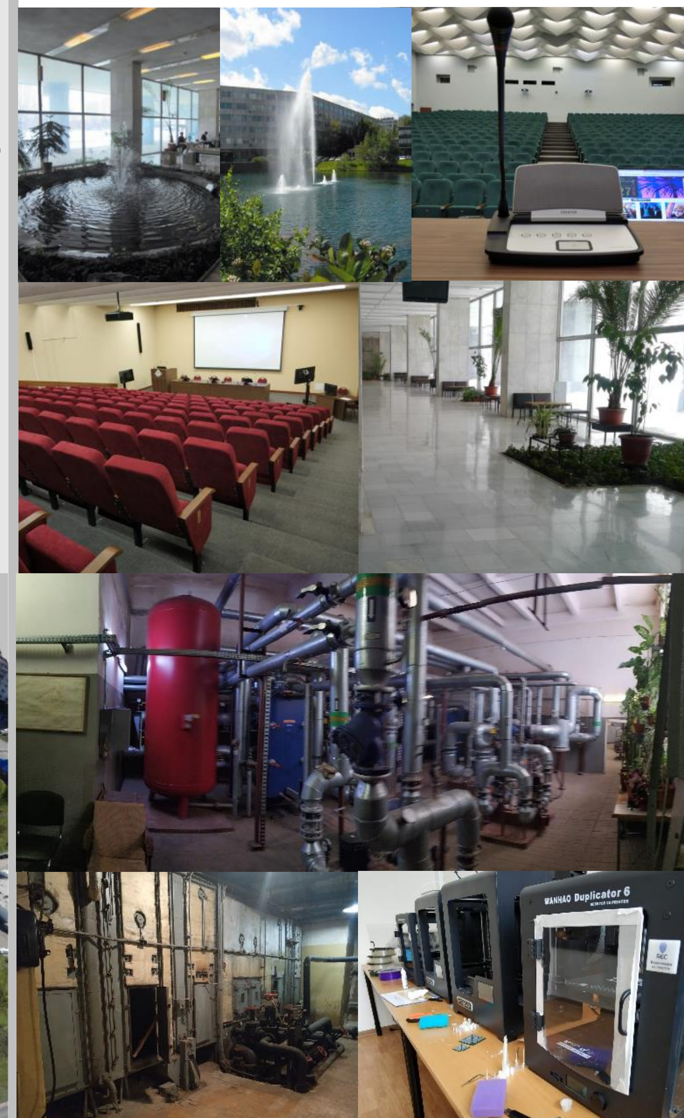
	Мин	Макс	Среднее
P1	0	1073.4	210.95
P2	116	1947.4	810.68
P3	958.2	5637.2	1940.46



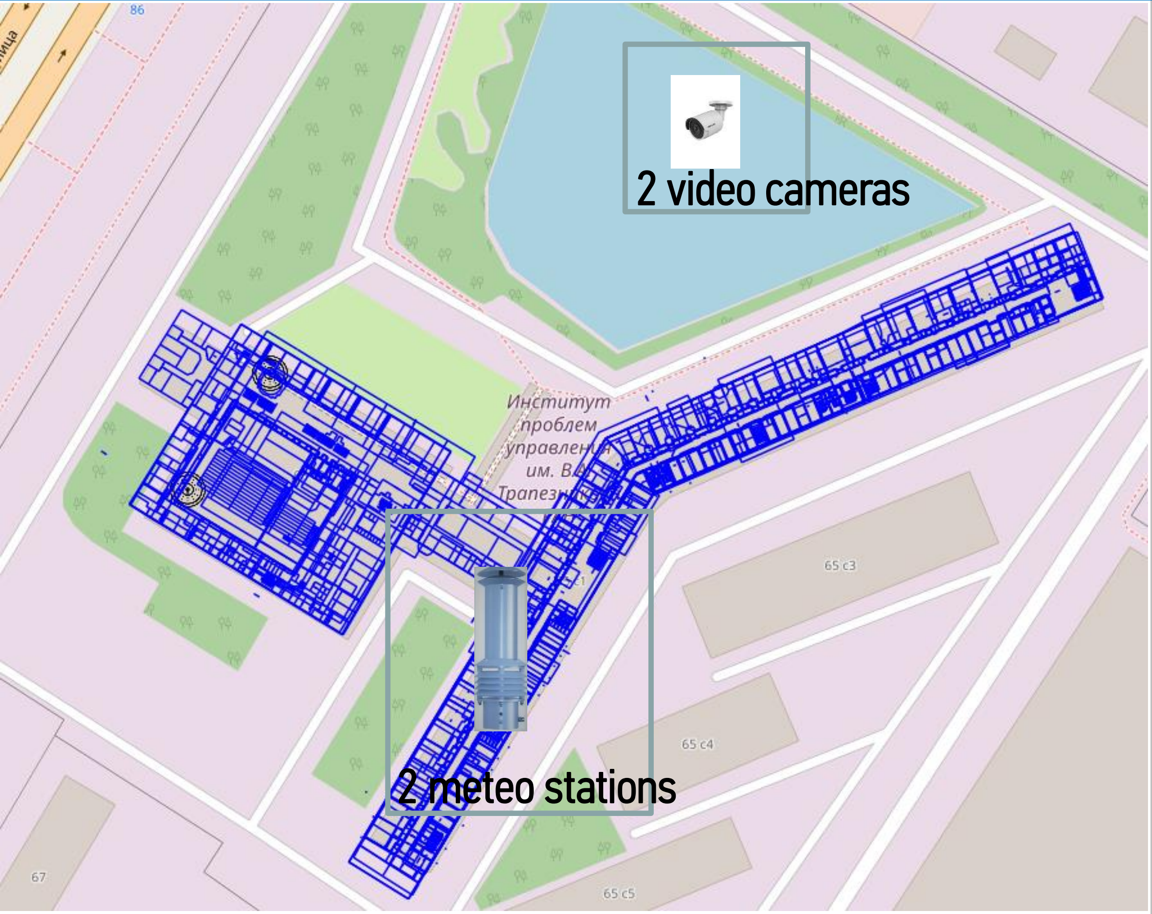
	Мин	Макс	Среднее
Q1	0	553.4	200.89
Q2	98	984	456.02
Q3	550.8	2584.6	1229.89

ELECTRICAL SUBSYSTEM: VARIETY OF LOADS

- Offices (laptops, PC, displays, office machines, aircons, infrared radiators, light, chargers)
- Canteen (electric ovens, boilers, refrigerators, kitchen appliances, light, TV, etc.)
- Conference halls and lobby (centralized ventilation and conditioning, upper/wall lights, video and audio equipment, speakers, pond circulation, lightning and waterworks, network equipment, chargers, etc.)
- Manufacturing machines (cutting, drilling, laser, 3d printers, hand tools, etc.)
- Public services (fire pumps, heat pumps, street light, waterworks, outdoor appliances, etc.)



ELECTRICAL SUBSYSTEM: AUXILIARY FEATURES



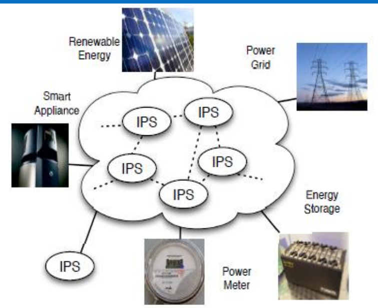
Instant power timeseries (even equipped with reactive power) itself do not provide information for energy consumption forecasting (at least, weather is needed).
Also, direct measurements are always better for disaggregation and forecasting than indirect features imperfectly correlating with real life events.

Auxiliary systems/datasets:

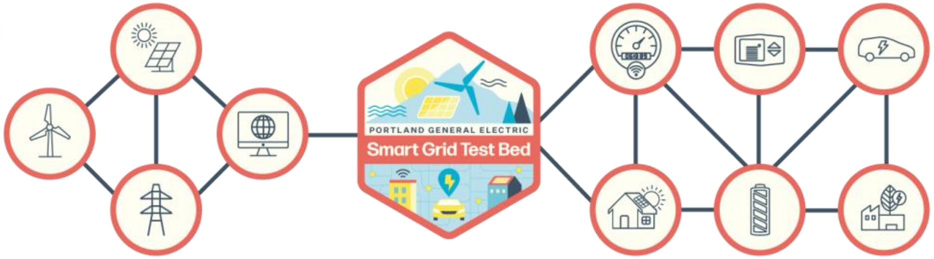
1. Video stream of the front side of the building
2. Online meteo data
3. Smart outlets
4. Indoor microclimate data
5. Heating system (heating battery temperature)

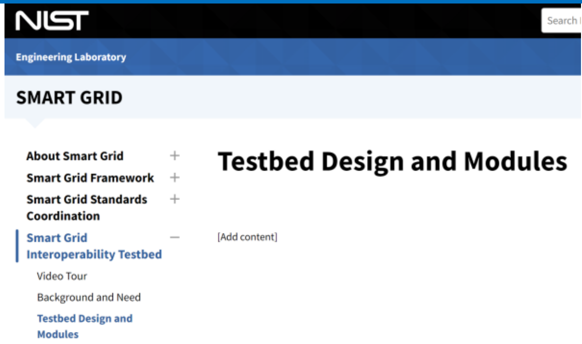
- Ubiquitous sensing – we use effectively existing sources of information instead of deploying global Smart Building systems
- For example, CO2 is not an air quality characteristics but also a good room occupation feature.
- We do not measure the flow in the heating system just because it has to be intrusive (laborious)

TRADITIONAL SMART GRID TESTBEDS



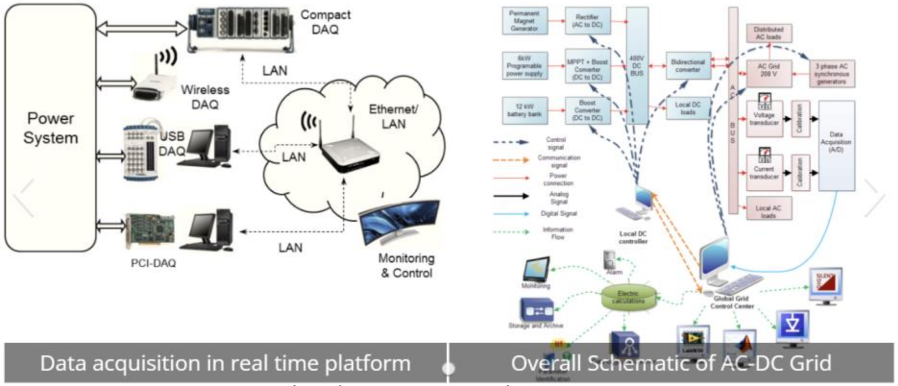
SmartGridLab (Cormell University)





DC Micro grids

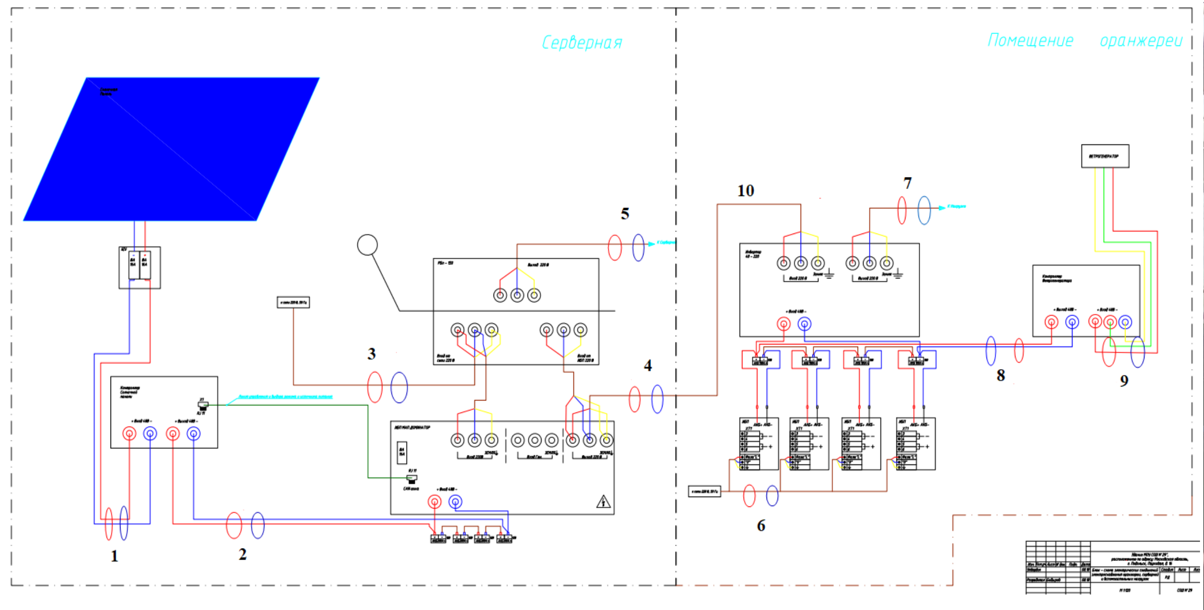
Renewable energy is one of the main sources which are implemented on the test bed research. Electronic converters are essential elements which must be installed on the power grid; however, connecting this element creates a challenge due to the EMC/EMI effects on its surroundings. These effects can lead to the failure of the communication and Data Acquisition (DAQ) systems.

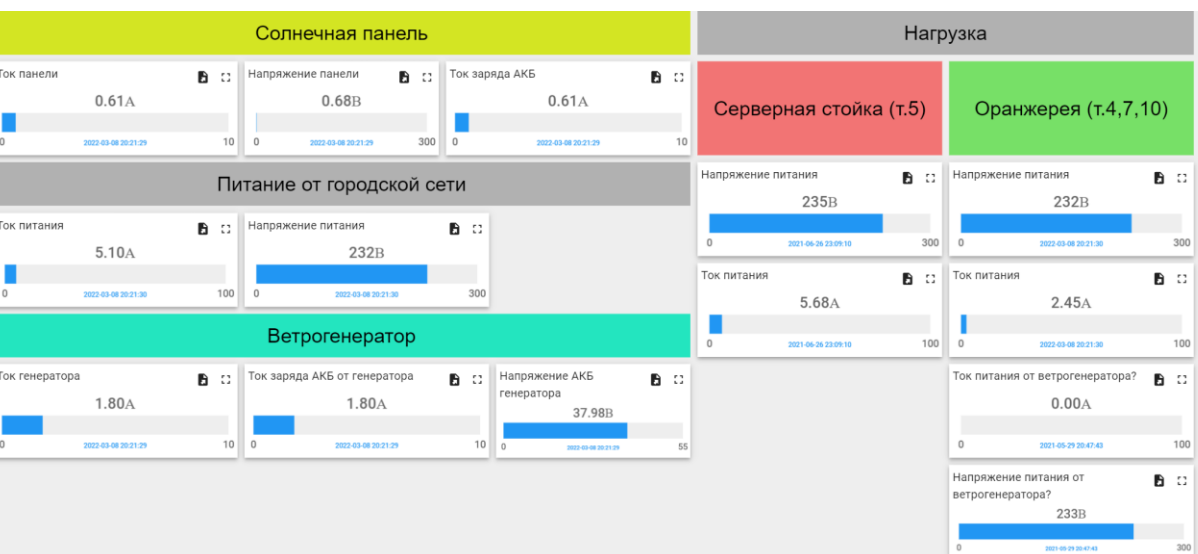


Data acquisition in real time platform | Overall Schematic of AC-DC Grid

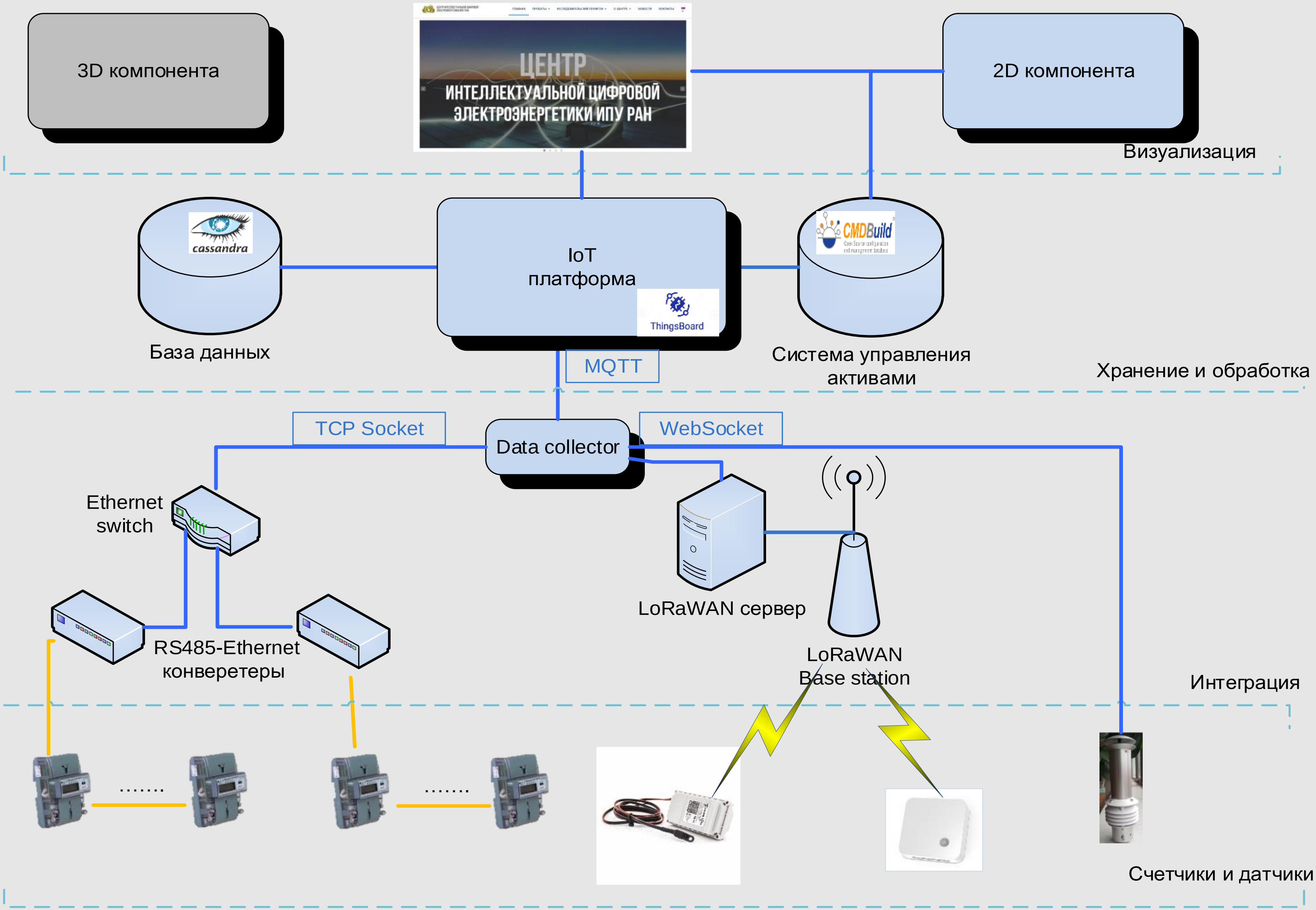
Florida International University

PARTNER SCHOOL 29 (PODOLSK, MOSCOW REGION): EXTERNAL EXPERIMENTAL SITE





ARCHITECTURE OF EXPERIMENTAL AREA



TECHNOLOGY STACK AND COMPONENTS

Data analytics and visualization:

1. Web portal energy.ipu.ru – joint entry point for the current information about the center and public datasets from our experimental area, and also to the cloud data storage and to all web components of the experimental area. WordPress, PHP MyAdmin.
2. 2D component visualizes all assets (devices, meters, current state) on the map of the institute binded to rooms and GPS coordinates: CMDBuild plugin.

Data storage and processing:

1. IoT platform receives information from sensors and sends control events to actuators. It also integrates the timeseries database into the whole system. ThingsBoard is used.
2. The real-time data base stores and the master data and timeseries, supports queries, and forms on-demand datasets from the collected timeseries. Based on Cassandra DB.
3. Asset management systems stores all information about physical components of the control object (engineering infrastructure of ICS RAS including power grid topology) and data acquisition system (sensors, meters, communication equipment). Built on CMDBuild platform.

Integration layer:

1. Collector scripts serve as drivers to different device groups (Lora devices, smart meters, meteo stations) collecting real-time data from sensors with different protocols and media. Protocols supported: MODBUS, MQTT, TCP socket, Web socket, http/https. The custom script is written on NodeJS.
2. Data collection network of the experimental site: protocol converters, routers and hubs. LAN of ICS RAS is used.
3. Wireless sensor network collects data from wireless autonomous sensors. Built using LoRaWAN technology. It includes the Lora server and several base stations to cover the area of ICS RAS and of the external site taking into account walls and other obstacles.

Physical layer:

Smart meters of electricity (Mercury 234), climate multi-sensors (Vega Absolyut, Elsys), meteo stations (Sokol,), contact temperature sensors (Vega Absolyut, customized firmware).

ELECTRIC SUBSYSTEM EQUIPMENT

1. **Commercial smart meters МЕРКУРИЙ**

   Data frequency <=1 Hz
   - Active/reactive powers
   - Currents
   - Phase and line voltages
   - Coefficient of non-linear distortion
   - Amplitudes of 3rd, 5th, and 7th harmonics

2. **Hi-end smart meter NEXUS**

   Data collection frequency <=10 MHz
   - Active/reactive powers
   - Currents
   - Phase and line voltages
   - Spectrum

ТРЕХФАЗНЫЕ СЧЕТЧИКИ

МЕРКУРИЙ 234 ARTM-03 PB.F04 – connected through current transformers

100+ 3-phase smart meters installed

NEXUS 1500

3-phase connected through current transformers.
Active power measurement error 0,06%
Color sensor display
Oscilogramms up to 10 MHz
1 Gb of embedded memory (90 minutes)
Ethernet connection 115 kb/sec

Installed at manufacturing equipment floor

Interface converter (RS-485 to Ethernet)

Installed 10+ pcs

CLIMATE SUBSYSTEM EQUIPMENT

1. Room microclimate multi-sensors

Frequency 5 minutes

ELSYS ERS, ERS Eye, ERS CO2

- Temperature
- Humidity
- CO2 (variant)
- Light
- Motion (PIR)
- Volumetric (variant)

10+ pcs installed (administrative building),
2 pcs installed in greenhouse of School 29

2. Outdoor climate multi-sensors

- Temperature
- Humidity
- Light
- Acceleration
- PIR motion sensor (optional)

3 pcs installed (admin building), 2 (greenhouse)

- Soil moisture
- Temperature
- Humidity
- Acceleration
- Atmospheric pressure

2 pcs (agrotechnology experimental site, cereal field)

3. Automatic meteo stations

The Weather Station

- Temperature
- Humidity
- Rain
- Wind Speed
- Wind Direction
- Dew Point
- Wet Leaf

2 pcs installed (roof of laboratory building)

CLIMATE SUBSYSTEM EQUIPMENT COVERAGE

1. Meteo stations
   - local weather ICS RAS
   - located on the roof
   - Shown at the official site ipu.ru

2. Climate multi-sensors
   - air quality at the administrative building
   - installed at halls, congerence rooms and lecture rooms

3. Video
   - horizon view (clouds)
   - building front view for energy disaggregation

4. Soil moisture sensors agrotechnology experimental site

HEAT SUBSYSTEM EQUIPMENT

Контактные датчики температуры Вега ТД-11

```
static void Send( void* context )
{
  /* КОД ИПУ РАН */
  uint16_t pressure = 0;
  int16_t temperature = 0;
  uint16_t humidity = 0;
  uint8_t batteryLevel;
  sensor_t sensor_data;

  if ( LORA_JoinStatus () != LORA_SET)
  {
    /*НЕ ПОДСОЕДИНИЛОСЬ, ПРОБУЕМ ЕЩЁ РАЗ*/
    LORA_Join();
    return;
  }
    /* ВЫВОЖУ В UART СТАТУС*/
  PRINTF("SEND REQUEST\n\r");

#ifndef CAYENNE_LPP
  int32_t latitude, longitude = 0;
  uint16_t altitudeGps = 0;
#endif
    /*ЧИТАЮ С АЦП НАПРЯЖЕНИЕ НА ТЕРМОРЕЗИСТ
  BSP_sensor_Read( &sensor_data );

#ifdef CAYENNE_LPP
```

- Class A device
- Archive of measurements
- External temperature sensor
- Internal clock
- Communication period - >5 min
- Built-in battery measurement
- USB port
- Measured temperatures, °C: -55...+100
- Internal LoRaWAN™ Antenna
- Radio communication range in the city up to 5 km
- Configurable transmit power (<100mW)
- Built-in battery capacity 3400 mAh
- Battery life up to 10 years
- Case dimensions, mm 95 x 50 x 45
- Case opening sensor (tamper)

> 50 installation points in the heating loop planned

Датчики тепла (расхода)

4 pulse inputs

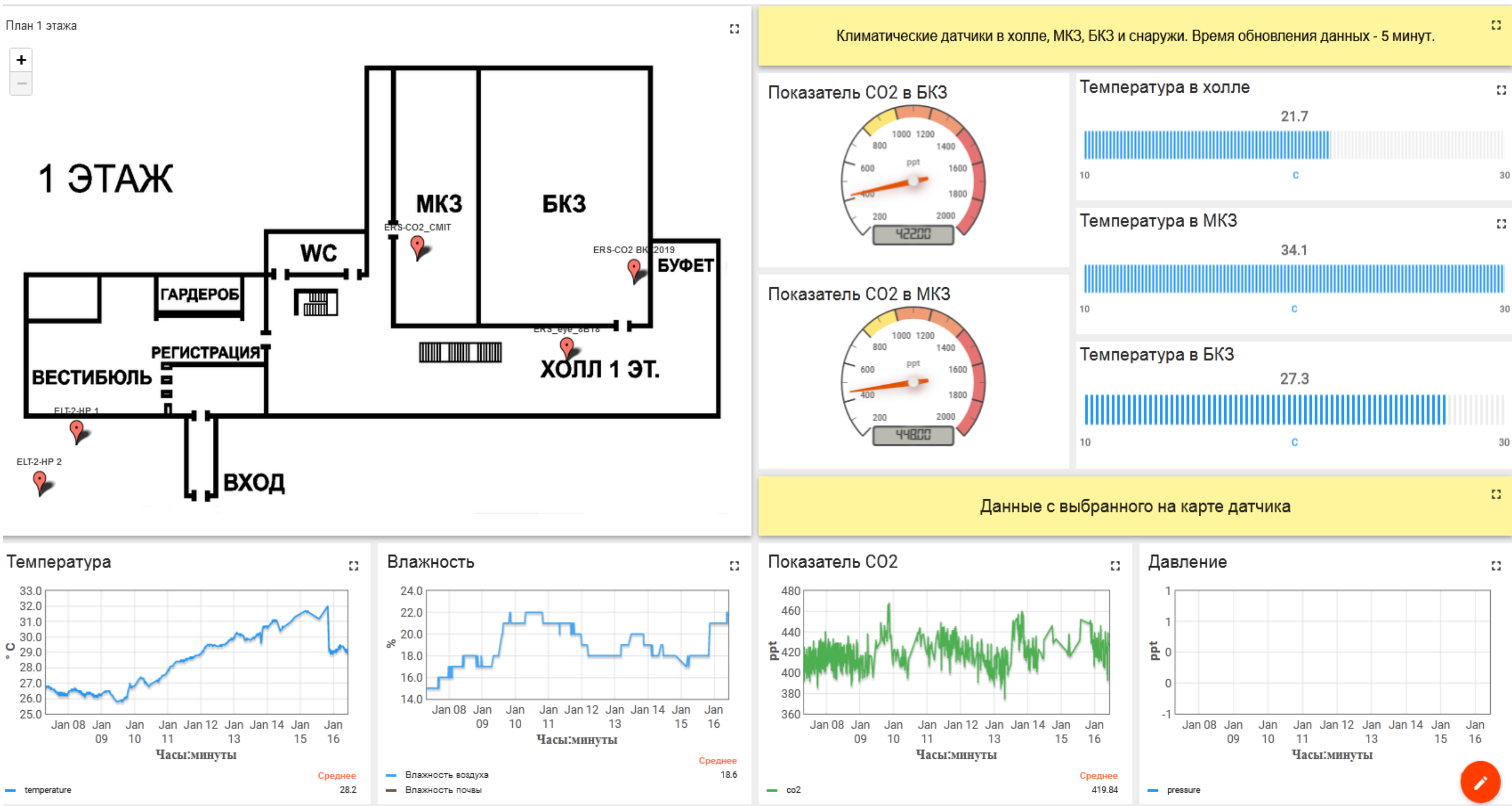
Pulse signal frequency < 200 Hz

- 2 open collector outputs
- Up to 4 security inputs
- USB port
- Operating temperature range, °C - 40...+85
- Built-in temperature sensor
- Class A or C depending on external power supply
- 16 LoRaWAN™ channels
- Contact period 1, 6, 12 or 24 hours
- Internal LoRaWAN™ Antenna
- Power supply external 5 V
- Case dimensions, mm 95 x 50 x 45

> 2 installation points planned

INDOOR MICROCLIMATE MONITORING

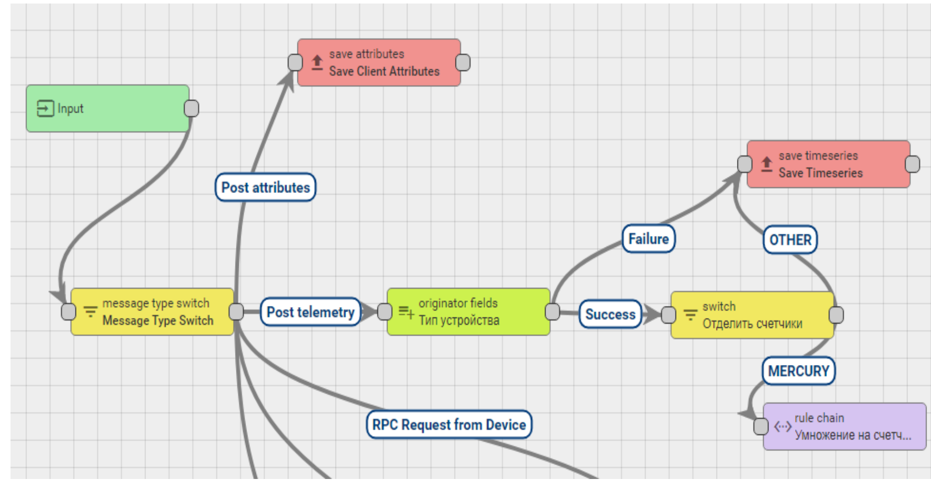
Common halls of the administration buildings

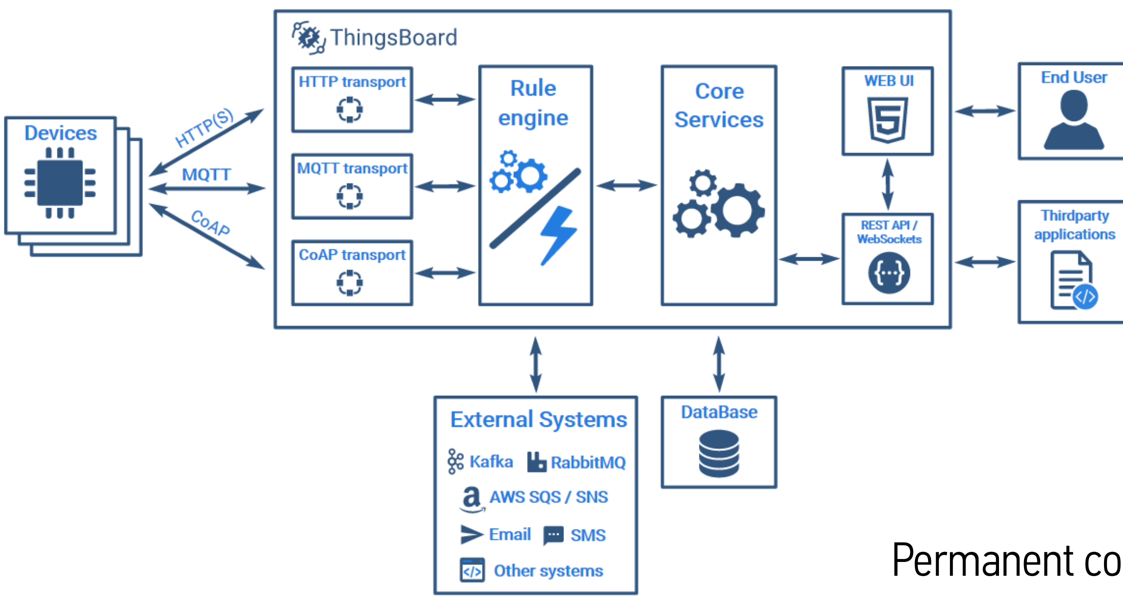


THINGSBOARD: IOT PLATFORM

ThingsBoard. Open-source IoT platform

- **Data transmission.** HTTP, MQTT, CoAP. Взаимодействие по REST API
- **Post-processing**. Rules engine (JavaScript)
- **Entities and relations.** assets, clients, devices
- **Visualization.** Analytical dashboards based on ready-to use customizable widgets (graphs, tables, charts etc.)





We use it for

- Data collection and pre-processing
- Electric and climatic data visualization
- Realtime operation control

Permanent connection link: https://energy.ipu.ru/user-login/

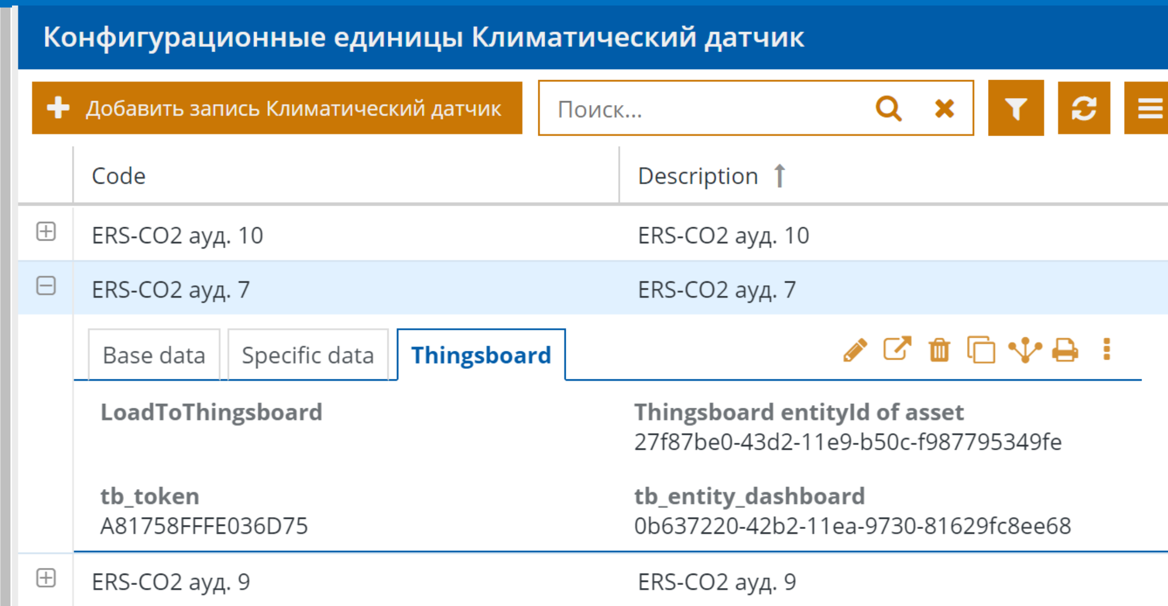
CMDBUILD: ASSET MANAGEMENT SYSTEM

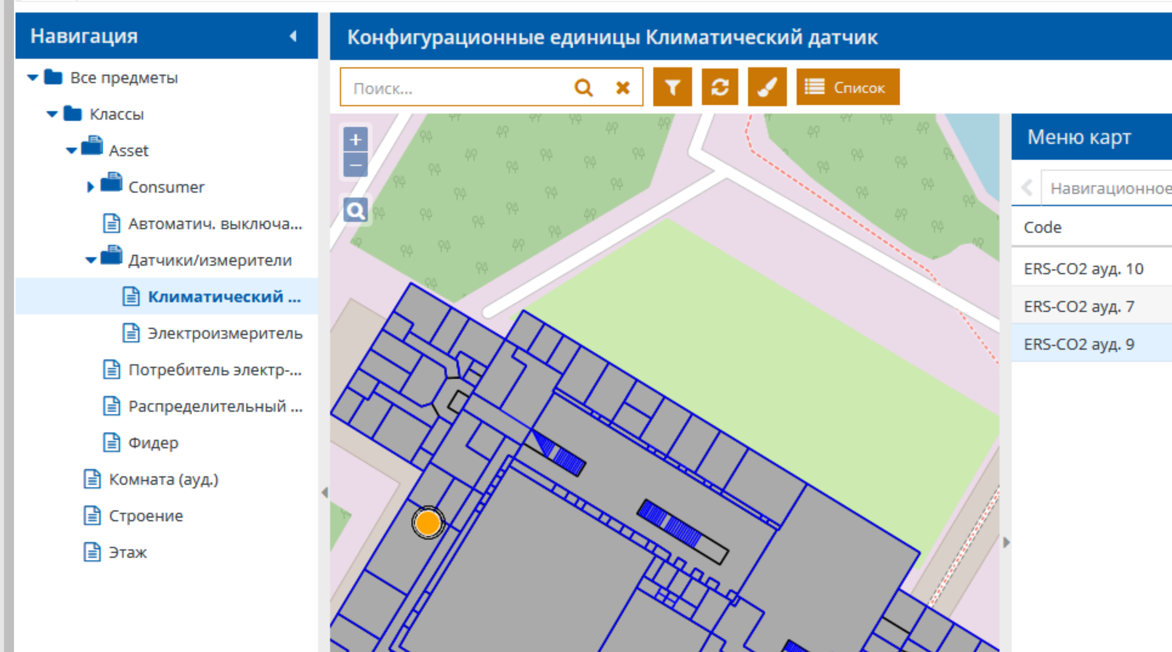
Managing all assets: devices, sensors, services, locations, e.t.c.

Topology of distribution grid of ICS RAS

Binding object location (maps) to assets

Integration of the experimental site components

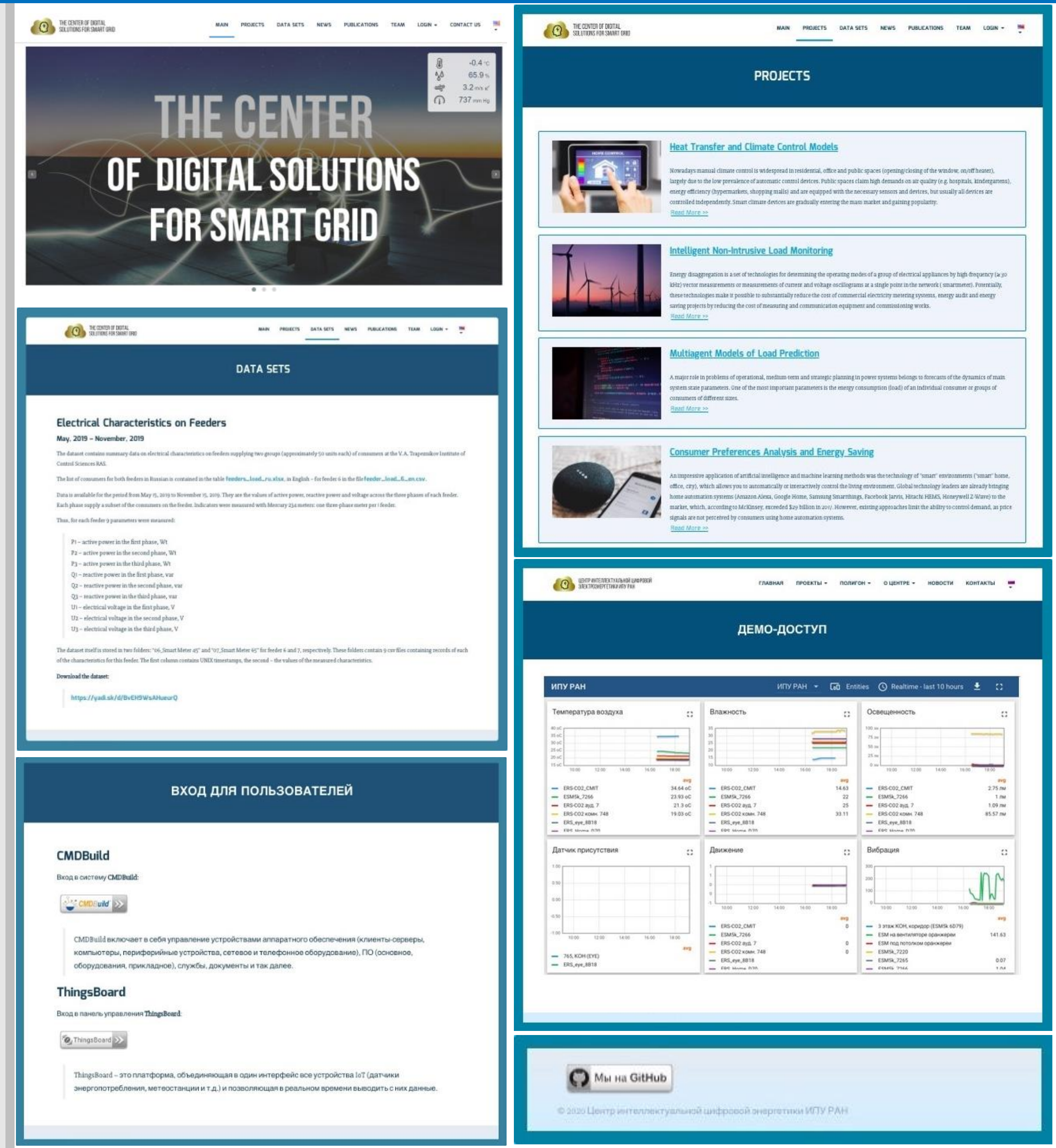




SITE ENERGY.IPU.RU

Site map

- PROJECTS
- DATA SETS
- NEWS
- PUBLICATIONS
- TEAM
- DEMO-ACCESS
- CONTACTS



DATASETS AVAILABLE

1. ICS Power and Climate Data, 2021, January – November
2. ICS Power and Climate Data, 2020, March – August
3. Measurements of the Microclimatic State, 2020, May – August
4. Measurements of the Microclimatic State, 2019, September – October

Smart meters parameters (0.2 Hz)
Active power at phases 1,2,3, W
Active power of the sum of the phases, W
Reactive power at phases 1,2,3, Var
Reactive power of the sum of the phases, Var
RMS voltage at phases 1,2,3, V
RMS current at phases 1,2,3, A
Angles between phase voltages, degrees
Frequency of the grid, Hz
Total harmonic distortion at phases 1,2,3, %

Equipped by weather measurements (1 Hz frequency)

- Temperature, ^{o}C
- Atmospheric pressure, Pa
- Dew point, ^{0}C
- Humidity, %
- Wind direction, degree
- Wind speed, m/s

Room measurements, interval: 5 minutes

- air temperature, ^{0}C
- the concentration of carbon dioxide, ppm
- relative humidity, %
- illumination, Lm

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• PROBLEMS, CHALLENGES, AND EXPERIENCE

1. Wireless sensors

- Lora technology
- Limitations of most domestic Lora devices (5 minutes min data exchange period)
- Custom firmware for thermal sensors
  - Measure every second
  - Transmit in packets
  - Differential compression (only deviation from the autoregression forecast is sent)

2. Smart meters heavy-duty collection system

- Avoid data gaps (offline)
- 24/7 operability control
- Hot reservation
- Notifications
- Reserve backup and restore from file
- We met problems with lags/packet loss in our LAN (unexpectedly lags become 100ms+!). change in architecture – shift the real time collectors towards the meters.

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RESEARCH PROJECTS

Heat Transfer and Climate Control Models

Nowadays manual climate control is widespread in residential, office and public spaces (opening/closing of the window, on/off heater), largely due to the low prevalence of automatic control devices. Public spaces claim high demands on air quality (e.g. hospitals, kindergartens), energy efficiency (hypermarkets, shopping malls) and are equipped with the necessary sensors and devices, but usually all devices are controlled independently. Smart climate devices are gradually entering the mass market and gaining popularity.

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Intelligent Non-Intrusive Load Monitoring

Energy disaggregation is a set of technologies for determining the operating modes of a group of electrical appliances by high-frequency (≥ 30 kHz) vector measurements or measurements of current and voltage oscillograms at a single point in the network (smartmeter). Potentially, these technologies make it possible to substantially reduce the cost of commercial electricity metering systems, energy audit and energy saving projects by reducing the cost of measuring and communication equipment and commissioning works.

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Multiagent Models of Load Prediction

A major role in problems of operational, medium-term and strategic planning in power systems belongs to forecasts of the dynamics of main system state parameters. One of the most important parameters is the energy consumption (load) of an individual consumer or groups of consumers of different sizes.

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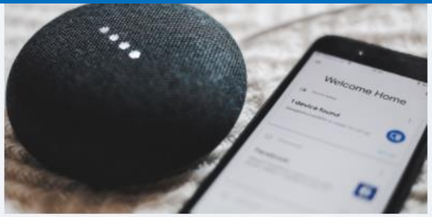
RESEARCH PROJECTS



An impressive application of artificial intelligence and machine learning methods was the technology of "smart" environments ("smart" home, office, city), which allows you to automatically or interactively control the living environment. Global technology leaders are already bringing home automation systems (Amazon Alexa, Google Home, Samsung Smartthings, Facebook Jarvis, Hitachi HEMS, Honeywell Z-Wave) to the market, which, according to McKinsey, exceeded $29 billion in 2017. However, existing approaches limit the ability to control demand, as price signals are not perceived by consumers using home automation systems.

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Mathematical and Simulation Models of Electricity Markets

In order to form an effective market policy and avoid costly mistakes in improving the electricity market, a methodology is required to test market mechanisms in a laboratory environment. An important aspect is the analysis of the manipulation of mechanisms, i.e. the ability of market participants to benefit from the reporting of inaccurate information. Analysis of the manipulability and search for optimal mechanisms requires the use of game theory methods and mechanism design.

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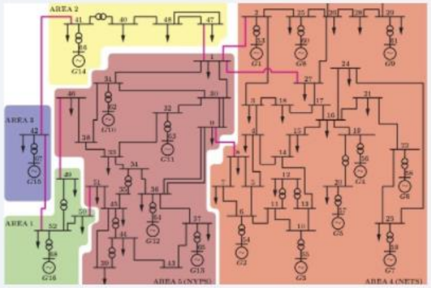

Management of Stability of Power Systems with Distributed Generation

Real-time control of distributed generation is not a problem, although it requires less human involvement in the management of generators and more fully automated control. However, the integration of distributed power into the backbone grid poses problems related to the dynamic interaction of main grid generators with high inertia with distributed generation, including RES, which have low inertia. As a result of such interaction, there are dangerous low-stable fluctuations, which can lead to the failure of technological equipment of consumers, or electrical equipment in the main network, as well as the development of cascade failure. A new task of monitoring the stability stock for main power grids arises.

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RESEARCH PROJECTS

Reliability of energy supply to electricity consumers is one of the two most important criteria of electricity quality. In the energy sector, there are no universal methods of solving problems of reliability analysis. An important part of these tasks is the simulation of failures of lines, generators, transformers, switchgear. The development of IT has led to the appearance of virtual failure analyzers, which form a reference (virtual) mathematical model of the functioning of the EES in normal mode, as well as the current mathematical model, which can be restored from the data of state measurements in such analyzers measured inconsistency between the parameters of the reference and the real system, which allows you to diagnose parametric failures.

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Algorithms for Grid Topology Optimization and Expansion Planning

The purpose of the development of the investment program of the UES of Russia is to ensure the reliability and quality of energy supply, i.e. only technical criteria are used to evaluate investment projects. Taking into account the price signals of the wholesale market in the development of the investment program will increase its efficiency.

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Information Security of Digital Electric Networks

With the adoption of the Federal Law "On the Safety of Critical Information Infrastructure of the Russian Federation", the responsibility of the owners and proprietors of power plants for ensuring their information security (IS) as significant objects of critical information infrastructure has increased dramatically. First of all, it is a problem of assessment of potential IS risks arising from the impact of computer attacks on the information technology infrastructure of the power plant, and management of these risks. It seems expedient to develop a number of intelligent IS risk management technologies oriented to the use of EES in the EMS and taking into account their peculiarities as significant objects of the critical information infrastructure of the Russian Federation.

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WE WELCOME COLLABORATION

Researchers, energy companies, equipment vendors

- ❖ Sharing datasets to solve problems
- ❖ Collecting datasets for different purposes
- ❖ Joint team for data collection system implementation
- ❖ Consulting in data science, machine learning, data acquisition networks
- ❖ Data acquisition system support

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