A living lab for integration of emerging technologies into distribution systems of the future:

A CPFL-UNICAMP collaboration

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Agenda

- Living lab: a definition
- Emerging technologies
- A platform for integration of emerging technologies: The largest living laboratory in Latin America – (partnership CPFL/UNICAMP):

Living Lab Barao Geraldo

- Potential future projects
- Final comments

Living laboratory: A definition

"Living Labs (LLs) are defined as ***user-centred****, open innovation ecosystems based on systematic* ***user co-creation approach****, integrating research and innovation processes in* ***real life communities*** *and settings.*

In practice, living labs place the ***citizen at the centre of innovation****, and have thus shown the ability to better mould the opportunities offered by new ICT concepts and solutions to the specific needs and aspirations of local contexts, cultures, and creativity potentials.*

5 key elements must be present in a living lab:

- ***active user involvement:*** *i.e., empowering end users to thoroughly impact the innovation process*
- ***real-life setting:*** *i.e., testing and experimenting with new artefacts "in the wild"*
- ***multi-stakeholder participation:*** *i.e., the involvement of technology providers, service providers, relevant institutional actors, professional or* ***residential end users***
- ***a multi-method approach:*** *i.e., the combination of methods and tools originating from ethnography, psychology, sociology, strategic management, engineering*
- ***co-creation:*** *i.e., iterations of design cycles with different sets of stakeholders"*

From: ENoLL – European Network of Living Labs - https://enoll.org/

Energy systems of the future: Emerging technologies

- Renewable generation (wind/photovoltaic generation)
- Distributed sensors (smart meters)

Well established market

- Electric mobility (electric vehicles)

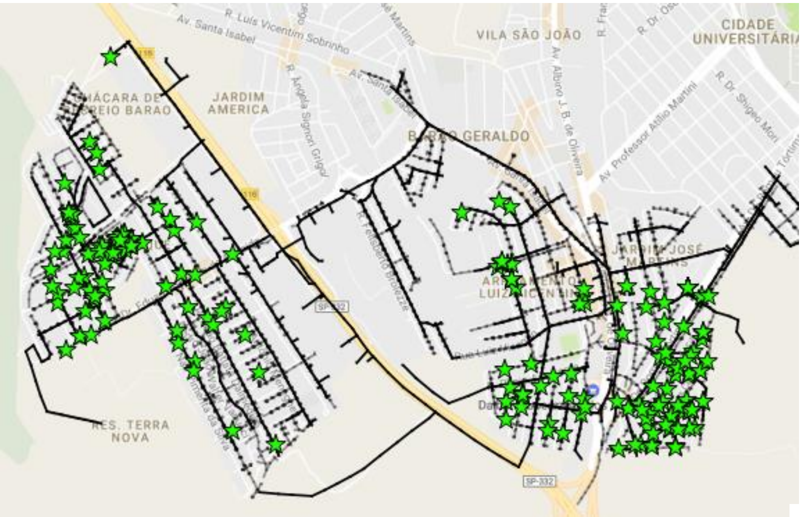
Market under development

- Energy storage systems (batteries, flywheels etc.)
- Power electronic-based devices for distribution systems – utility and customer side solutions

Market to be developed

PA3012: PV rooftop

- ✓ Pilot-project: installation of 230 rooftop PV panels (~850 kWp) in residential circuits (all connected to the same feeder)

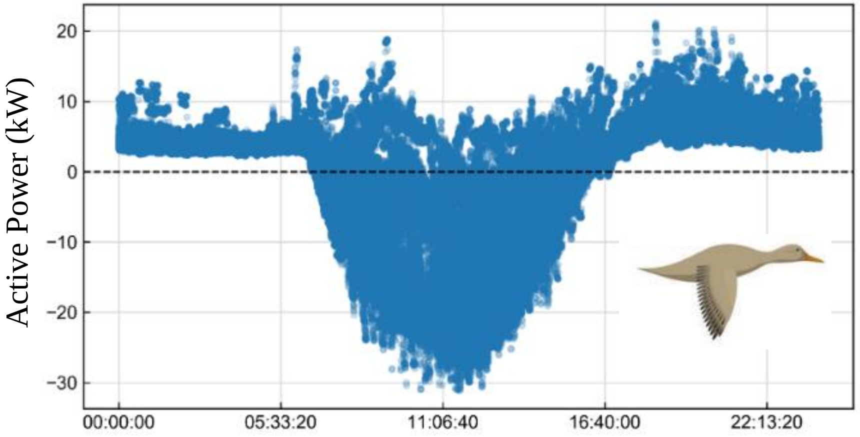


- ✓ 100% real-time measurements (smart meters) + power quality meters + weather station

- ✓ Period: 10/2014 – 09/2018 (4 years)

- ✓ Objectives:
  - ➢ Investigate the main technical impacts and mitigation solutions
  - ➢ Investigate the integration into engineering procedures
  - ➢ Collaborate with regulatory aspects
  - ➢ Develop new markets and services

- ✓ Investment: R$ 14.4 million



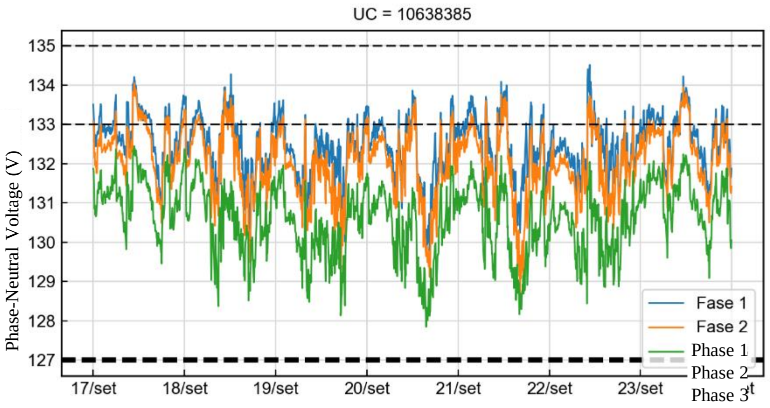
MV/LV transformer power curve – 30 days

Imported energy = 2.230 MWh
Exported energy = 2.454 MWh

Direct peak = 21.18 kW
Reverse peak = 31.10 kW

Measurement Assessment:

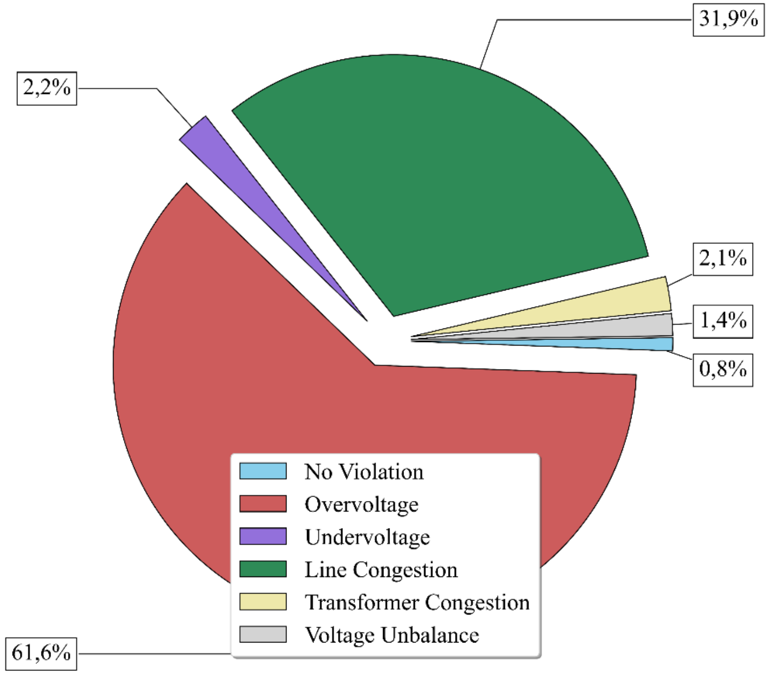
- ✓ **45 power quality meters** installed in MV/LV transformers and customers – 10 seconds/30 days
- ✓ **231 AC/DC meters** installed in PV generators – 1 min/1 year
- ✓ **231 smart meters** installed in customers – 5-60 min/1 year
- ✓ **+2 billion measurements data**



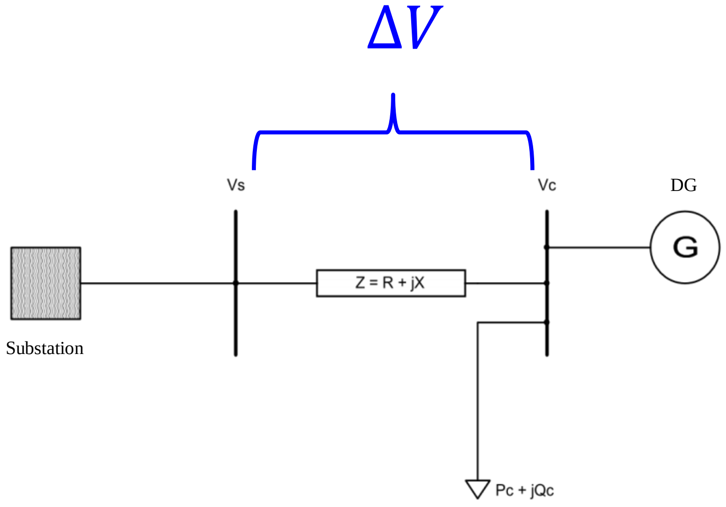
Voltage violation: DRP > 20%

Simulation Assessment:

- ✓ +85,000 analyzed secondary systems based on **Monte Carlo** simulation
- ✓ **+8 billion power flow solutions**



Analytical Analysis:

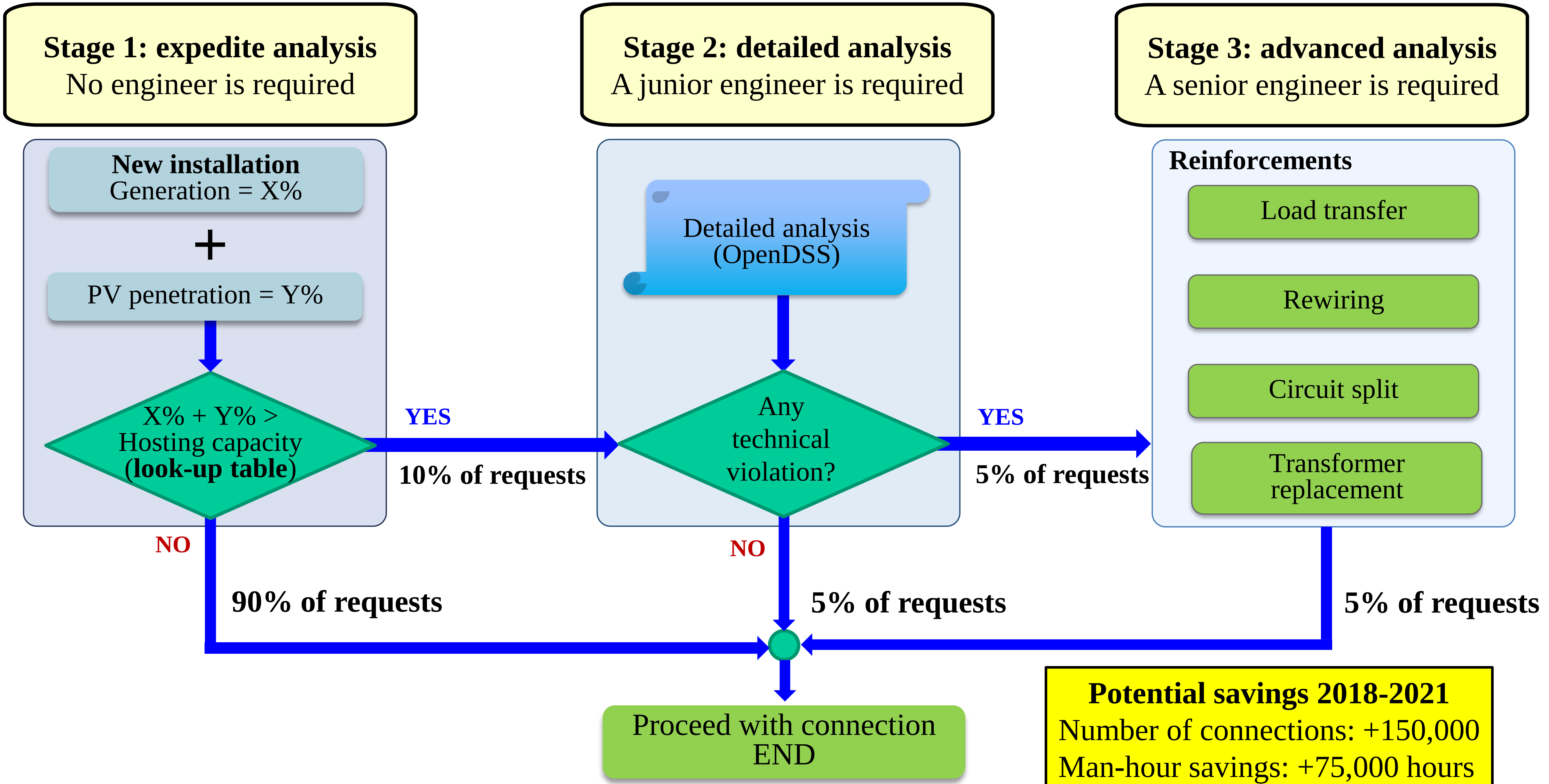


$$\Delta V \approx \frac{R(P_G - P_C) + X(Q_G - Q_C)}{V_C}$$

$$\Delta V_G \approx R P_G + X Q_G$$

More information: R. Torquato, D. Salles, C. Pereira, P. Meira, W Freitas, “A Comprehensive Assessment of PV Hosting Capacity on Low-Voltage Distribution Systems,” IEEE Transactions on Power Delivery, vol. 33, pp. 1002-1012, 2018. Nominated Papers Received Favorable Reviews (3 papers in 2018)

PA3012: PV rooftop – integration into engineering procedure

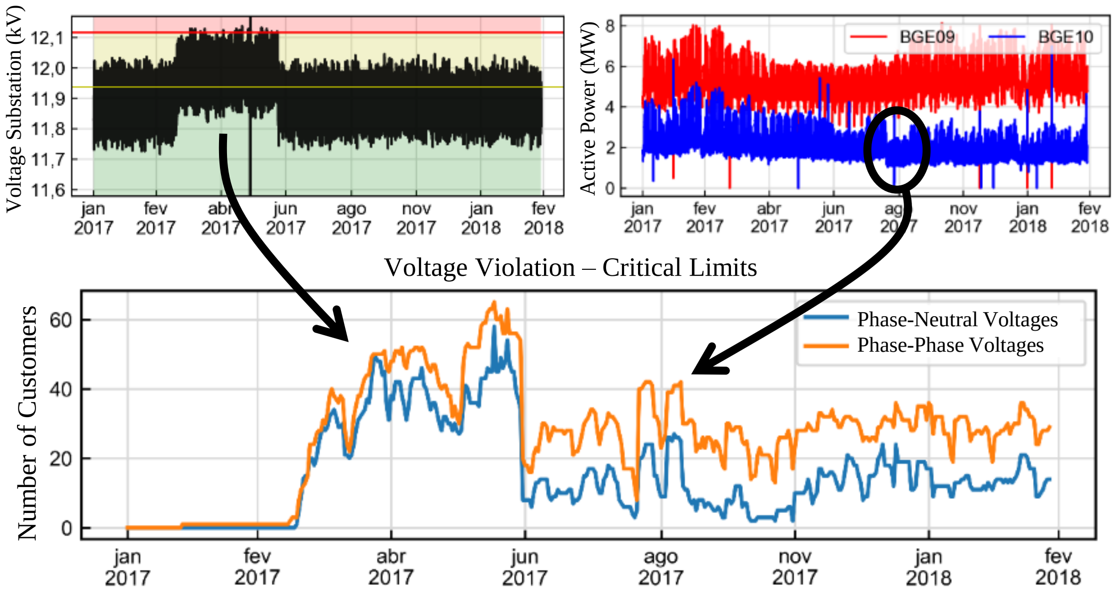


Potential savings 2018-2021
Number of connections: +150,000
Man-hour savings: +75,000 hours
Cost savings: +R$ 3,500,000

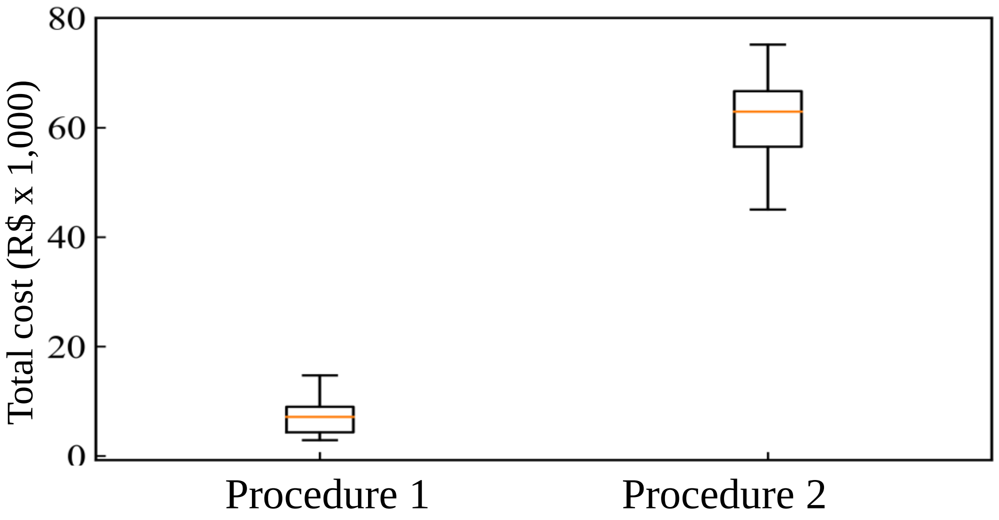
More information: Patent BR1020180154540

PA3047: Volt/var control – micro generation

- ✓ Pilot-project: Develop new procedures and test technologies for voltage and var control in distribution systems with high penetration of PV generation
- ✓ Period: 11/2018 – 10/2022 (4 years)
- ✓ Objectives:
  - ➢ Develop new procedures: develop a probabilistic technical-economic method to decide the best solution (voltage violation, power factor violation, technical losses, equipment maintenance)
  - ➢ Test new technologies: low voltage regulators, dynamic var compensators, smart inverters
  - ➢ Collaborate with the regulatory model (*e.g.*, power factor limits)
- ✓ Investment: R$ 4.6 million



Conflict with current practices (measurements)



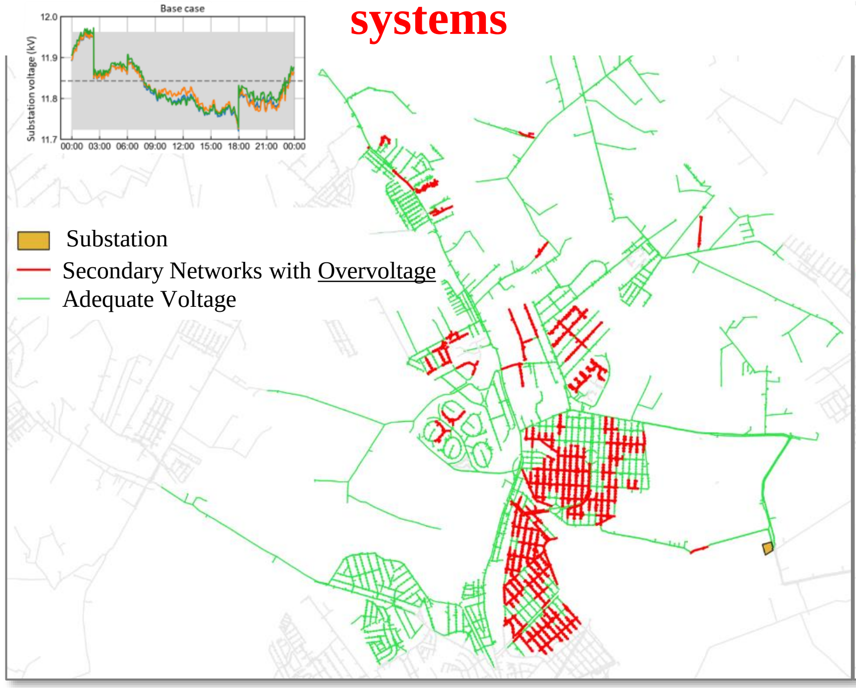
Probabilistic-technical-economic approach for decision-making process

Voltvar Analytical Research

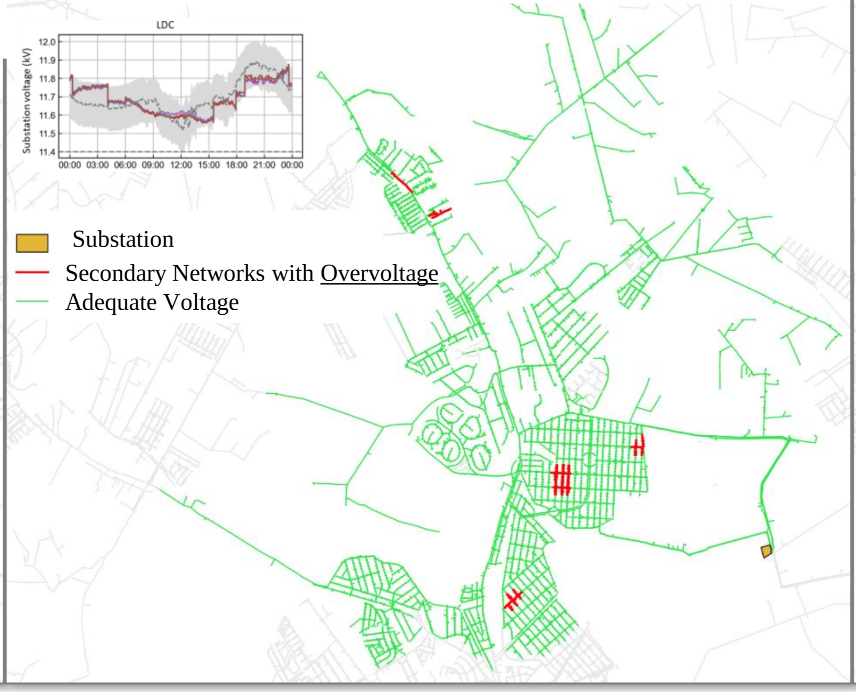
A start-up company developing analytical tools for volt/var control

PA3047: Volt/var control – micro generation: new procedure

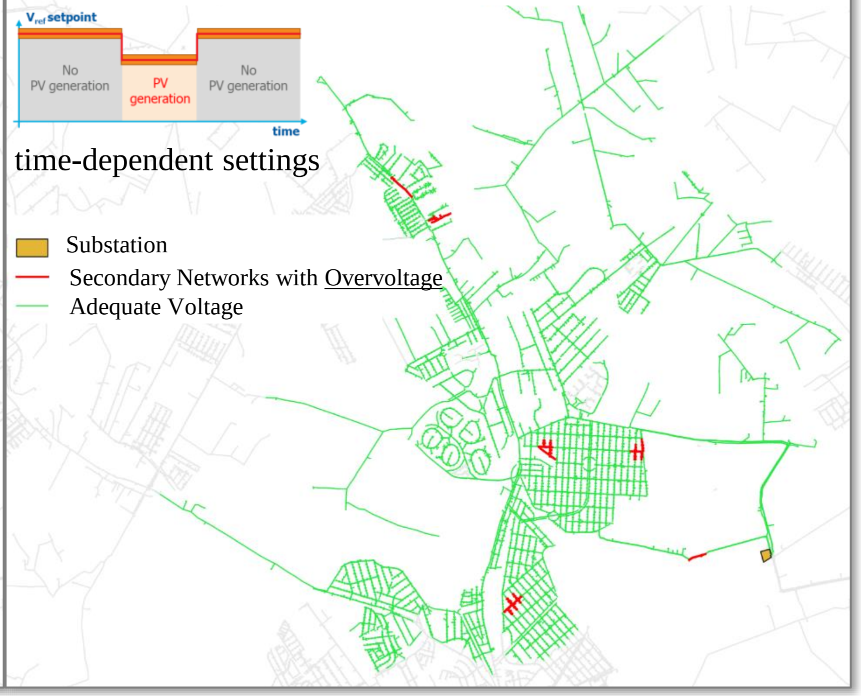
Base Case, 1,040 customers, 83 LV systems



LDC, 56 customers, 6 LV systems



MAP, 58 customers, 6 LV systems



Substation: 23% - residential (B1) customers with PV

Costs (67 Circuits)	Undervoltage	Overvoltage	Total
25% PV Penetration	577,141.26	**29,224,229.64**	30,228,465.32
25% PV Penetration + MAPA	**789,522.95**	**7,425,224.53**	**8,549,324.31**

Potential savings R$ 50 - 100 million/year

Decision making:

Current strategy:

Higher and **dispersed** cost (with dominant overvoltage)

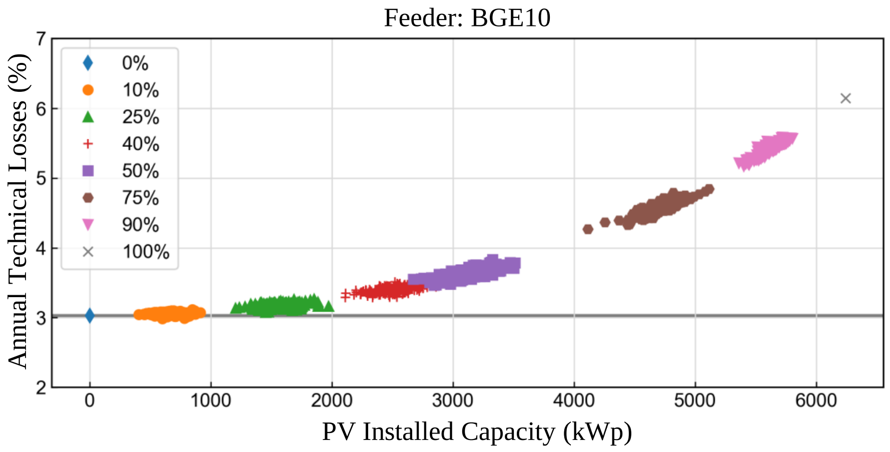
Proposed strategy:

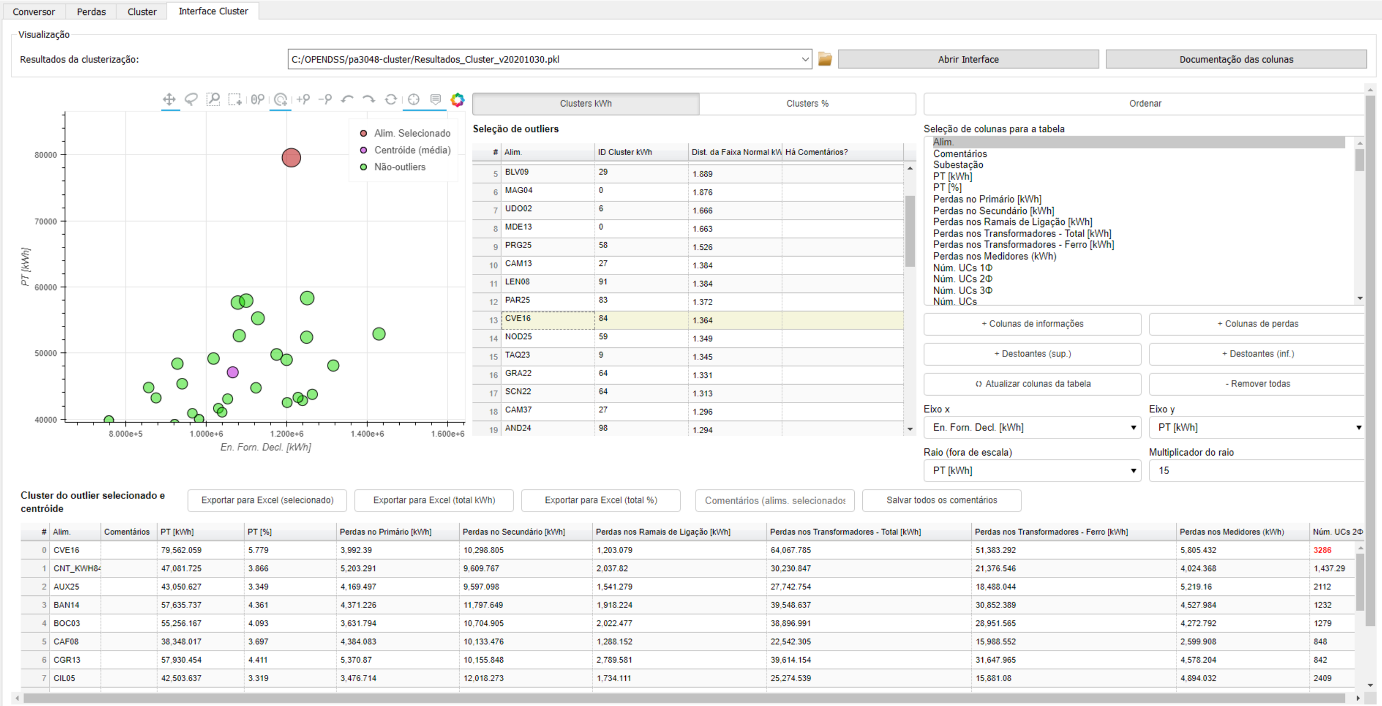
Lower and **concentrated** cost (with dominant undervoltage)

PA3048: Technical losses assessment and management

CPFL ENERGIA · PORAKÊ · UNICAMP · P&D ANEEL

- ✓ **Issue**: In Brazil, the technical losses are evaluated by using BDGD database and OpenDSS. However:
  - ➢ The regulatory model may underestimate the losses – financial impact for utilities
  - ➢ The method is time-consuming (20-30 days for a large utility)
- ✓ **Period**: 11/2018 – 10/2022 (4 years)





- ✓ **Objectives**:
  - ➢ Collaborate with regulatory aspects
  - ➢ Develop computing techniques to speed up the technical losses evaluation
  - ➢ Integrate BDGD into OpenDSS
  - ➢ Develop tool for loss management
- ✓ **Investment**: R$ 4.1 million

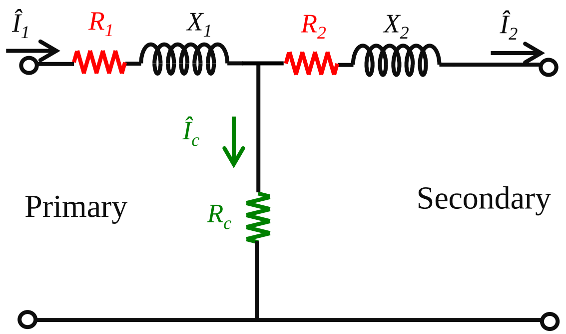
Final product will be partially available for ANEEL and other utilities

PORAKÊ

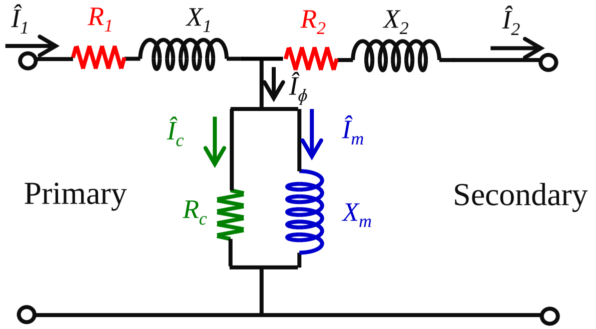
A start-up company developing integrated software for system and big data analysis

PA3048: Technical losses assessment and management – regulatory model and computational aspects

- ✓ Issue 1 – accuracy relevance: assess and plan actions to (a) improve the system efficiency; (b) combat the non-technical losses
- ✓ Solution: suggestion for improvement based on physical models: transformer model and parameters



ANEEL model – parameters based on ABNT



Real/field model

Utility	TL Impact (2019)	NTL Impact (2019)
A	+15.5%	-14.0%
B	+14.2%	-18.3%

*Note: total non-technical loss values are extracted from ANEEL, "Metodologia de Cálculo Tarifário da Distribuição – Perdas de Energia." Available at: https://www.aneel.gov.br/metodologia-distribuicao/-/asset_publisher/e2INtBH4EC4e/content/perdas/654800?inheritRedirect=false.

- ✓ Issue 2 – processing time relevance: enable the use of the regulatory model/structure for loss management (cost savings of man-hours and computational infrastructure)
- ✓ Solution: use proper OpenDSS models; recode some OpenDSS functionalities, replace COM interface, integrate BDGD**

Step	CPFL Paulista	RGE
Conversion	0h54min	0h17min
Complete loss calculation	2h40min	1h50min
Total	**3h34min**	**2h07min**
Total for the 2 utilities : 5h41min		

WorkStation: 2 processors Intel® Xeon® E5-2630 v4 CPU @ 2.20 GHz (20 cores), 48 GB de RAM, 256 GB de SSD

Current solution: several weeks

** To be done

PA0060: Electric mobility

✓ Pilot-project:

➢ Installation of 20 public stations (12 normal, 5 semi fast, and 3 fast charging stations) + 5 home charging stations

➢ Monitoring of 16 electric vehicles in corporate fleet (companies, car rental agencies, taxi)

✓ Period: 08/2013 – 07/2018 (5 years)

UNICAMP

✓ Objectives:

➢ Investigate the main technical impacts

➢ Build behavior models for studies

➢ Contribute to regulatory aspects

➢ Develop new services and market (public stations)

✓ Investment: R$ 16.7 million

Total: 25 stations

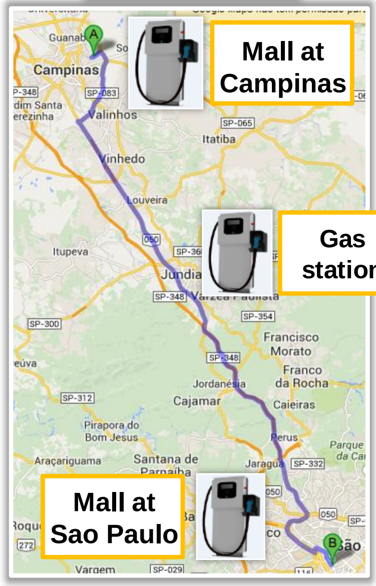
Normal (4h – 8h)
Number: +08 (04 installed)

Semi Fast (1h – 2h)
Number: 05

Fast (30 minutos)
Number: 03

Home Charger (4h – 8h)
Number: +05

Campinas – SP



Total: 27 vehicles (until 2015)

	Vehicles				Usage Profile
Phase 01	 (Kangoo) 05	 (ZOE) 01		06 EVs	Companies
Phase 02	 (Kangoo) 08	 (ZOE) 02	 TWIZY' 04	21 EVs	Car Renters
	 BYD - E6 04	 BYD - Hybrid 01	 Fluence ZE' 02		Taxi
					Executive

CS3060: Platform for electric mobility

CPFL ENERGIA · CPqD · Andrade Analytics · UNICAMP · P&D ANEEL

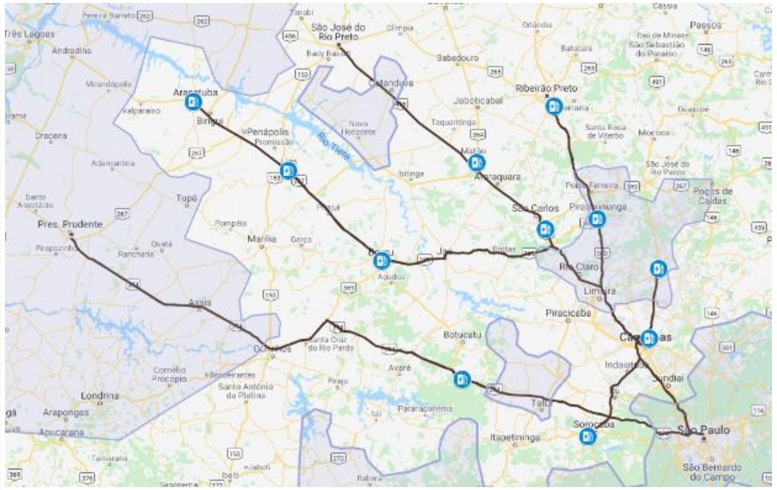
- ✓ Pilot-project and prototypes:
  - ➢ Urban and intercity infrastructure in two states
  - ➢ Experimentation for billing, clearing, and roaming
  - ➢ Services for electromobility: planning and management
- ✓ Period: 03/2020 – 02/2024 (4 years)
- ✓ Objectives:
  - ➢ Development of a software for planning and management of electromobility business
  - ➢ Deployment of city and intercity infrastructure
- ✓ Investment: R$ 47.7 million

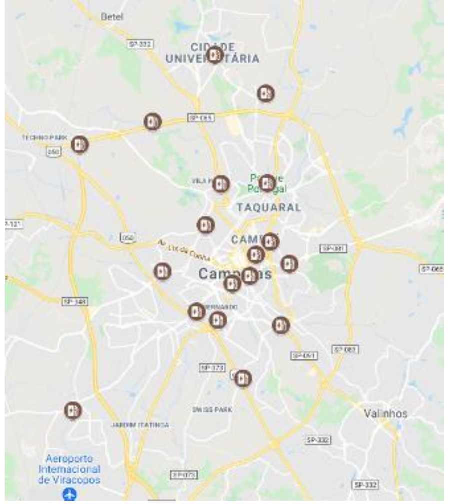
LIVING LABs

Phase 1:
Campinas and Intercity corridor in SP and RS

↓

Phase 2
Touristic corridor RS





Partners

Electric vehicles
BYD · BMW · RENAULT · CAOA CHERY

Mobility services suppliers
diaentregue · movida · Uber · TRANSPASS RENT A CAR · beepbeep

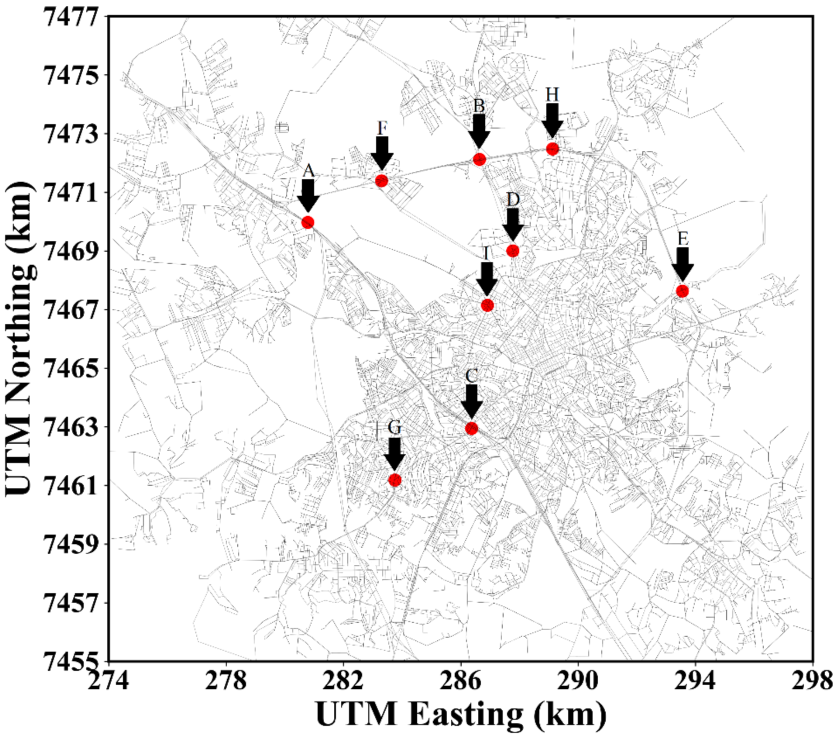
EP
Graal · Ipiranga · makro group · VIRACOPOS

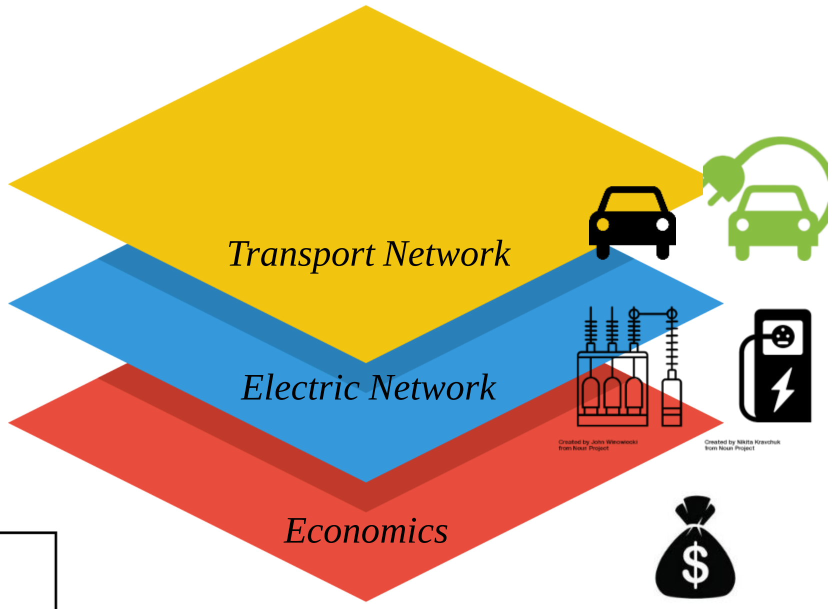
EP suppliers
ABB · EMB electricmobility brasil · ELECTRICUS

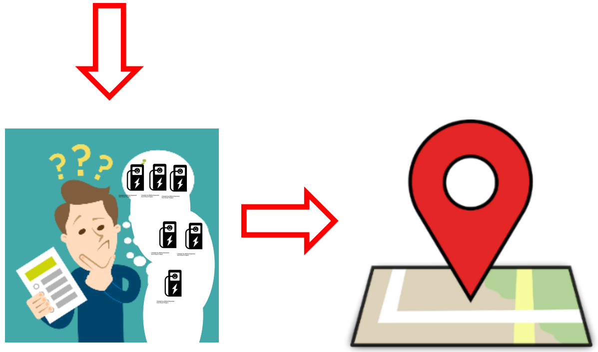
Andrade Analytics A start-up company developing analytical tools for electric mobility

Composition (layers):

- ✓ Traffic flow:
  - Driver - Stochastic behaviour
  - Strategic points - Airports, Malls etc.
- ✓ Electric:
  - EVs and FCS profiles
  - Network operation and reinforcements
- ✓ Economic:
  - Investment
  - Maintenance
- ✓ Social:
  - Population and city
- ✓ Perspectives:
  - Smart City - Government
  - Third-part Investor
  - Distribution utility







Result comes from the combination of layers: Cost-effective solutions (number, location, and size of FCSs)

PA3018: Energy storage (battery)

- ✓ Pilot-projects:
  - ➢ 1 x 1 MW/2 MWh energy storage system installed into a HV/MV substation for application at MV feeder level
  - ➢ 1 x 100 kW/225 kWh ground mounted energy storage systems installed into a gated community and 1 x 25 kW/75 kWh pole mounted for application at LV circuit level (PV and EV)
  - ➢ 2 x 5 kW/14 kWh energy storage systems installed into an LV facility for application at customer level (PV)

Barao Geraldo HV/MV Substation

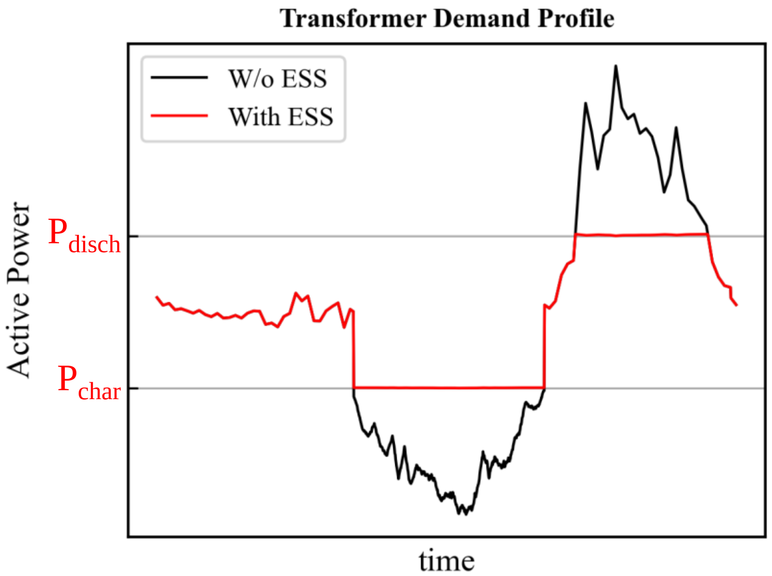
- ✓ Period: 07/2017 – 06/2022 (5 years)
- ✓ Objectives:
  - ➢ Develop new applications
  - ➢ Develop new services and markets
  - ➢ Contribute to regulatory aspects
- ✓ Investment: R$ 26.8 million

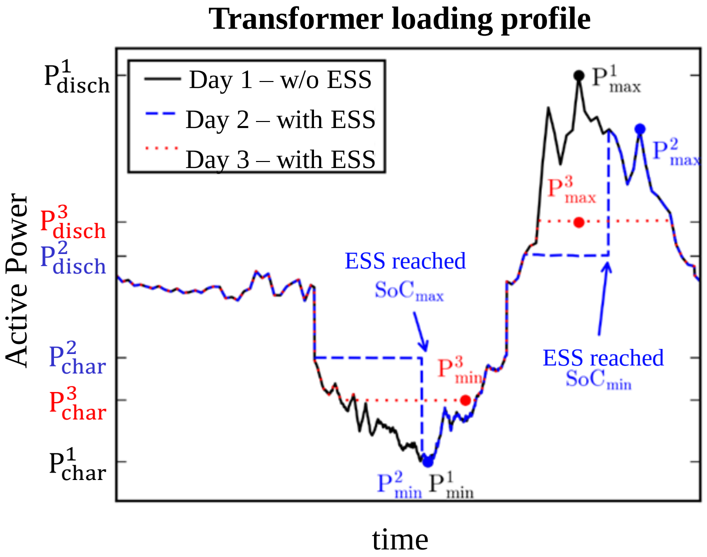
Pole mounted - applications in LV circuits

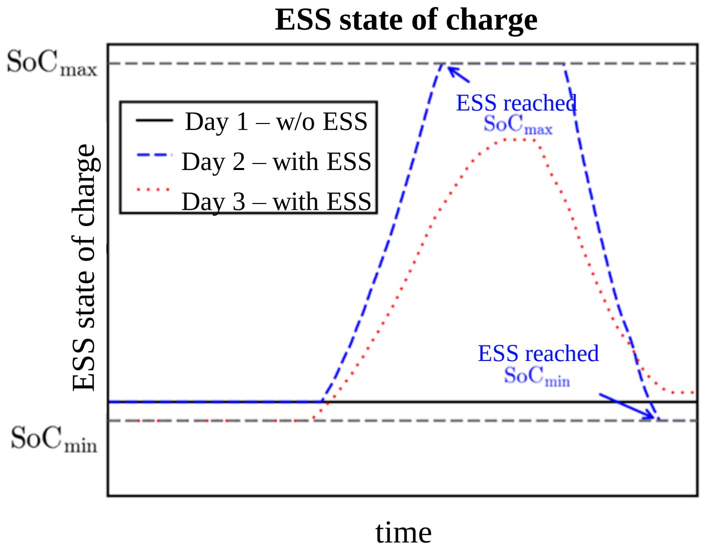
Pad mounted - applications in LV circuits

PA3018: Energy storage (battery) – integration of rooftop PV and EV slow charger

- Problems to be solved: (a) decrease peak load; (b) improve MV/LV transformer loading factor; (c) increase the PV and EV hosting capacity
- Difficulties: how to determine charging and discharging times and rates (load behavior in MV/LV transformers is difficult to predict)
- Developed solution (patented): daily self-adaptable thresholds







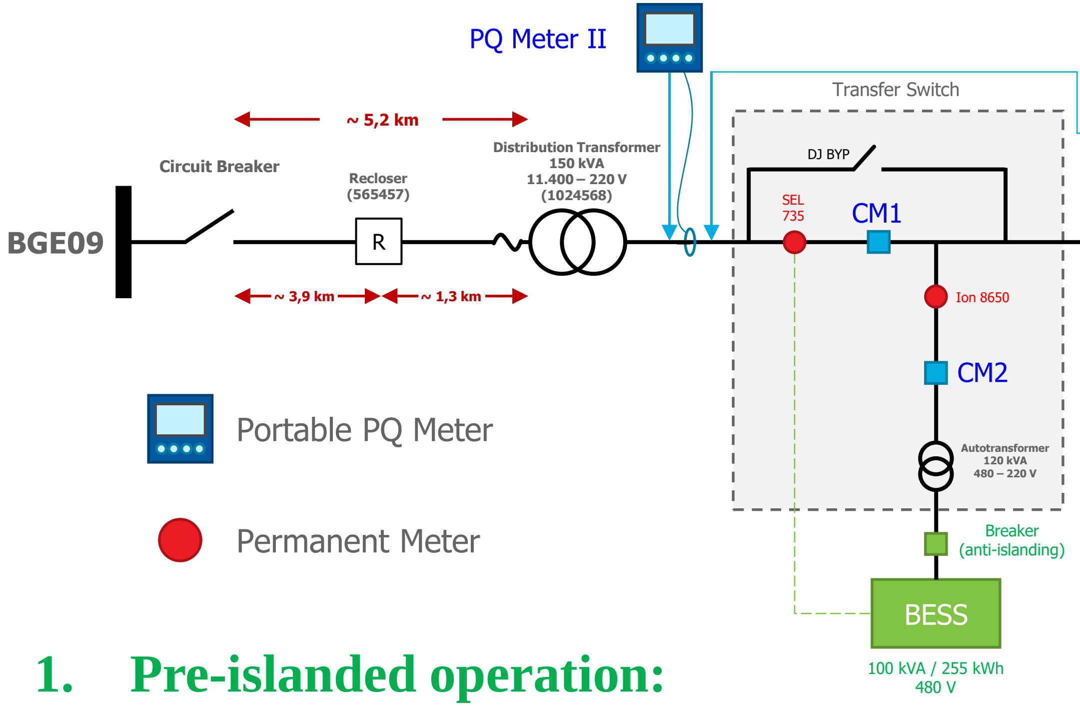
Results over 1 year:

- ✓ +20% average reduction of transformer peak demand throughout the year
- ✓ +10% average increase of transformer load factor
- ✓ 0% voltage violations (originally, +20% of customer units with voltage violations)

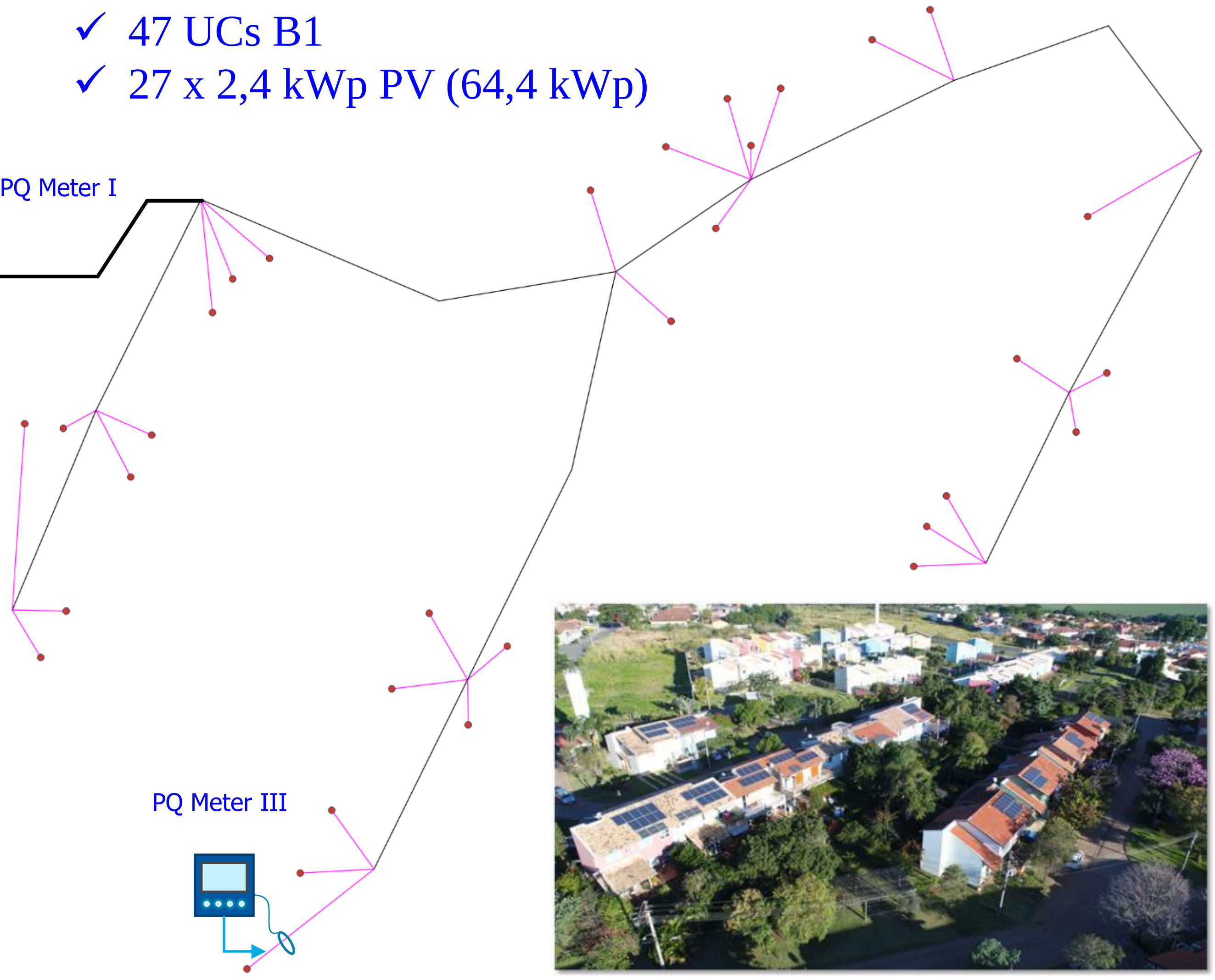
Hosting capacity – PV (kW)			
%Cons. - PV (kW)	5%	15%	25%
Without ESS	5	7	10
With ESS	8	15	17

More information:
Patent BR10202101479

PA3018: Energy storage (battery) – microgrid



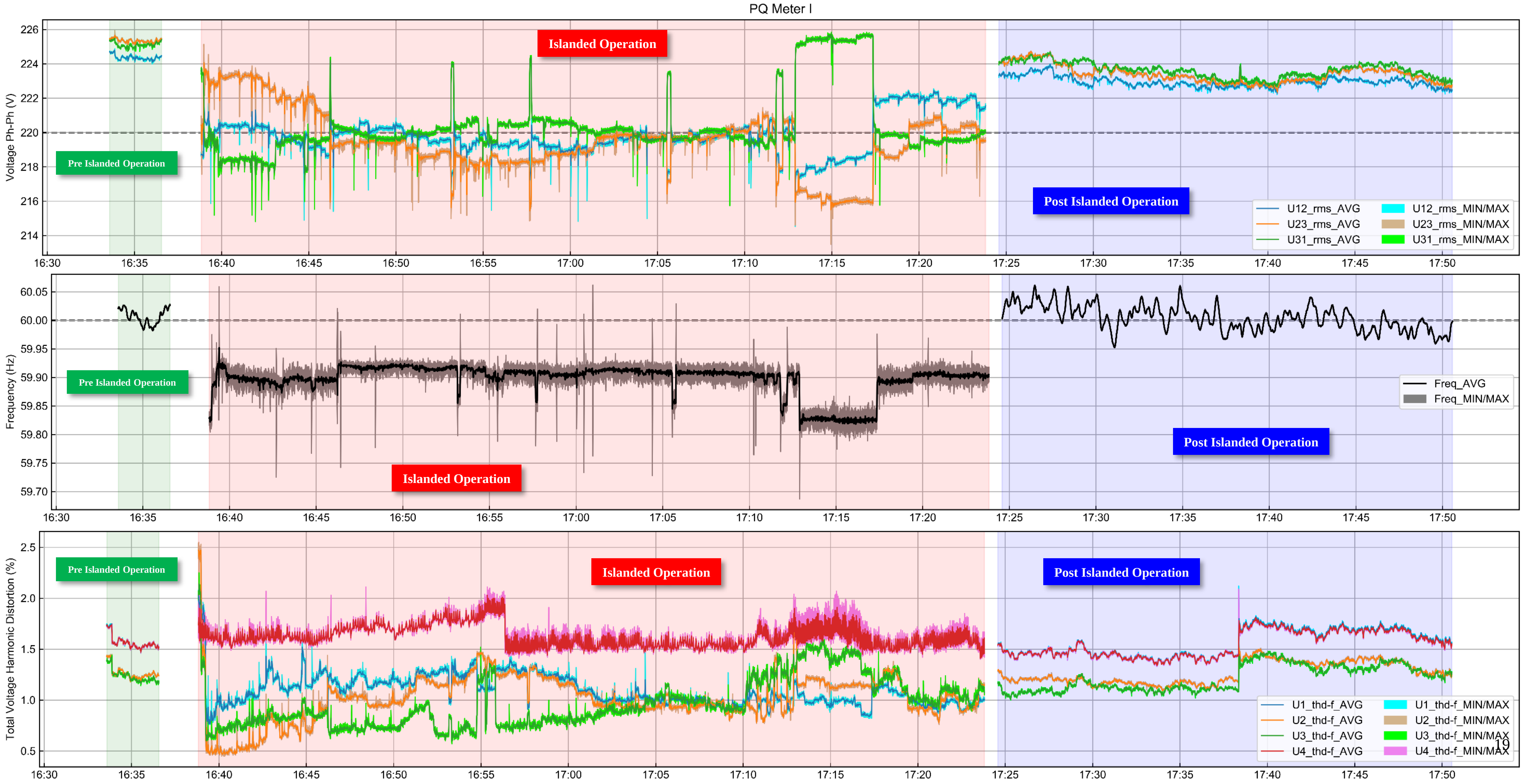
- ✓ 47 UCs B1
- ✓ 27 x 2,4 kWp PV (64,4 kWp)



1. **Pre-islanded operation:**
   24/06/2022 16:33:35 à 24/06/2022 16:36:34
   (3 min, 180 samples)
2. **Islanded operation:**
   24/06/2022 16:38:50 à 24/06/2022 17:23:49
   (45 min, 2.700 samples)
3. **Post-islanded operation:**
   24/06/2022 17:24:35 à 24/06/2022 17:50:34
   (26 min, 1.560 samples)

■ CM1, CM2 – Remotely operated switch

PA3018: Energy storage (battery) – microgrid



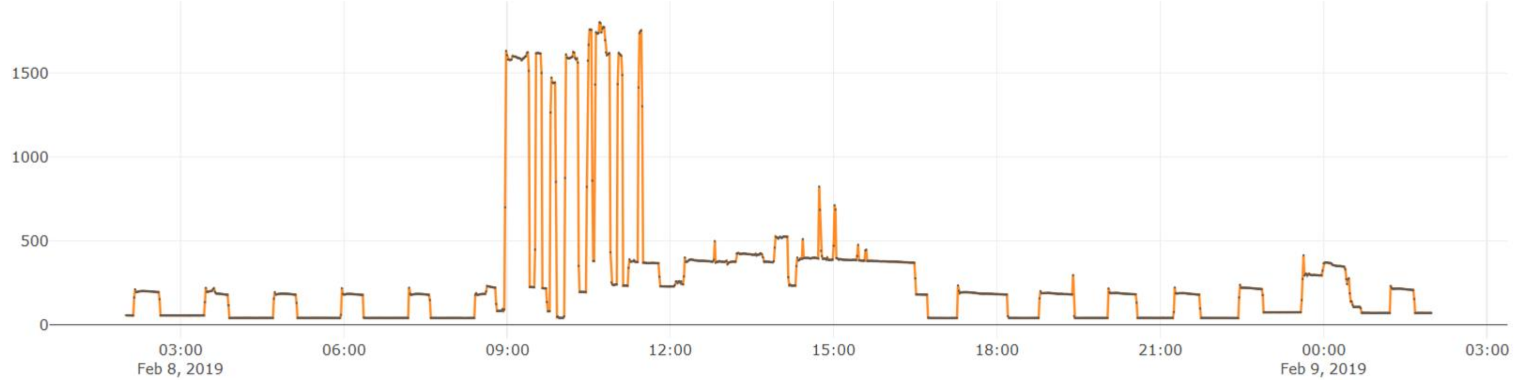
PA3020: Load disaggregation – smart meter application

- ✓ Pilot-project: 10 houses with 100% real-time monitoring
- ✓ Period: 11/2016 – 05/2019 (2.5 years)
- ✓ Objectives:
  - ➢ Use only one sensor (smart meter) to determine the individual energy consumption per appliance (bill breakdown)
  - ➢ Create database for R&D (centralized, partially distributed and distributed monitoring)
  - ➢ Develop new services
- ✓ Investment: R$ 2.5 million

- ✓ Integrated into the smart meter (centralized)
- ✓ Service supplied by the utility

- ✓ Integrated into the electric panel per circuit (partially distributed)
- ✓ Service supplied by third-party

- ✓ Installed at each plug (distributed)
- ✓ Service supplied by third-party

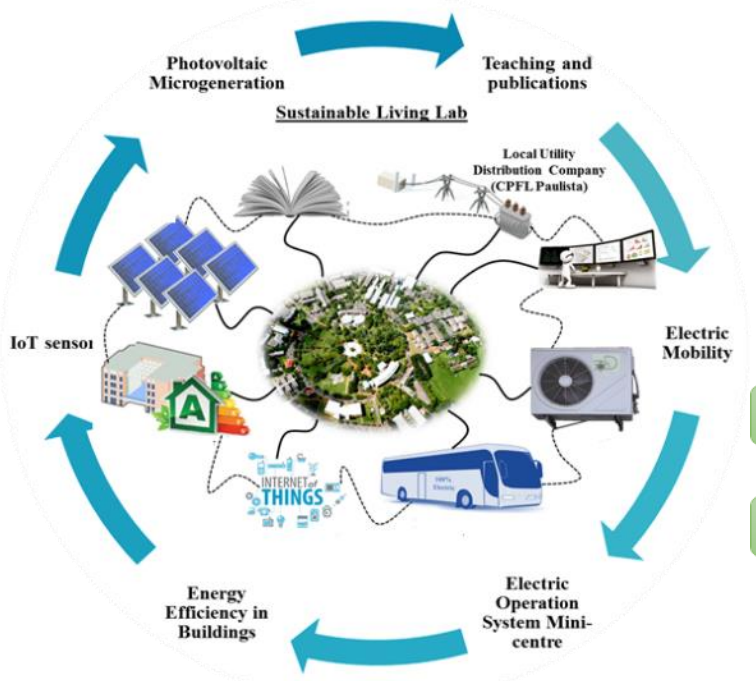


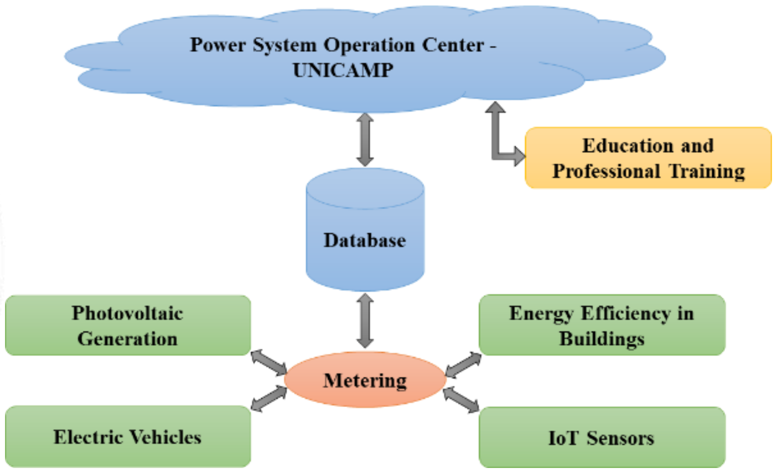
TIME ENERGY
http://www.timeenergy.com.br

Products developed by TE - a start-up company (now a scale-up company) in sensors and meters

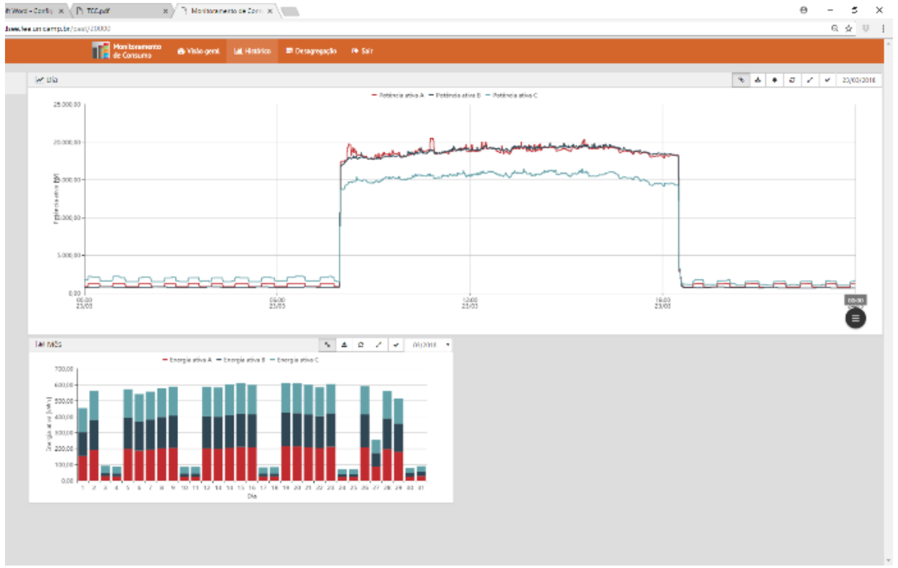
PA3032: Sustainable campus (R&D + EE)

- ✓ Pilot-project/objective: Develop a sustainable campus by using smart grids and smart cities technologies at UNICAMP:
  - ➢ Monitoring of the electrical system
  - ➢ Renewable generation (573 kWp – PV)
  - ➢ Electric mobility
  - ➢ Energy efficiency
  - ➢ IoT management
  - ➢ Energy management
  - ➢ Benchmarking for energy efficiency





- ✓ Investments:
  - ➢ EE: R$ 3.4 million
  - ➢ R&D: R$ 6.3 million
  - ➢ Partnership: R$ 2.3 million



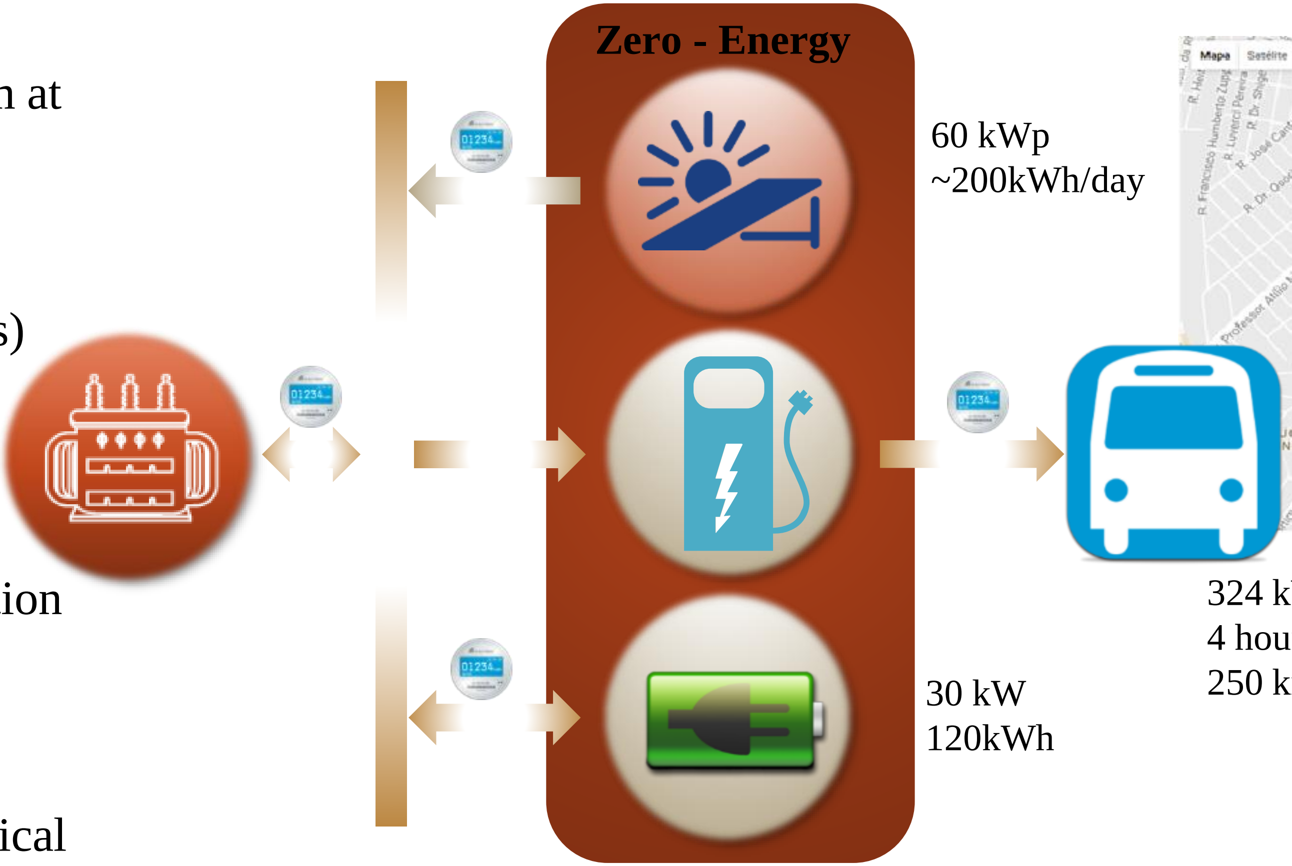
PA3043: Electric bus – net zero energy charging station

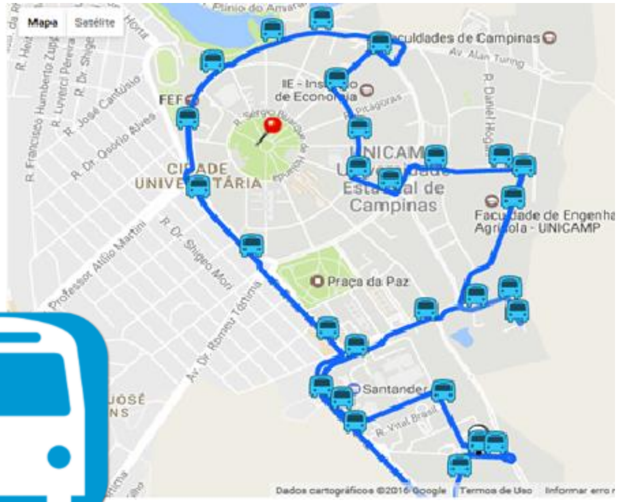
- ✓ Pilot-project: Introduce an electric bus into the public transport system at UNICAMP with 100% monitoring

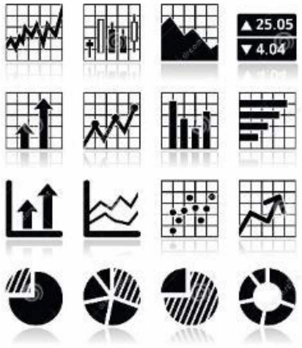
- ✓ Period: 11/2018 – 10/2022 (4 years)

- ✓ Objectives:
  - ➢ Develop net zero charging station
  - ➢ Use the bus as a real-time "sensor" of the campus
  - ➢ Understand technical, economical and regulatory aspects

- ✓ Investment: R$ 6.4 million







PA3058: MERGE – Microgrid for Efficient, Reliable, and Greener Energy

- ✓ Four microgrid pilot projects:
  - ➢ LabREI: Smart Grid Laboratory
    - Flexibility, experimentation, and development
  - ➢ NanoGRID: DC microgrid
    - High-tech case, showroom, and integration
  - ➢ CampusGRID: AC microgrid at UNICAMP Campus
    - Real environment, retail customer, consolidated solutions, and large application
  - ➢ ConGRID: Microgrid in a gated community
    - Experimentation with residential customers, regulatory challenges, and complex business models
- ✓ Period: 01/2020 – 12/2023 (4 years)
- ✓ Investment: R$ 45.3 million

- ✓ Objectives:
  - ➢ Develop, integrate, and test technologies for intelligent microgrids
  - ➢ Study and propose standards, regulations, laws, and cybersecurity for Brazilian perspective
  - ➢ Expand the national scenario of intelligent microgrids for efficient, reliable, and greener energy

Investments 2014 – 2024 and start-ups/scale-ups

Projects	Investments (R$)	PI – UNICAMP
PV rooftop	14.4 MM	Walmir Freitas
Electric mobility	16.7 MM	Walmir Freitas Fernanda Trindade
Energy storage	26.8 MM	Walmir Freitas Fernanda Trindade
Technical losses	4.1 MM	Walmir Freitas Fernanda Trindade
Volt/var control	4.6 MM	Walmir Freitas Fernanda Trindade
Load disaggregation	2.5 MM	Luiz C. P. Silva Walmir Freitas
Sustainable campus - R&D+EE	9.7 MM	Luiz C. P. Silva
Electric bus	6.4 MM	Madson Cortes Luiz C. P. Silva
Microgrid Project	45.3 MM	Luiz C. P. Silva Antenor Pomilio
Platform for electric mobility	47.7 MM	Walmir Freitas Fernanda Trindade Luiz C. P. Silva Marcos Rider
Total	**R$ 178.2 MM** **~US$ 35 MM**	

ERA – Energy Research and Analytics: A consulting and development company promoting a new ERA for energy and society

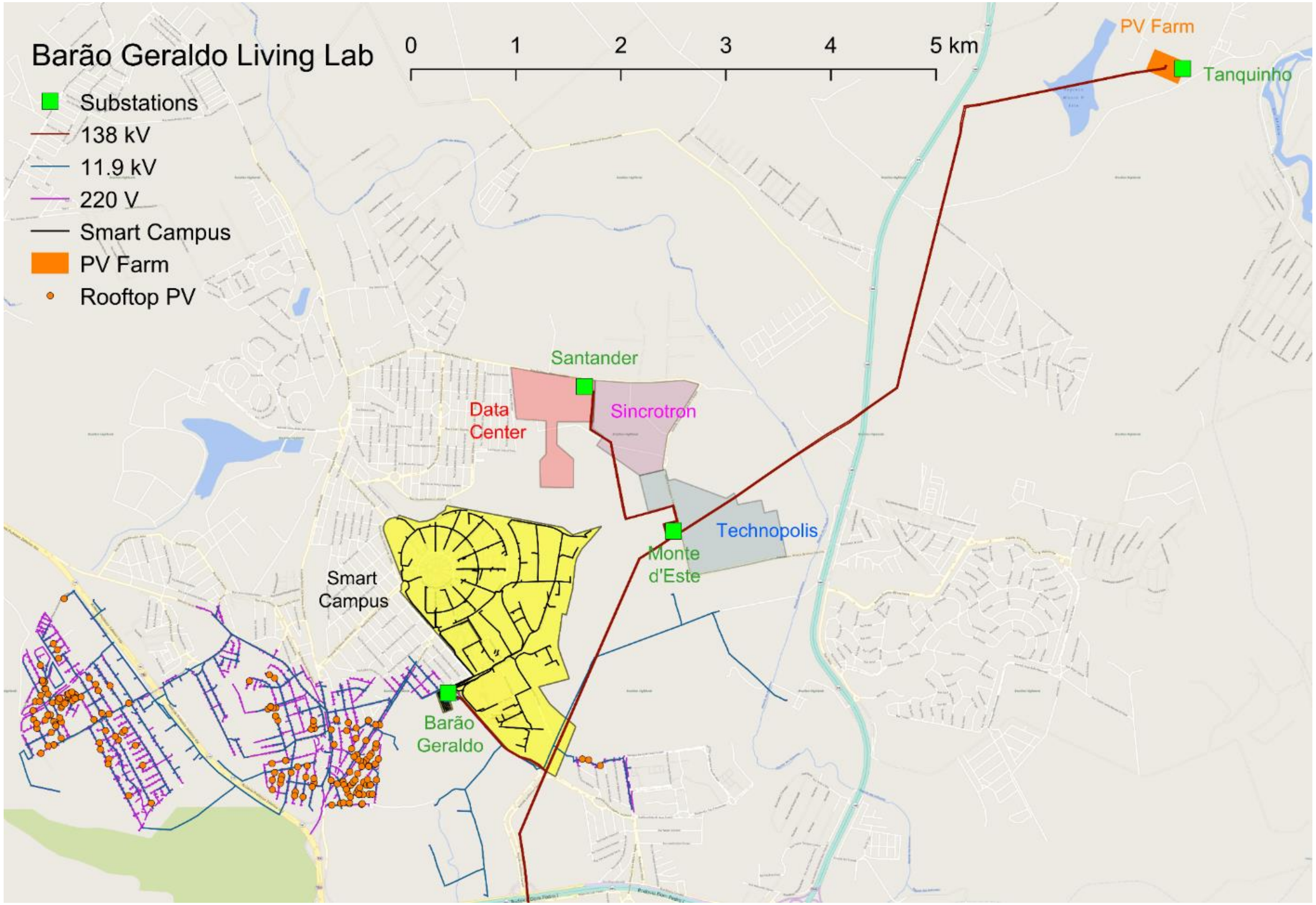
PORAKÊ: A start-up company developing integrated software for systems and big data analysis

Voltvar Analytical Research: A start-up company developing analytical tools for volt/var control

Andrade Analytics: A start-up company developing analytical tools for electric mobility

TE – Thinking Smart – TIME ENERGY http://www.timeenergy.com.br: A start-up company (now a scale-up company) in sensors and meters

A Platform for smart grid technologies integration: one of the largest living labs in Latin America



A Platform for smart grid technologies integration: one of the largest living labs in Latin America

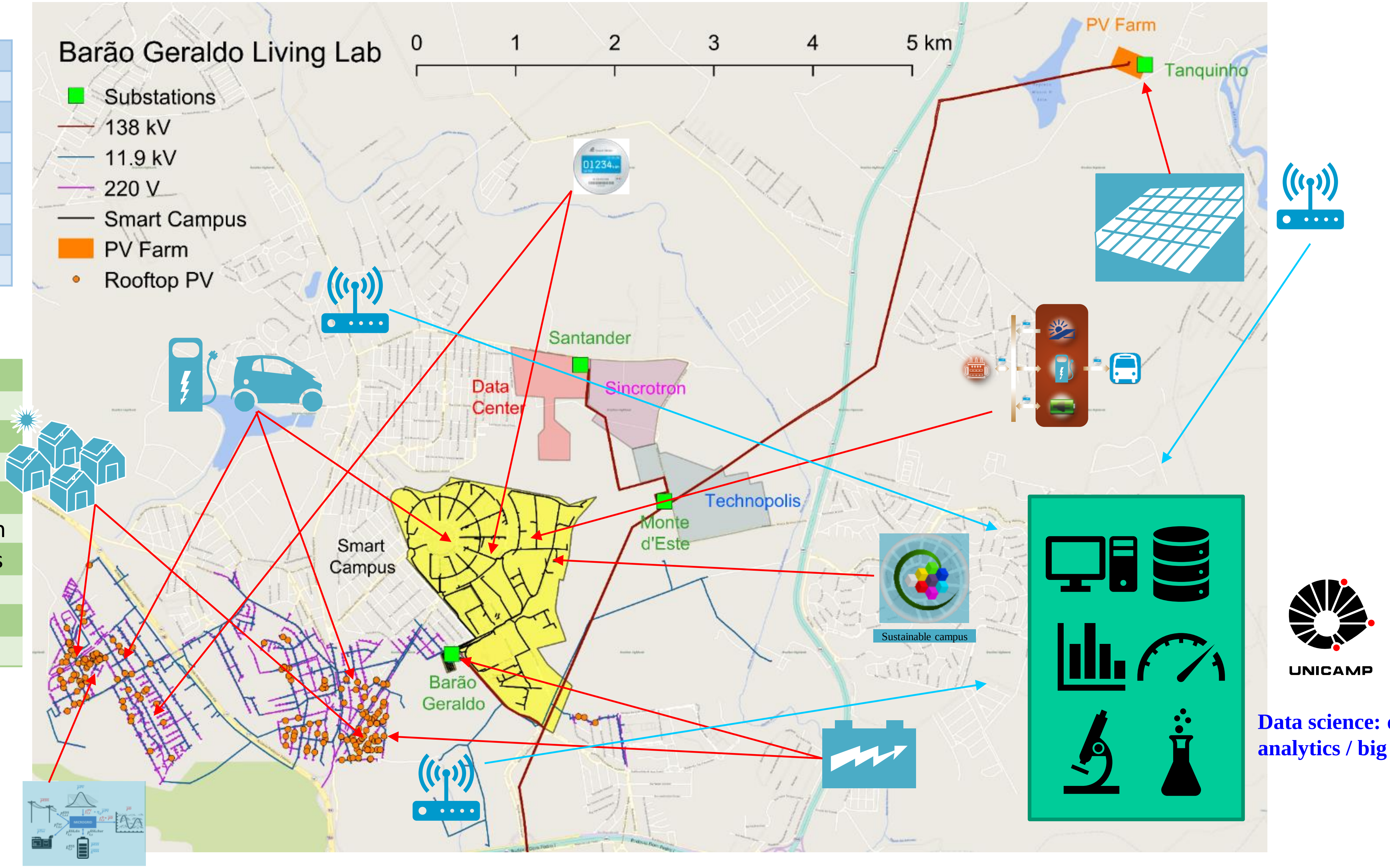
Technologies

PV generators
Electrical vehicles
Storage systems
Smart meter
Electronic-based regulators
Microgrids
A-DMS
Data analytics / Big data

Projects

PA3012: PV rooftop
PA0060: Electric mobility
PA3018: Energy storage
PA3048: Technical losses
PA3047: Volt/var
PA2030: Load disaggregation
PA3032: Sustainable campus
PA3043: Electric bus
CS3060: Electromobility
PA3058: Microgrids

Investment:
~R$ 180 million



Data science: data analytics / big data

R&D: Sustainability – from research to commercialization

Intensity of participation

Development of ideas, concepts and methods (**Research**)

Teamwork:

- UNICAMP
- Research Centers
- High tech consulting company (start-up company – e.g., ERA)
- CPFL Technological Depart.

Intensity of participation

Development and application of products (**Development**):

Teamwork :

- High tech consulting company (start-up company – e.g., ERA)
- CPFL Technological Depart.

Commercialization and maintenance of products (**Sustainability**):

Teamwork:

- High tech consulting company (start-up company – e.g., ERA)
- CPFL Technological Depart.

Internationalization

Academic collaboration:

1. University of Alberta – Canada
2. Ryerson University – Canada
3. Carleton University – Canada
4. University of Texas at Austin – USA
5. Texas A&M University – USA
6. Washington State University – USA
7. University of Manchester – UK
8. Cardiff University – UK
9. University of Melbourne – AU
10. Technical University of Delft – NL
11. University of Southern Denmark – DK
12. Carnegie Mellon University Africa – RW

Utilities:

1. Hydro One – Canada
2. Toronto Hydro – Canada
3. EPCOR – Canada
4. ATCO – Canada
5. ENMAX – Canada
6. Nova Scotia Power – Canada
7. BC Hydro – Canada
8. Tata Power – India
9. Rwanda Energy Group – Rwanda
10. LUMA – Puerto Rico (TBC)

Research Centers/Initiatives:

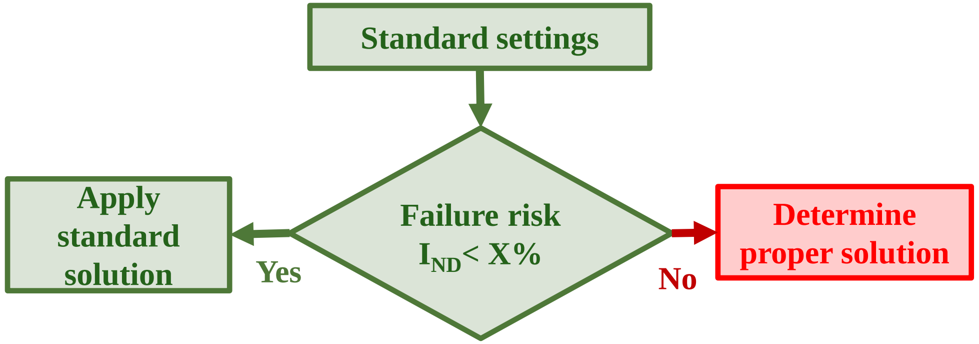
1. Alberta Power Industry Consortium – Canada
2. Centre for Urban Energy – Canada
3. NEST/NSERC – Canada
4. Natural Resources of Canada (NRCan) – Canada
5. PowerTech – Canada
6. EPRI – USA
7. NREL – USA

Sample of products/awards/responsibilities:

- ✓ IEEE/PES Technical Report: Electrical signatures of power equipment failure – T&D Committee Award for Outstanding Technical Report "For Advancing the Power Quality Data Analytics Domain by Demonstrating Techniques for Prediction and Analysis of Electric Power Equipment Failure," 2020 – **Chair: Walmir Freitas**
- ✓ CIGRE/CIRED: Methods for hosting capacity estimation: technical report on best engineering practices, 2022-2024 – **Member: Walmir Freitas**
- ✓ NSERC Energy Storage Technology Network (15 universities, 26 industrial, utility and government partners - the largest Canadian initiatives on energy storage), 2015-2021 – **Member of the Board of Directors: Walmir Freitas**

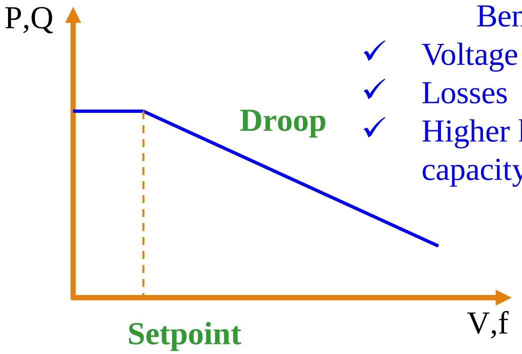
Next steps: DER protection, regulation, and network costs (started: 09/2022)

- ✓ Issue 1: **ONS** proposed minimum DER protection settings concerned with the interconnected system security → potential impact on islanding protection (safety of collaborators and customers)
- ✓ Solution: develop a **risk-based method** to determine the minimum requirement for DER protection settings – decision-making process



risk-based approach

- ✓ Issue 2: **ANEEL** is investigating the possibility of proposing minimum DER regulation curves to support the system (**TS 11/2021**)
- ✓ Solution: develop a **compromise solution-based method** to determine the potential benefits from DERs by using regulation curves considering perspectives of utilities and customers and the cost for DER owners



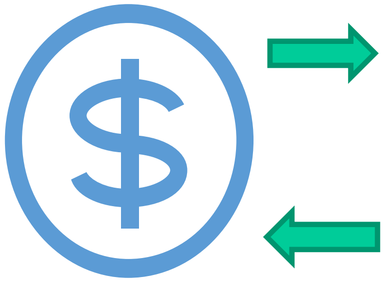
Benefits:
- ✓ Voltage quality
- ✓ Losses
- ✓ Higher hosting capacity

Costs:
- ✓ Individual generation reduction
- ✓ Higher inverter rating

Cost/Benefits $

compromise solution-based approach

- ✓ Issue 3: **ANEEL** has to determine the system benefits/costs inputted by DERs (**PL 5829/29**)
- ✓ Solution: develop an **expedite technical-economic method** to estimate the cost inputted by DERs considering system investment and the benefits of loss reduction



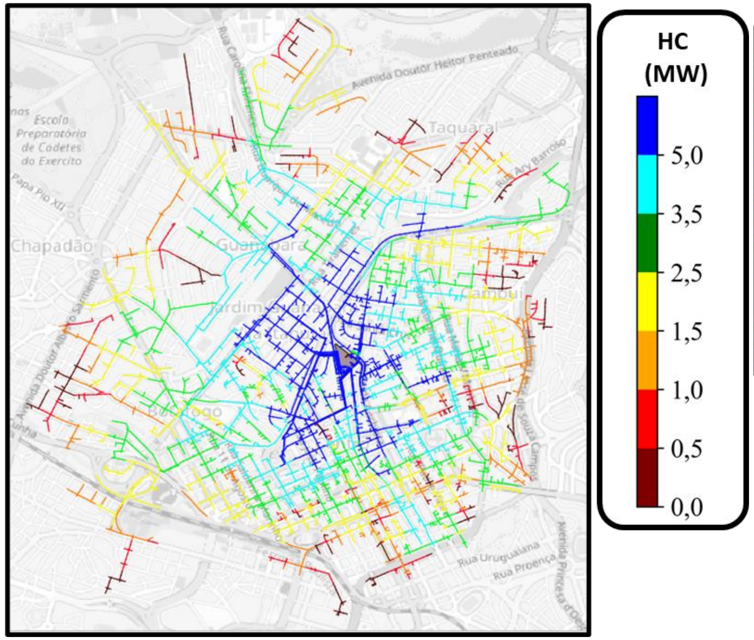
Upgrade costs inputted for:
- ✓ Customers
- ✓ Distribution system operators

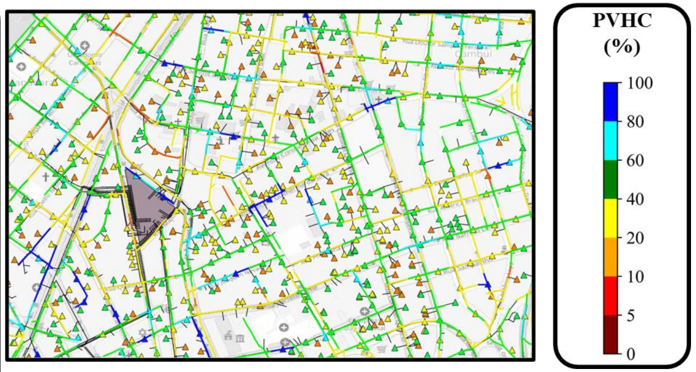
Loss reduction benefits for:
- ✓ Customers
- ✓ Distribution system operators

expedite technical-economic approach

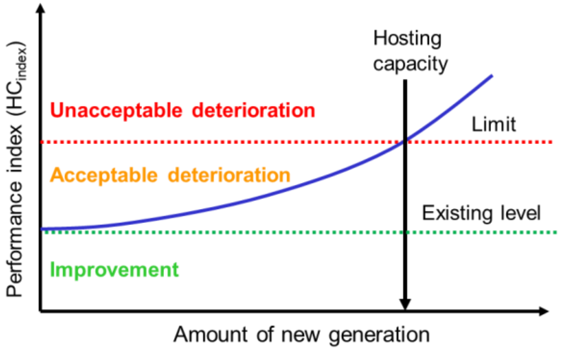
Next steps: Advanced assessment and management of DER hosting capacity (approved)

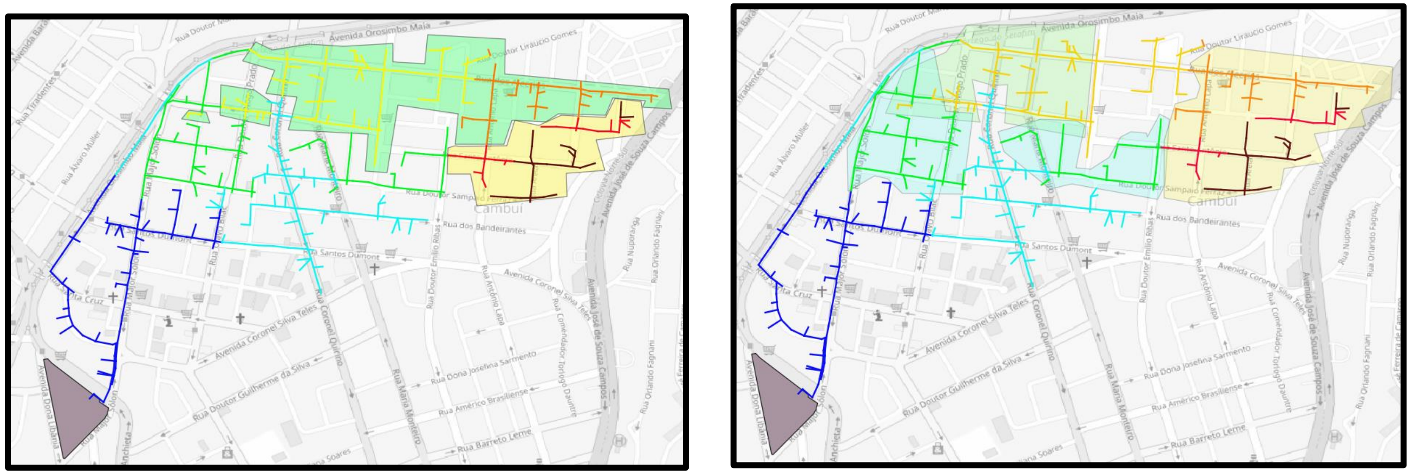
- ✓ Issue 1: how to calculate the DER hosting capacity efficiently for MV and LV systems?
- ✓ Issue 2: how to use such results for HC management?
- ✓ Solutions:
  - ➢ develop **analytical and expedite methods** to dynamically update the results
  - ➢ develop GIS-based methods (**mapping**) to aggregate the results for **technical** and **general public**
  - ➢ develop methods for decision on system upgrade with integration of hosting capacity and costs





hosting capacity mapping for **situational awareness** (internal and external)



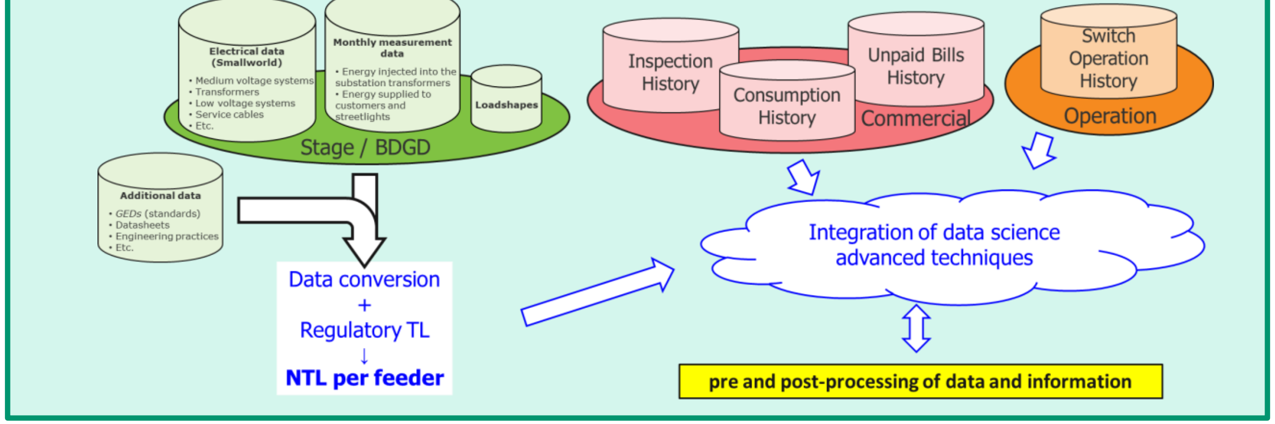


hosting capacity mapping for **decision-making process on upgrade investment**

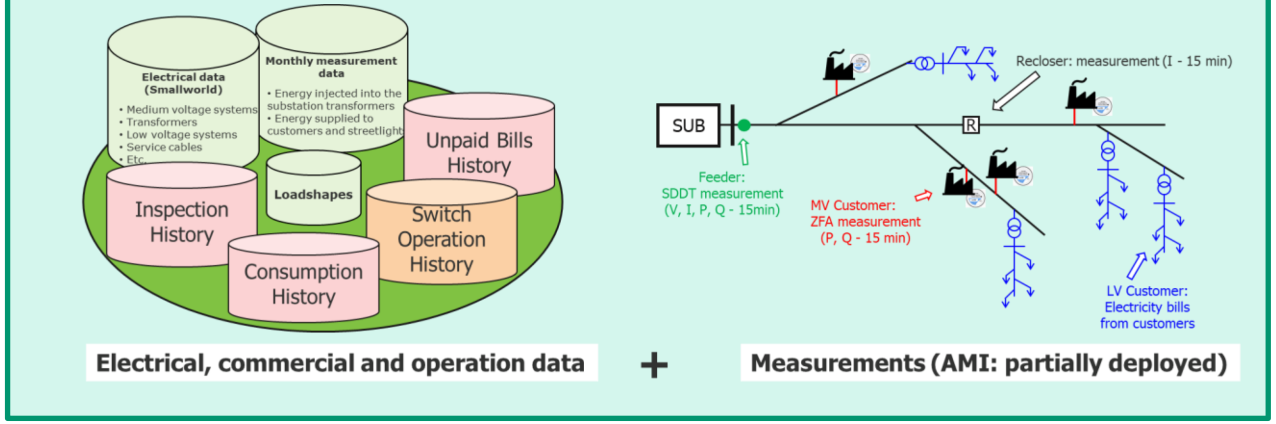
Next steps: Non-technical losses – detection and location (approved)

- ✓ Issues: (a) most of the methods used nowadays are based on pattern recognition and AI developed by computer scientists, which do not take into consideration technical aspects of power systems; (b) the distribution systems are evolving from a passive, non-supervised structure to an active, supervised structure
- ✓ Solution: develop a hybrid, evolutionary method

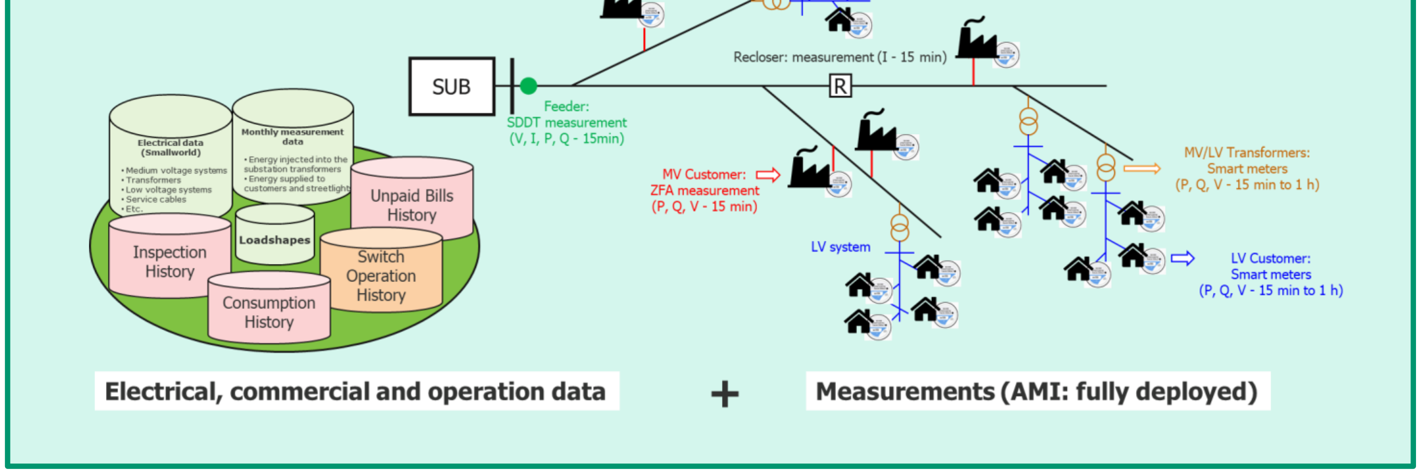
Evolution 1

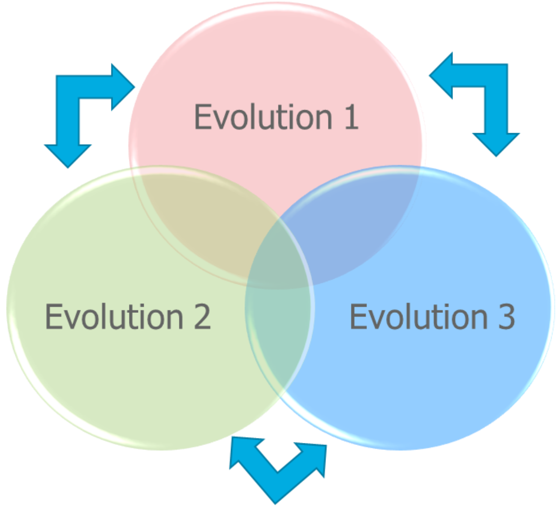


Evolution 2



Evolution 3





Center of Intelligence

Future project: Smart meter data analytics – GIS/BDGD automated correction (to be submitted)

Issue: Utilities GIS and other related databases presents errors and inconsistencies due to:

- ✓ wrong data registration
- ✓ absence of data
- ✓ line parameter variations due to weather conditions and equipment aging
- ✓ manual procedures for database update from field crew

Idea: Combine customer smart meter data and data science to automatically correct:

- ✓ **system topology**
- ✓ **line parameters**
- ✓ **transformer parameters**
- ✓ **customers phase connection**
- ✓ **switch status**
- ✓ **MV/LV transformer tap**
- ✓ **voltage regulator settings**
- ✓ **capacitor bank settings**

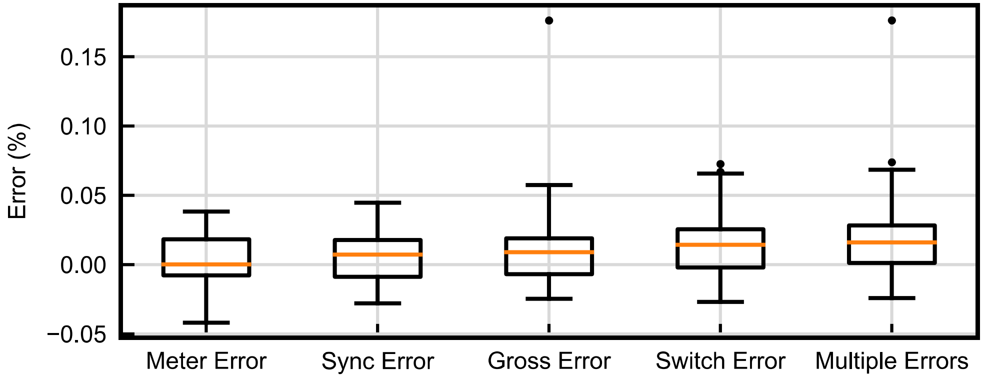
Sample case:

Real MV/LV systems: 2,175 buses; 2,000+ customers (87% residential); 76 MV/LV transformers

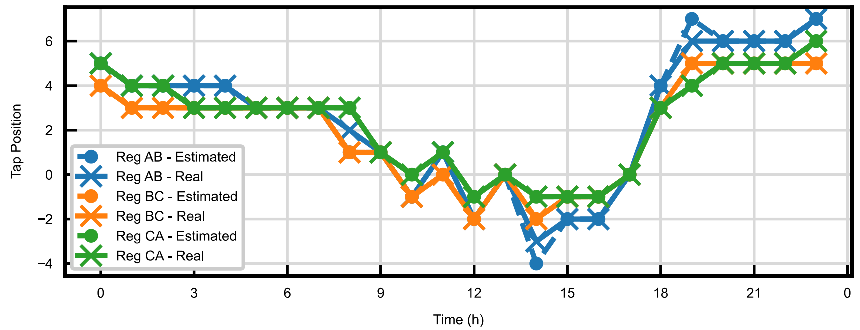
Estimation system topology e line parameters

Metric	Success Rate (%)		
Resolution (min)	**15**	**30**	**60**
Estimated LV lines	92	92	91
Customers phase connection	100	100	100

Estimation Error of Tap Position – Distribution Transformers



Estimated Tap Position – Voltage Regulator



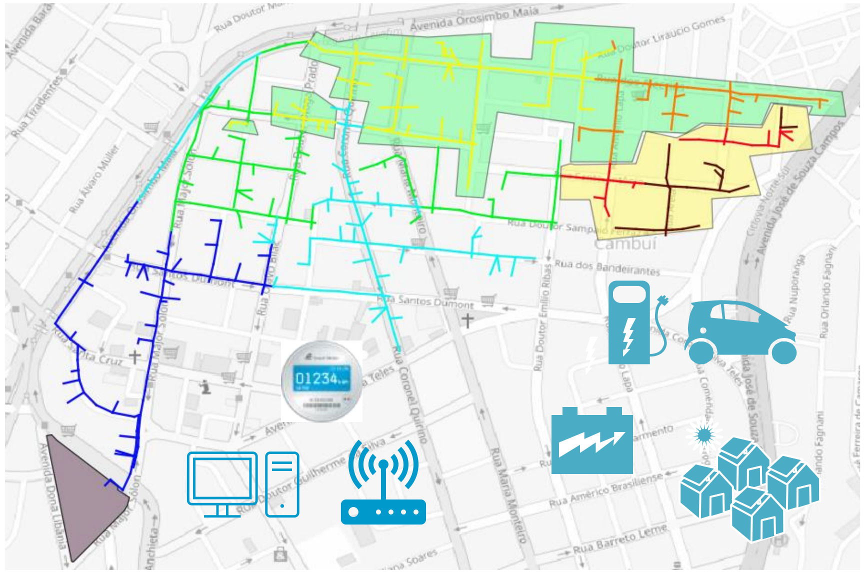
Sources:

V. C. Cunha, W. Freitas, F. C. L. Trindade and S. Santoso, "Automated determination of topology and line parameters in low voltage systems using smart meters measurements," IEEE Transactions on Smart Grid, vol. 11, pp. 5028-5038, 2020 - © IEEE 2020

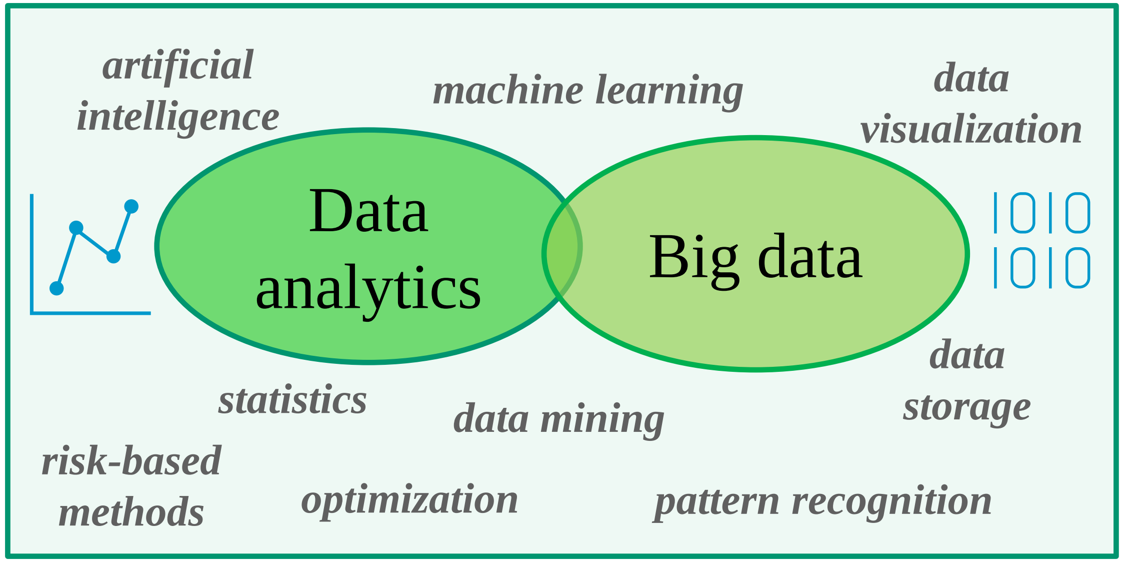
V. C. Cunha, W. Freitas, and S. Santoso, "Determination of tap position of transformers and status of switches in distribution systems using a generalized state estimator," submitted to IEEE Transactions on Power Delivery

V. C. Cunha, W. Freitas, and S. Santoso, "Determination of physical status and control settings of capacitor banks and voltage regulators in distribution systems using a generalized state estimator," to be submitted to IEEE Transactions on Power Delivery

Active, supervised distribution systems (grid-edge technologies)



Data Science



Potential data sources

- AMI (**smart meters**)/SCADA
- PQ and waveform measurement units
- GIS database
- Commercial database
- Weather stations
- Demographic/economic database

Potential applications

- **Active risk-based** asset management
- **Proactive** protection and control
- **Active** system/equipment condition monitoring
- **New** services, business, and market models

Final comments: Living laboratory

✓ Why a living lab?

- Technological researches should go outside the university walls to reach the end users/customers – higher probability of technological success (value for society)
- Technological developments must be in accordance with economic, regulatory and market issues (value for the electrical sector - including customers)
- Technological developments should lead to successful start-up/scale-up companies (value for national economy) – new products and jobs
- Not to be misunderstood: although technical researches and product developments are important, academic/basic researches are vital, as main breakthroughs come from these ideas/concepts

Thank you

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