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Electricity access in Sub-Saharan Africa through the expansion of mini-grids

Seoul National University – Imperial College London Event

Adria Junyent-Ferre

Outline of the session

- Who am I?
- Challenges in electricity access
- The Moving IMPACT project
- Our previous work
- Final remarks

Dr Adria Junyent-Ferre

Reader in Power Electronics, Imperial College London

Academic background:

- PhD Electrical Eng., 2011, Universitat Politecnica de Catalunya
- Master in Automatica i Control, 2009, Dept. Eng. Sistemes, Automatica i Control, UPC.
- Enginyer Industrial, 2007, ETSEIB, UPC.

Areas of application: HVDC transmission, Wind farms, Low Voltage DC (LVDC)

Recent research grants: PI of Moving IMPACT on rural electrification (25-28)

Recent industry work:

- **22-23 Ionate** “Support control implementation for a distribution network FACTS device”.
- **22-23 Carbon Trust** “Evaluation of Synthetic Inertia from Offshore Wind”.

Dynamic studies to characterise the performance of the Synthetic Inertia service offshore wind farms can provide.

Professional bodies:

- Associate Editor of IEEE Trans. on Power Delivery 2017-2021, IEEE Trans. on Sustainable Energy 2016-2020. Senior Member IEEE since 2019.

Challenges in Electricity Access

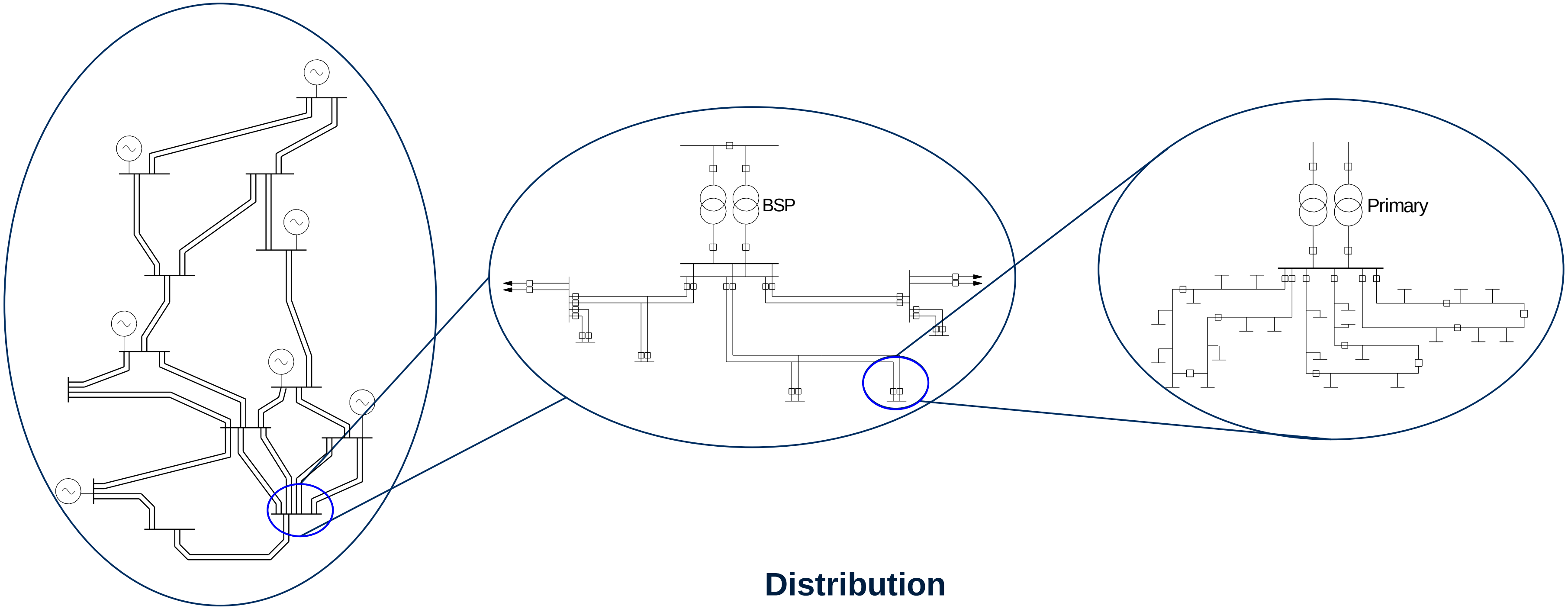
Context

Affordable access to reliable and clean energy is the 7th UN Sustainable Development Goal and is critical for ending hunger, improving health, enhancing education, and tackling climate change.

In 1998, 27% of the global population lacked access to electricity.
By 2019, this was reduced to 10% but progress has been uneven.

Sub-Saharan Africa accounted for 38% of global energy poverty in 1998, by 2018 it was 80%.

The conventional electrical power system
Transmission and distribution systems

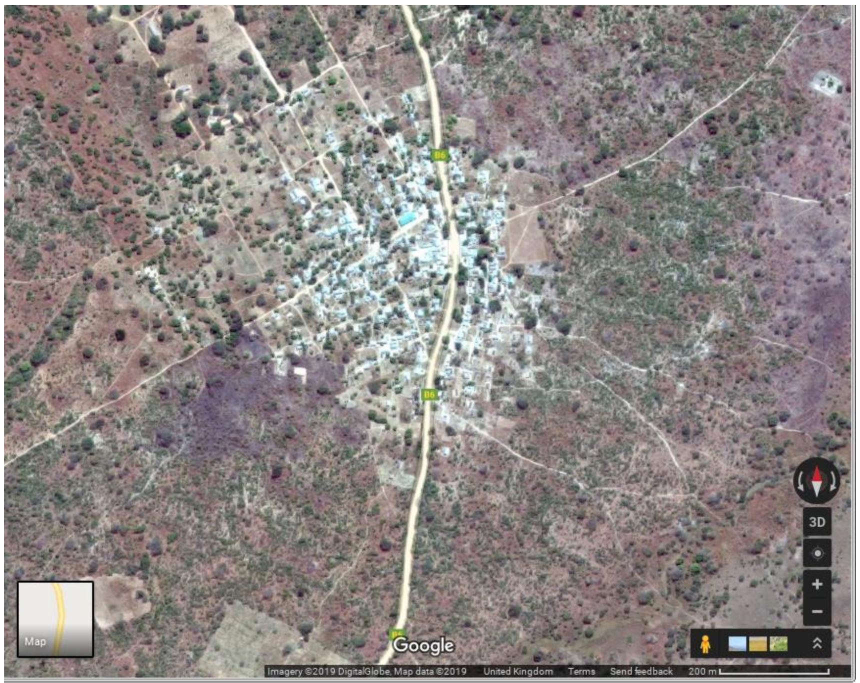


Distribution
- Role is to serve loads
- Few generators now but increasing
- Structure is radial not meshed
- Alternative routes available through switching
- Double circuits used at higher levels, single circuits at lower levels
- Lower voltages than transmission and higher losses.
- Smaller degree of redundancy –interruption rate is low

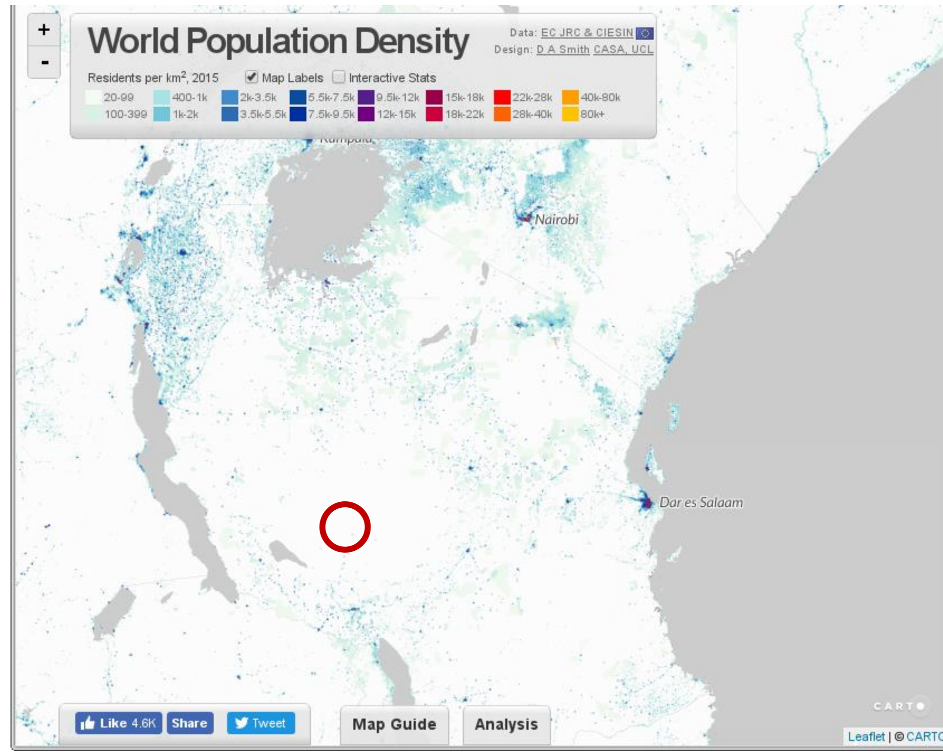
Transmission
- Role is bulk transfer of energy
- Routes are all double circuits
- Network is meshed to provide multiple routes to loads and generators
- EHV low loss network
- Large degree of redundancy –interruption rate is extremely low

An example study case in Ilungu, Tanzania

Basic data of Ilungu
Region: Mbeya (270k people)
Population: ~10k
Population density: ~50/km^2



src: Google Maps.



src: Luminocity3d http://luminocity3d.org/WorldPopDen

An example study case in Ilungu, Tanzania

Existing electrical power system around Ilungu:

Figure 5: Population distribution map in Tanzania (2012)

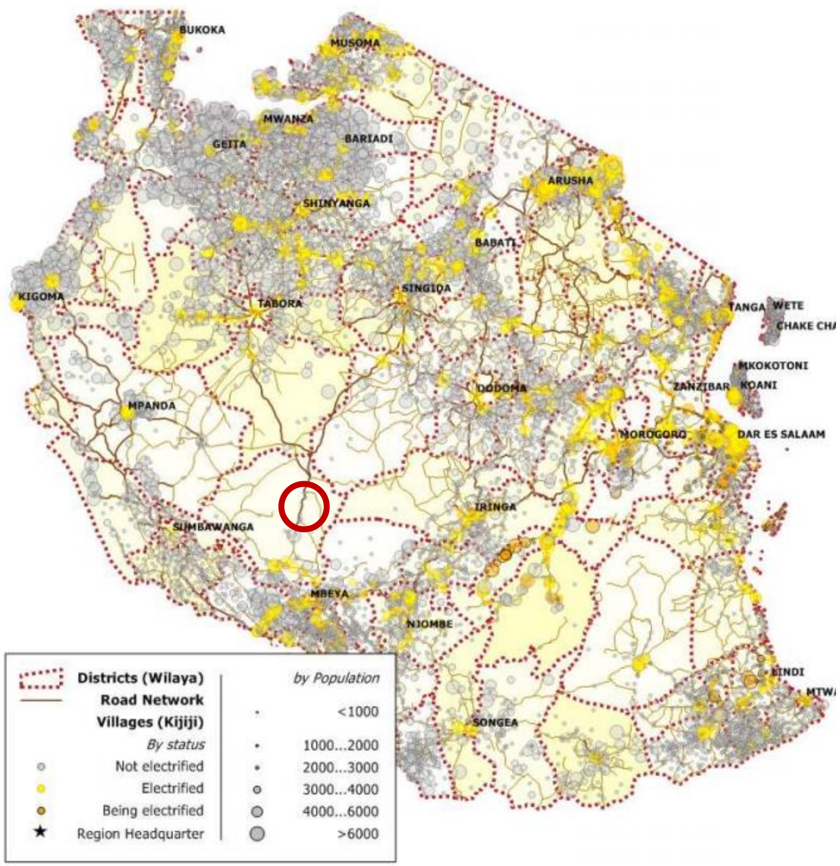
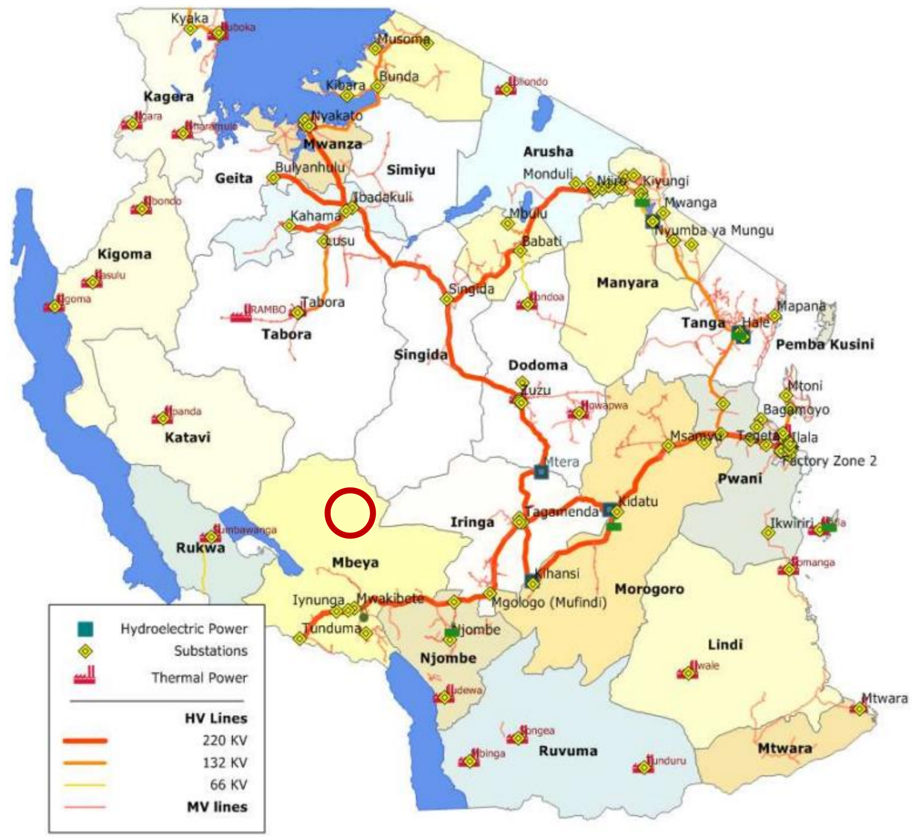


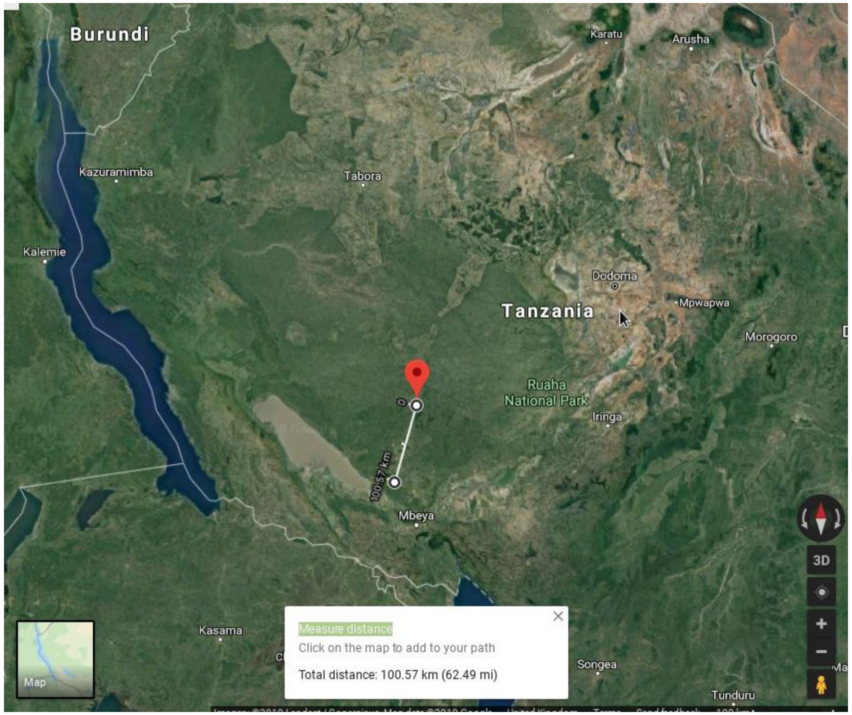
Figure 2: Existing Transmission Network in Tanzania 2013



Source: Republic of Tanzania National Electrification Program Prospectus http://www.rea.go.tz/Default.aspx?tabid=132&id=53

An example study case in Ilungu, Tanzania

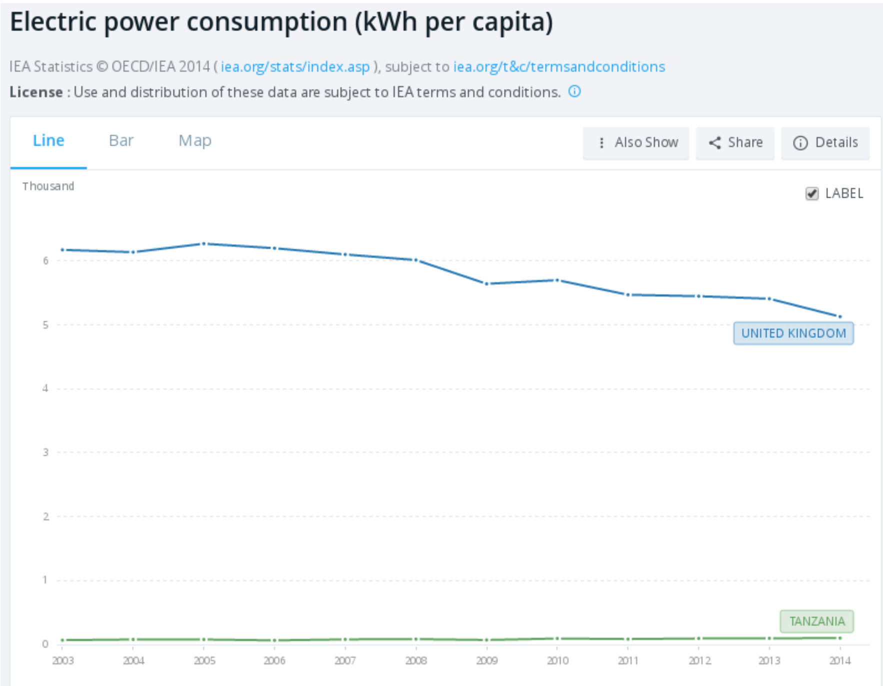
According to the map, the closest feeder is a 132 kV line at 100 km



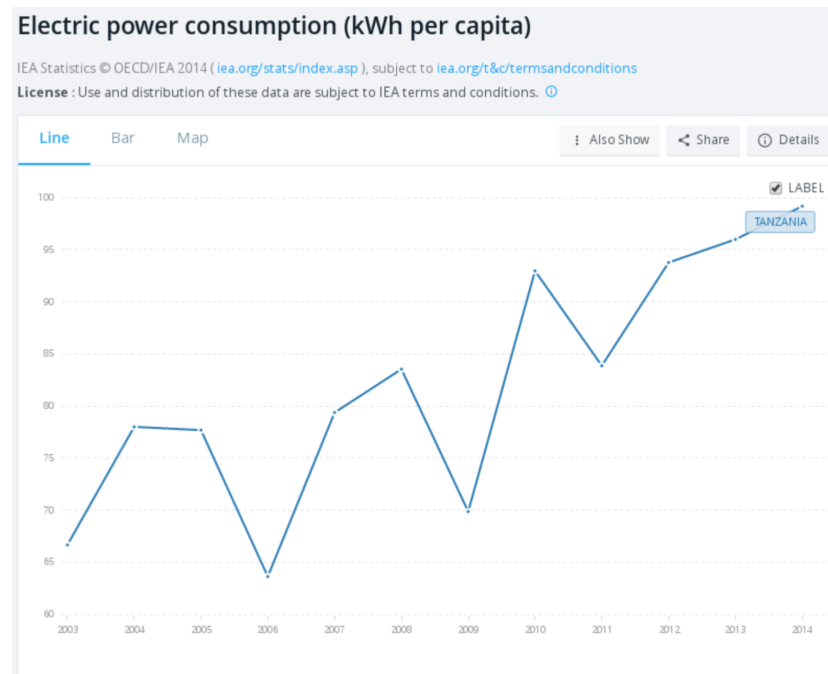
- **Is it worth building a 100 km transmission line?**
- **How much power is people going to use?**
- **How long is it going to take for this asset to be fully utilised?**
- **Is there a better way of supplying the power?**

A quick comparison

UK vs Tanzania



Tanzania



Great Britain
Population: ~60 million
Surface: 209,000 km^2
5 MWh per capita

Tanzania
Population: ~57 million
Surface: 945,000 km^2
0.1 MWh per capita

Solar Home Systems and Mini-Grids

Two types of local ad-hoc solutions to generate electricity co-exist.

Solar Home Systems

Stellenbosch, South Africa
src: Mr Novel https://www.shutterstock.com/g/MrNovel?sort=popular

Characteristics
- Single household.
- 0 to 1 kW
- Light, phone charging, TV, fridges

Bright solar lamp
https://www.indiegogo.com/projects/bright-solar-lamp-phone-charger

Mini-grids

Mini-grid in Nigeria
src: https://www.nigeriaalternativeenergyexpo.org

Characteristics
- Multiple households + businesses
- 1 kW to 1 MW
- fridges, waterpumps, welding equipment, grain mills, etc..

Project Moving IMPACT

Integrated Means to Power Agriculture, Clean Cooking and Transportation

Our vision

“Linking PV generation, agricultural production, small-scale EV transportation and national grids will be vital for ensuring the economic viability of rural mini-grids. The success of this development will drive sustainability, economic empowerment and health.”

A solar mini-grid in Bagira, DRC. Image courtesy of BBOXX Ltd.

Our vision

- Solar Home Systems can charge phones and provide light but they lack the potential to grow.
- Mini-grids are costly but can be built around a need:

  eg health centres, telecoms, agriculture or EV.

  - Spare capacity can feed local demand

    eg small businesses and household cooking (!)
- Autonomous mini-grids can share their resources
  - Mini-grid to mini-grid
  - Supporting local distribution systems.

The project at a glance

- A 3-year project (Jan 2025 – Dec 2027)
- Supported by the UKRI Ayrton Challenge Programme
  “Interdisciplinary, challenge-led research enabling the transition to low carbon energy in developing countries”

- Partner research institutions:

UK IMPERIAL UNIVERSITY OF LEEDS

Rwanda AIMS African Institute for Mathematical Sciences RWANDA UNIVERSITY of RWANDA KCRC

Kenya Strathmore UNIVERSITY

Ghana UENR University of Energy and Natural Resources

Industry partners and stakeholders

A group of industry partners and stakeholders supported our application and offered to help us through our yearly advisory board meetings.
Meshpower and Bboxx offered to help us run a pilot trial of an off-grid EV charging system.

Work package structure

- **WP0: Socio-economics**
  Led by Dr Chiara Candelise (Imperial Centre for Environmental Policy)

- **WP1: Agrivoltaic systems**
  Led by Prof Jenny Nelson (Imperial Department of Physics)

- **WP2: Whole-systems approach household energy access**
  Led by Prof Izael Da Silva (Strathmore University)

- **WP3: Mini-grids that support local distribution systems**
  Led by Dr Adria Junyent-Ferre (Imperial Electrical & Electronic Eng.)

- **WP4: Flexible solar EV charging infrastructure**
  Led by Dr Sheridan Few (University of Leeds)

- **WP5: Capacity building in the Sub-Saharan solar mini-grid sector**
  Led by Mr Patrick Mwanzia (Strathmore University)

Our previous work

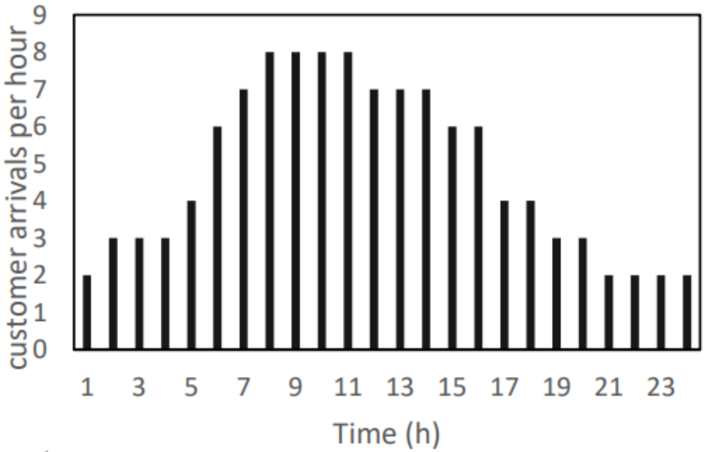
The success of electric motorbike taxis

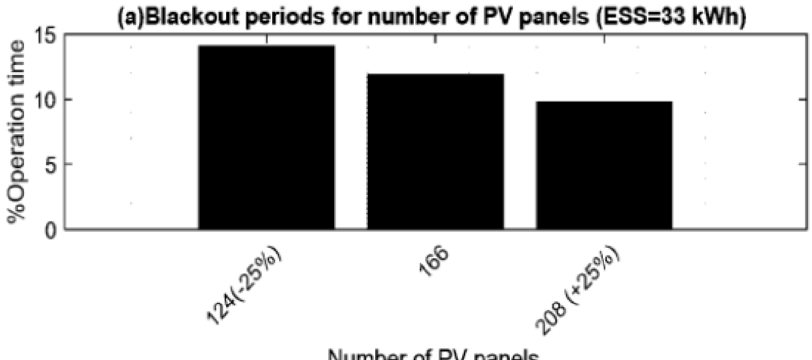
Images courtesy of Ampersand Ltd. Rwanda

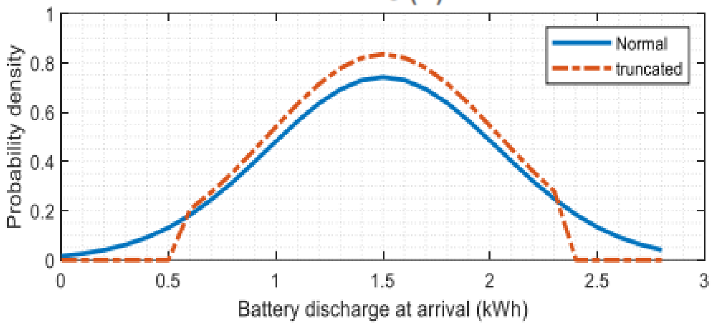
Motorbike taxis in cities like Kigali or Nairobi travel some 200 km a day. Because they have high-utilisation and produce revenue, they were the most likely to switch to electric vehicles once their costs fell below a threshold. This has happened already and companies are looking into options to move away from the big cities to sub-urban and rural areas where power would be generated from PV.

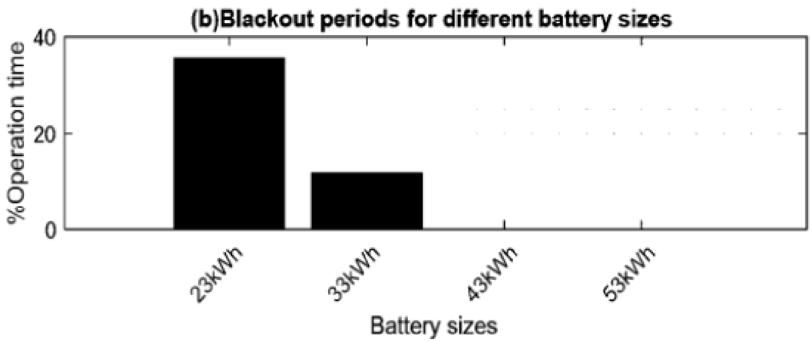
Sizing requirements of the photovoltaic charging station for small electrical vehicles

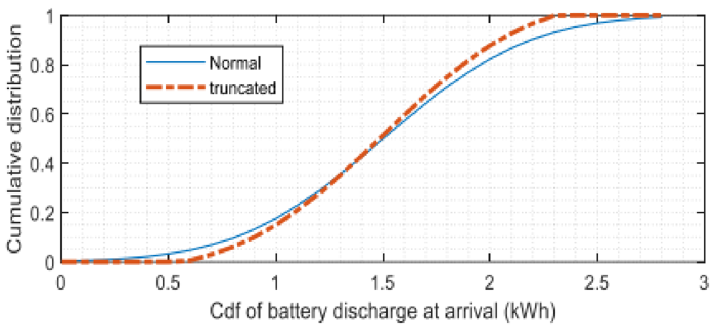
We modelled the demand of EV charging stations based on data from existing petrol stations. Our model simulates long periods of operation and uses different metrics (eg queueing time, outage time) to assess the adequacy of sizing of a charging station.
The work was done in collaboration with ModularityGrid, a mini-grid technology developer.











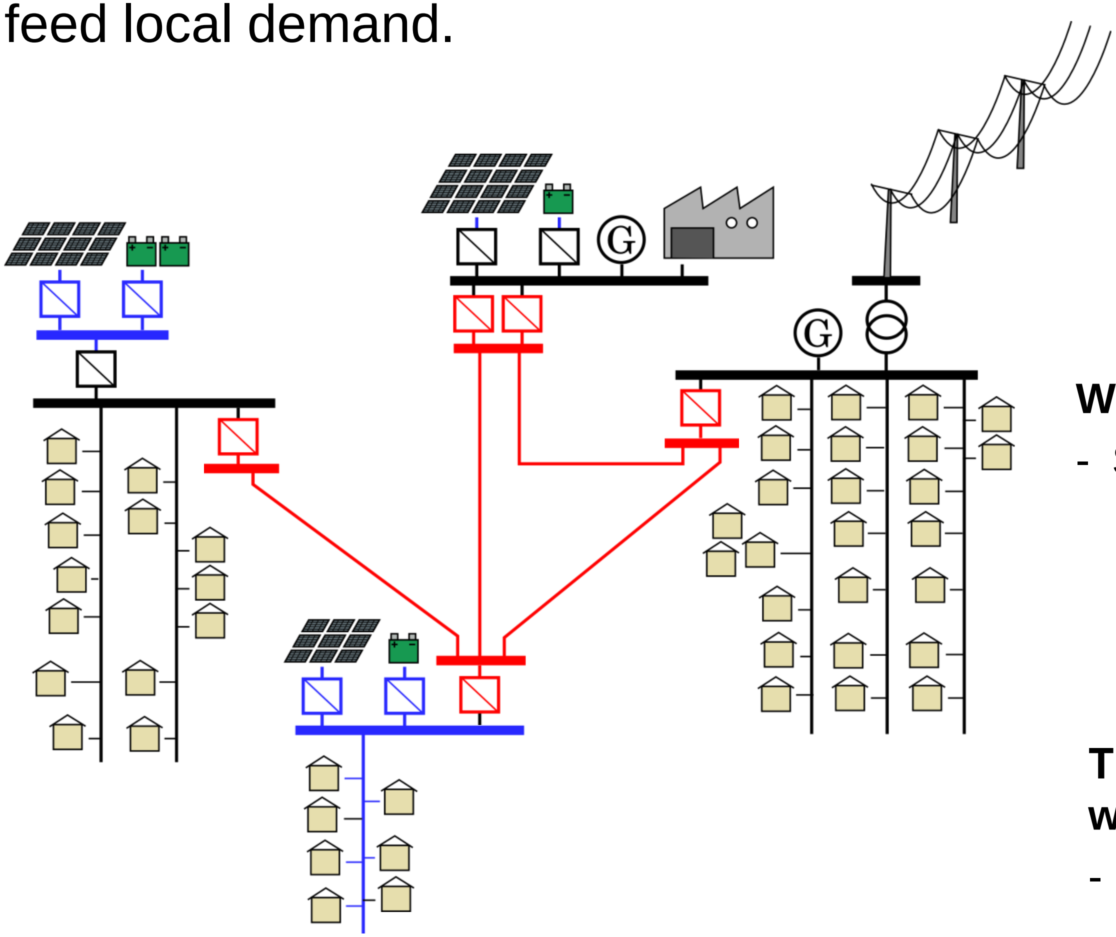
Ngendahayo, A., Junyent Ferré, A., Rodríguez Bernuz, J.M., Nyeko, E. and Ntagwirumugara E.. "Sizing requirements of the photovoltaic charging station for small electrical vehicles." *International journal of renewable energy development* 13, no. 4 (2024):

Interconnecting mini-grids

Vision: building a system through interconnection

A system where autonomous generation and storage systems are built ad-hoc to feed local demand.

HOW CAN THEY SHARE THEIR RESOURCES?



Our proposal:

- **Use power electronics to interconnect.**
- **Operate as constant power units.**
- **Minimise updates required.**
- **Enable improved supply and growth.**

Why the conventional way might fail

- Systems not ready for direct coupling
  - Incompatible protection
  - Incompatible standards
  - Incompatible control

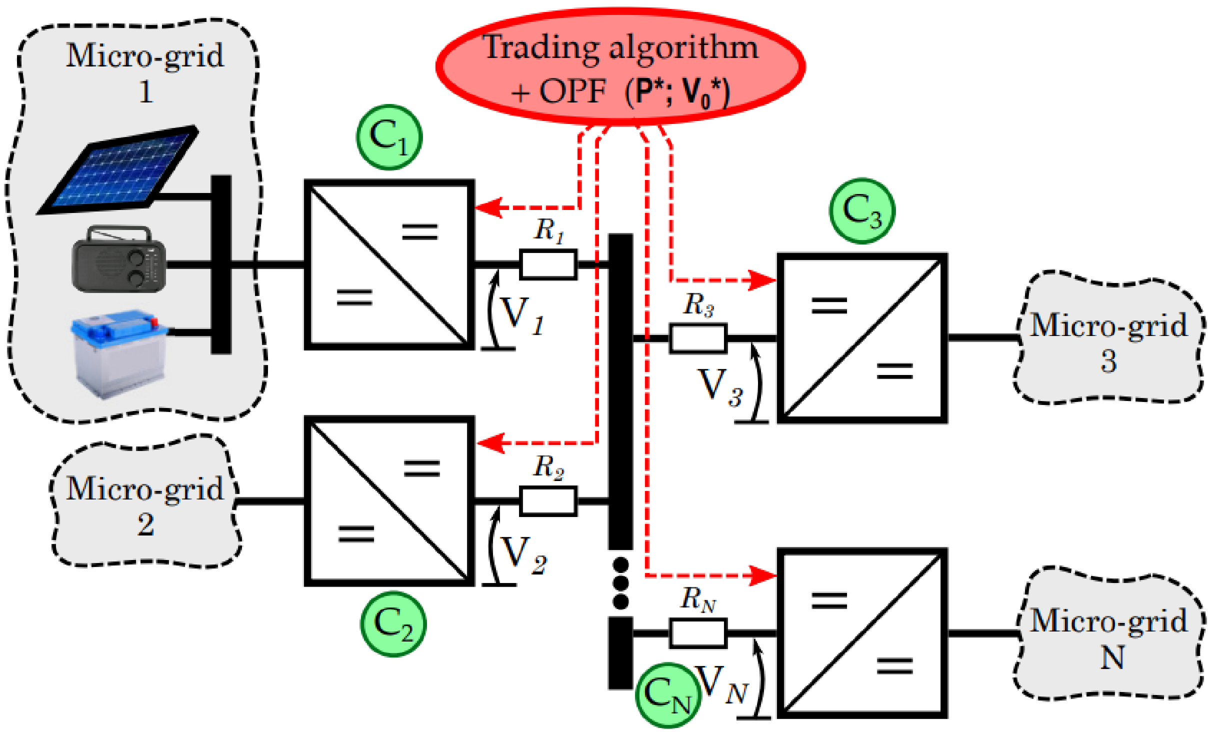
Things you'd need to do if you wanted direct coupling:

- Decommission units.
- Reprogram controllers.
- Replace protection devices.

Operating the interconnection system

Different layers working together:

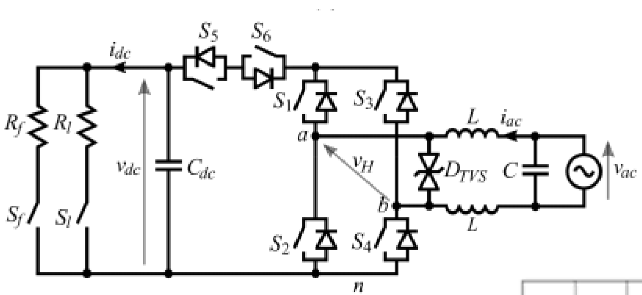
- An energy trading layer deciding power exchanges over settlement periods.
- A decentralised low-level controller runs the system in a way that is robust to uncertainties (eg losses) and unscheduled disconnection of units,
- Separate interconnection systems can co-exist.
- LVDC simplifies the control and brings opportunities for state estimation and on-line anomaly detection.
  - New concepts of control, monitoring and protection for LVDC could be brought to LVAC.

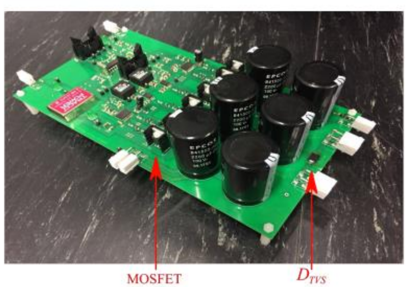


Power electronics technology and new forms of protection for LVDC

Inverters for controlled DC fault current provision

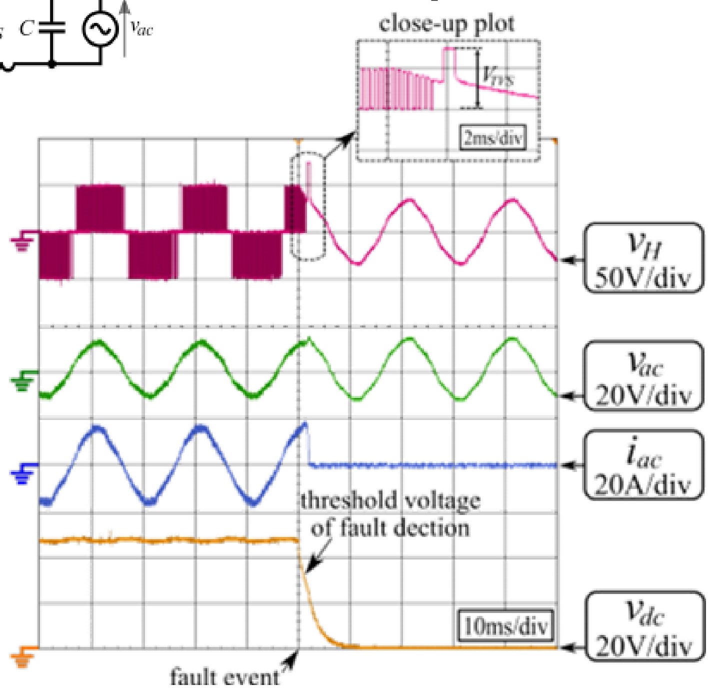
Reliable DC distribution may require converters to self-diagnose faults and automatically rearm with minimal or no operator intervention. The H5+ is a modification of a common inverter topology that can interrupt DC short circuits and deliver controlled fault current.



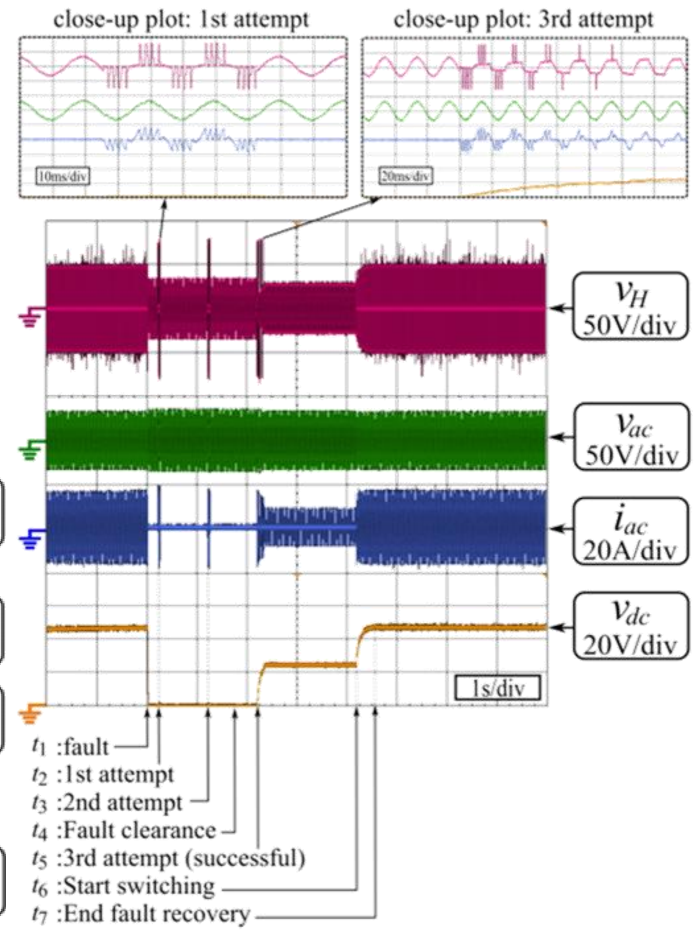


Y. Wang, Y. Li, A. Junyent Ferre, M. Kim, "H5+ Converter: A Bidirectional AC-DC Converter with DC-Fault-Blocking and Self-Pre-Charge Capabilities," in IEEE Trans. on Power Electronics (Early access)

Fault interruption



Fault interruption and automatic reclosure

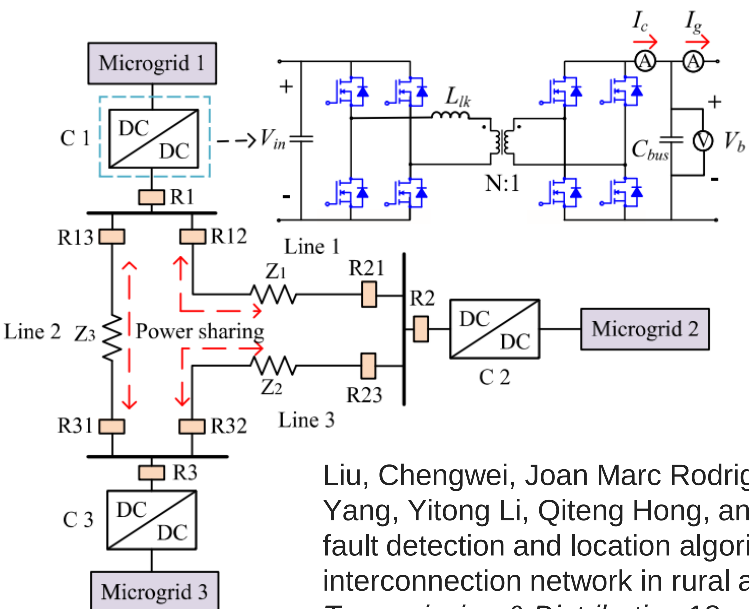


Fault identification in LVDC interconnection networks

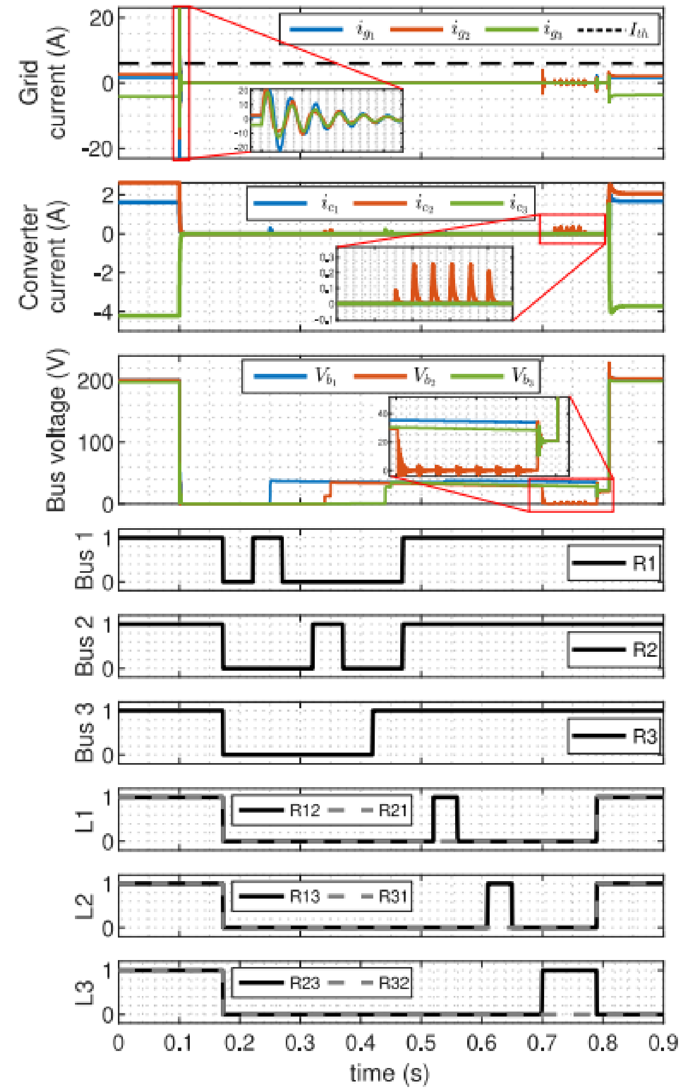
Protection of non-radial LV networks fed by power electronic converters is challenging (small time-scales, low fault current, low-cost).

We investigate **fault identification methods that probe the network using fault current injection under collapsed voltage conditions**.

- Inexpensive (existing sensors, low-bandwidth comms)
- Exploits underutilised modes of the converters.
- Suitable if minute time-scale interruptions are ok



Liu, Chengwei, Joan Marc Rodriguez-Bernuz, Di Liu, Saizhao Yang, Yitong Li, Qiteng Hong, and Adrià Junyent-Ferré. "A fault detection and location algorithm for the LVDC interconnection network in rural area." *IET Generation, Transmission & Distribution* 18, no. 24 (2024): 4291-4301.



Final remarks

Our ambition

We envision that big electricity users will provide the incentive to build mini-grids and de-risk those projects.

We want to make a case for headroom to be added to mini-grid designs to benefit small electricity users.

Sharing energy resources between mini-grids will be crucial for their growth and will enable building resilient interconnected electricity systems.

LVDC and power-electronic-based local electricity grids can be used to build interconnection and form a “grid of grids” that is decentralised and resilient.

Mini-grids and national grids can co-exist and benefit from working together.

Power-electronic-based local electricity grids require smart control and protection schemes with continuous self-diagnosis that make them safe, reliable and autonomous.

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Thank you

Adria Junyent-Ferre

Mini-grid in Bagira, DRC
Picture by courtesy of BBOXX Ltd.