Study Committee C6

ACTIVE DISTRIBUTION SYSTEMS AND DISTRIBUTED ENERGY RESOURCES

PS 3 / Aggregated DER for enhancing resilience, reliability and energy security of distribution systems

Paper ID_10971

CONTROL IN A.C. MICROGRIDS: HIERARCHICAL CONTROL, TECHNOLOGIES, AND REGULATIONS - COLOMBIA

José Miguel RAMÍREZ*, Martha OROZCO*, Eduardo GÓMEZ-LUNA* and Alejandro GARCÉS**

*Universidad del Valle ** Universidad Tecnológica de Pereira

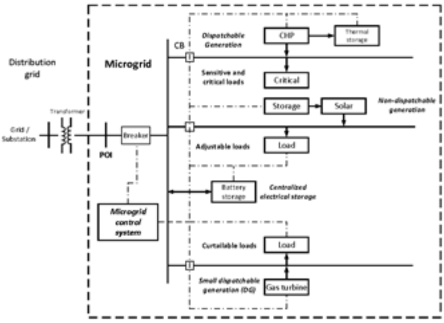
Motivation

- MicroGrids MGs is a viable option to integrate Distributed Energy Resources DER
- MGs have specific electrical characteristics and operational requirements, which requires different control strategies
- This work presents initiatives in Colombia to promote MGs and control functions, hierarchical control structure, and physical infrastructure for control implementation

Approach

- CIGRE Colombia, WG C6.6 ‘Control and Operation of MGs’, prepared a technical report from international regulations, to describe AC MGs, control functions, hierarchical control structure, and physical infrastructure for control implementation →Reference for national companies planning to implement MGs in Colombia

Microgrids



From (IEEE Std 2030.7, 2017). Group of interconnected loads and DER, with defined electrical boundaries, which acts as a single CONTROLLABLE entity with respect to the grid and can operate in interconnected or isolated mode

Colombia Situation in Microgrids

- Capacity (2020): 17.572 MW, 70% renewable, 68% hydraulic, 30% thermal. In 2023 12% non-conventional renewable sources (PV, Solar, Biomass)
- 425.000 homes without electricity mainly rural; Non-Interconnected Zone NIZ - 53% of national territory. In 2021: Installed capacity in NIZ - 295.2 MW, 91% Diesel Generators, 9% DER
- Investment of $Us 1852 billion for universal access to electricity, 48% isolated microgrids (257) with 15% annual diesel energy (UPME – PIEC 2019-2023)

Regulations

2014 LAW 1715: Non-renewable energy integration
2015 UPME 281, CREG 024: small-scale self-generation
2016 CREG 029, 051: Demand response program
2017 XM-CND 048: Connection of inverters
2018 CREG 030, 038: Small-scale self-gen and DER
2019 LAW 1964: E-mobility. CREG 098: Energy storage
2020 CREG 170: C&O solar and wind plants
2021 LAW 2099: Energy transition, MME 40094: MG/NIZ
2022 CREG 101-001 AMI

Microgrids Hierarchical Control

- Control functions: 1) **Transition** between connected and island operations. 2) DER **Dispatch**: Gen/Load Balance. Internal gen/load events. External orders from PS; MG power references to DERs. Frequency and voltage regulation
- Hierarchical control divided into three levels

Technologies and Control Validation

- From power electronics, to wide MG monitorization→ fulfill **interoperability**, critical times, control algorithms, processing time, measured and controlled variables, communication protocols…
- To analyze, design and implement control with different dynamic ranges:
  - ➢ IEEE 2030.8-2018 recommend the tests for the MG control system
  - ➢ Real-time simulation system with a Hardware-In-the-Loop (HIL)

Conclusions

- Different initiatives and regulations to develop MGs in Colombia
- Hierarchical control in AC MGs allows: Integrate DG with conventional generation, f and V regulation, power sharing, buy/sell to power system, control phase imbalance and harmonic distortion
- **Primary** control: fast frequency and voltages regulation. High R/L ratio → virtual impedance, R, L identification; low impedance lines; lack of infinite bus in isolated operation → inertia emulation
- **Secondary** control restores nominal voltage and frequency, **tertiary** control (if any) optimizes MG operation
- Consider the interoperability of technologies and digital twins for control design and implementation

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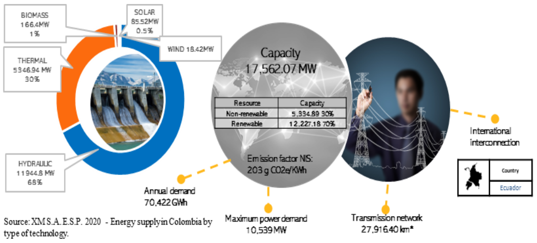
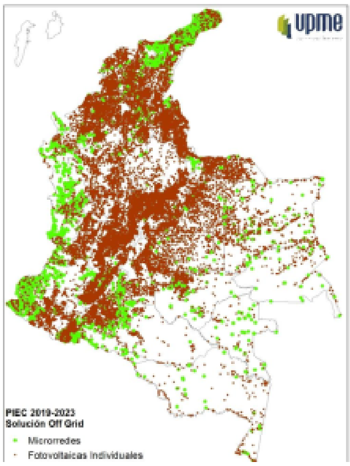


Sources: Mining and Energy Planning Unit (UPME), Commission for Electricity and Gas Regulation (CREG), Ministry of Mines and Energy (MME), National Dispatch Center (XM-CND); acronyms in spanish.

In 2020, 35th Energy sustainability ranking (2020, World Energy Council)
25th Energy Transition Index (2020, World Economic Forum)



425.000 homes without electricity mainly rural
NIZ - 53% of the national territory
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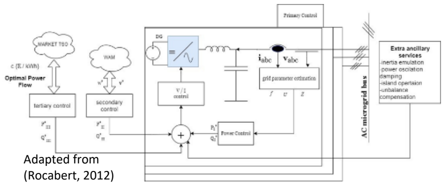
91% Diesel Generators, 9% DG
Investment of $Us 1852 billion for universal access to electricity in Colombia, 48% isolated microgrids (257) with 15% annual diesel energy
Sources: UPME – PIEC 2019-2023 / IPSE 2021

Microgrids Hierarchical Control

- Control functions: 1) **Transition** between connected and island operations. 2) DER **Dispatch**: Gen/Load Balance. Internal gen/load events. External orders from PS; MG power references to DERs. Frequency and voltage regulation
- Hierarchical control divided into three levels:



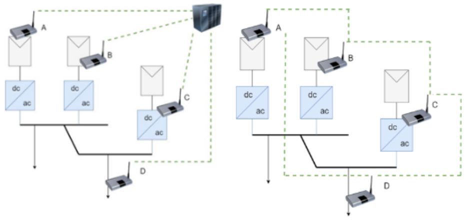
Adapted from (Rocabert, 2012)

- Primary Control:

Local measurements, fast, regulates f, V and shares or regulates P and Q, ancillary services.
Looks for a stable equilibrium, f and V ≠ nominal.
VSI: Grid-forming, grid-feeding, grid-supporting.
For synchronous generators, speed governors and automatic voltage regulators

- Secondary Control:

Wide area measurements, communications are critical: Delays and loss of information, cyber attacks → Use of real-time simulation.
Slow (m), centralized or distributed.
AGC: w = nominal at steady state.
V profiles at operational limits.



Left: Central controller: PI: local→saturation, two-way communication infrastructure.
Right: Consensus-based or distributed optimization-based, NO central controller: Channel does not compromise MG stability, allows Plug-and-play.

- Tertiary Control:

Slow (m), centralized.
Coordination with PS, EV, virtual power plants.
Storage.
High R/X ratio.
Load flow $f(V,\delta)$ non-linear/non-convex
Optimal Power Flow:

$$\min \; C(P,Q)$$
$$P,Q = f(V,\delta),$$
$$P_{min} \le P \le P_{max}, \; Q_{min} \le Q \le Q_{max}, \; V_{min} \le V \le V_{max}$$

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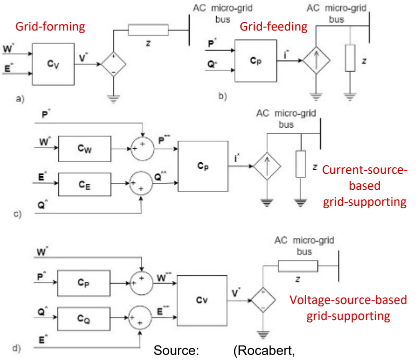
Technologies and Control Validation

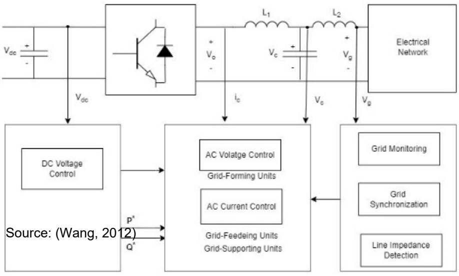
- From power electronics, to wide MG monitorization→ fulfill **interoperability**, considering critical times, control algorithms, processing time, measured and controlled variables, communication protocols…

Power electronics converters:

- Power Management: DC/DC: Bidirectional Converter in a Battery Energy System, MPPT Converters, DC/AC Inverters: Front-End in AC Microgrids
- Design Aspects: Ripple, size of components, stress of devices, number of elements, control complexity.
- Challenges: Standardization and Interoperability, Modularity and Scalability, Costs and Performance
- Several Topologies depending of the purpose (Control of Voltage, Frequency, Power; Type of Power, Harmonics, MPPT, Isolation, etc).



Source: (Rocabert, 2012)



Source: (Wang, 2012)

Grid-forming: Master Control of Vc, ic slave
Grid-feeding: Master Control of P y Q, Vc o ic slave
Control of Vc, ic :
α-β: Concordia, PR + harmonic rejection
d-q: Park, PID
Virtual impedance
Ancillary services

Communications:

- Protections require high dynamic response, so fast transmission of signals.
- Central control requires high capacity of data transmission and quality (Technology: PTN (Packet Transport Network), protocol IEC 61850-9-2+GOOSE).
- Monitoring level must take into account demand of control, objective and velocity (Technology: Ethernet Network).
- Communication between microgrid and power system requires monitoring and control of the PCC switch (Technology: Wireless such as GPRS (General Packet Radio Service), CDMA (Code Division Multiple Access) and LTE (Long Term Evolution).

Digital Twins:

- Required to analyze, design and implement control at all three levels, with different dynamic ranges: from steady state, to fast dynamic control response in faults, protection, resynchronization and reconnection
- IEEE 2030.8-2018 recommend tests for MG control system:
  1. Test scenarios for central functions,
  2. Performance measures from applicable standards
  3. Test environment, from a fully simulated system to field installed equipment.

→ Real-time simulation system with a Hardware-In-the-Loop (HIL); also used in Factory Acceptance Tests (FAT)

Conclusions

- Different initiatives and regulations to develop MGs in Colombia
- AC MGs use the hierarchy control of power systems: Integrate DG with conventional generation; frequency and voltages profile regulation (connected and islanded), power sharing, electricity sales to PS, control of phase imbalance and harmonic distortion.
- Primary control: fast frequency and voltages regulation. Usually droop control, Challenges: High R/L ratio → virtual impedance, *R*, *L* identification; low impedance lines; lack of infinite bus in isolated operation → inertia emulation
- Secondary control restores nominal voltage and frequency, tertiary control (if any) optimizes MG operation
- Consider the interoperability of technologies and digital twins for control design and implementation