Microgrids and Energy Management

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Why Distributed Generation?

- Increase in load growth and depletion of fossil fuel
- Proximity of load and source - reduce T&D losses
- Standalone and grid connected systems can be used for augmentation and hence improving power quality and reliability of supply
- Peak operating costs
- Increase system-wide reliability
- Give customer more choices.
- Efficiency of system can be improved by using CHP, co-generation and tri-generation
Microgrid

- Microgrid is a formed by integrating distributed generators, loads and storage devices
- It is capable of operating in parallel to the grid in three modes
  - Grid Connected mode
  - Autonomous power or Island mode
  - Transition between the two above
- No huge investment required for transmission of power
- A stable and controllable microgrid is always an asset to the power system operator
- Provide local voltage support and also increase system reliability
Microgrid

- **Challenges**
  - Islanding
  - Load Sharing
  - Stability
  - Power Quality
  - Critical loads

- **Classification**
  - AC microgrids
  - DC microgrids
  - Hybrid microgrids

- **Microgrid Control**
  - Centralized
  - Decentralized

A part of electric power system with distributed energy resource (DER) and is capable of operating:

- Parallel with the Grid
- Islanding
- During transition
Issues With Microgrids

- Protection
- Synchronization – Reconnection – Restoration
- Islanding
  - Intentional
  - Unintentional
- Power Management
- Power Quality and Reliability
- Storage
Themes

- Microgrids
- Demand Side Management
- Control and Stability
- Source and Load Emulation
- Smart-grids
- Multi Agent Systems
Objective

Energy Management

DR

Diversity

DS

Trading
Hierarchical Control of Microgrids

- Tertiary Control
  - Import and Export of Power

- Secondary Control
  - Restoration/ Synchronization

- Primary Control
  - Inner Loop (droop, load sharing), MPPT
Approach

Hierarchical agent architectures
- Auction based Trading SS & DS
- Developing Agents

Incorporating DSM
- Smart DR options
- Incentive Mechanisms

Incorporating Energy Storage
- Trading
- Coordinating with Smart DR loads

Network Monitoring & Loss Allocation
- Making the network self-healing
- Allocating the losses to traders
Implementation

- System tested for Markets (CDA), DR and DS
- Priority Index
- Shiftable (Continuous & Discontinuous), Curt
- Initial attempt is a simple network → Extended

Who will pay for “Power Loss” in the network?

Control of Active and Reactive Power

- The flows of active and reactive power in a transmission network are fairly independent
  - \( P \) is closely related to frequency
  - \( Q \) is closely related to voltage

- Interconnected system with two or more independently controlled areas
  - Control of frequency
  - Maintain scheduled power interchange
  - Interconnected system with two or more independently controlled areas

- Control of generation and frequency is known as **load frequency control (LFC)**
Speed Governing Mechanism

\[ T_m = \text{mechanical torque} \quad T_e = \text{electrical torque} \]
\[ P_m = \text{mechanical power} \quad P_e = \text{electrical power} \quad P_L = \text{load power} \]

\[ T_m + T_a = \frac{1}{2Hs} \rightarrow \Delta \omega_r \]

\[ \Delta P_m + \Delta P_e = \frac{1}{Ms} \rightarrow \Delta \omega_r \text{ in pu} \]

\[ M = 2H \]
Generators with Droop Characteristic

Governor with State feedback

\[ T_G = \frac{1}{KR} \]
What is Droop?

- The ratio of speed deviation or frequency deviation to change in valve/gate position or power output.
- 5% droop or regulation means that 5% frequency deviation causes 100% change in valve position or power output.

![Graph showing the relationship between frequency deviation and power output or valve/gate position.](image-url)
Load sharing by parallel generators

Frequency is unique when they share a load change

\[ \Delta P_1 = P_1' - P_1 = \frac{\Delta f}{R_1} \]
\[ \Delta P_2 = P_2' - P_2 = \frac{\Delta f}{R_2} \]

\[ \frac{\Delta P_1}{\Delta P_2} = \frac{R_2}{R_1} \]

Amount of load picked up by each unit depends on droop characteristic

If % of regulation of units is nearly equal, the change in the output of each unit will be nearly in proportion to its rating
Load Sharing by Parallel Generators

There is a steady state error associated with load sharing.
Power Management in Microgrids

Grid connected systems
- DG shall maintain a constant power output as the power mismatch are compensated by the main grid.

Unit output power control
- DG is constantly controlled to supply power according to the reference
- Droop control (P-f) is employed
- When the load increases, DG output power increases and frequency decreases

Feeder flow control
- The power in feeder is manipulated according to flow reference - Feeder droop control
- When load increases during grid connected operation, the DGs increase output to maintain a constant feeder flow
- Some of the DGs are excessively loaded during transition

Mixed control
- Combination of UPC anf FFC
Droop Control in Microgrids

Power transfer between two nodes

\[ P = \frac{VE}{X_s} \sin \delta \]
\[ Q = \frac{E}{X_s} (E - V \cos \delta) \]

- Real Power Vs Frequency droop Control
  \[ f - f_0 = -k_P (P - P_0) \]

- Reactive Power Vs Voltage droop Control
  \[ V - V_0 = -k_q (Q - Q_0) \]
Power sharing in DG’s

At steady state, the active power flow is always from the source with higher frequency to the other with lower frequency, before the connection takes place.
Unit Power output Control (UPC)

The power injected by the DG is regulated to $P_{\text{ref}}$

Power injection is calculated from $V$ and $I$ and fed back to the generator controller (GC)

In autonomous mode, the DG follows (P-f) droop curve to maintain load balance

$$f^\text{new} = f^\text{old} - K_U (P^\text{new} - P^\text{old})$$
Feeder Flow Control (FFC)

- DG output is controlled to maintain active power flow in the feeder (FL\text{line}) constant, irrespective of changes in load.
- Microgrid resembles a controllable load from utility point of view.
- In autonomous mode: Flow versus frequency droop characteristic is used:

\[ f^{\text{new}} = f^{\text{old}} - K^F (F^{\text{new}} - F^{\text{old}}) \]
Inverter Dominated Microgrids

- Master slave control
- Droop control
Droop Control for Load Sharing

\[ \omega = \omega_n - m_p(P) \]

- Choice of Droop is based on rating of the DG
- Higher droop is desired for better transient response
- Higher droop may lead system to unstable region
- No communication is required for primary control
- Secondary control to restore the frequency, synchronize to main grid

Need for Virtual Inertia

- **Generators Connected to load**
  - Increase in load results in frequency decay at a rate determined by the inertia of the rotor
  - As speed drops, $P_m$ begins to increase and hence reduces the rate at which speed is reducing

- **Higher Penetration of DGs (inverter dominated systems)**
  - Inertia of the system reduce significantly
  - Change in frequency for a load change (same) is higher
  - Lead to large frequency variation $\rightarrow$ Stability Issues
A full order model accurately represents a real synchronous machine

- Adds unnecessary complexity, if goal is only to add virtual inertia
- Practical implementation issues reported for higher order models

First order of VSM emulates inertia (swing equation)

Simplest and most common approach for load sharing is based on conventional droop control.

Inertia in Droop Control based Microgrids

\[ \omega = \omega_o - m_p (P - P_0) \]

\[ P = \frac{\omega_f}{s + \omega_f} P_{el} \]

\[ \frac{1}{\omega_f m_p} s \omega = P_0 - P_{el} - \frac{1}{m_p} (\omega - \omega_o) \]

\[ \frac{T_a}{s} \omega = P_0 - P_{el} - k_d (\omega - \omega_0) \]

- Inertia is inherent in Droop based Microgrids
- May not be sufficient for transient response, depending on load change
- Inertia is related to droop constant and cut-off frequency of the LPF
- Is it possible to add inertia during transient response?
Summary

- Issues related to Microgrids
- Absence of Inertia
- Systems to work during grid outage (?)
- Parallel operation of roof-top systems
Thank you!

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http://www.ese.iitb.ac.in/~suryad/
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