Distributed Generation and Microgrids

Challenges and Research Opportunities

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Sources Distributed Power Generation

- Wind power
- Natural gas
- Biogas
- Solar thermal
- Solar PV
- Fuel cell
- Combined Heat and Power
- Micro Turbines
- Sterling Engines

Why Distributed Power Generation

- Increase in load growth and depletion of fossil fuel
- Proximity of load and source - reduce T & and 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

Definition-Advantages

- Microgrid is formed by integrating distributed generators, loads and storage devices
- Operate 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

Issues in MicroGrids

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

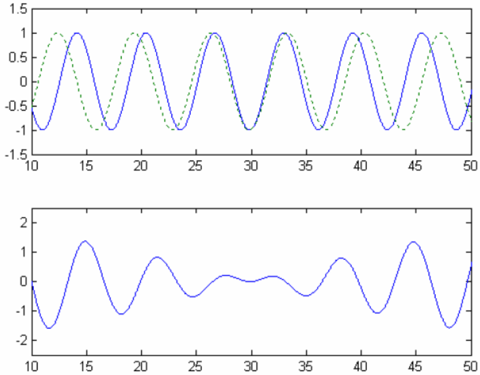
Synchronization

- Re/connection is made when the main grid and MG are synchronized at the PCC in terms of voltage, frequency and phase angle
- Limit values for synchronous interconnection between MG and main grid

Total DG rating (kVA)	ΔF	Δ V	Δ $\varnothing$
0 – 500	0.3	10	20
>500 – 1000	0.2	5	15
> 1000–1500	0.1	3	10

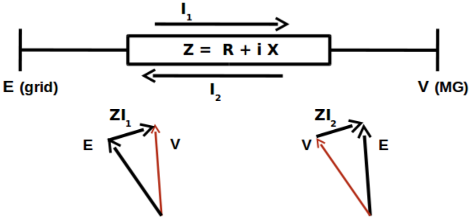
Synchronization

- Frequency is not uniform on both sides
- Phase angle is varying between 0^0 and 180^0.



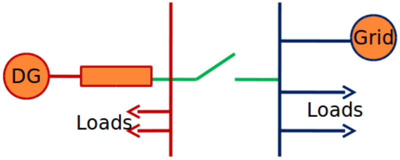
Synchronization

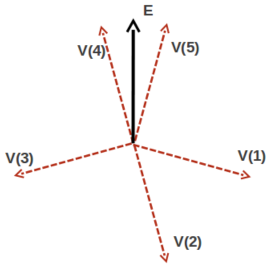
- Closing a switch in a RL circuit with zero initial current
- The relative placement of voltages at the instant of closing decides the direction of current flow



Synchronization

- Conditions for synchronization
  - Voltage across the switch/contactor must be small
  - The voltage with higher frequency shall lead the voltage with lower frequency.
- Power flow is always from unit operating at higher frequency to unit operating at lower frequency





Islanding – Planned/Unplanned

- *"The process whereby a power system is split into two or more segments, each with its own generation. Islanding is a deliberate emergency measure, the result of automatic protection or control action, or the result of human error."* -IEEE Std. 1547
- It can be either planned or unplanned
- DERs continue to provide energy to the isolated system after islanding.

Islanding – Planned

- It is possible to plan load sharing
- Transients can be minimized
- Frequency of the utility side falls below a threshold
    - Lack of generation on grid side
- Poor voltage quality
    - Unbalance due to nearby asymmetrical loads
- Sensitive Loads
    - Last longing voltage dips
- Fault in the system
- Direction of current flow

Islanding – Unplanned

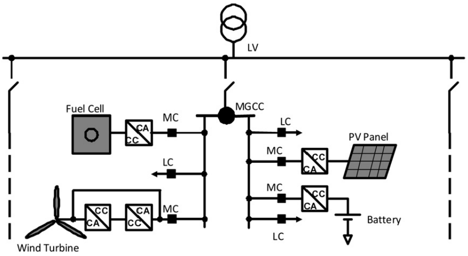
- Primarily due to fault in the system, blackouts, voltage drops, short-circuits etc.
- Severity of transients depend on:
  - Operating condition before islanding
  - Importing of Power
  - Exporting of Power
  - Floating point
  - Location of disturbance
  - Type of DGs in the microgrid
- Reconnection to main grid is possible when the fault is cleared and system is restored.

Islanding Detection Techniques

- Passive
  - Under/Over Voltage
  - Under/Over Frequency
- Active
  - Algorithm based on current injection
  - Sandia national laboratory algorithm
- Utility Control
  - Island detection by communication signals
  - SCADA – Supervisory control and data acquisition system

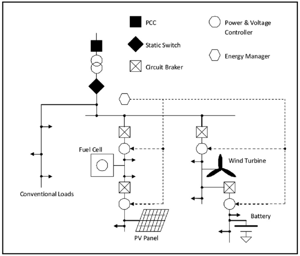
EU – MicroGrids

- Two level architecture (MGCC & MC)
- MGCC established set points (techno & economical)
- MC & LC execute the setpoints to obtain regulate active and reactive power and best service respectively



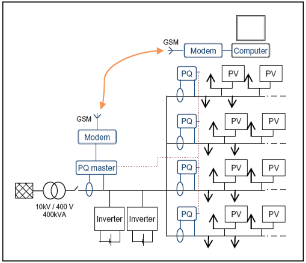
CERTS – Microgrid

- Peer-peer control, any device can connect or disconnect independently
- Operation of generators is locally controlled by droop
- Energy manager is to give initial set points
- High intelligence level is required
- Unit output power control (UPC)
- Feeder flow control (FFC)



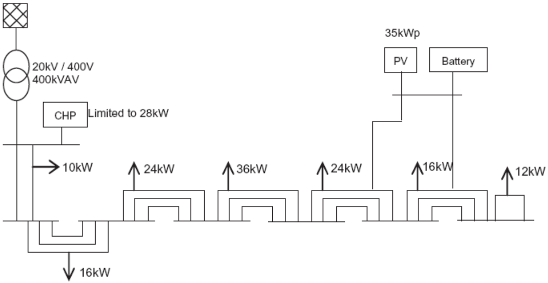
Brosenbean Holiday Park – MoreMicrogrid

- 108 roof top solar PV with capacity of 315 kWp
- Centralized control
- Exchange of data via GSM communication
- Automatic isolation and reconnection



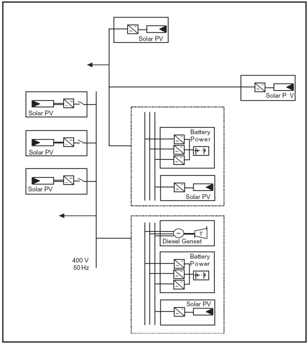
Residential Microgrid of Am Steinweg in Stutensee-Germany.

- 101 apartments are linked to the microgrid with PV and CHP as sources
- System is operated using power flow and power quality management system
- Centralized controller and several decentralized interface boxes
- Communication used is TCP/IP



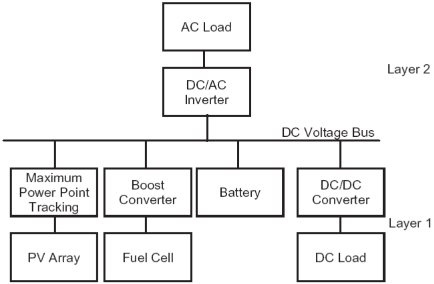
The Kythonos Island Microgrid - Greece

- It electrifies 12 houses having load controllers
- The generation constitute of 10 kW (PV), 53 kWh battery bank, 5-kW diesel generator set and 2 kW(PV rooftop).
- Battery Management
  - When the state of charge of the battery is low, the controllable loads are tripped off thus reducing the consumption
  - When the battery bank is approaching full charge, PV inverters are able to sense this and they continuously de-rate the power outputs



DC linked Microgrid

- Battery is responsible for transient operation
- Fuel cell operates in steady state mode
- Fuel cell is turned off when battery is fully charged
- Solar PV Control
  - MPPT Control
  - Battery Voltage Limit



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

$$P = \frac{EV}{X_s} sin\delta \qquad Q = \frac{E}{X_s}(E - Vcos\delta)$$

- Real Power Vs Frequency droop Control

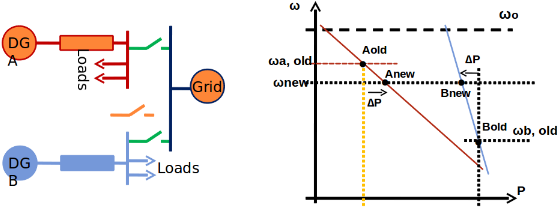
$$F - F_0 = -k_P(P - P_0)$$

- Reactive Power Vs Voltage droop Control

$$V - V_0 = -k_P(Q - Q_0)$$

Power Sharing in DCs

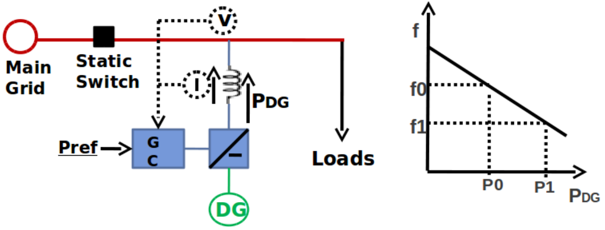
- At steady state, the active power flow is always from the source with higher frequency to the other with lower frequency, before the connection takes place.



Unit output Power Control

- The power injected by the DG is regulated to P_{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

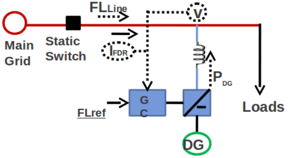
$$F^{new} = F_{old} = -K^{U}(P^{new} - P^{old})$$

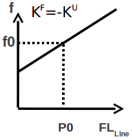


Feeder Flow Control

- The power injected by the DG is regulated to Pref
- 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

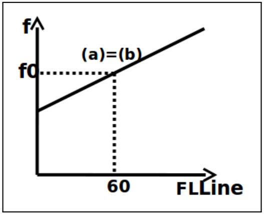
$$F^{new} = F_{old} = -K^{U}(P^{new} - P^{old})$$

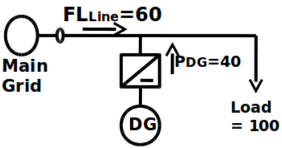


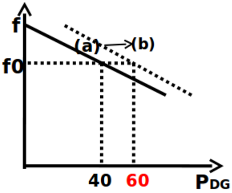


Case–A: Load increase – Grid Connected System

- The feeder flow shall remain constant
- The generator (DG) increases its output to cater to the new load requirements

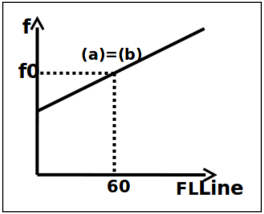


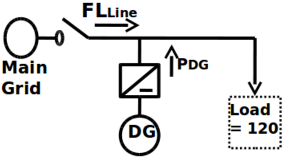


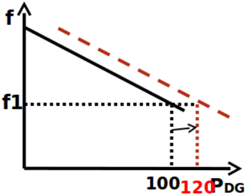


Case–B: Load increase – Isolated System

- During isolated system, frequency changes only if DG cannot maintain feeder flow.
- Feeder flow is Zero, in the case of FFC

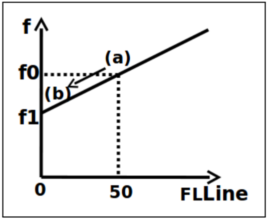


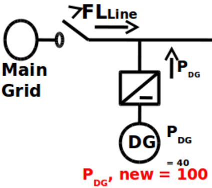


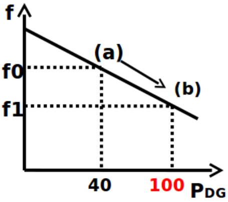


Case–C: Loss of Mains

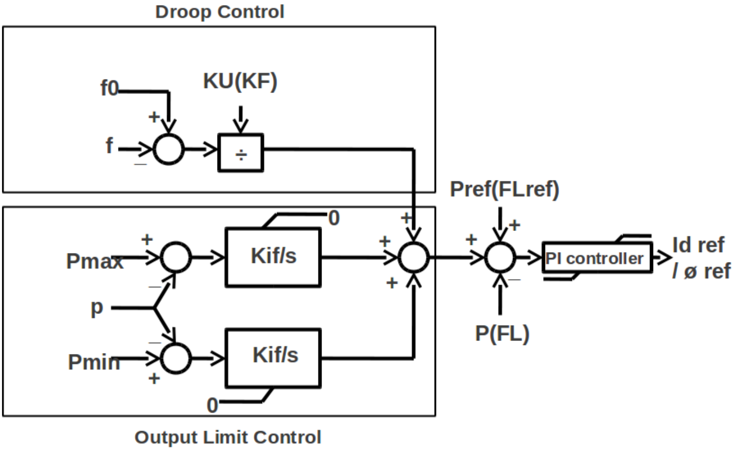
- The feeder flow is zero at this new condition and hence power flow measured by DG is Zero.
- DG increases its output from 40 kW to 100 kW to compensate the decreased feeder flow





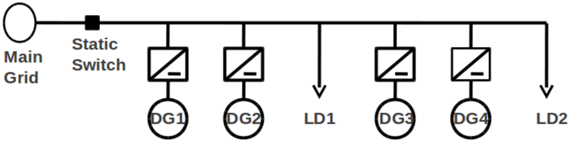


Droop Control – Active Power block diagram



Mixed Configuration

- DGs operate in UPC Mode
- DG1 operate in FFC mode others in UPC mode
- DG1 and DG3 operate in FFC and others in UPC mode



Analysis

- Power from grid is constantly changing with load in UPC mode
- When microgrid is isolated, DGs adjust their output until they reach a new steady state - Result in change in frequency
- In Islanded operation, frequency is always changing in UPC mode which is harmful for loads
- In case of microgrid with single FFC configuration, the DG size should be dominant
- The power picked up by the DG's is not uniform

Research Areas

- Wide area active control
- Adaptive protection and control
- Network management and devices
- Real time network simulation
- Advanced sensors and measurements
- Distributed pervasive communication
- Knowledge extraction by intelligent methods
- Novel design of transmission and distribution systems

About the author

Prof. Suryanarayana Doolla is faculty at the Department of Energy Science and Engineering, Indian Institute of Technology Bombay.

Research Interests:

- Distributed Generation and MicroGrids
- Multi Agent Systems in MicroGrids
- Grid integration of distributed energy resources
- Power systems operation and control
- Converter topologies and control