Smart Inverter Control for Microgrids

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Power Electronics Symposium
July 22, 2011
Outline

- Distributed energy and storage interfaces
- Microgrid configuration and functionality
- Adaptive PI control
- DE/DS active and reactive power control
- Microgrid control: frequency control, voltage control, power dispatch
- Smart inverter control for PV
- Technology transfer
Evolution of Microgrid

Add a diesel generator

- Power grid
- Circuit breaker
- Load
- Energy source
- Smart inverter
- Inverter for DC microgrid
- Control signal
- Relay protection
- Integrated signal

Microgrid Control & Protection

Microgrid Central Controller

Distribution Substation

Feeder N
Microgrid Challenges

Compared to transmission systems, distribution systems have

- More complex and variable topologies
- More unpredictable loads
- Distributed and intermittent energy sources
- Less information available on system topology and parameters
- Cannot afford massive computing
- Calculation and control are still the same!

Unique features of microgrids

- Islanding detection
- Transition between on-grid mode and islanding mode
- High penetration of DE/DS
- New protection technique needed
Microgrid Solutions

- DE/DS is a double-edge sword
- Communication and network technology
- High speed microprocessor for data acquisition and processing, calculation and control
- Layered control and communication topology
- Fundamental control/protection are performed locally and autonomously.
- Autonomous and infrequent microgrid control, and its failure will not endanger system stability and reliability in a short time period.
- Standardize: plug and play, reduce cost, increase stability and reliability.
# Smart Inverter Control

## Adaptive PI control
- Local voltage control
- Independent of system parameters
- Improved steady-state stability
- Faster transient response
- Self-configurable controller gains

## Multiple inverter control
- Independent control (P or frequency, Q or V)
- Power (P, Q) dispatch using droop control
- Voltage control coordination of inverters
- Coordination to prevent unwanted inverter competition

## Smart inverter for Microgrid
- Smart inverter topologies
- MPPT
- Frequency control
- Voltage control
- Active and reactive power dispatch
- Load sharing
- Power factor correction control
Smart Inverter Control

Smart inverter control methods

- Adaptive proportional-integral (PI) control
- Local Voltage/VAR regulation
- Decoupled PQ control
- Harmonics mitigation
- Unbalance compensation
- Smart PV inverter control
Adaptive Proportional-Integral (PI) Control

- **Conventional PI control**
  - Fixed gains
  - Needs complete system data
  - Trial and error
  - Inadequate performance, oscillation, or unstable

- **Adaptive PI control**
  - Gains are changing in real-time
  - Adapt to the system automatically
  - Guaranteed steady state stability and fast transient response

The desired and actual response of the controller.
Adaptive PI Control for Voltage

Fig. 1. PCC voltage at the inverter without voltage regulation.

Fig. 2. PCC voltage with non-adaptive voltage regulation.

Fig. 3. PCC voltage (in RMS) with adaptive voltage regulation.

Fig. 4. Comparison of the desired and actual voltage deviations.
Active Power (P) and Reactive Power (Q) Control

- Linearized and decoupled

\[
P = \frac{V_t V_c}{X_c} \sin \alpha \approx \frac{V_t V_c}{X_c} \alpha
\]
\[
Q = \frac{V_t}{X_c} (V_t - V_c \cos \alpha) \approx \frac{V_t}{X_c} (V_t - V_c)
\]

- Smooth transition when control objectives are different
- Current limiter to ensure that inverter is not overloaded

Sign of Q:
+ inductive
- capacitive

Fig. 1. Active power and reference
Fig. 2. Reactive power and reference
Fig. 3. Inverter current
Harmonics Mitigation and Unbalance Compensation

Harmonics mitigation

Fig. 1. Diode rectifier with resistive load.

Fig. 2. Source current after compensation.

Unbalance Compensation

Fig. 3. Unbalanced local load.

Fig. 4. Source current after compensation.
PV Modeling and Control

DC-AC only

- Simpler and less expensive topology higher efficiency
- Inverter does MPPT and controls Q or local voltage
- Inverter DC link voltage varies
- Higher $V_{pv}$ is required
- MPP is a critical point and does not tolerate much of a disturbance.
- Higher DC capacitor can mitigate the voltage variation
PV Modeling and Control

DC-DC and DC-AC
- MPPT control in DC-DC converter
- Inverter maintains a constant $V_{dc}$
- Inverter controls Q or local voltage
- Constant inverter DC link voltage
- Improved reactive power and voltage regulation capability
- PV can be isolated by the DC-DC converter and the high capacitor on the DC link – more stable
- More complicated topology, lower efficiency
PV Modeling and Control

**MPPT with solar change**

![Graph showing MPPT performance with and without solar change](image)

**Local Voltage Regulation & MPPT with no solar change**

![Graph showing voltage regulation and MPPT performance with no solar change](image)
## Controllable Variables

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<th>Reactive power related variables</th>
<th>Active power</th>
<th>Active current</th>
<th>Power factor</th>
<th>Frequency</th>
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<tr>
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<tr>
<td>Local voltage</td>
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</table>
- Artificial droop
- Different slopes to have different responses
- Applicable to P-f and Q-V control
- P and Q can be dispatched to multiple DE without communication and central controller
- Further communication and “Secondary Control” needed for more accurate performance
Active Power and Frequency Control

On-grid
- MPPT is a higher priority
- Response to high frequency
- Or can follow a P schedule

Islanding
- Frequency control is a higher priority
- 2 groups of DE and 2 control zones
- Frequency within f2 and f3: normal and only droop control
- Secondary control is kicked in when f is out of normal range
- Voltage is a local variable
- Droop control is applicable
- Possible challenge: Q circulation because of improper voltage references
- 3 approaches
  - Local voltages without communication
  - Local voltages with central dispatch
  - PCC voltage with central dispatch
Technology Transfer

Academia
- Theory
- Simulation & Modeling

Utilities
- Application
- Field Demo

Manufacturing
- Testing & Tech Transfer
- Commercialize

ORNLE/DECC
Summary

- The challenges of microgrids are discussed, and a microgrid control and protection topology is proposed.
- Smart inverter control methods are developed and tested.
- Microgrid control principles (frequency, voltage, power dispatch) are proposed.
- The long term goal is to build DECC lab as a demonstration of smart inverter controls and microgrid interoperation.
- ONRL/DECC is strongly motivated to promote the technology transfer of microgrid technologies.
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