NSF Center for GRid-connected Advanced Power Electronic Systems (GRAPES)

GR-17-10 - Distributed Energy Resources; Nasiri/Balda; A Distributed Autonomous Control Concept and Architecture for Microgrids

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Semi-Annual Meeting

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Project Overview

- Anticipated Project Dates
  January 2, 2017 - December 31, 2017

- PI Names
  Adel Nasiri (UWM); Juan Balda (UA)

- Overall Project Budget
  $102,160
Decentralized MG Control System

- Centralized methods of operation are more susceptible to single point failures.
- Emerging smart grid concept compels microgrids to adopt decentralized methods as a result of the highly dynamic behavior for microgrids.
- How: Decentralize the system while maintaining or improving system capabilities.

Decentralization of control has two major advantages:
1. Control commands to power components will be generated locally, thus avoiding long distance command (based on the physical location of the controller).
2. Improvement of reliability by eliminating the single-point-of-failure formed by the centralized controller. Scalability with minimum reengineering.
- Primary and secondary control will be combined into one physical layer.
- Tertiary control will be a responsibility of the controller located at the PCC.
- Each controller must be aware of its peers and their status. This shall form general awareness of the microgrid status.
- Each controller will be responsible of broadcasting its status (plus the power source).

Decentralization Requirements:
- Decentralized: Multiple local controllers in order to achieve seamless transients during the operation and acts as if the system has one central controller.
- Resource sharing: Every controller shares the status of its own DER with other controllers in real-time.
- Concurrency: Each controller must have an up-to-date status all peers. Otherwise, inconsistent algorithm outputs and control commands may arise, which can lead to disturbance in the microgrid operation.
- Scalability: The architecture allows the microgrid to be scaled up. Minimum engineering time.
- Fault-tolerance/Self-healing: The system must maintain available and operating at the minimum level of reliability. This also include the recovery process in case of faults and possible redundancy that may boost the reliability of the microgrid.

In Each Controller

\[ P_{\text{net}} |_{t} = \sum_{i=1}^{n} (e_{p} P_{C_{i}}) = 0 \text{ p.u} \]

\[ Q_{\text{net}} |_{t} = \sum_{i=1}^{n} (e_{q} Q_{C_{i}}) = 0 \text{ p.u} \]

\[ V_{\text{bus}} |_{t} = e_{V} V_{C_{i}} = 1 \text{ p.u} \quad i = 1, 2, \ldots, n \]

\[ F_{\text{bus}} |_{t} = e_{F} F_{C_{i}} = 60 \text{ Hz} \quad i = 1, 2, \ldots, n \]

\( n \): Number of DGs in MG
\( e_{x} \) is the allowed mismatch factor to remain in normal operation state

Fault is reported when these rules (and others) are violated.
Reliability Assessment (Markov Chain Modeling)

Due to large MC number of states. Lumping technique is used to simplify the transition matrix for the Microgrid System.

Transition Matrix M (No repair after Failure)

\[
M = \begin{bmatrix}
-\left( \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 \right) & \lambda_1 & \lambda_2 & \lambda_3 & \lambda_4 \\
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 \\
\end{bmatrix}
\]

Transition Matrix M (With repair after Failure)

\[
M = \begin{bmatrix}
-\left( \lambda_1 + \lambda_2 + \lambda_3 + \lambda_4 \right) & \lambda_1 & \lambda_2 & \lambda_3 & \lambda_4 \\
\mu_1 & -\mu_1 & 0 & 0 & 0 \\
\mu_2 & 0 & -\mu_2 & 0 & 0 \\
\mu_3 & 0 & 0 & -\mu_3 & 0 \\
\mu_4 & 0 & 0 & 0 & -\mu_4 \\
\end{bmatrix}
\]

Markov Chain Reliability Curves
Each Branch has different reliability curves, based on the reliability of the DG.

With decentralized control system, components’ reliability has less influence on the overall reliability of the system.
Each controller runs the entire algorithm including other controllers’ controls (based on inputs from local sensors and peers reports).

- Natural Gas Generators: Synchronization before connection, breaker control, active/reactive power commands, and unit commitment following Energy Storage SOC.
- Energy Storage: Voltage/Frequency regulation
- Wind/Solar: Running on MPPT, operates breakers for isolation in case of emergency or frequent disturbing fluctuations.
- Generation and load forecasting will be integrated in the control algorithm.

Each controller commands its designated power source based on local output of the control algorithm. Others’ commands are buffered for verification purposes (diagnosing faults or performance degradation).
5 Decentralized Controllers: Control Algorithm, Controller model, and Interaction model are applied.

\[ P_{\text{Load}} = P_L + P_{\text{loss}} - P_{pv} - P_{\text{wind}} = P_{\text{NG1}} + P_{\text{NG2}} + P_{\text{ES}} \]

For \( F_{\text{max}} < F_{\text{virtual}} < F_{\text{rated}} \)

\[ P_{\text{NG1 CMD}} = \left( \frac{P_{\text{NG min}} - P_{\text{NG rated}}}{F_{\text{max}} - F_{\text{rated}}} \right) F_{\text{virtual}} - F_{\text{rated}} + P_{\text{NG max}} \]

For \( F_{\text{rated}} < F_{\text{virtual}} < F_{\text{min}} \)

\[ P_{\text{NG1 CMD}} = \left( \frac{P_{\text{NG1 rated}}}{F_{\text{max}} - F_{\text{rated}}} \right) F_{\text{virtual}} - F_{\text{rated}} + P_{\text{NG max}} \]

For \( V_{\text{max}} < V_{\text{virtual}} < V_{\text{rated}} \)

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For \( V_{\text{rated}} < V_{\text{virtual}} < V_{\text{min}} \)

\[ Q_{\text{NG1 CMD}} = \left( \frac{Q_{\text{NG rated}}}{V_{\text{max}} - V_{\text{rated}}} \right) V_{\text{virtual}} - V_{\text{rated}} + Q_{\text{NG max}} \]
Main Deliverables

- A distributed microgrid control concept and architecture
- Hardware-in-the-loop implementation of the control concept
- Communication delay analysis
- Reliability analysis
- Two publications on the proposed concept and system.
- Possible IP development.
This work will create expertise in the center on MG controls.

The developed distributed control concept and analysis can be applied to other systems, e.g. DC MG.

The work will lead to more reliable control systems for MGs and other electrical systems.
References


