Impact of Power Management Strategies on Micro-Grid Dynamic Performance

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Outline

- Definitions
- Assumptions
- Benchmark System(s)
- Investigation Tools
- Power Management and DR Controls
- Study Results
- Conclusions
Definitions

- A Distributed Resource (DR) unit includes either a Distributed Generation (DG) unit, a Distributed Storage (DS) unit, or a hybrid of DG and DS units.

- A micro-grid is a cluster of loads and distributed resource units serviced by a distribution grid and capable of
  - operation in a grid-connected mode,
  - operation in an autonomous (islanded) mode,
  - ride-through between the above two modes.
Assumptions

- Radial distribution system
- Dispatchable DR units
- No spinning reserve or back-up units
- No communications
- Frequency deviation (and frequency control) considered
Benchmark System

Bus 3 : Sensitive load–bus
DG1 : Synchronous Generator
DG2, DG3 : Electronically–Interfaced Sources

V(base) = 13.8 KV
S(base) = 10 MVA

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Investigation Methods

- Digital time-domain simulation in PSCAD/EMTDC environment

- Small-Signal dynamic analysis based on eigen analysis in MATLAB environment
Small-Signal Model
Power Management and DR Controls
dq current controllers for an electronically-interfaced DG unit

\[ V_d' \rightarrow -+ \rightarrow V_d \rightarrow ++ \rightarrow V_d \text{ (ref)} \]

\[ +\rightarrow \rightarrow PI \rightarrow \rightarrow P I \rightarrow \righta
Power Management Strategies

A Power Management System (PMS) assigns references for real and reactive power components of DR units within a micro-grid to:

- share real-/reactive-power among DR units,
- (rapidly) respond to small-signal and large-signal disturbances,
- determine final operating conditions of DR units to balance power and restore micro-grid frequency,
- assist in re-synchronization of an autonomous micro-grid to the main grid.
PMS (Real Power)

- Frequency-droop characteristic and frequency restoration algorithm
PMS (Reactive Power)

- **Strategy I**: Voltage-droop Characteristic
- **Strategy II**: Voltage Regulation
- **Strategy III**: Power Factor Correction
- **Strategy IV**: Hybrid of I to III
Case Studies

- **Case I:**
  Real PMS: frequency-droop,
  Reactive PMS: voltage-droop characteristics for DG2 and DG3

- **Case II:**
  Real PMS: same as Case I,
  Reactive PMS: voltage-droop for DG2 and voltage regulation for DG3

<table>
<thead>
<tr>
<th></th>
<th>Case I</th>
<th>Case II</th>
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<tbody>
<tr>
<td></td>
<td>Eigen values</td>
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<tr>
<td></td>
<td>Real (1/s)</td>
<td>Im. (rad/s)</td>
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<tr>
<td></td>
<td></td>
<td>Real (1/s)</td>
</tr>
<tr>
<td>DG1: 1.47-MW 0.59-MVAr</td>
<td>1.2  -219.556 ± 2164.05</td>
<td>-2298.7 ± 2139.14</td>
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<tr>
<td>DG2: 1.87-MW 1.06-MVAr</td>
<td>3.4  -366.93 ± 1175.57</td>
<td>-290.0 ± 1278.64</td>
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<tr>
<td>DG3: 0.96-MW 0.41-MVAr</td>
<td>5.6  -18.0 ± 725.9</td>
<td>-62.6 ± 706.99</td>
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<td></td>
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<td>7.8  -39.56 ± 507.59</td>
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<td></td>
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<td>9, 10  -110.71 ± 427.52</td>
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<td></td>
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<td>11,12  -1710.09 ± 389.43</td>
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<td></td>
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<td>13,14  -748.57 ± 380.52</td>
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<td></td>
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<td>15,16  -365.37 ± 386.08</td>
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<tr>
<td></td>
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<td>17,18  -425.76 ± 377.0</td>
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<td></td>
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<td>19,20  -56.46 ± 336.43</td>
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<tr>
<td></td>
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<td>21,22  -193.0 ± 77.35</td>
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<td>23,24  -0.738 ± 9.98</td>
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</tbody>
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Eigen Analysis

Change in the gain of real power controller for DG2

Change in the gain of real power controller for DG3
Eigen Analysis

Change in the gain of reactive power controller for DG2
Intentional Islanding

Intentional islanding, PMS I
Intentional Islanding

Intentional islanding, PMS II and PMS III
Accidental Islanding (Fault)

- **PMS:** PMS I
- **Disturbance:** 3-Phase to ground fault at t=0.8s
Accidental Islanding (Fault)

- **PMS:**
  - PMS II and PMS III

- **Disturbance:**
  - 3-Phase to ground fault at t=0.8s
Autonomous Operation

Load Change

- **PMS:**
  Droop characteristics

- **Disturbance:**
  Real power of Load-3 is doubled at $t=5$ seconds
Autonomous Operation

Loss of a Generation Unit

- **PMS:** Droop characteristics
- **Disturbance:**
  - DG3 is disconnected at $t=5s$

![Graphs showing bus voltages, real power generation, reactive power, and generator speed during loss of DG3.](image-url)
Conclusions

- Optimized controls and PMS parameters of DR units can provide satisfactory performance of the microgrid under both grid-connected and islanded modes of operation.

- A hybrid of voltage droop, voltage regulation and power factor correction in conjunction with frequency droop and frequency restoration can minimize dynamic interactions among DR units and assist in microgrid transition between grid-connected and islanded modes.