Comparison of Islanding and Synchronization for a Microgrid with Different Converter Controls

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Outline

- Introduction
- Work description
- Simulation & results.
- Conclusion
- Reference
Operation modes of microgrids.
Main scope:

A comparison of microgrid performance during islanding and synchronization when different voltage source converter (VSC) controls are adopted.

1. An overview of VSC controls, namely: 1) grid-following, 2) grid-forming, and 3) grid-supporting.

2. A Comparison of microgrid performance is conducted in two testbeds built in MATLAB/SimPowerSystem environment. The two testbeds are compared side by side for their dynamic performance.
Overview of VSC controls

1. Grid-Following VSC:

- **Active & reactive power at the PCC are controlled by tuning the converter AC current.**

- Also, **DC voltage & the PCC voltage** could be regulated.

- It is operated as a **current source** [7].

- A synchronization mechanism “PLL” is required in order to be **synchronized** with the grid by extracting the grid frequency and PCC voltage angle $\theta_{PLL}$.

Fig. 1: Schematic control structure of grid-following VSC
2. Grid-Forming VSC:

- It is operated in MGs as the source of voltage & frequency control by regulating the AC current of the converter.
- It is operated as an ideal AC voltage source [2].
- It is similar to the grid-following control structure except the outer loop.

Fig. 2: Schematic control structure of grid-forming VSC.
3. Grid-Supporting VSC:

- It can operate either in grid-connected mode or autonomous mode.
- No need to re-configuration the converter control.
- Droop controls are implemented on top of a grid-following control structure.
- It can contribute controlling the MG voltage, frequency, active & reactive power at the PCC through its droop design, in both modes:

\[
\begin{align*}
    f - f^* &= -m(P - P^*) \\
    V - V^* &= -n(Q - Q^*)
\end{align*}
\]

Fig. 3: Schematic control structure of a grid-supporting VSC.
Two testbeds built in MATLAB/SimPowerSystem as follows:

**Testbed 1.**
A VSC switches back and forth between *grid-following* and *grid-forming* control during islanding and synchronization “grid-connected mode”.

**Testbed 2.**
A VSC works in *grid-supporting* mode regardless of the microgrid operation mode.

**Fig.4:** an *islanding scheme* and a *grid-back detection scheme* are designed to automatically switch the operation modes of the VSC.
The testbeds parameters:

<table>
<thead>
<tr>
<th>Description</th>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Grid side</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transformer 1</td>
<td>$T_1$</td>
<td>400 kVA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>260 V \ 25 kV</td>
</tr>
<tr>
<td>Transformer 2</td>
<td>$T_2$</td>
<td>400 kVA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25 kV \ 120 kV</td>
</tr>
<tr>
<td>Transmission line</td>
<td>$R_L, X_L$</td>
<td>0.1X_L, 0.2 pu</td>
</tr>
<tr>
<td><strong>DG side</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VSC</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Rated power</strong></td>
<td>$S_b$</td>
<td>400 kVA</td>
</tr>
<tr>
<td><strong>Rated voltage</strong></td>
<td>$ac/dc$</td>
<td>260/500 V</td>
</tr>
<tr>
<td><strong>Converter filter</strong></td>
<td>$R_f$</td>
<td>0.156/50 pu</td>
</tr>
<tr>
<td></td>
<td>$X_f$</td>
<td>0.156 pu</td>
</tr>
<tr>
<td><strong>Shunt capacitor</strong></td>
<td>$C_f$</td>
<td>0.25 pu</td>
</tr>
<tr>
<td><strong>Load</strong></td>
<td>fixed load</td>
<td>300 Kw</td>
</tr>
</tbody>
</table>

**Reference control settings:** \( P_{pcc}^* = 1 \text{ pu} \quad V_{pcc}^* = 1 \text{ pu} \quad \omega^* = 60 \text{ Hz} \)
Simulation & Results

- **Comparison #1: Grid-connected mode to Autonomous mode:**
  - Three phase fault occurs in the transmission line at 1 s.
  - Islanding mode is detected after 3 ms.

Testbed # 1: grid-following / grid-forming

Testbed # 2: grid-supporting

\[ \Delta \omega = 0.475 \text{ Hz} \]
Comparison #1: Grid-connected mode to Autonomous mode:

- Active power responses: converter output, load, and grid.
- The VSC injects a fixed active power (400 Kw) to the load (300 Kw) and the grid (100 Kw).

Testbed #1: grid-following / grid-forming

\[ P_{pcc}^* = 1 \text{ pu} \]
\[ P_{\text{Load}} = 0.75 \text{ pu} \]
\[ P_{\text{grid}} = 0.25 \text{ pu} \]

Grid-connected mode

\[ P_{pcc}^* = 1 \text{ pu} \]
\[ P_{\text{Load}} = 0.75 \text{ pu} \]
\[ P_{\text{grid}} = 0 \]

Autonomous mode

Testbed #2: grid-supporting

\[ P_{pcc}^* = 1 \text{ pu} \]
\[ P_{\text{Load}} = 0.75 \text{ pu} \]
\[ P_{\text{grid}} = 0.25 \text{ pu} \]

Grid-connected mode

\[ P_{pcc}^* = 1 \text{ pu} \]
\[ P_{\text{Load}} = 0.75 \text{ pu} \]
\[ P_{\text{grid}} = 0 \]

Autonomous mode

generates \( \Delta \omega \)
Comparison #2: Autonomouse mode to Grid-connected mode:
- Three phase fault is cleared at 5 s.
- The operation mode is switched back to grid-connected mode at 5.37 s in testbed 1 and 5.11 s in testbed 2.

Testbed #1: grid-following / grid-forming

Testbed #2: grid-supporting

\[ \Delta \omega = 0.475 \text{ Hz} \]
Comparison #2: Autonomous mode to Grid-connected mode:

- Synchronization process between the VSC system and the grid in both testbeds:

  Testbed #1: grid-forming / grid-following

  Testbed #2: grid-supporting

- The Gridback detection signal switches the frequency mode from free-running frequency by VCO to the PLL frequency (*imposed by the grid*).
Comparison #2: **Autonomous mode** *Grid-connected mode*:

- Active power responses: converter output, load, and grid.
- The VSC injects a fixed active power (400 Kw) to the load (300 Kw) and the grid (100 Kw).

**Testbed #1:** *grid-forming \ grid-following*

- \( P_{pcc} = 1 \text{ pu} \)
- \( P_{Load} = 0.75 \text{ pu} \)
- \( P_{grid} = 0 \)

*Autonomous mode*

**Testbed #2:** *grid-supporting*

- \( P_{pcc} = 1 \text{ pu} \)
- \( P_{Load} = 0.75 \text{ pu} \)
- \( P_{grid} = 0.25 \)

*Grid-connected mode*
Conclusion

- The simulation results of switching from one operation to another operation, namely, islanding and re-synchronization, are examined.

- Compared to either the grid-following or grid-forming VSCs, grid-supporting VSC has the advantage of operating in the both operation modes without changing control configuration.

- The droop control has been identified as an effective tool to participate in regulating the frequency, voltage, and power of the microgrid.


Thank You
For Your Attention

Questions ?