Transient Stability of Hybrid Stand-alone Microgrids Considering the DC-Side of Photovoltaics

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Overview

- Fundamentals
- Methodology
- Selected results
- Conclusions and outlook

Motivation and aim

- The number of off-grid hybrid microgrids in developing and under-developed countries will continue to increase significantly.
- In order to increase the economic benefits and security of supply, several neighbouring hybrid microgrids can be interconnected.
- To achieve convincing results in the quantitative transient stability assessment of hybrid microgrids, the system dynamics during the first few milliseconds are crucial.
- The detailed modelling of PV systems is fundamental in the short-circuit investigations regarding reactive current / power provision.

- Analysis of a cluster of three exemplary stand-alone hybrid microgrids with DG and PV with their DC-side.
  - Investigation of the influence of different ratios of active and reactive current provision (ACP : RCP) as well as with respect to transient stability.
Fundamentals

Block diagram of PV systems with DC-side Modulus and symmetrical optimum for PV controllers
Reactive current provision
In microgrids with DG units, PV systems are usually operated according to the current injection principle, so called grid-feeding. Depending on the DC-link voltage deviations with respect to the voltage based on the maximum power point tracking (MPPT), the d-axis reference current signal will be varied. Three PI controllers are employed in PV systems: PLL, current controller and DC voltage controller.
The outer DC voltage control loop is slower compared to the inner current control loop.

Dimensioning of the PI controllers:
- Current control loop \( \rightarrow \) modulus optimum
- DC voltage control loop \( \rightarrow \) symmetrical optimum
The short-circuit current of power electronic based PV systems is limited to 1 pu.

In transmission systems (R/X ratio of lines close to 0.1) the provision of reactive current is preferred over active current (red profile).

By giving more priority to active current, the provision of reactive current can be varied (blue, green and yellow profile) in microgrids.
Methodology

System modelling

Calculation of the control parameters in PV systems

Overview of the performed analyses
The DG were modelled using the 5th order detailed dynamic model along with DEGOV1 and ESAC2(3)A

The composite loads were assumed to be static and constant impedance

The R/X ratio of the lines:
- within microgrids: 1.62
- Interconnectors: 1.07

Operating point: High loading of 80% of the nominal power of the loads on a sunny day

The cluster microgrid model with a total installed capacity of 760 kW:

System modelling

<table>
<thead>
<tr>
<th>Generation</th>
<th>Load</th>
<th>DG : PV</th>
</tr>
</thead>
<tbody>
<tr>
<td>DG</td>
<td>PV</td>
<td>Total</td>
</tr>
<tr>
<td>1</td>
<td>119</td>
<td>54</td>
</tr>
<tr>
<td>2</td>
<td>92</td>
<td>48</td>
</tr>
<tr>
<td>3</td>
<td>125</td>
<td>36</td>
</tr>
<tr>
<td>Σ</td>
<td>336</td>
<td>137</td>
</tr>
</tbody>
</table>
Calculation of the control parameters in PV systems

Inner current control loop

- Both the open- and closed-loop transfer functions of the inner and outer control loops are stable.

Outer DC voltage control loop

- However, $T_{iv}$ of the PI controller in the voltage control loop was exemplarily multiplied by 100 and is equal to 2.3 s. As a result, the grid simulations were comprehensible and no long-lasting oscillations were observed.
Before carrying out grid investigations, the cluster microgrid model was validated – according to ISO 8528-5 – at the operating point in the steady-state and step-load change.

Carried out investigations:
- Sudden change in solar irradiance
- Different reactive current provision
- Disconnection of critical generation units
- Central and decentral distribution of PV

Reference scenario: 100 % RCP (RCP : ACP :: 100 : 0)
Comparison between 50 % and 0 % RCP
System dynamics were studied for a 3-phase fault cleared after 185 ms → critical clearing time (CCT) of the reference scenario
If the rotor angle of any DG with respect to the centre-of-inertia (COI) reference machine > 180° → out-of-step and thus instable!
Selected results
(Impact of different reactive current provision)

100 % RCP

Comparison between 50 % and 0 % RCP
- The angular frequency of the DG located close to the fault location, i.e., DG 3.1 and DG 3.2, drops because of mainly the subtransient short-circuit current and also residual voltage: $P_e >> P_m$

- Due to the rotors’ deceleration, the speed governors increase the mechanical power input (with a delay of just several ms) → Further ↑ in the rotor angle deviation
Soon after the fault occurrence, $I_{PV}$ remains unchanged, since it depends on the module temperature and solar irradiance.

The current difference ($I_{PV} - I_{DC}$) flows into DC-link capacitor $\rightarrow U_{DC}$ $\uparrow$, which is however less than the maximum allowable DC input voltage (1000 V) of the inverters.

The operating point of the PV generator drifts away from the MPP $\rightarrow I_{PV}$ $\downarrow$.

Due to the 100 % RCP: $I_{PV}$ $\downarrow\downarrow$ (up to 0).

A clear distinction between the effect of the DC voltage control and 100 % RCP is not possible, since both of them occur simultaneously.
Since the R/X ratio of the lines is slightly > 1, the grid voltages do not depend particularly on the reactive power – instead more on the active power.

The subtle difference in the voltage profiles particularly just before clearing the fault has a significant impact on the system behaviour.

Since $P_e$ of the DG depends on the residual voltage, a slight improvement in the voltage profiles $\rightarrow (P_m - P_e) \downarrow \rightarrow$ rotor angle deviations $\downarrow$ and $\rightarrow$ CCT $\uparrow$.

The complete curtailment of the reactive power of the PV systems leads to the best voltage and frequency profile.
Comparison between 50 % and 0 % RCP (2/2)

100 % RCP

<table>
<thead>
<tr>
<th>Time in s</th>
<th>Rotor Angle (COI) in degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>2.2</td>
<td>50</td>
</tr>
<tr>
<td>2.4</td>
<td>100</td>
</tr>
<tr>
<td>2.6</td>
<td>150</td>
</tr>
<tr>
<td>2.8</td>
<td>100</td>
</tr>
<tr>
<td>3</td>
<td>50</td>
</tr>
</tbody>
</table>

Legend:
- DG 1.1
- DG 1.3
- DG 2.1
- DG 2.3
- DG 3.1
- DG 3.2
Higher ratio of ACP to RCP → significant increase in the CCT

By giving an entire priority to the active current, i.e., 0 % RCP, the CCT can be improved by about 70 %
Conclusions and outlook
Conclusions

- The higher the ratio of ACP to RCP is, the better is the effect on the voltage and transient stability.

- If the provision is given entirely to the active current, a significant improvement in the CCT by 70% is observed.
  - It is recommended not to provide reactive power by PV systems in case of short-circuits in hybrid microgrids.

- The significant reduction in the solar irradiance of about 55% within 2.5s has a negligible influence on the transient stability of the studied microgrid.

- The disconnection of the critical PV/DG does not pose serious problems regarding transient stability (even in the high loading condition).

- The decentral distribution of PV systems has both positive and negative impact on the transient stability.
In a cluster microgrid environment, it is a tedious and ineffective process to assess solely the CCT with the help of time-domain simulations.

Using a hybrid method – combining both time-domain simulations and energy function for synchronous generators – transient stability of hybrid microgrids can be quantitatively assessed.

With the help of a hybrid method in hybrid microgrids numerous cases can be effectively studied and compared:
- central vs. decentral distribution of PV
- clustering possibilities
- various operating points with different power allocation
- controllers' settings
- etc.
Thank you for your attention!
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