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1 Presentation of the study

Study Context: High Voltage Direct Current (HVDC) networks

Objectives: Suggesting an automated method to build system models, keeping analytical expressions. Merging Stability and Quality criteria in order to size filter parameters.

2 Load model building - Equivalent admittance

Considered load: A drive (a Permanent Magnet Synchronous Machine (PMSM) associated to a three phase inverter)

Load model building: Equivalent admittance analytical expression

3 Automated model building on Maple software

Using the drive admittance model, the whole system analytical state equations are automatically derived from a network circuit description:

4 Stability criterion - Routh-Hurwitz

Routh-Hurwitz absolute stability criterion is applied to the established model

Stability is discussed according to $l_p$ and $C_p$ filter parameters.

5 Quality criteria - Filtering & damping conditions

Two quality criteria are added to the stability criterion:

- Filtering condition, through the filter cut-off frequency. It corresponds to the purple line on Fig.10.
- Damping factor condition, computing system poles and considering the dominant one. This condition allows to complete the filter sizing (point n°3) on Fig.10.

Figure 13: Frequency analysis performed on $V_{Bus}$ voltage without and with the filter

Figure 12: Transient analysis on simulation model to check the damping, with sizing n°3

Figure 11: Plotted abacus represents stable and unstable areas according to filter parameter values.

Figure 9: Input drive voltage evolutions for sizing marked 1 and 2 on Fig.8.
Analytical Input Filter Design in DC Distributed Power Systems Approach taking Stability and Quality criteria into account

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6 Introduction of optimization algorithms

In order to increase the number of handled parameters, optimization algorithms are introduced.
- Criteria are transformed into constraints:
- Convergence criterion minimize the stored energy in the filters:

\[ E_{\text{stored}} = \sum \left( \frac{X_c - X_n}{X_n} \right)^2 \]

7 Gradient algorithm results

First, to compare algorithm results using gradient convergence with abacus ones, only two parameters are studied: \( L_1 \) and \( C_2 \).

Figure 14: Results obtained with “Abacs” method. The yellow line gives the solutions which check stability and quality constraints.

Figure 15: Results obtained with Gradient algorithm. Additional weightings can be introduced to guide the algorithm toward different optimums.

8 Genetic algorithm results

To spread the results spectrum, a crowding based GA is used: it can look for several solutions in the given excursion windows (within the bounds).

Figure 16: Results obtained with Genetic algorithm. Several points have been selected and theirs \( E_{\text{stored}} \) values are given in Fig 17.

Figure 17: Objective function values allow to qualify the obtained solution: thus, designer can make his choice considering realization constraints.

9 Study of more complex systems

Study is processed on all the filter parameters with RTS, to illustrate the ability to size more than two parameters:

<table>
<thead>
<tr>
<th>Found solution</th>
<th>Associated constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L_1 = 53.22 \mu \text{H} )</td>
<td>Highest pole real part = -31.65 (&lt;0)</td>
</tr>
<tr>
<td>( C_1 = 118.98 \mu \text{F} )</td>
<td>( f_1 = 2000 \text{Hz} )</td>
</tr>
<tr>
<td>( R_{\text{L}2} = 100 \Omega )</td>
<td>( f_2 = 1500 \text{Hz} )</td>
</tr>
<tr>
<td>( C_2 = 1.061 \text{mF} )</td>
<td>Damping of dominant pole = 0.179</td>
</tr>
</tbody>
</table>

Eventually, this tool is applied on a network constituted of 2 loads:

Table 1: Optimum values obtained with RTS

RTS allows to size all the filter parameters:

<table>
<thead>
<tr>
<th>Found solution</th>
<th>Associated constraints</th>
</tr>
</thead>
<tbody>
<tr>
<td>( L_1 = 61.13 \mu \text{H} )</td>
<td>Highest pole real part = -267.36 (&lt;0)</td>
</tr>
<tr>
<td>( C_1 = 102.94 \mu \text{F} )</td>
<td>( f_1 = 2000 \text{Hz} )</td>
</tr>
<tr>
<td>( L_2 = 64.80 \mu \text{H} )</td>
<td>Damping of dominant pole = 0.171</td>
</tr>
<tr>
<td>( C_2 = 97.75 \mu \text{F} )</td>
<td>( f_{\text{min}} = 2000 \text{Hz} )</td>
</tr>
<tr>
<td>( R_{\text{L}2} = 100 \Omega )</td>
<td>( f_{\text{min}} = 2000 \text{Hz} )</td>
</tr>
<tr>
<td>( C_{\text{f}1} = 1.416 \mu \text{F} )</td>
<td>( f_{\text{f}2} = 1124 \text{Hz} )</td>
</tr>
</tbody>
</table>

Table 2: Optimum values obtained with RTS

With the followings weightings:
- 25% for inductance \( L_1 \) \( f_{\text{f}1} \)
- 10% for capacitance \( C_2 \) \( f_{\text{f}2} \)
- 15% for filter cell \( V_{\text{DC}1} \) \( V_{\text{DC}2} \)

Figure 18: Voltage \( V_{\text{DC}1} \) evolution after a step applied on \( V_{\text{i}1} \) with found parameters

Figure 19: Second considered network, composed by two loads

Figure 20: Voltage \( V_{\text{DC}1} \) and \( V_{\text{DC}2} \) evolutions after a step applied on \( V_{\text{i}1} \) with found parameters

10 Conclusion

An automated model building has been developed with Maple software.
- A tool based on optimization algorithm attempts to find filter parameter values which minimize the stored energy, while ensuring stability and quality criteria.
- Eventually, the crowding based genetic algorithm allow to size two HVDC network filters, suggesting several solutions in order to give the possibility for the designer to fix these parameter values considering realization constraints.