Optimization-Enabled PSCAD Transient Simulation

Electromagnetic transient simulation programs find numerous applications in the design of complicated nonlinear circuits, where they are used to accurately simulate the performance of a new design. With the level of nonlinearities increasing, analytical design methods find more limitations in practice and as such simulation-based methods are becoming more viable solutions.

The design procedure often requires several simulations before an optimal setting for the design parameters is obtained. To address this issue, simulation programs are equipped with search engines, such as the Multiple-Run component in the PSCAD/EMTDC, that enable successive simulations for a pre-specified (or sometimes randomly selected) group of parameter sets. With regard to the fact that transient simulation is a computationally intensive process, it becomes evident that design using conventional sequential or random search methods can be overwhelmingly intense in terms of computer resources required.

Optimization-enabled transient simulation is a powerful alternative, which combines the power of transient simulation in describing a nonlinear system with the power of an optimization algorithm in efficiently searching for the optimum. The basic idea in optimization-enabled simulation is to replace the unsupervised sequential (or random) search with an optimization algorithm, which intelligently selects parameter sets and steers the design towards the optimal parameter set.

As shown in Figure 1, a parameter set generated by the optimization algorithm is used in the transient simulation program, which simulates the network and evaluates its corresponding objective function [1].

The objective function is a mathematical representation of the design specifications and shows a figure of merit for the current parameter set. The optimization algorithm uses the objective function evaluation to generate a parameter set with a better figure of merit.

The most prominent feature of this tool is its capability of finding the optimal parameter set even under situations where the complexity of the network prohibits an analytical formulation of the objective function in terms of the design parameters. The intelligence incorporated into the design through the use of an optimization algorithm leads to orders of magnitude reduction in the number (and hence the intensity) of the simulations and also improves the accuracy of the results.

Example Case

In this section, the design procedure using optimization-enabled transient simulation is demonstrated through an example. The circuit under consideration is a dc power supply, as shown in Fig. 2(a). In this circuit, a diode bridge is used to rectify the three-phase ac source and produces (after filtering) an unregulated dc voltage. The IGBT switch is then used to regulate the voltage across the load and thereby to control the load current. Regulation of the load current to a reference value is usually done through a closed loop control system, as shown in Fig. 2(b). The control system uses the error between the actual and the reference values of the load current to adjust the duty cycle of the switch, which is turned ON and OFF according to a PWM scheme [2].

Figure 1 Optimization-enabled transient simulation.
The objective of the design is to determine the optimal values for:
1. the dc filter elements \((L_{dc}, C_{dc})\), to minimize the ripple on dc side voltage and current;
2. the gain and time constant of the PI controller \((K_p, T_i)\), to obtain smooth load current dynamics with little overshoot and minimum steady state error; and
3. the switching frequency of the IGBT \((f_{sw})\), to minimize the switching losses.

The above objectives are formulated in the following objective function.
\[
OF(K_p, K_i, f_{sw}, L_{dc}, C_{dc}) = W_1 \cdot ISE_1 + W_2 \cdot f_{sw} + W_3 \cdot ISE_2
\]
where \(ISE_1\) and \(ISE_2\) are the partial indices used to penalize the deviation in the load current dynamic response and the dc side quantities [1]. The indices are designed such that a closer match between the actual and the reference values results in a smaller value for the index. The overall goal of the design is therefore to find a parameter set that minimizes the objective function \((OF)\) given above. The weighting factors \(W_i\) are used to signify the relative importance of the design specifications.

Table I shows the results obtained from the optimization-based design for an operating point of 45 A. The design is carried out in less than 300 simulation runs, whereas a similar design using the conventional Multiple-Run approach with a coarse grid of 10 steps for such a problem with 5 variables requires \(10^5 = 100,000\) simulations.

Table 1

<table>
<thead>
<tr>
<th>Optimization Parameters</th>
<th>(K_p)</th>
<th>(K_i\ (1/T_i))</th>
<th>(f_{sw}) (Hz)</th>
<th>(L_{dc}) (mH)</th>
<th>(C_{dc}) (μF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial value</td>
<td>2.0</td>
<td>90.0</td>
<td>2000</td>
<td>50.0</td>
<td>150</td>
</tr>
<tr>
<td>Optimized value</td>
<td>1.83</td>
<td>101.3</td>
<td>819.9</td>
<td>5.5</td>
<td>172.4</td>
</tr>
</tbody>
</table>

Table 1 Optimization results.

Figure 3 shows the load current dynamics and the dc side voltage and current waveforms for the initial parameter set, as well as for the optimized parameters. It is observed that the optimization has successfully resulted in a much smoother load current and has reduced the ripple on the dc side quantities as well. It should also be noted that the optimized switching frequency is more than 50% less than its initial value, which translates into a significant reduction of the switching losses.
The concept of optimization-enabled transient simulation has been implemented in the PSCAD/EMTDC and is now available in the Version 4.1 of the program. The optimization algorithms incorporated are the Simplex method of Nelder and Mead, Hooke-Jeeves and Golden Section. The algorithms are suitable for nonlinear single- and multi-variable optimization problems; inclusion of other methods, such as the Genetic Algorithms and gradient-based optimization methods is currently under consideration, and will be available in future releases.

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References


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