REDUCED MODELS FOR OPERATION MANAGEMENT OF DISTRIBUTED GENERATION

Bernhard WILLE-HAUSSMANN
Fraunhofer ISE - Germany
bernhard.wille-haussmann@ise.fraunhofer.de

Christof WITTWER
Fraunhofer ISE - Germany
christof.wittwer@ise.fraunhofer.de

Stefan TENBOHLEN
University of Stuttgart - Germany
stefan.tenbohlen@ieh.uni-stuttgart.de

ABSTRACT

Distribution grids evolve more and more to a decentralised structure with a high amount of distributed generation. With a high penetration of DER and RES it will be necessary to control the generators to avoid instabilities in the grids. Decentralised generation also offers the possibility to manage the load flow of the voltage level they are connected. Experience has shown that the complexity of a detailed distribution grid model is far too extensive for the operation management. For an efficient calculation, model reduction techniques may be employed for reducing the model complexity and thereby the computational effort. The reduction method presented in this paper focuses on the aggregation of grid segments, which are reduced to their dominant properties. Using the mathematical method of symbolic model reduction, the model of a low voltage grid will be analysed. Depending on the load and generation within the grid, the reduced model will reproduce the behaviour of the voltages and currents at the points of connection in comparison to the original detailed model. The reduced model shows a small but controllable deviation resulting from the application of the model reduction techniques.

INTRODUCTION

Distribution grids evolve more and more to a decentralized structure with a high amount of electricity produced by renewable energy systems (RES) and distributed energy resources (DER) [1]. Currently, as a result of fixed feed-in tariffs, most RES and DER operate uncoordinated [2]. With a higher penetration this will lead to instability in the grid. To counter these effects a grid-oriented operation of distributed sources will be necessary to integrate as much renewable generation as possible into the grids [3]. Most of the distributed generation is installed in low voltage grids. For that reason a grid-oriented management of distributed generation, that avoids violations of power quality criteria, must take place in all grid layers.

In [3] a local variable tariff was examined to manage distributed generation in a local low voltage grid. In this vision a variable feed-in tariff is distributed to each local controllable device. For example for the management of cogeneration plants local conditions like temperature ranges must be fulfilled. In contrast to a centralised operator the local plant management knows his local operation conditions best and can decide, if he wants follow the given price curve. With a local variable price curve that is derived from the net load of the local grid it is also possible to control distributed generation in a “soft” manner. It has been shown that this method shifts operation of cogeneration plants and helps to guarantee power quality criteria in grids with a high amount of distributed generation.

If local management and control strategies should be carried out to a whole distribution grid the usage of complexity reduction techniques is necessary to evaluate the effects of the management. Experience has shown that a detailed simulation of the low voltage grid is far too extensive for the operation management of the grid. Thus, model reduction techniques may be employed for reducing the computational effort and thereby yielding a much more efficient calculation of the grid. Based on the detailed model of a typical distribution grid, the paper investigates model reduction technologies to simulate the real operation of so called “smart grids” with a high penetration of DER and RES. The reduction method will focus on aggregation of grid segments, which reduce the grid model to its primary properties. The reduced model can be seen as a variable PQ-node and defines a relation between the power at the point of connection and the installed loads and generators in the subgrid. Using the input parameters (input voltage, installed loads and generators) the simulation can calculate the total power consumption and report, if violations of power quality criteria occur. The investigations are carried out using the method of symbolic model reduction. In the following, the method will be explained and the effect of reduction will be shown on an example of a low voltage grid. The resulting reduced grid model will be compared with the detailed model. The new reduced model can be used for an efficient analysis of the grid behaviour. Typically, for the simulation of a distribution grid, which connects several low voltage grids, low voltage grids are aggregated to one point. Instead of this, the new reduced model can be used to make this simulation much more exact but still efficient.

SYMBOLIC MODEL REDUCTION

The application of optimization and control tasks requires parameterized model descriptions. The setup of such models is therefore one central part of the optimization problem. For large systems such as energy distribution grids, the model formulation itself is quite a laborious step and yields very complex mathematical descriptions, which make an efficient optimization rather difficult. One method that supports analytical model formulations and additionally an automatic and error-controlled complexity reduction is the symbolic modelling approach. The idea of symbolic analysis and model reduction originates from the area of analog circuit design [4]. In the recent years this approach has been successfully applied to other physical domains such as hydraulic systems or mechatronical systems [5]. Within the BMBF-funded project NetMod (http://www.netmod.org), this modeling approach has also been transferred to energy distribution grids [6]. Moreover, a symbolic model library containing the main components of such systems has been implemented.

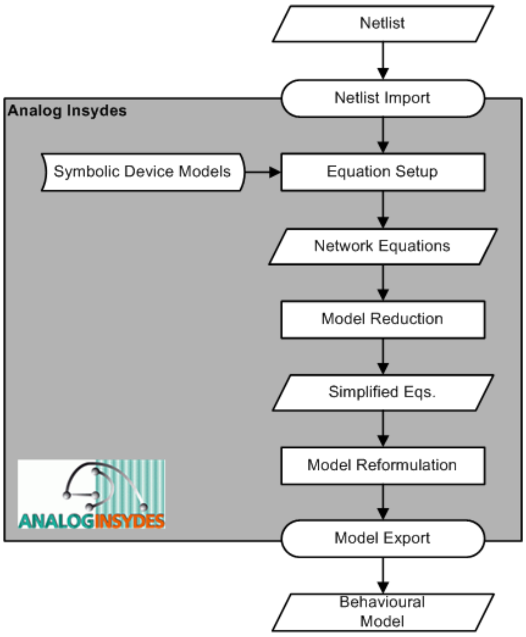

Figure 1: Flow of symbolic model reduction approach.

In Figure 1 the flow of the symbolic model reduction approach is presented. Analog Insydes provides functionality to automatically set up network equations from a netlist description and to use them as a basis for generating a behavioural model. In general, the generated equations form nonlinear DAE systems. In this context symbolic means, that all variables and parameters are available as symbols in the model and are not replaced by numbers. Normally this leads to very big DAE systems.

The symbolic model reduction approach starts with a reference simulation of the detailed model, which is used as benchmark for the reduced models. Model reduction methods can be applied to reduce the complexity of the equations by e.g. term reduction techniques at the benefit of ensuring a user-specified accuracy.

SHOWCASE RURAL GRID

Grid definition

A low voltage grid, a typical rural grid with distributed energy generation (Figure 2), has been chosen as example application of the modelling approach. The system contains 3 photovoltaic units with a peak power of 4 kWp each, a biomass cogeneration plant with a nominal power of 60 kW as well as a wind turbine with a nominal power of 1.2 MW. The low voltage grid provides 4 households with a connection power of 20 kW.

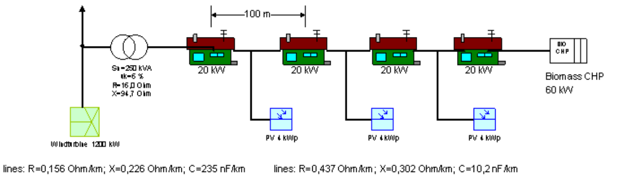

Figure 2: Structure of the simulated low voltage rural grid.

Modelling of the system

The corresponding detailed mathematical model consists of 228 equations. In the model it is assumed, that all loads and generators are three phase symmetric. For the symbolic model reduction at first a symbol matching is done. In the detailed model all parameters can be chosen arbitrarily. For the simulation as a first model reduction the feed-in of all PV-plants is set to:

$$P_{PV1} = P_{PV2} = P_{PV3} = P_{PV}$$

$$Q_{PV1} = Q_{PV2} = Q_{PV3} = Q_{PV}$$

In the same way the load for the 4 households is set to:

$$P_{house1} = P_{house2} = P_{house3} = P_{house4} = P_{house}$$

$$Q_{house1} = Q_{house2} = Q_{house3} = Q_{house4} = Q_{house}$$

For the symbolic model reduction it is necessary to define the input an output variables. The output of the reduced system is the current I_{grid} at the point of connection of the grid segment. This current depends on the voltage at the point of connection V_{grid}, the load P_{house} and the generation within the subgrid P_{CHP}, P_{PV}, P_{wind}. Finally the current

$$I_{grid} = f\left(V_{grid}, P_{house}, P_{CHP}, P_{PV}, P_{wind}\right)$$

can be defined as a function, which is parameterized by the input variables.

As basis for the reduction process the range of validity for the input parameters must be defined. It must be mentioned that all voltages and currents are given in dq-coordinates. The range of validity is defined as:

$$\begin{array}{ll} V_{grid} & \frac{1}{\sqrt{3}}\begin{pmatrix}19\ldots21\\19\ldots21\end{pmatrix}\text{ V} \\ P_{house} & -20\ldots0\text{ kW} \\ P_{CHP} & 0\ldots60\text{ kW} \\ P_{PV} & 0\ldots4\text{ kW} \\ P_{wind} & 0\ldots1.2\text{ MW} \end{array}$$

After application of the symbolic model reduction this system can be automatically reduced to only 5 remaining equations where a model accuracy of 10 mA has been chosen for the grid currents I_{grid} at the point of connection. Moreover, the reduced system still includes the parameter dependencies (generation and loads) of the original system. This model represents now the basis for a much more efficient application of optimization and control tasks due to the largely decreased computational effort.

Results

With the method of symbolic model reduction a reduced model of the introduced rural grid has been derived. For the further evaluation of the model the input parameters are defined to:

$$\begin{array}{ll} V_{grid} & \frac{1}{\sqrt{3}}\begin{pmatrix}20\\20\end{pmatrix}\text{ V} \\ P_{house} & -20\text{ kW} \\ P_{CHP} & 60\text{ kW} \\ P_{PV} & 4\text{ kW} \\ P_{wind} & 1.2\text{ MW} \end{array}$$

With this set of parameters a variation of parameters is done to evaluate the sensitivity of the parameters. For that in each step just one parameter has been varied within the range of validity. Figure 3 shows the results of the detailed and reduced model for varying P_{wind} from 0 to 1.2 MW. The currents (upper diagram: d-values, lower diagram: q-values) at the point of connection are shown in dependency of the varied feed-in of the wind turbine. The diagram shows over the whole range a constant deviation, which mainly is a result of neglecting some line parameters in the reduced model. The biggest deviation can be mentioned in the q-values.

Figure 4 shows the equivalent diagram for varying the power of the cogeneration plant P_{CHP} from 0 to 60 kW. The diagrams show that mainly for small CHP powers the deviation is highest. With a small CHP power, most of the power must be delivered by the medium voltage grid, which will be stronger influenced by the neglected line parameters than a generation within the grid.

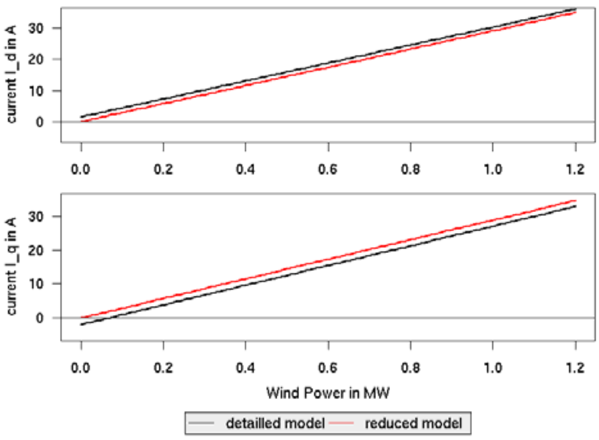

Figure 3: Varying P_{wind} from 0 to 1.2 MW. The resulting currents at the point of connection for the detailed and reduced model are compared.

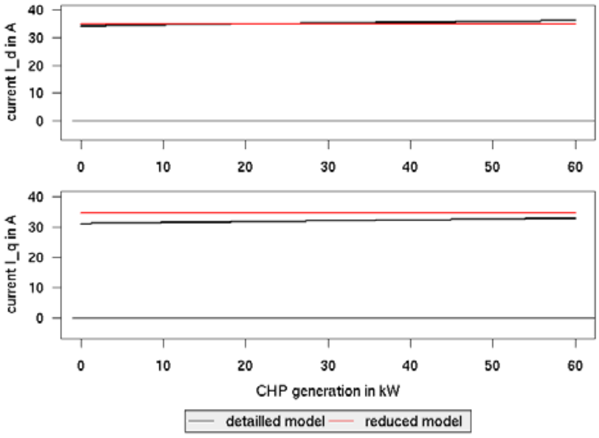

Figure 4: Varying P_{CHP} from 0 to 60 kW. The resulting currents at the point of connection for the detailed and reduced model are compared.

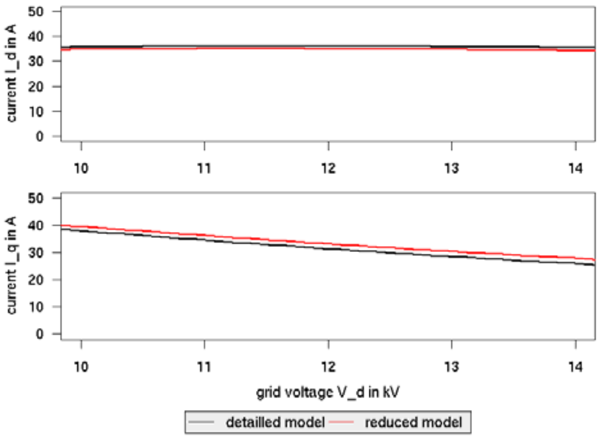

Figure 5: Varying V_{grid} (d-value) from 10 to 14 kV. The resulting currents at the point of connection for the detailed and reduced model are compared.

Finally the grid voltage V_{grid}, which is provided to the subgrid, is varied. Figure 5 shows the resulting currents at the point of connection for a varying the d-value of V_{grid}. Figure 6 shows the same results for varying the q-value of V_{grid}. Both figures show that the reduced model fits the results of the detailed model quiet well.

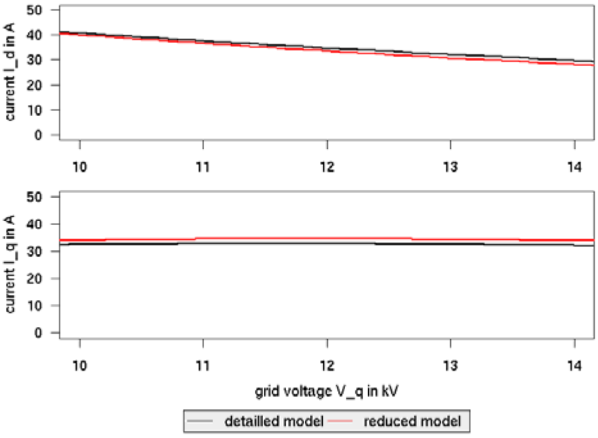

Figure 6: Varying V_{grid} (d-value) from 10 to 14 kV. The resulting currents at the point of connection for the detailed and reduced model are compared.

The reduced model results in a small simulation error. But the model implementations, which were done within this paper, showed a performance gain of about one order of magnitude compared to the detailed model.

CONCLUSION

The reduced model of the low voltage grid shows that the simulation is faster compared with the detailed model. This offers the possibility to use the model for a grid-sensitive operation management of a distribution grid, which connects several low voltage grids. With the reduced model it is possible to make the simulation of the whole distribution grid much more efficient but still accurate enough.

ACKNOWLEDGEMENTS

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