Analysis of Inverter-Controlled Island Grids
- Transient Simulations with ATP-EMTP and *PowerFactory*

Martin Braun, Thomas Degner, Alfred Engler
Institut für Solare Energieversorgungstechnik (ISET) e.V.
Koenigstor 59
D-34119 Kassel
fon: +49 (561) 7294-118
fax: +49 (561) 7294-400
e-mail: mbraun@iset.uni-kassel.de
http://www.iset.uni-kassel.de

Abstract

This conference paper introduces parts of an ATP-EMTP model library, which was developed at ISET. The paper concentrates on two battery inverter models which are implemented in ATP-EMTP as well as in *PowerFactory*. Transient simulations in both tools show the response of the modelled battery inverter to load steps. The results of the simulations in the two tools are compared and verified against laboratory measurements. Finally, two applications give examples of the dynamics in microgrids which comprise parallel-operated droop-controlled inverters.

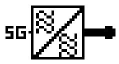
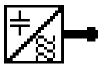
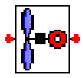
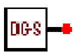
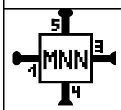
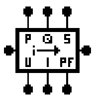
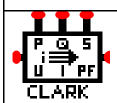
1. Introduction

Distributed Energy Resources (DER) gain importance in today's power systems. Battery inverters with adequate controls offer the fundamental possibility to form low-voltage grids, esp. island- and microgrids, which comprise DER and renewable energy resources. A parallel operation of grid-forming inverters is possible with a frequency and voltage droop control. The fluctuating behaviour of many renewable energies and the specific control characteristics of DER require manifold investigations. ATP-EMTP and *PowerFactory* from DIgSILENT are suitable software tools for such investigations. ISET utilises both tools for studies of island grids comprising DER. However, both tools require the addition of models of DER which are not yet available within the software distributions.

2. ATP-EMTP Model Library

ISET uses successfully ATP-EMTP for the investigation of power systems including DER. For these activities ISET has developed suited models for some DER and as a support of the analyses, suited measuring devices have been compiled. These allow to measure the power flow in the model grid which enhances ATP-EMTP for power flow analyses in addition to the original focus on transients. Table 1 shows some of the developed models and measuring devices which form a model library (cf. [1]).

Table 1: *DER models, grid components and measurement devices*

Models of grid components	
	Speed variable generator set with limiting adaptive droop and secondary control
	Three-phase battery inverter with droop mode
	Wind turbine generator
	Diesel generator set
	Medium voltage network simulator
Measuring devices	
	Measurement device for P,Q,S,Urms,Irms,PF of single-phase lines
	Three-phase measurement device for P, Q and S

2. Verification of the battery inverter model in *PowerFactory* as well as the battery inverter model in ATP-EMTP with laboratory measurements

A three-phase voltage source inverter model is implemented in ATP-EMTP (see [1], [2] and [3]). It is compared to the model of the bi-directional battery inverter Sunny Island 4500 from SMA AG, which is implemented in *PowerFactory* [4]. Both models use the droop mode, which is an advanced grid-forming mode [5]. In droop mode, the inverter varies the grid's frequency depending on its active power supply, and the grid's voltage depending on its reactive power supply. The droop mode allows the parallel connection of several inverters each acting as a grid-forming device. The share of load is automatically distributed between the connected inverters corresponding to the slopes of their droops. The *selfsync*™ [6] control approach is utilised to achieve the parallel operation without the need for communication between the inverter units.

The battery inverter model in *PowerFactory* was originally designed for a detailed representation of the Sunny Island 4500 by particularly modelling the inverter's output filter with its voltage controller and a subordinated current controller [4]. A comparison of the measured data in laboratory with the simulation data verifies the model by an analysis of transients which result from ohmic, inductive and capacitive load steps for balanced and unbalanced load connections. The simulation data generated by a simplified model, which neglects the filter and uses a ten times larger simulation step size, show results which are comparable to the detailed model. However, with this simplified model it is not possible to analyse the inverter's switching transients, harmonics and an extremely capacitive load at the inverter output (cf. also [7]). For standard transient and RMS analyses, the application of the simplified battery inverter model generates similar good simulations. As an advantage, it requires only a tenths of time for simulation as well as a fraction of data storage capacities.

The simulation results with the voltage source inverter model in ATP-EMTP and the simplified battery inverter model in *PowerFactory* are compared to laboratory measurements. Generally, the measured values show variations between each phase, even in balanced situations. This behaviour results for instance from tolerances of real system components and measurement errors. Consequently, there is always a small deviation between the measured and simulated values. Figure 1 shows examplarily the connection of an inductive load at phase A with three different signals: measurement in DeMoTec (one of ISET's laboratory environments), simulation in *PowerFactory* and simulation in ATP-EMTP.

Generally, the comparison between the measured data and the simulated data shows a good congruence of the signals. Three fundamental types of load changes, namely ohmic, inductive and capacitive load changes, verify the model for respective load changes. Moreover, balanced and unbalanced load changes verify the model for load changes that occur asymmetrically distributed over the three phases. The small differences between the simulation results by ATP-EMTP in comparison with the simulation results by *PowerFactory* are related to differences of the models, e.g. a master/slave configuration vs. a three-phase-coupled configuration, as well as differences between the two considered simulation tools.

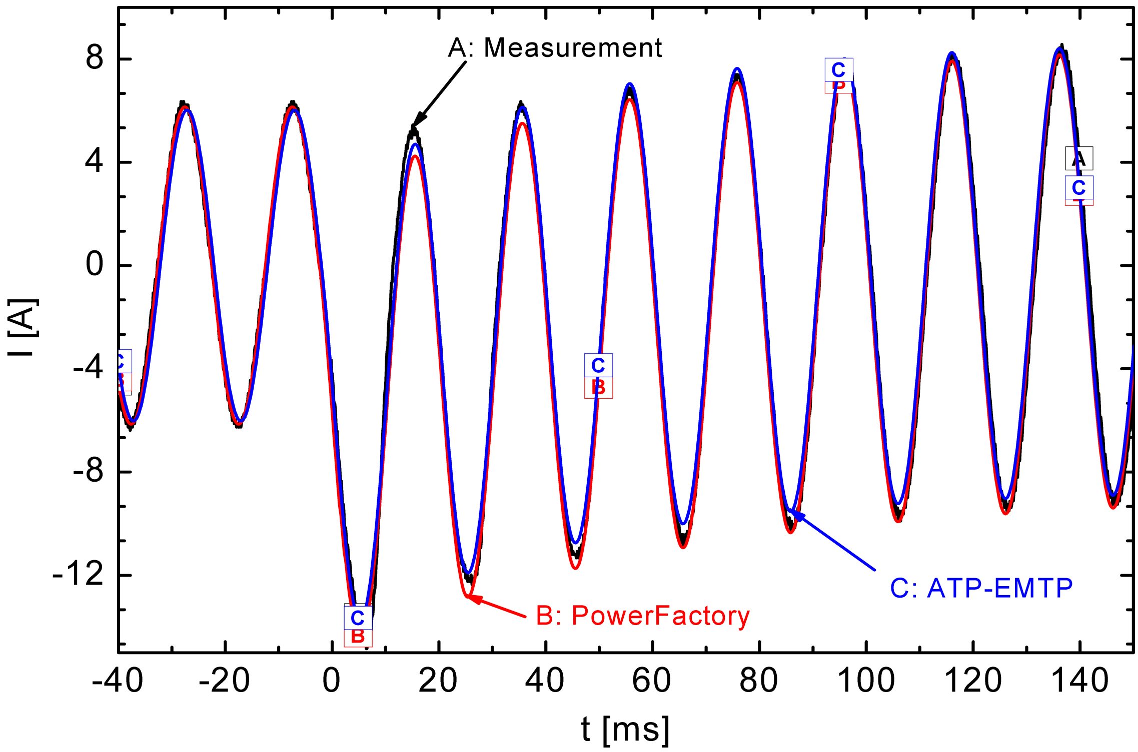


Figure 1: *Transient currents I of the battery inverter supplying a 3 kW ohmic load at the time t < 0 ms. A 1 kVAr inductive load is connected at the time t = 0 ms in parallel at phase A.*

3. Application examples

One application is presented in [7] using *PowerFactory*. This application demonstrates the connection of an asynchronous motor in an island grid controlled by three battery inverters which share the active power supply according to the setting of their droop slopes.

This paper presents another application example, which is performed with ATP-EMTP. A speed variable generator operates over a 10 km medium voltage cable in parallel with a battery inverter. Both generators use the droop mode to allow power sharing between the two components. In addition, the speed variable generator uses a limiting and adaptive droop [8]. Three behaviours are distinguished in Figure 2. Directly after a fast load change (in Figure 2: “Adaptive”), the limiting adaptive droop limits the transient power output of the speed variable generator and allows a smooth load following by adapting the power output. This function avoids overloading and fast fluctuations of the combustion engine which can result in a reduced lifetime. During this transient situation the battery inverter delivers the short-term storage. The secondary control (in Figure 2: “Secondary Control”) increases the power output towards the demand in order to reduce the loading of the battery inverter. Finally (in Figure 2: “Limiting”), the steady-state maximum power output of the genset is limited. This requires the battery inverter to participate in case that the load exceeds the maximum power output of the genset .

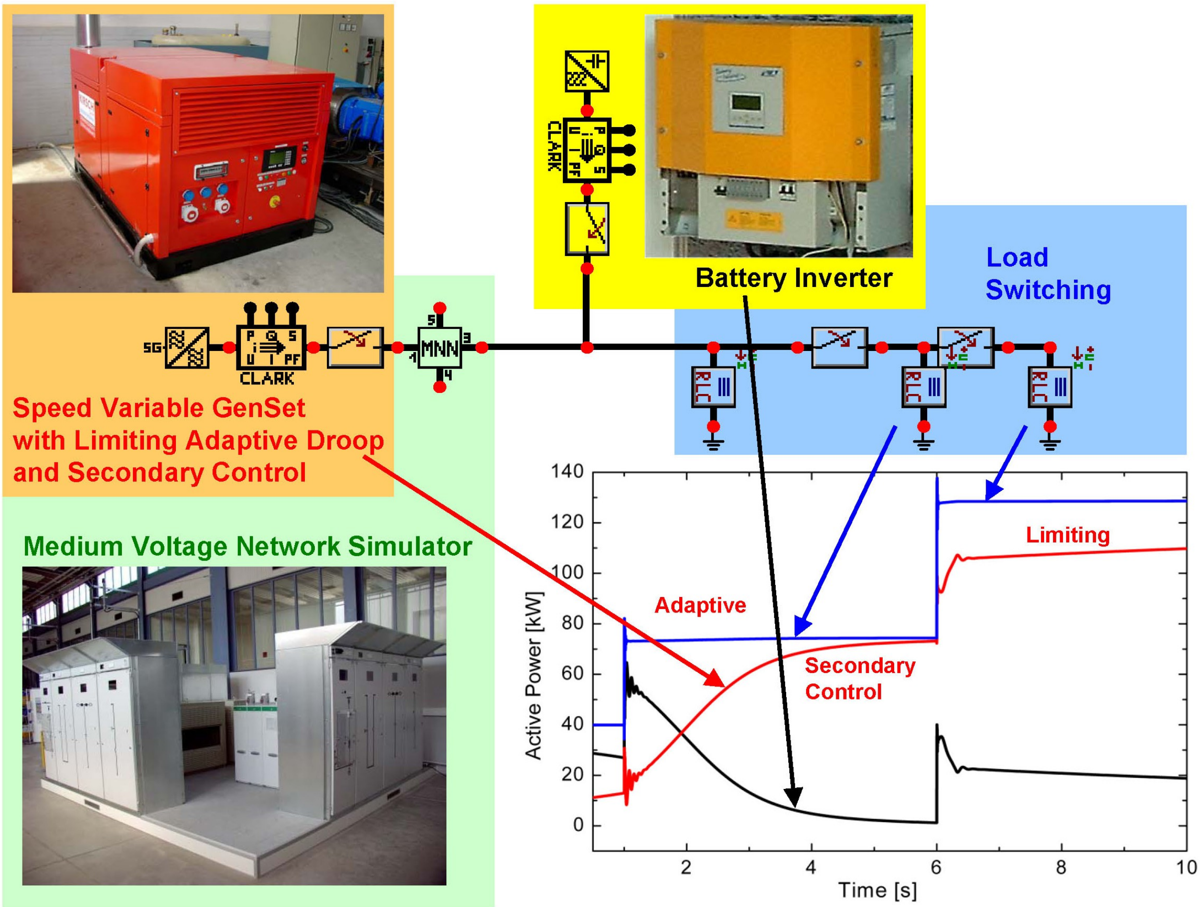


Figure 2: *ATP-EMTP-Simulation of the behaviour of a speed variable synchronous generator set with a limiting adaptive droop and a secondary control which is connected via a medium voltage cable to a battery inverter (which provides the short-term storage) and loads.*

Acknowledgement

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