Simulation of Inverter Dominated Minigrids

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1. Summary

In order to assess the load flow, the transient behaviour and the stability of inverter dominated minigrids, a model for inverters and a transmission system has been developed. The inverters are represented by a frequency and voltage controlled three phase voltage source and the transmission systems consists of switches, overhead lines (π-equivalent), transformers and a load. The inverters operate in parallel via the MV-distribution system and supply an active load. The contribution of each inverter is determined by the setting of the applied droops (similar to conventional power plants). Furthermore an approach for stability assessment of such systems is introduced. This research work is related to the EC-funded project MicroGrids.

2 . Principle of Paralleling Voltage Source Inverters

In [1] a concept has been developed using reactive power/voltage and active power/frequency droops for the power control of the inverters. The droops are similar to those in utility grids. The supervisory control just provides parameter settings for each component. This way expensive control bus systems are replaced by using the grid quantities voltage and frequency for co-ordination of the components. Such approach results in the following features:

- simple expansion of the system
- increased redundancy, as the system does not rely on a vulnerable bus system
- for optimisation a simple bus system is sufficient
- a simplified supervisory control
- more complex control tasks in the components.

Additional redundancy in minigrids can be achieved by using **v**oltage **s**ource **i**nverters (VSI) in parallel. This approach avoids the master/slave operation. In fact all VSIs form the grid. The inverters are coupled via the inductances resulting from cabling and filters for the pulse suppression of the inverters.

A phase shift between two voltage sources causes active power transmission. Reactive power transmission is due to voltage differences U_1-U_2. Assuming standard values for the coupling inductances results in very sensitive systems, where even smallest deviations of the phase and the magnitude cause high currents between the inverters[1].

3. Modelling of Inverters controlled with Droops

The implementation outlined below is based on [2]. The output voltages of the inverters are directly derived from the active and reactive power. The active power is delayed for purposes of decoupling and determines the frequency of the output voltage via the frequency droop. A phase correction is introduced for reasons of stability. The reactive power is delayed for purposes of decoupling and determines the magnitude of the of the output voltage. The control-loop is closed via the process, i. e. the lines and loads. The resulting current is fed back for power computing.

This approach has been modelled with the simulation tool ATP-EMTP. The "Models"-language, which is a feature of ATP-EMTP, enables the direct encoding of such inverters as a kind of macro (s. Fig. 1). These macros can be graphically connected to lines, transformers and loads. This way, the parallel operation of the inverters in distributed systems can be investigated.

The computation of active and reactive power in Fig. 1 is based on the space vector theory and provides instantaneous power values.

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[1] This sensitivity is the reason why fixed frequency and voltage inverter concepts fail. There is always a voltage difference due to tolerances of the sensor, references, temperature drift and ageing (e. g. 1 - 5%) and also crystals are not equal and the angle difference is the integral of the frequency error over time!

```
EXEC
   -------------------------------------------------------------------
   f1:=f-STP                            -- frequency droop / reference
   w1:=2*pi*f1                          -- cycle frequency
   wt:=integral(w1)                     -- reference angle(time function)
   Amp1:=Amp+STQ                        -- voltage droop / reference
   -------------------------------------------------------------------
   A:=Amp1*sin(wt+STPH)                 -- output voltage A
   B:=Amp1*sin(wt+2.09+STPH)            -- output voltage B
   C:=Amp1*sin(wt+4.18+STPH)            -- output voltage C
   -------------------------------------------------------------------
   UB1:=2/3*(sqrt(3)/2*B-sqrt(3)/2*C)   -- Clark transformation
   UA1:=2/3*(A-0.5*B-0.5*C)             -- for voltages and
   IB1:=2/3*(sqrt(3)/2*IB-sqrt(3)/2*IC) -- currents
   IA1:=2/3*(IA-0.5*IB-0.5*IC)          --
   -------------------------------------------------------------------
   P:=3*(UA1*IA1+UB1*IB1)/2             -- calculation of active power
   Q:=3*(UB1*IA1-UA1*IB1)/2             -- calculation of reactive power
   S:=sqrt(P*P+Q*Q)                     -- apparent power (just info)
   -------------------------------------------------------------------
   LAPLACE(PV/P):=(1|s0)/(1|s0+tau|s1)  -- decoupling delay (mechanical)
   LAPLACE(QV/Q):=(1|s0)/(1|s0+tau|s1)  -- decoupling delay (excitation)
   -------------------------------------------------------------------
   STP:=PV*kp                           -- frequency droop
   STQ:=QV*kq                           -- voltage droop
   STPH:=PV*kph                         -- phase correction
   -------------------------------------------------------------------
 ENDEXEC
```

Fig. 1: Executable part of ATP-EMTP models description for the frequency and voltage variable inverter

4. Simulation of power sharing in a distributed island system

In order to assess the transient behaviour and the stability of the above outlined approach, a simulation with three inverters coupled via a distribution system (15 kV) has been carried out. The inverters are represented by frequency and voltage controlled three phase voltage sources and the distribution system consists of switches, overhead lines (π-blocks), transformers and a load (Fig. 2). The three inverters operate in parallel via the MV distribution system and supply the ohmic load with total power 100 kW.

By means of the implemented control functions, the contribution of each inverter is determined by the setting the applied droops. In the case of Fig. 3 the contribution of the inverters are set to 20, 30 and 50 kW by the slope of the frequency droop of each inverter. The slope of the frequency droop can be used for e. g. taking the size of the inverter into account. The setting of the idle frequency f_0 can be used for the

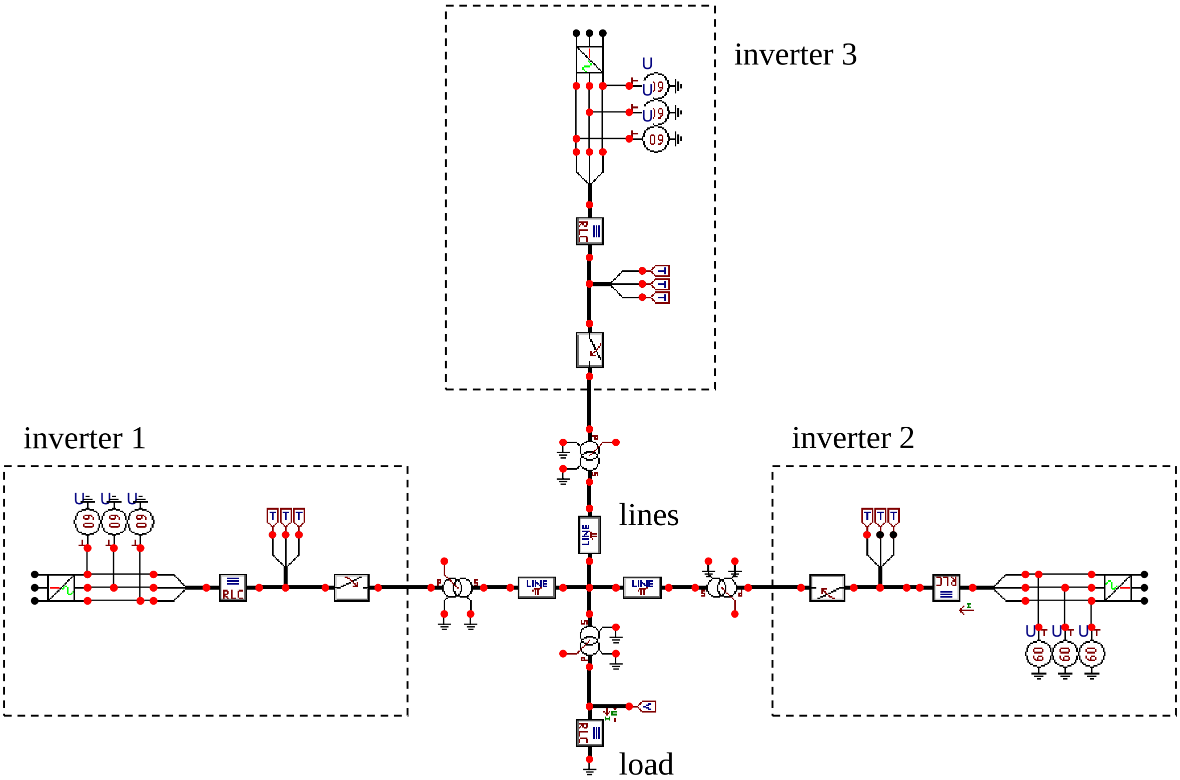

Fig. 2: Simulation of inverter dominated distribution system (ATP-EMTP)

control of the energy flow. The setting of the slope of the voltage droop results in a variable virtual inductance between the respective inverter and distribution systems. It should be chosen in order to ensure a stable operation. The idle voltage should be set for minimising reactive power. But certain voltage limits have to be guaranteed.

The idle frequencies of the three inverters are set to 50 Hz. Due to the loading the systems frequency decreases to 49 Hz (s. Fig. 4). The frequencies of all inverters oscillate around a common mean frequency. A supervisory control – which is normally not part of the inverter's controller – could restore the frequency to 50 Hz by changing the idle frequencies of the inverters.

5. Stability assessment

Ensuring stability of distributed multi-inverter systems in microgrids and determining a set of parameters for the inverters, which enables a wide range application, requires a methodology for stability assessment. One approach is to consider

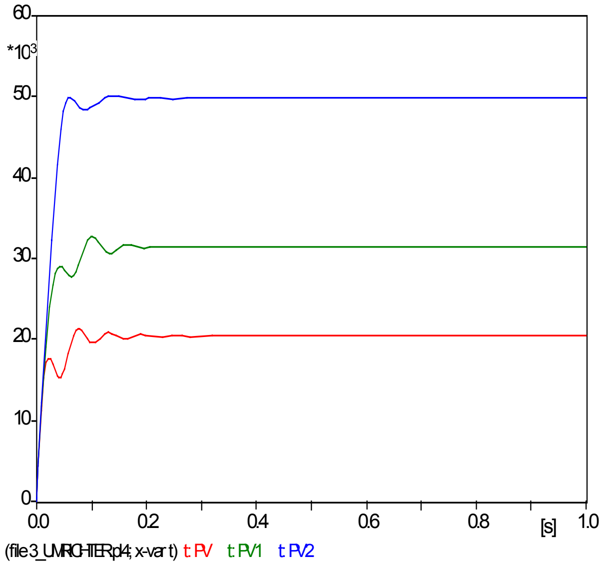

Fig. 3: Load shared between the three inverters (100 kW)

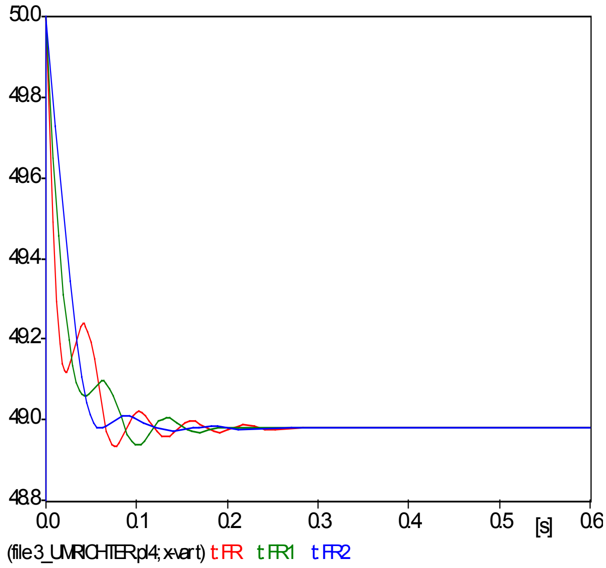

Fig. 4: Frequency change in island system due to load step (100 kW)

active and reactive power control to be decoupled. Furthermore the process of active and reactive power control has to be modelled in way, which is suitable for linearisation and which allows the coupling of several units (inverters). Fig. 5 depicts the modelling of the active power control of two coupled inverters using MATLAB/Simulink. The inverters are coupled by the overall system's mean frequency, which enables an easy expansion of the simulation with regard to the numbers of inverters. Furthermore MATLAB is capable of linearising such systems and of determining its stability by means of pole-zero-placement.

Stability has to be assessed with regard to the parameter settings of the inverter but also has to take the distribution system into account. First operational experience reveals that it is possible to find settings for wide range application concerning the numbers of inverters as well as different kinds (e. g. length) of wiring.

6. Acknowledgement

We would like to express our thanks to the European Commission for their support in the MicroGrids Project ENK5-CT-2002-00610.

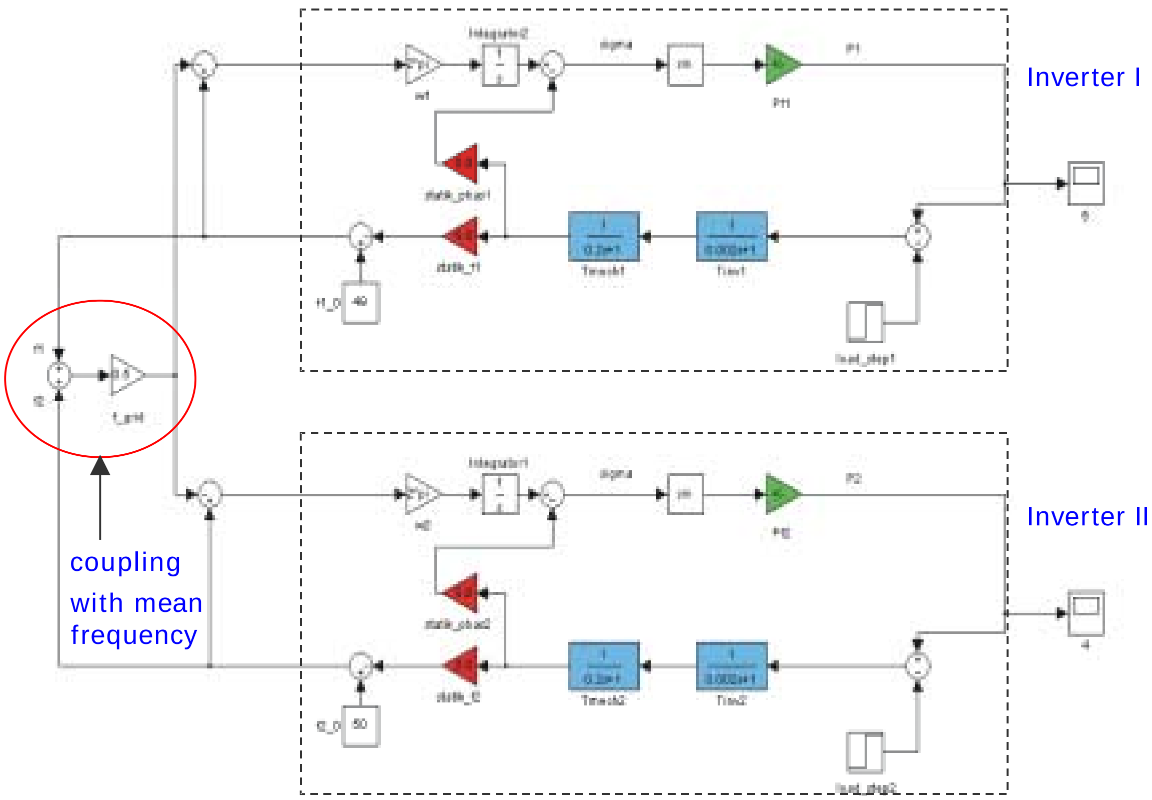

Fig. 5 : Stability assessment based on the system's mean frequency

7. References

[1] Engler, A.:
Regelung von Batteriestromrichtern in modularen und erweiterbaren Inselnetzen.
Verlag Dissertation.de, Berlin, 05/2002, ISBN 3-89825-439-9

[2] Engler, A.:
Vorrichtung zum gleichberechtigten Parallelbetrieb von ein- oder dreiphasigen Spannungsquellen
German patent (pending) No.: 101 40 783.1
also:
Device for equal-rated parallel operation of single- or three-phase voltage sources
European patent (pending) No.: 02 018 526.26
US patent (pending) No.: 10/222,310
Japanese patent (pending) No.: 2002-240991