PARALLEL OPERATION OF VIRTUAL SYNCHRONOUS MACHINES

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Integration of renewable energy sources and more efficient utilisation of primary energy sources due to local generation result in a large number of decentralised generators in the LV-Grid. Most microturbines, wind plants, fuel cells and photovoltaic cells generate electrical power as direct current (DC) and converted to an alternating current (AC) by means of inverters. Inverters influence the frequency and the voltage of the grid, consequently, the stability and operation of the grid depends on their behaviour. In order to solve this problem in a conventional and robust way has been developed the concept of a Virtual Synchronous Machine (VISMA). The main idea is to construct the inverter, which is able to work similar as an electromechanical synchronous machine. More detailed description of the VISMA-concept with a basic machine mode and an equation set (seventh order synchronous machine d-q flux model) can be found in [1]. This type of model delivers necessary means to support the grid with dynamic properties of the synchronous machine. The next task is to ensure stable and expandable operation of the electrical grid with inverters. Therefore, the control of active and reactive power is needed. It can be realised through active power/frequency and reactive power/voltage droops (primary control functions), similar to those in utility grids (Fig.1). The differential flux- and electromechanical equations of the VISMA with frequency and voltage droops are:

$$\frac{d\Psi_d}{dt} = U_d - R_d \cdot i_d + \omega \cdot \Psi_q$$

$$\frac{d\Psi_q}{dt} = U_q - R_q \cdot i_q + \omega \cdot \Psi_d$$

$$\frac{d\Psi_Q}{dt} = -R_Q \cdot i_Q$$

$$\frac{d\Psi_D}{dt} = -R_D \cdot i_D$$

$$\frac{d\Psi_e}{dt} = (k_u \cdot (U_0 - \sqrt{U_d^2 + U_q^2}) + U_e) - R_e \cdot i_e$$

$$\frac{d\omega}{dt} = \frac{1}{J} \cdot (m_{el} - k_f \cdot (\omega_0 - \omega))$$

$$\frac{d\vartheta}{dt} = \omega$$

Due to this concept, it is possible to operate in a grid-tied mode (interconnected to low voltage public grid) or to stay in a stand-alone (island) mode, with seamless transfer from the one mode to the other. However, the ensuring of stability must be taken into account. In case of transients, oscillations may occur, which must be damped in order to guarantee operational conditions in the network.

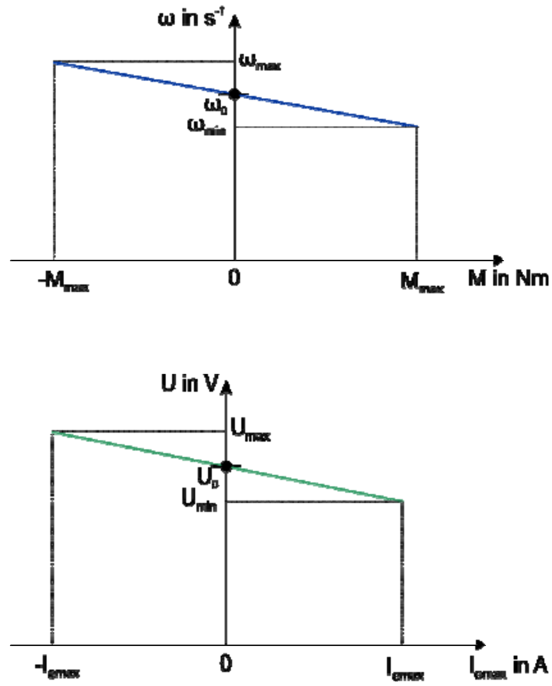


Fig. 1: VISMA control droops: a) frequency droop; b) voltage droop

Fig. 2 presents an example of two parallel connected VISMAs with a resistive load (20 kW). The VISMAs have constant excitation and are controlled with frequency droops (Fig.1 a).
The frequency droops are not equal, the ratio is ¼. They are operated in no-load condition. The load will be connected after two seconds in order to cause a disturbance and will be distributed between VISMAs due to their frequency droops.

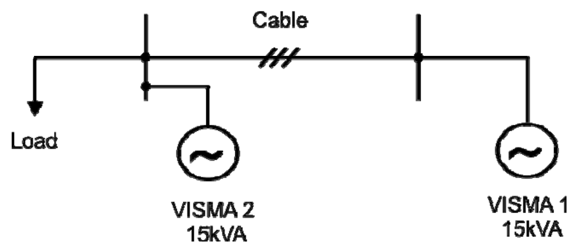


Fig. 2: Parallel operation of the VISMAs with a load

The virtual masses of VISMAs play an important role in transient time (Fig. 3 und 4). It is very important to match a frequency droop coefficient (K_f) with the virtual mass inertia (J), in order to avoid undesired oscillations during the transients. It can be achieved if the imbalance of the active power in the grid during the transients is reduced. In ideal case the setting active power via frequency droop must be equal to the power in the rotating mass (virtual mass). That means:

$$k_{f1} \cdot J_1 = k_{f2} \cdot J_2 = const \ ,$$

there J_1 und J_2 the virtual mass inertia of the VISMAs.

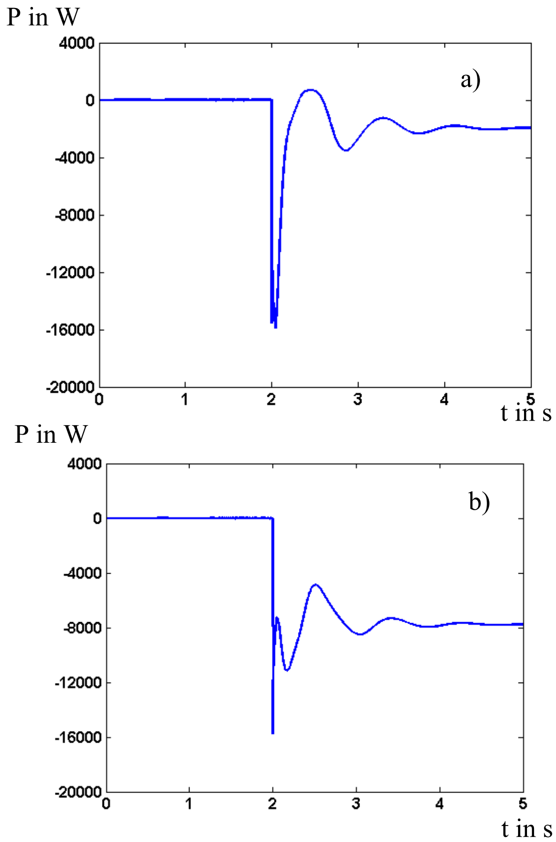
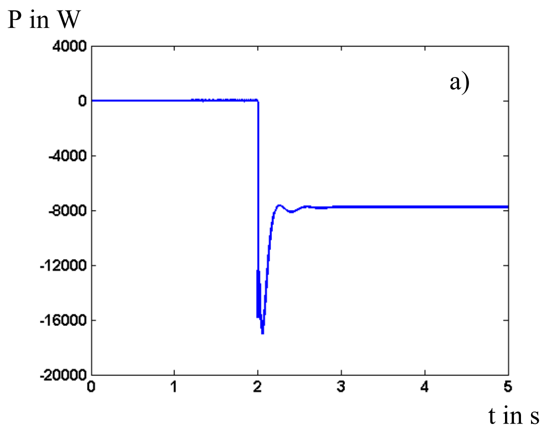


Fig 3: Output active power of the VISMA after load step 20 kW with inept K_f und J: a) VISMA 1; b) VISMA 2



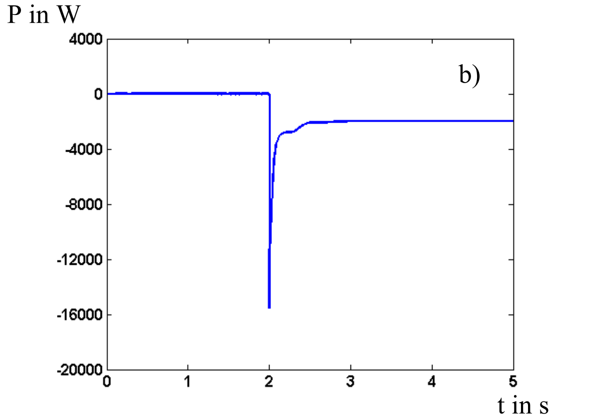


Fig 4: Output active power of the VISMA 1 after load step 20 kW with matching K_f und J: a) VISMA 1; b) VISMA 2

So, the combination of virtual masses and frequency droops allows to keep frequency stability and to set output active power of inverters. In order to prevent possible oscillations is important to use combination of both components. The grid frequency drops without virtual mass very fast and deep due to the time delay in the control loop of inverter (Fig.5 a). Vice versa, without frequency droop, the grid frequency drops, using the “inertia reserve” to support frequency. It helps only for the relative small time, therefore frequency droop is used to stabilise the grid frequency (Fig.5 b).

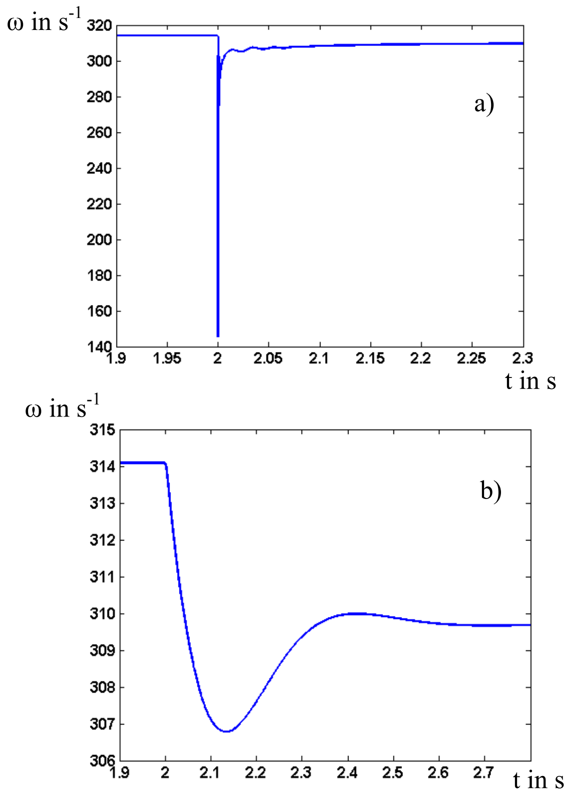


Fig. 5: Output frequency of the VISMA 1 with frequency droop after load step: a) without virtual mass; b) with virtual mass

The difference between nominal (idle) value and set value of the grid frequency can be eliminated theoretically through overlapping an integral control, like a secondary control in utility grids.

Without any kind of the voltage control the output voltage sags deeply, that is ineligible for the grid (Fig.6 a). The voltage control can be realised via P-controller (voltage droop). The output voltage can be controlled through an excitation current (Fig.1 b). Therefore, the voltage drop after load is going to be smaller (Fig.6 b). The use of the PI-voltage controller get the possibility to restore the voltage in the generation node, but the reactive power balance in the grid must be taken into account. The reactive power imbalance can lead to the voltage collapse in the grid, therefore the availability of reactive power must be checked.

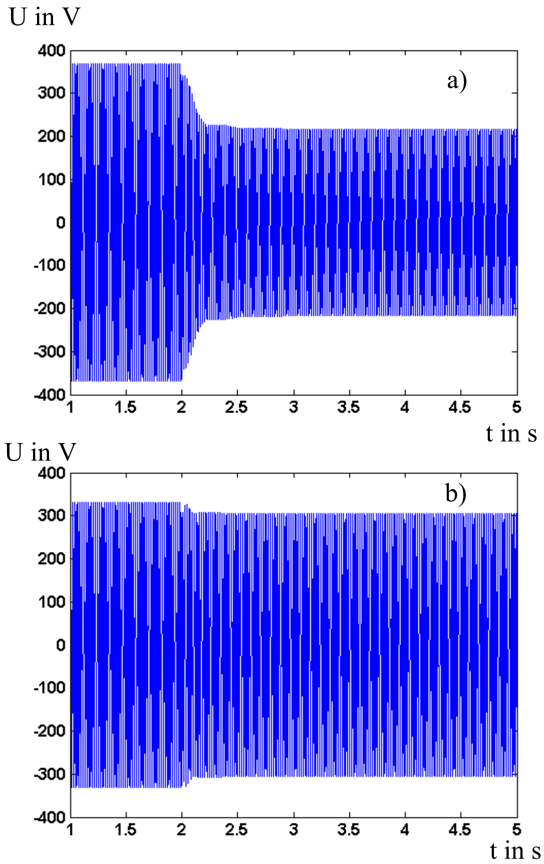


Fig 6: Output voltage of the VISMA 1 after load step 20 kW: a) with constant excitation; b) with P-controller (voltage droop)

The next problem is a combination of inverters different power classes. In this case the synchronous machine models of different power classes are needed. The combinations of the frequency droops (ratio) of the parallel connected VISMAs must be verified in order to ensure operation and stability of the grid. The maximal ratio between frequency droops goes to be 1/10 in order to guarantee an operation with power classes 1/10 with primary control capabilities.

The smaller sources can be connected in parallel without frequency droops (without participation in primary control). VISMA-models with appropriate damping ensure a stable operation with very different frequency droop settings. More important are outputs currents to parameterise the inverters. The smallest inverter tries to deliver more current in the first moment of time in spite of the frequency droop (Fig.7 a). Therefore, via dimensioning of inverter this must be taken into account, in order to prevent overheating of the power electronic components.

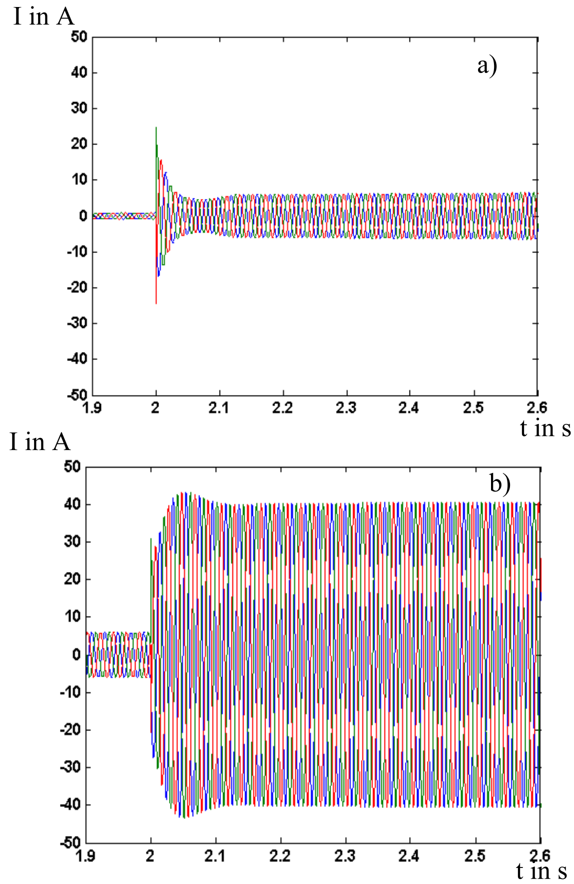


Fig 7: Output currents of the VISMAs after load step 20 kW: a) VISMA 1 with K_f=1 (15 kVA); b) VISMA 2 with K_f=10 (60 kVA)

Conclusions:

The research study shows that inverter-dominated islanded grid with VISMAs has to cope with load steps in the range of the installed power. Due to the properties of the virtual synchronous machine and applied droops, all inverters are well synchronized and provide voltage and frequency control. A stable parallel operation of inverters with VISMA-concept in the wide range of the output power can be ensured.

REFERENCES

[1] Osika, O: Erprobung von Betriebsmitteln: Stabiler Netzbetrieb von Micro-Grids am Beispiel des Energieparks Clausthal. FEN, Dezentrale Energiesysteme, Tagungsband, Braunschweig, Germany, 2008

[2] Hesse, R.; Turschner, D.; Beck, H.-P.: Micro grid stabilization using the Virtual Synchronous Maschine (VISMA). International Conference on Renewable Energies and Power Quality, Barcelona, 15th to 17th April 2009

[3] Osika, O.; Beck, H.-P.: Dämpfende Eigenschaften der virtuellen Synchronmaschine- Verbesserung der Netzstabilität. Energiewirtschaft eW 12/2010, S. 42-45