European Association for the
Development of Renewable Energies, Environment
and Power Quality (EA4EPQ)

International Conference on Renewable Energies and Power Quality
(ICREPQ'12)
Santiago de Compostela (Spain), 28th to 30th March, 2012

Comparison of methods for implementing virtual synchronous machine on inverters

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Abstract

Virtual Synchronous Machine also called VISMA [1] is a control algorithm to make an inverter operated as a conventional electromechanical synchronous machine. It is a promising solution to overcome the problems of the grid stability and quality, which have been exacerbated by increasing integration of distributed generation units into the grid. Compared to the conventional power plants, in which the synchronous machine dominate, the distributed generation units have either significantly smaller or no rotating mass and damping effect. These weaknesses can be compensated by using the VISMA concept and thus the power system quality will be improved. Furthermore, the penetration level of the DG sources won't be restricted any more.

Up to now the VISMA was implemented by using a voltage-to-current model on a hysteresis controlled inverter [1][2][3]. This method will be called VISMA-Method 1 here. Since the most products of inverters in the market are PWM controlled, the VISMA-Method 1 cannot be easily applied on these inverters. Therefore, a new method is developed to implement the VISMA by using a current-to-voltage model on the currently widely applied PWM controlled inverter. This new method is called VISMA-Method 2 in this paper and will be compared with the VISMA-Method 1 by simulation results.

Key words

Virtual Synchronous Machine (VISMA), inverter, hysteresis controller, pulse-width modulation (PWM), distributed generation (DG), stand-alone grid, virtual rotating mass, virtual damping

1. Introduction

The diffusing utilization of the renewable energy resources is driven by the limited fossil energy store on the one hand and the exacerbated environmental issues as well as energy politics on the other hand.

The diversity of the renewable energies and its strong dependence on the geological location and meteorological situation make the change that the electricity will be generated more and more by small distributed generation (DG) units. Most of these DG technologies only consider supplying maximum power into the grid but taken the stability of the power system not into account. Generally, a few small-size DG units will not influence the safe operation of the power network in the presence of large centralized power stations thus their influences can be neglected. But with a larger numbers of DG units with higher capacities, the overall dynamics of power systems are significantly affected [4]. Therefore the solutions to improve the power system stability and at the same time ensure the increasing integration of the DG units are necessary.

The concept of virtual synchronous machine describes a new type of grid feeding inverter, which operates with a storage system entirely as an electromechanical synchronous machine. The basic idea of the VISMA bases on reproducing the static and dynamic properties of a real synchronous machine on a power electronic interface between a DG unit and the grid, in order to inherit the advantages of a synchronous machine in consideration of power system stability such as adjustable active and reactive power, dependence of the grid frequency on the rotor speed and the effect of the rotating mass and damping windings as well as stable operation with a high parallelism level. Fig. 1 illustrates the basic idea of the VISMA.

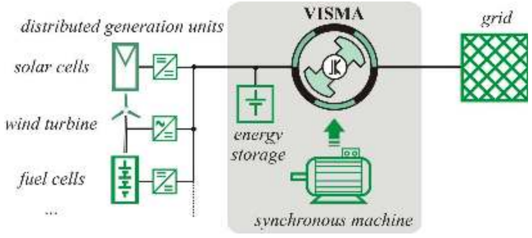

Fig. 1. Basic idea of the VISMA.

This paper presents firstly two methods for impelmenting the VISMA on an inverter. Then the static and dynamic properties of both methods are compared by the simulation results in a parallel operation with the stiff grid. Futhermore it is also disscussed that whether both VISMA-Methods are able to be operated in a stand-alone grid. Finally the relavant conclusions are drawed at the end of this paper.

2. Implementation Methods of the VISMA

In this section two methods to implement the VISMA on an inverter will be discussed here. They will be called VISMA-Method 1 and 2 in this paper. The VISMA-Method 1 was already presented in [1][2][3] and will be applied as a reference here for the comparison with the VISMA-Method 2.

A. VISMA-Method 1: using voltage-to-current model

The complete VISMA functional chain is shown in Fig. 2. It starts with the real-time measurement of the grid voltage to feed the virtual synchronous machine algorithm on the process computer and delivers the stator currents of the virtual synchronous machine as the results which presented as process variables. The fast hysteresis controlled inverter carries over the current signals to drive these currents at the grid immediately**.**

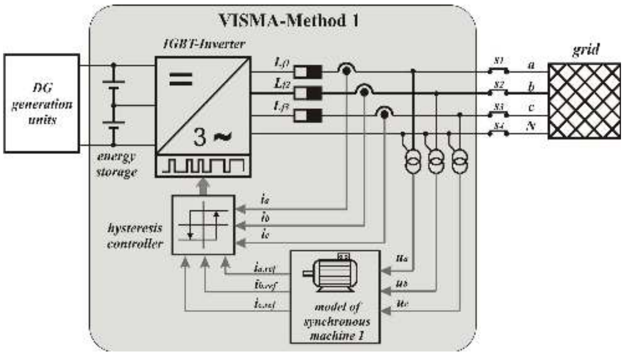

Fig. 2. Concept of the VISMA-Method 1.

The synchronous machine model used in this method is shown in Fig. 3 and was introduced in [5].

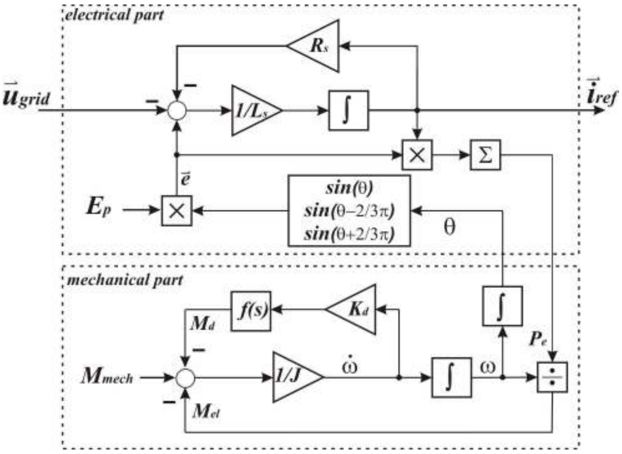

Fig. 3. Block diagram of the VISMA-Model 1.

B. VISMA-Method 2: using current-to-voltage model

Compared with the VISMA-Method 1, the currents will be measured in the VISMA-Method 2 and the reference voltage will be calculated in the VISMA-Model 2, and then sent to a pulse-width modulator, which generates switch signals for the inverter. The inductors L_f und capacitors C_f are used to filter the harmonics of the output voltage of the inverter. Fig. 4 demonstrates the basic concept of the VISMA-Method 2.

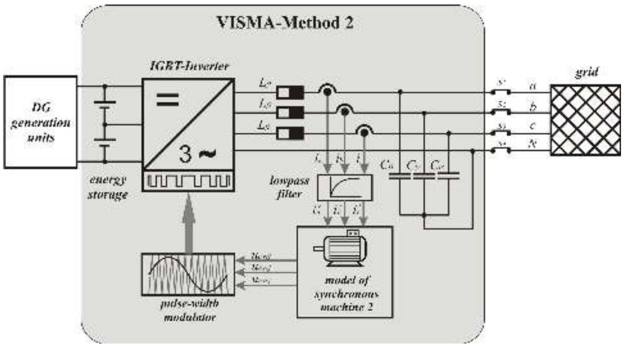

Fig. 4. Concept of the VISMA-Method 2.

The synchronous machine model used in VISMA-Method 2 is a current-to-voltage model as shown in Fig. 5. This is an inverse model of VISMA-Model 1, namely the current as input and voltage as output. After the model inversion a differentiator occurs, which could lead to instability of the model. Hence a low-pass filter should be applied to reduce the disturbance of the model input (current i_{grid}) and enable a stable computing process of VISMA-Model 2.

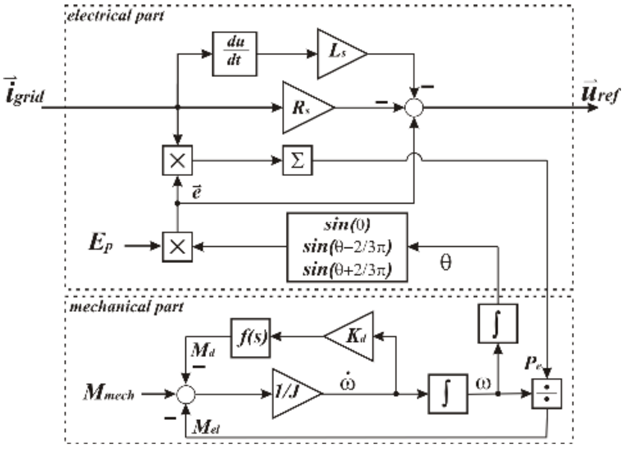

Fig. 5. Block diagram of the VISMA-Model 2.

3. Simulation Parameters

The simulations presented in this paper were carried out in Matlab-Simulink. The important parameter setups during the simulations are shown in table I.

Table I. – Simulation parameters

Voltage of DC site	±350V
Nominal frequency	50Hz
Nominal phase voltage (rms)	230V
Inductor L_f	4mH
Capacitor C	5μF
Tolerance band of hysteresis controller for phase currents	±1A
Switching frequency of the IGBT inverter	2,8kHz ~ 15kHz for VISMA-Method 1 15kHz for VISMA-Method 2 using PWM controller
Time step for simulation	1μs

4. Parallel Operation with Stiff Grid

In this section the two VISMA-Methods are discussed under the parallel operation with a stiff grid. The static and dynamic properties of the VISMA-Method 2 are compared with the reference VISMA-Method 1 by simulation results.

A. Synchronisation of the VISMA with the grid

The VISMA must be synchronized with the grid firstly before connecting to the grid, since an adverse switching could lead to large transient currents between the VISMA and the grid, which could damage the equipments. Due to the different control concepts, both VISMA-Methods will be synchronized with the grid in different ways.

Since the currents in the VISMA-Method 1 are controlled directly by using a hysteresis controller, the transient currents can be regulated nearly to zero by setting the reference currents closely to zero. After that, the VISMA can be connected to the grid, because the hysteresis controller and IGBT-module track the reference currents very fast.

Compared to the VISMA-Method 1 the synchronizing of the VISMA-Method 2 is more complicated, since the currents between VISMA and grid cannot be directly controlled but only indirectly through the voltage controller. In this case the VISMA behaves as a voltage source. Therefore the VISMA can be synchronized with the grid in the same way as a real synchronous generator. Thereby the following parameters should be adjusted according to the grid voltage at PCC: amplitude, phase and frequency. The voltage difference between VISMA and grid should be so small that transient currents values are acceptable.

B. Power setting of the VISMA

The power of the VISMA can be set similarly as a real synchronous machine. The following shows separately the active and reactive power setting of both VISMA-Methods with discussions.

1). Active power setting of the VISMA

The active power of the VISMA can be easily set by adjusting the model parameter M_{mech}, which is called *virtual torque*. Fig.6 shows the active power setting of the VISMA for both methods.

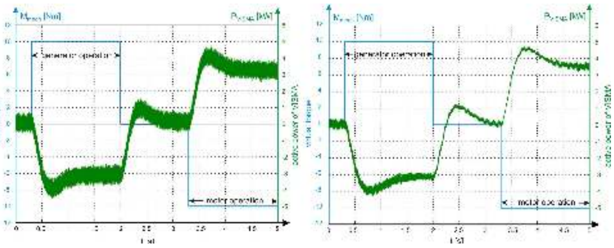

Fig. 6. Active power setting of the VISMA (left: VISMA-Method 1; right: VISMA-Method 2).

The simulation results prove that the VISMA-Method 2 is able to behave the same dynamic property as the VISMA-Method 1. A positive torque means the VISMA supplies an active power into the grid and operates as a generator. For a negative torque the active power will be taken from the grid and then the VISMA operates as a motor. The only difference between both VISMA methods consists in the noise component of the P_{vsima}. In VISMA-Method 1, because of the hysteresis controller, which works at a fixed tolerance band, the switching frequency of the inverter is not constant but varying within a frequency band. Therefore there are harmonics with different frequency terms in the output currents. However, in Method 2, by using PWM-controller a constant switching frequency can be reached thus the output of the inverter will be more easily and better filtered by selecting a proper filter.

2). Reactive Power setting of the VISMA

The reactive power of the VISMA can be regulated by setting the virtual excitation E_p in the same way just as a real synchronous machine in a power plant. This will be demonstrated in Fig. 7 through the simulation results.

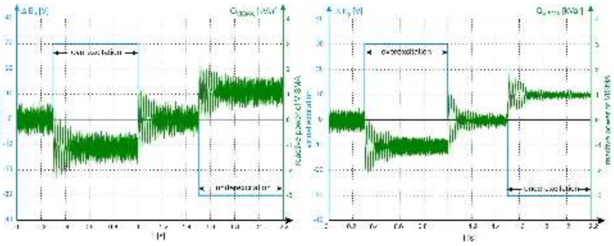

Fig. 7. Reactive power setting of the VISMA (left: VISMA-Method 1; right: VISMA-Method 2).

Both VISMA-Methods supply a capacitive reactive power while over excited and an inductive reactive power while under excited. The VISMA-Method 2 has the same dynamic property as the VISMA-Method 1 but the output signal has a lower noise because of the PWM-controller compared to VISMA-Method 1.

The power of the VISMA can be regulated dynamically during the changes of the grid frequency and voltage, in case that the frequency and voltage controls are added to the VISMA [6].

C. *Reaction of the VISMA to a grid frequency drop*

In this section the dynamic properties of both VISMA-Methods, the *virtual rotating mass* and *virtual damping*, are compared by simulations results.

1). Different virtual rotating mass

Fig.8 recorded the simulation results which demonstrated how both VISMA-Methods respond to a grid frequency drop from 50Hz to 49.5Hz with different virtual rotating mass.

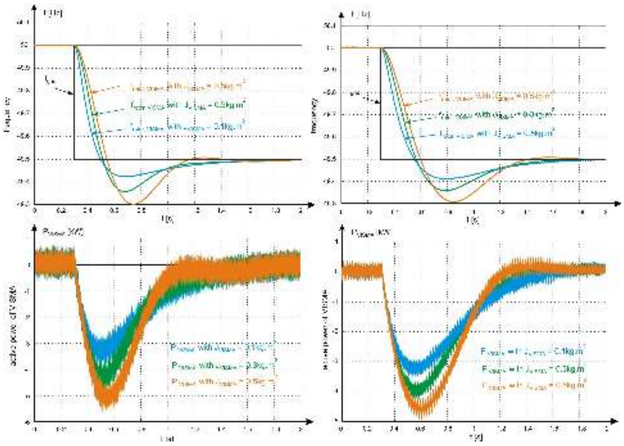

Fig. 8. Reaction of the VISMA to a frequency drop with different virtual mass J_{VISMA} (left: VISMA-Method 1; right: VISMA-Method 2).

It can be clearly seen that both VISMAs provide an active power into the grid immediately as the grid frequency drops. Comparing the power reactions with J_{VISMA} = $0.1kgm^2$, $0.3kgm^2$, and $0.5kgm^2$, it can also be observed in both VISMA methods that the VISMA with a larger virtual mass will provide more active power into the grid and therefore the grid will be more supported.

2). Different virtual damping

The virtual damping of the VISMA can reduce the oscillations in the grid. To prove this effect in VISMA-Method 2, the simulations with two different damping factors k_d were carried out and the results are compared with the VISMA-Method 1. It is demonstrated that the virtual damping can also be realized in the VISMA-Method 2 as Method 1, which is observed in Fig. 9 that a larger damping factor has a stronger effect on reducing frequency and power oscillation of both VISMAs.

D. *Reaction of the VISMA to a voltage drop*

The VISMA can support the grid during a voltage drop by supplying a capacitive reactive power. This dynamic property can be achieved in both VISMA methods as shown Fig. 10.

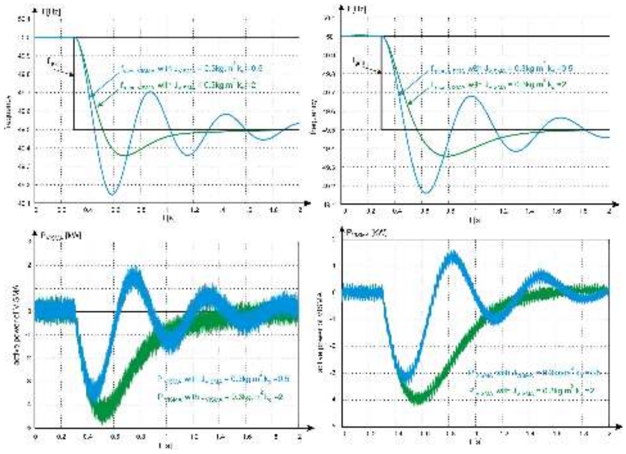

Fig. 9. Reaction of the VISMA to a frequency drop with different virtual damping k_d (left: VISMA-Method 1; right: VISMA-Method 2).

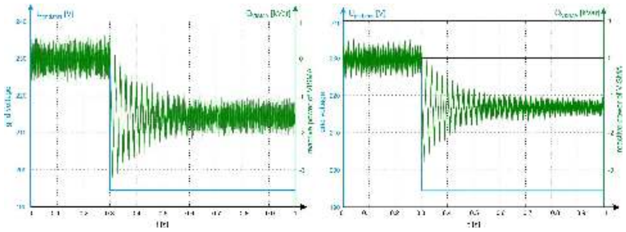

Fig. 10. Reaction of the VISMA to a voltage drop (left: VISMA-Method 1; right: VISMA-Method 2).

5. Failure of Stiff Grid – Island Mode

In the following section the island mode of both VISMA-Methods will be investigated by simulation. At the beginning both VISMAs are connected with the grid. After 0.2s the VISMAs will be switched off from the grid and they should build a local stand-alone grid. In all simulations the VISMA didn't have frequency and voltage control mechanisms.

A. *Island mode of the VISMA-Method 1*

For the parallel operation with the stiff grid, the capacitors which are shown in green color in Fig. 11 are not necessary in the VISMA-Method 1, because it presents itself as a current source. If there is no stiff grid in this configuration, then the VISMA cannot operate as a synchronous machine, since no currents flow in the inductors and the hysteresis controller cannot work properly. Therefore, extra capacitors must be installed in the VISMA for the island function, see Fig. 11.

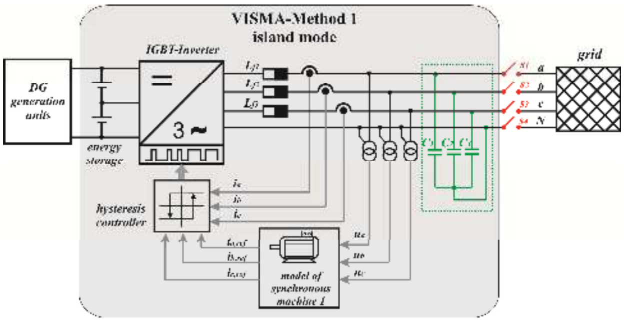

Fig. 11. Enable the island function of the VISMA-Method 1 by extending the capacitors.

Fig. 12 shows the simulation results under the condition that the VISMA changed from grid connected mode to island mode in cases of without and with a load.

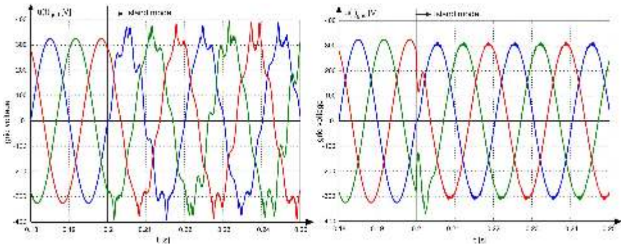

Fig. 12. Output voltage of the VISMA-Method 1 by changing to island mode (filter capacitors $C = 5\mu F$, left: VISMA without load; right: VISMA with a load).

It is obviously to see that the VISMA has built the voltage continuously after switching off the public grid. Without a load the voltages have a large distortion, because the switching frequency of the hysteresis controller is varying and the *LC*-filter could not filter out all frequency parts; whereas the VISMA under island mode with a resistive load, the harmonics could be damped almost completely and rapidly. Another way to reduce the harmonics is to choose larger capacitors and make sure that the corner frequency of the LC-filter is under the minimal switching frequency of the hysteresis controller.

B. Island mode of the VISMA-Method 2

For VISMA-Method 2 a modification of the hardware configuration is not necessary. The VISMA operates here as a voltage source. Under the same simulation conditions the VISMA-Method 2 provided following results illustrated in Fig.13.

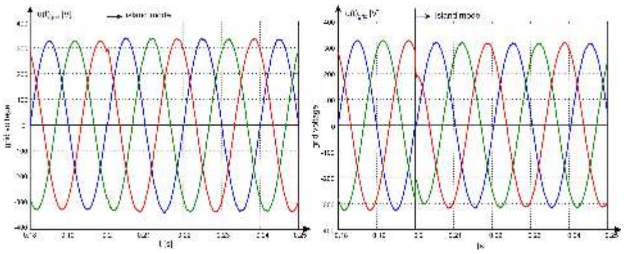

Fig. 13. Output voltage of the VISMA-Method 2 by changing to island mode (filter capacitors $C = 5\mu F$, left: VISMA without load; right: VISMA with a load).

Firstly, the VISMA-Method 2 could build the three phase voltages immediately after switching off the public grid. Secondly, the voltages of the VISMA have almost no harmonics compared to the VISMA-Method 1 because of the constant switching frequency of the PWM controller and the proper output filter. In the case of VISMA with a load into island mode, the voltages dropped in short period and then rose quickly to a stabile value. Because of the virtual inertial of the VISMA the voltages cannot collapse suddenly. In order to keep a stable long-term voltage under island mode, the voltage and frequency controller must be applied.

6. Comparison of both VISMA-Methods

In table II a comparison of both VISMA-Methods is presented by considering the important properties of the VISMA system.

Table II. – Comparison of VISMA-Methods

	VISMA-Method 1	**VISMA-Method 2**
VISMA-Model	voltage-to-current model	current-to-voltage model
Control mechanism	Hysteresis controller	PWM controller
Control variable	Phase currents	Phase voltages
Measurement variable	Phase voltages am PCC	Phase currents in output inductors
Switching frequency (assumed: max. f_s=15kHz for IGBT)	2,8kHz ~ 15kHz in simulation (depends on the setting of hysteresis controller)	15kHz in simulation (depends on the setting of PWM controller)
Synchronizing with the grid	VISMA currents almost equal to zero	The same as the real synchronous generator
Parameter for power setting	Virtual excitation E_p Virtual torque M_{mech}	Virtual excitation E_p Virtual torque M_{mech}
Dynamic properties	Virtual rotating mass (virtual inertial J_{VISMA}) Virtual damping k_d	Virtual rotating mass (virtual inertial J_{VISMA}) Virtual damping k_d
Low-pass filter	Not necessary	Necessary for the measurement of the phase currents
Island mode	Possible with extending filter capacitors Frequency and voltage controller are necessary for a stable long-term island grid	Possible without hardware reconfiguration Frequency and voltage controller are necessary for a stable long-term island grid

7. Conclusions

This paper presents a new method to implemente the VISMA on the PWM controlled inverter by using a current-to-votage model. A comparison of this new method with VISMA-Method 1 by using a voltage-to-current model on the hysteresis controlled inverter has been performed by simulation results. It has been proved that the VISMA-Method 2 is able to behave almost the same static and dynamic properties such as flexible power setting, energetic reproducing the virtual rotating mass and virtual damping in a parallel operation with the public grid as the VISMA-Method 1.

Both VISMA-Methods can be operated under an island mode. The VISMA-Method 2 can achieve a better voltage quality compared to the VISMA-Method 1, which needs larger capacitors in order to having the same voltage quality. For building a stable island grid the frequency and voltage controller should be applied in both VISMA-Methods.

Considering the widely applied PWM controlled invertes in the current market, the VISMA-Method 2 is tended to be more easily utilized.

References

[1] R. Hesse, D. Turschner, H.-P. Beck, Die virtuelle Synchronmaschine, VDE Verlag Berlin, Etz Elektrotechnik + Automation S2/2007, pp. 38-44.

[2] R. Hesse, H.-P. Beck: Virtual Synchronous Machine, Proceeding, 9th International Conference on Electrical Power Quality and Utilisation, Barcelona (Spain), 2009.

[3] Y. Chen , R. Hesse, D. Turschner, H.-P. Beck, Dynamic Properties of the Virtual Synchronous Machine (VISMA), in Proc. ICREPQ’11, Las Palmas (Spain), 2011.

[4] J. G. Slootweg, W. L. Kling, “Impacts of distributed generation on power system transient stability”, Power Engineering Society Summer Meeting, 2002 IEEE, Vol.: 2, 21-25 July 2002, Pages:862 - 867 vol.2

[5] Y. Chen, R. Hesse, D. Turschner, H-P. Beck, Improving the Grid Quality by Using Virtual Synchronous Machine, in Proc. PowerEng 2011, Málaga (Spain), 2011.