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Micro grid stabilization using the Virtual Synchronous Machine (VISMA)

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Abstract

Up to now, the electromechanical synchronous machine rules the domain of electrical power generation devices and that way the public power grids. Its specific characteristics guarantee the stable highly parallel grid operation, automatic power balancing and damping. Not least the rotating mass is related to some dynamic properties and the condition for the grid short time frequency stability.
The progressive integration of renewable sources is accompanied by questions concerning the loss of these features using inverters for grid feeding.
The paper shows an approved concept that combines inverter technology and synchronous machine properties.

Key words

Virtual synchronous machine, VISMA, power electronics, inverter, generator, renewable sources, grid, rotating mass, power balancing, damping

1. Introduction

Usual in trade grid feeding inverters are mostly and solely designed for the transfer of local energy yield into the public grid. At this, it was still assumed, the grid represents an ideal electrical source with an energy receptiveness at will.
With the growing integration of conventional inverters, operation problems are increasingly observed. Interferences due to impedance test pulses, the problem of master-slave-mode selection and output power sharing among themselves are generally known.
The stable highly parallel operation of numerous synchronous machines with power station control scheme was the starting point to combine power electronics with synchronous machine behaviour.
This consideration leads to the concept of the virtual synchronous machine (VISMA) [1 .. 4] shown in Fig. 1.

The VISMA is deemed to be a special controlled inverter to integrate decentral, mainly renewable electrical sources to the grid.

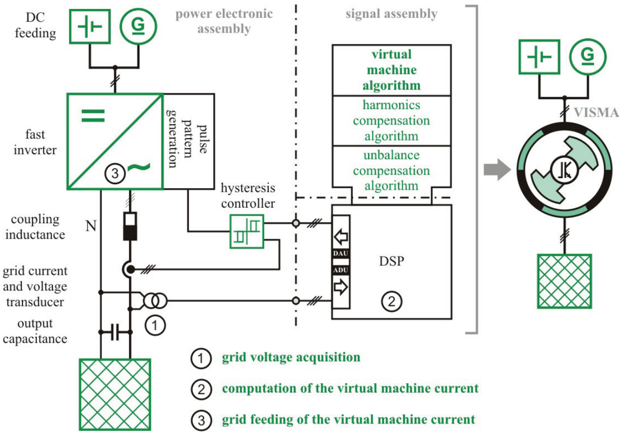

Fig. 1. Block diagram of the VISMA

To work equally to an electromechanical synchronous machine, the VISMA picks up the instantaneous grid voltage to supply the virtual machine algorithm on the DSP to determine the also instantaneous stator current of the virtual machine. The inverter closes the cause and effect cycle feeding the computed current into the grid.

All static and dynamic properties of the VISMA, disregarding the specific high frequency effects caused by the inverter switching activity, are like an electromechanical machine with the same parameter set.
The parameters of a linear and ideal synchronous machine with electrical excitation and damper are shown in Fig. 2. Resistances (R) and Inductances (L) are specified in d-q-notation for stator (lower case indexes), damper (higher case indexes) and exciter (index "e"). The mutual inductances are "M"-indexed.
The embedded DSP computer runs a d-q-modelled VISMA and has to transform the gathered three phase grid voltage to the d-q-stator voltage using

$$\begin{bmatrix} u_d \\ u_q \\ u_0 \end{bmatrix} = \mathbf{P} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \qquad (1)$$

with

$$\mathbf{P} = \begin{bmatrix} \frac{2}{3}\cos(\varepsilon) & \frac{2}{3}\cos\left(\varepsilon - \frac{2}{3}\pi\right) & \frac{2}{3}\cos\left(\varepsilon + \frac{2}{3}\pi\right) \\ -\frac{2}{3}\sin(\varepsilon) & -\frac{2}{3}\sin\left(\varepsilon - \frac{2}{3}\pi\right) & -\frac{2}{3}\sin\left(\varepsilon + \frac{2}{3}\pi\right) \\ \frac{1}{3} & \frac{1}{3} & \frac{1}{3} \end{bmatrix} \qquad (2).$$

The absolute rotor angle for the transformation is taken from the virtual mass term (eq. 17).

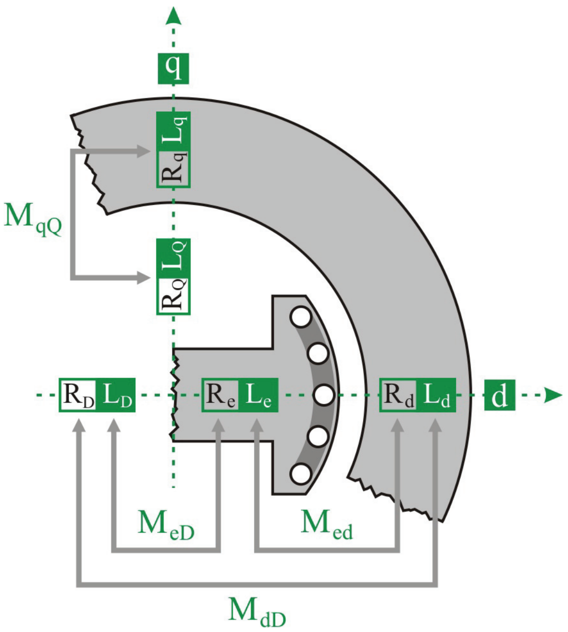

Fig. 2. Parameter set of a linear and ideal synchronous machine

The voltage – flux equations of the synchronous machine standard modell give after conversation the stator current

$$i_d = \frac{1}{L_d}\left(\Psi_d - M_{dD} i_D - M_{ed} i_e\right) \qquad (3)$$

and

$$i_q = \frac{1}{L_q}\left(\Psi_q - M_{qQ} i_Q\right), \qquad (4)$$

the damper current

$$i_D = \frac{1}{L_D}\left(\Psi_D - M_{dD} i_d - M_{eD} i_e\right) \quad (5)$$

and

$$i_Q = \frac{1}{L_Q}\left(\Psi_Q - M_{qQ} i_q\right), \quad (6)$$

each both in longitudinal and transverse axis, as well as the exciter current

$$i_e = \frac{1}{L_e}\left(\Psi_e - M_{eD} i_D - M_{ed} i_d\right). \qquad (7)$$

The resulting explicit flux relations for stator, damper and exciter are computed by

$$\Psi_d = \int \left(u_d - R_d i_d + \omega \Psi_q\right) dt \qquad (8)$$

$$\Psi_q = \int \left(u_q - R_q i_q + \omega \Psi_d\right) dt \qquad (9)$$

$$\Psi_D = \int \left(-R_D i_D\right) dt \qquad (10)$$

$$\Psi_Q = \int \left(-R_Q i_Q\right) dt \qquad (11)$$

$$\Psi_e = \int \left(u_e - R_e i_e\right) dt\,. \qquad (12)$$

On the analogy of the electromechanical synchronous machine, the inner torque is specified by

$$m_{el} = \frac{3}{2}\left(\Psi_d i_q - \Psi_q i_d\right). \qquad (13)$$

The electrical effects of the virtual moment of inertia in the speed equation

$$\omega = \frac{1}{J}\int \left(m_{el} - m_{mech}\right) \qquad (14)$$

on the grid caused by transient processes are also equal to the electromechanical machine.

To generate the instantaneous current set values for the hysteresis controlled inverter, the d-q-notated stator current has to be retransformed to the three phase notation using

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \mathbf{P}^{-1} \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} \qquad (15)$$

with

$$\mathbf{P}^{-1} = \begin{bmatrix} \cos(\varepsilon) & -\sin(\varepsilon) & 1 \\ \cos\left(\varepsilon - \frac{2}{3}\pi\right) & -\sin\left(\varepsilon - \frac{2}{3}\pi\right) & 1 \\ \cos\left(\varepsilon + \frac{2}{3}\pi\right) & -\sin\left(\varepsilon + \frac{2}{3}\pi\right) & 1 \end{bmatrix} \quad (16)$$

and the absolute rotor angle

$$\varepsilon = \int \omega \ dt . \quad (17)$$

The user operates the VISMA in the basic machine mode for the purpose of active and reactive power transfer by setting the virtual torgue (eq. 14) or setting the virtual excitation voltage (eq. 12).

2. VISMA compensation mode

As seen in Fig. 1, the instantaneous current set point for the hysteresis controlled inverter is basically allowed to be arbitrary. In the standard VISMA mode, the current is computed in the way shown above to let the VISMA work as synchronous machine. Algorithms for harmonics and unbalance compensation are also available.
In the following, a wideband compensation method using the fast VISMA inverter should be discussed.

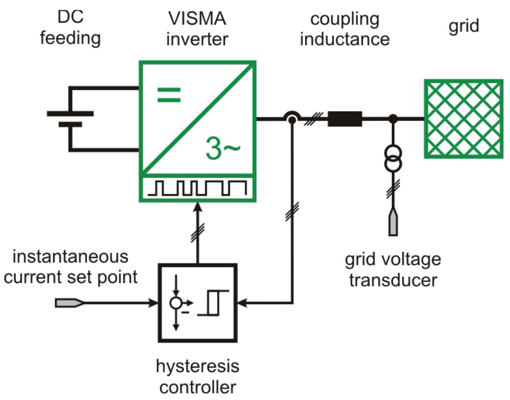

Fig. 3. Using the hysteresis controlled inverter of the VISMA to compensate grid disturbances

Fig. 3 shows the VISMA inverter connected to a disturbed grid getting the instantaneous current set point from a compensation algorithm which extracts the disturbance component from the grid voltage course. It consist of the subsystems shown in the Fig. 4 .. 8.
The PLL in Fig. 4 generates a normalized 2π angle ramp synchronous to the first phase of the grid. As opposed to standard PLL structures, a PI loop controller is inserted behind the standard loop filter. In this way, a statical phase error can be avoided. The integrated sum of center frequency and controller acting results in a angle ramp considering the modulo limitation of the integrator block averting overflow problems. Because of the ramp output shape, the phase discriminator needs a sine function in the feedback line.

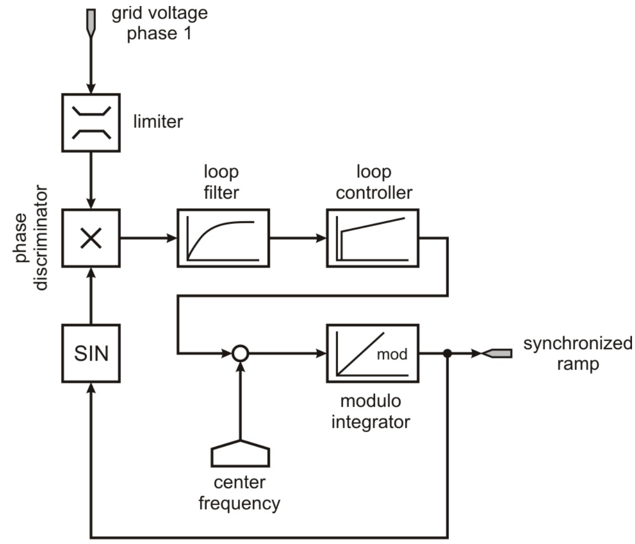

Fig. 4. PLL subsystem

Taking the synchronized ramp, the phase generation subsystem referring to Fig. 5 is creating the phase true courses of the desired auxiliary grid.

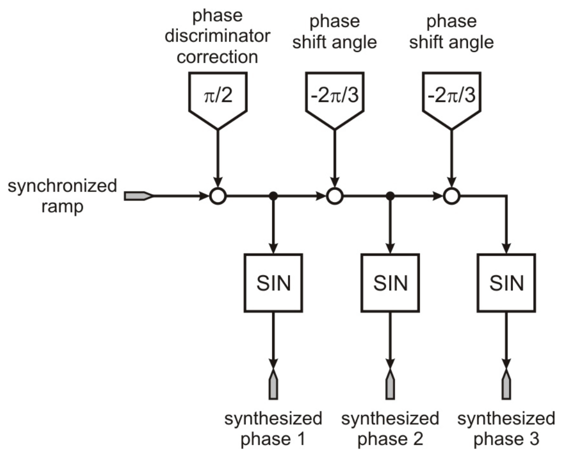

Fig. 5. Phase generation subsystem

On the basis of the grid voltage long term root mean square values according to Fig. 6, the amplitude weighted auxiliary respectively synthesized grid is at disposal appropriate to Fig. 7.

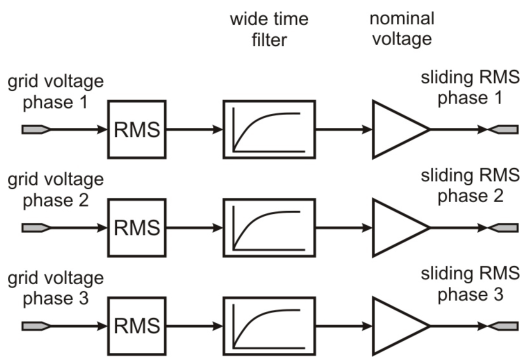

Fig. 6. Amplitude generation subsystem

To compensate wideband grid disturbances corresponding to Fig. 8, the noise component is removed form the grid voltage course by real time substraction of the grid and auxiliary voltage signals. The noise component is inverted and weighted with the distortion compensation factor DCF and finally forwarded to the hysteresis controller of the VISMA inverter.

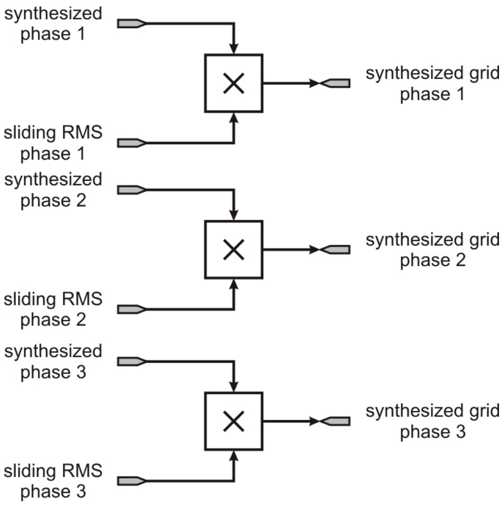

Fig. 7. Grid synthesizing subsystem

By this means, a compensation owing to antiphase superposition is precipitated. This is a known an efficient method successfully applied in antinoise systems as yet. The key prerequisite for the use within the scope of electrical grids is the very fast acting hysteresis controlled inverter.
The distortion compensation factor DCF determines the intensity of antiphase injection. Is it a matter of parasitic grid oscillation, the operator initially set a hight DCF value to suppress the oscillation by deprivation of energy. If the oscillation is damped down, the DCF can be reduced.

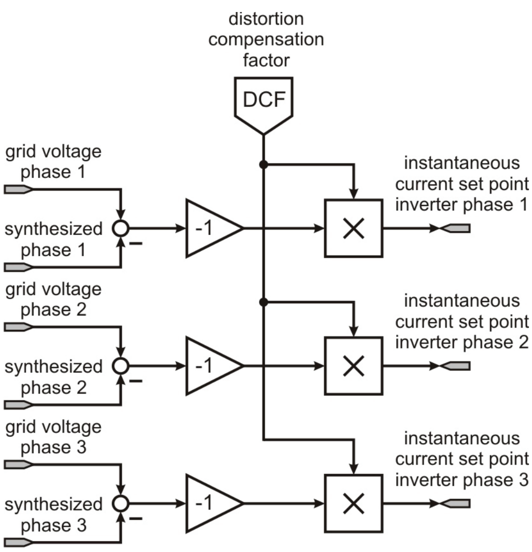

Fig. 8. Compensation subsystem

The mode of operation explains the wideband properties of the compensation method.

3. Measurements

The visualized method was implemented on a VISMA system connected to an intermeshed grid of a research company. The grid contains loads with entirely different and stochastic operating properties, a fundamental mode power electronics conditioner and several CHPs with asynchronous generators.
Driving the grid with the CHPs in island mode, parasitic grid oscillations often occur and lead to a complete mains failure in spite of the operating power electronics conditioner.
The problem has been solved applying this VISMA with wideband compensation algorithm. It would be also possible to operate the VISMA standard model to damp the oscillation. Corresponding measurements are in process of planning.
The following plots demonstrate the compensation of these parasitic grid oscillations.

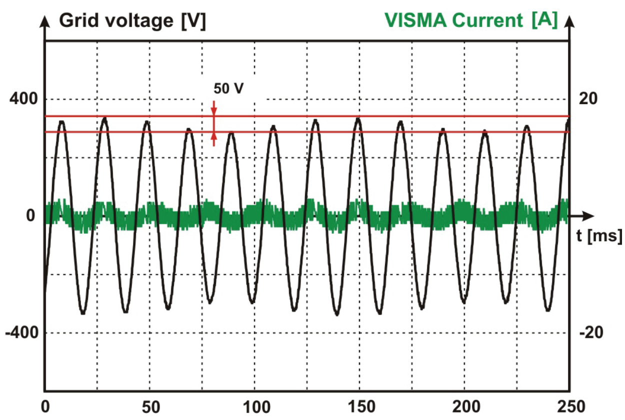

Fig. 9. Vast 8 Hz grid oscillation, VISMA is starting

Switching the company grid to island mode and starting the main support diesel CHP, strong grid oscillation shown in Fig. 9 are noticeable. If the oscillation exceeds 50 V peak variation, the grid is going to fail.

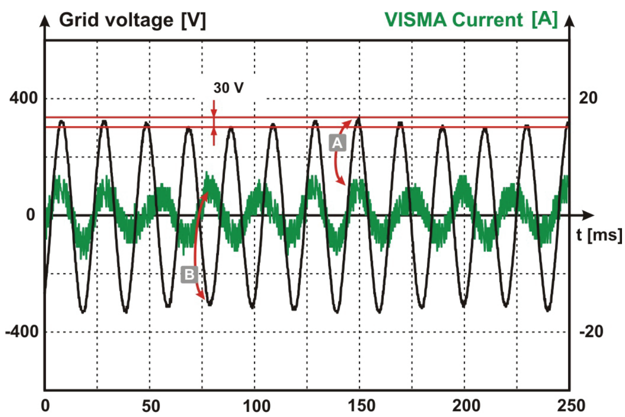

Fig. 10. VISMA is right in the middle of damping, the oscillation amplitude decreases

Because of the oscillation character of the disturbance, it will do to set a constant DCF value. The VISMA compensation current is immediately getting higher in dependence on the DCF value. Due to the compensation principle, the phase relation of the compensation current compared to the grid voltage matches concerning oscillation energy deprivation anytime, visible in the details A and B in Fig. 10.

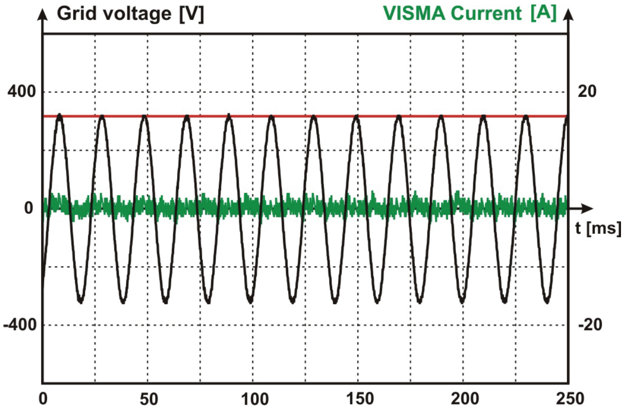

Fig. 11. VISMA fully suppressed the grid oscillation

While damping, the compensation current amplitude automatically decreases with the fading oscillation.

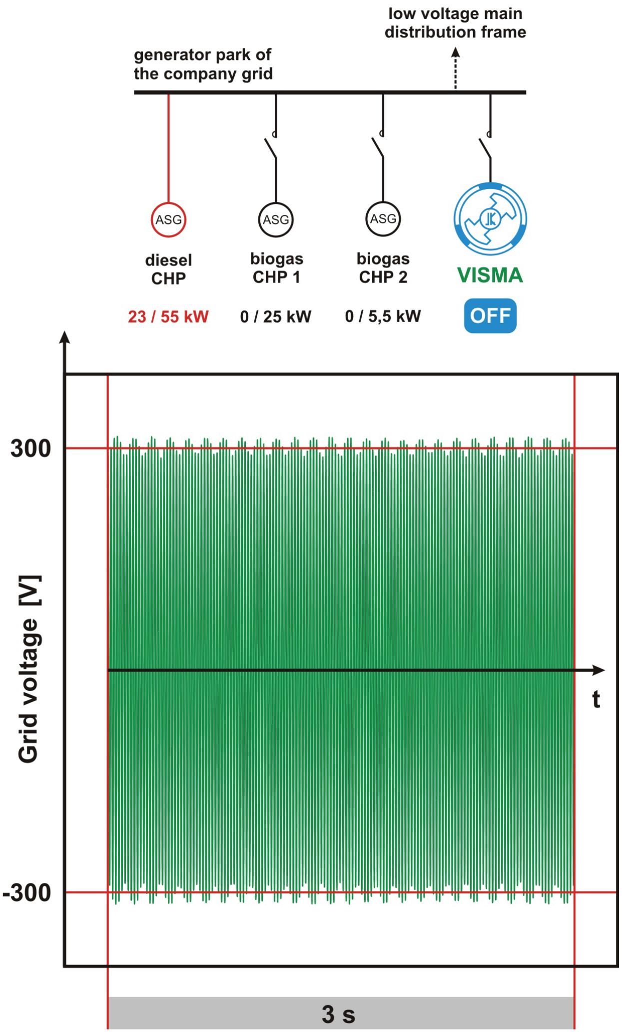

Fig. 12. Longer record of the oscillating grid while running the main diesel CHP: VISMA switched off

Pointed in Fig. 11, the compensation current and the oscillation disturbance finally disappear and the VISMA stands by or supresses growing oscillations.
Fig. 12 and 13 clarify the compensation performance by means of a longer range record.

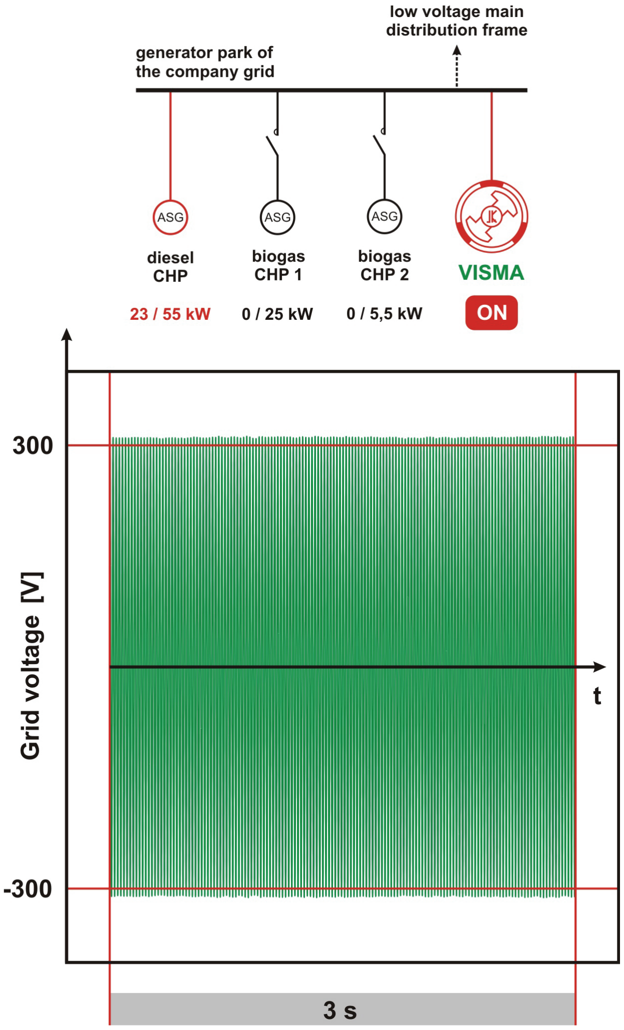

Fig. 13. Longer record of the oscillating grid while running the main diesel CHP: VISMA switched on

4. Conclusion

The VISMA concept contains on the one hand the virtual machine algorithm to let any DC feeding generators, preferably wind, solar, fuelcell or CHP systems appear and operate entirely as synchronous machine to the grid.

On the ather hand and shown in this paper, performing the wide frequency range compensation algorithm, the VISMA suppresses grid disturbances effectively.
Using powerfull embedded computers, it is possible to run both algorithm simultaneous and superimpose both the virtual machine and the compensation current signals to input the hysteresis controlled inverter.

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