Technical description of the Optislip® feature in VESTAS wind turbines

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1 Introduction

The aim of this document is to provide a technical description of the OptiSlip® feature which is a part of Vestas V39/V42/V44-600 kW and V57/V63-1.5 MW wind turbines.

The OptiSlip® feature allows the generator to operate with optimum slip, resulting in minimal fluctuations in the drive train torque and in the power output.

The OptiSlip® mode is always active when the generator is connected to the grid.

OptiSlip® is achieved by using a special asynchronous generator, a variable slip generator, in combination with the wind turbine controller; the VMP controller (Vestas Multi Processor controller).

2 Variable slip generator

The variable slip generator is a special asynchronous generator with wound rotor and an integrated RCC (Rotor Current Controller).

The RCC is mounted to the shaft end at the rear end of the generator. The RCC consists of resistors, power electronics, current sensors and a microprocessor based control unit, see figure 1.

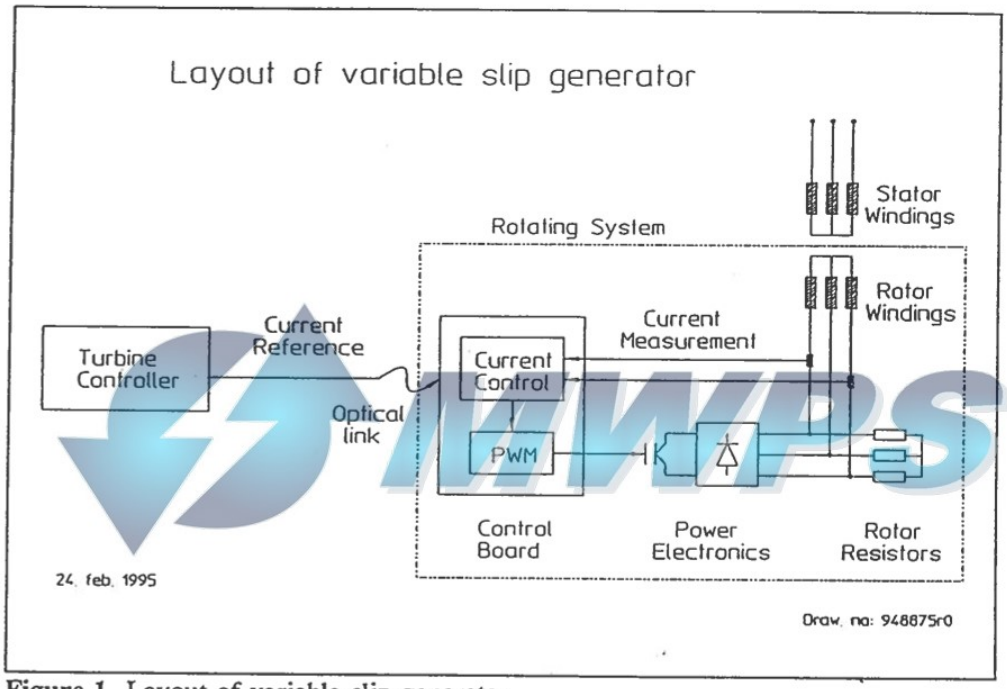

Figure 1 Layout of variable slip generator.

The RCC unit is rotating in order to avoid slip rings and brushes. Communication signals to and from the VMP controller are transmitted via a maintenance free optical connection.

The major task of the RCC is to control the rotor current which is proportional to the power output: The VMP controller sends a requested current reference to a fast rotor current controller which compares it to the actual rotor current, and adjusts the resistance accordingly. The required resistance is achieved by a pulse wave modulation of the resistors using IGBT's (Insulated Gate Bipolar Transistors) as DC switches. The switch frequency is approximately 3 kHz. In this way it is possible to adjust the average external resistance almost continuously between zero and maximum.

Figure 2 shows power vs. slip for a standard asynchrounous generator with rated 2 % slip.

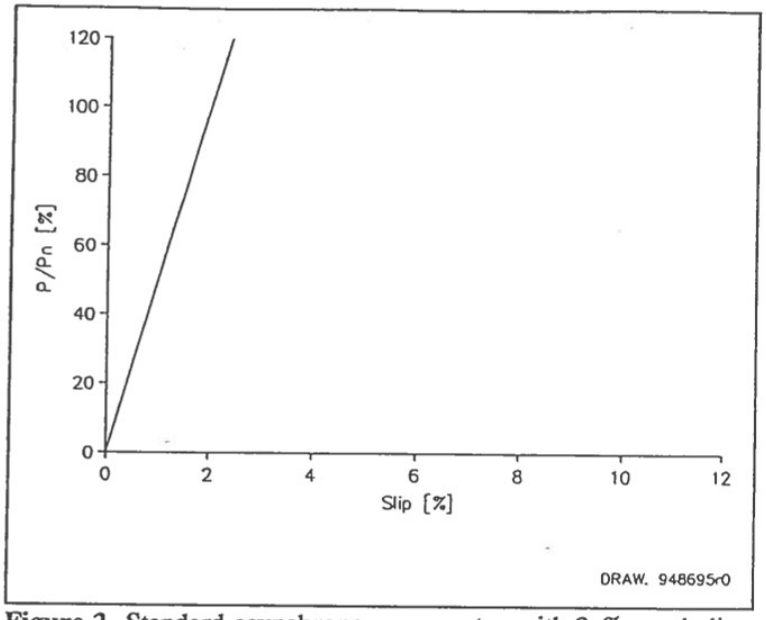

Figure 2 Standard asynchronous generator with 2 % rated slip.

Slip is here defined as

$$slip = \frac{n_{gen} - n_{syn}}{n_{syn}} \cdot 100\ \%$$

where

n_{gen} : actual generator speed [rpm]
n_{syn} : synchronous speed [rpm]

Figure 3 shows power vs. slip for the variable slip generator.

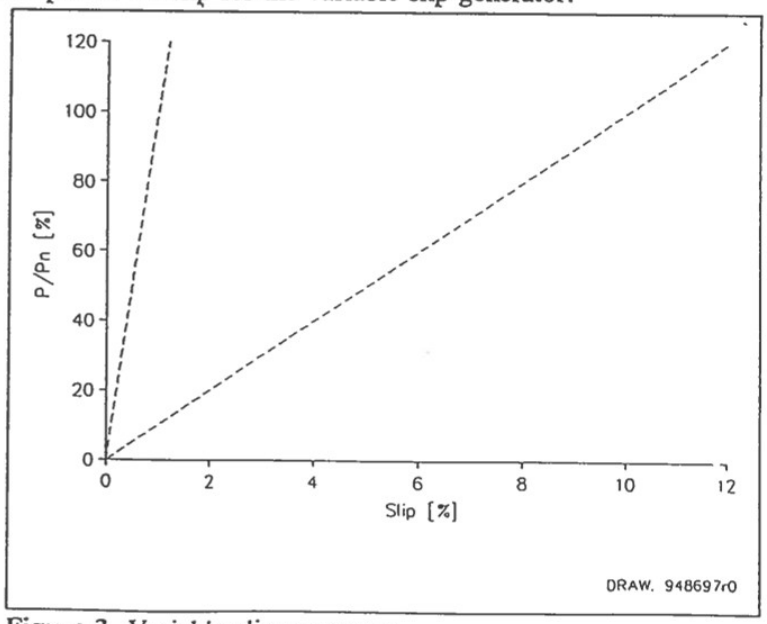

Figure 3 Variable slip generator.

For a given power reference is it possible to vary the slip within an interval limited by the two straight lines. 0 % duty cycle of the resistors corresponds to the left line, and 100 % duty cycle corresponds to the right line. The slip can e.g. vary between 1 % and 10 % at rated power.

3 Power and speed control systems

The VMP controller consists of several controllers, which are presented in figure 4.

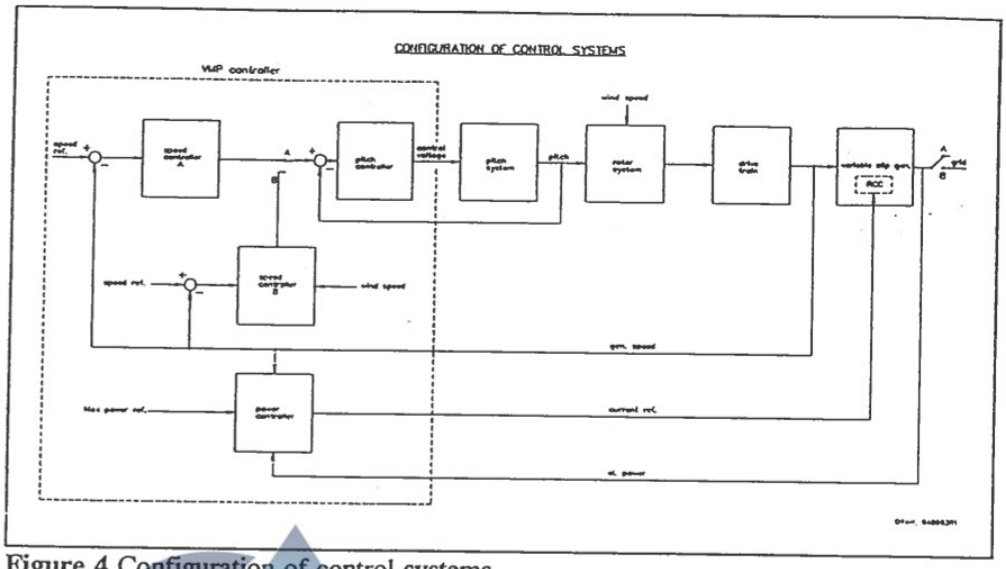

Figure 4 Configuration of control systems
A: generator disconnected from the grid
B: generator connected to the grid

Blade pitch is controlled by speed controller A before cut-in and during cut-out of the generator.

When the generator is connected to the grid, and the power output is below rated, blade pitch is controlled in relation to the wind speed. This control ensures maximum energy production and is called OptiTip®.

The generator power is controlled by changing the power reference to the generator depending on the actual slip, see figure 5.

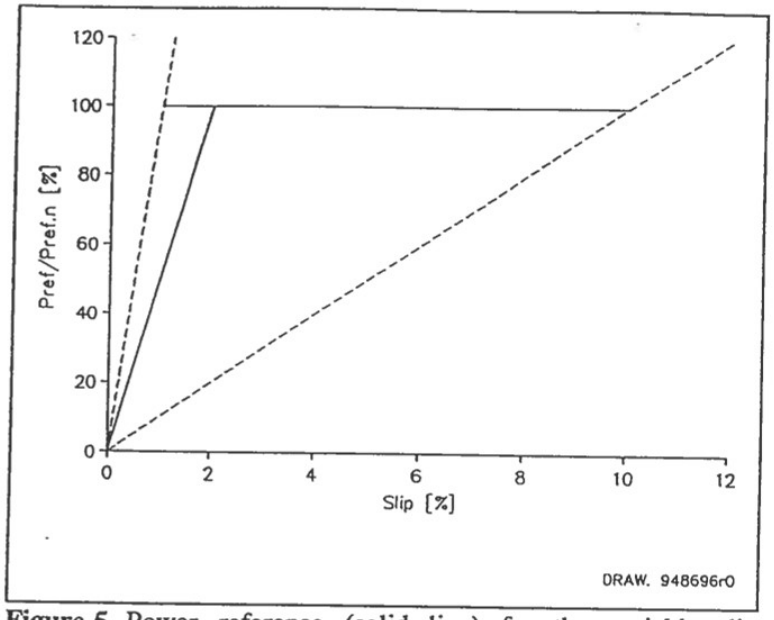

Figure 5 Power reference (solid line) for the variable slip generator.

If the generator rpm is below 2 % slip, the power reference will follow the 2 % rated slip line. The power controller is designed to smoothen the output by allowing the generator speed to vary around the 2 % rated slip line. In this way the efficiency of the variable slip generator will be equal to a standard asynchronous generator will be with 2 % rated slip.

If the wind speed increases above nominal, the generator speed will increase above 2 % slip and the power reference will be held constant at rated power. The variations in the wind speed will cause variations in the speed, because the fast rotor current controller will maintain the rotor current, and thereby the power, constant. This also means that the main shaft torque is almost constant and that the peak loads on the gearbox are minimized. The speed controller B (see fig. 4) will control the speed by adjusting the blade pitch so the average slip will be 4-5 %.

The combination of speed and power control and the variable slip generator is called OptiSlip®.

4 Performance

4.1 Measurements of power output.

In figure 6 and 7 measured time series from a V42-600 kW wind turbine is shown. The wind speed is measured approximately 100 m upwind from the turbine and the sampling frequency is 16 Hz.

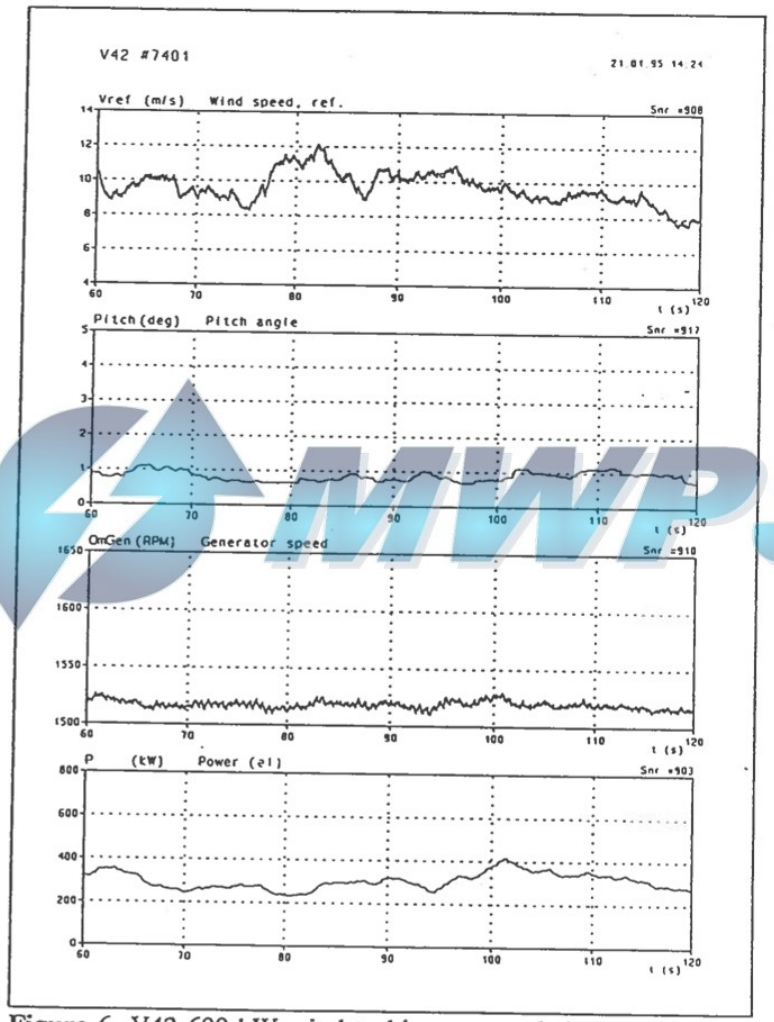

Figure 6 V42-600 kW wind turbine; power below rated.

The time series in figure 6 are measured where the power output is below rated. The measurements show that the power output is smoothed and that the 3 p (1.5 Hz) variations (which are always present in the rotor torque) result in speed variations instead of power variations.

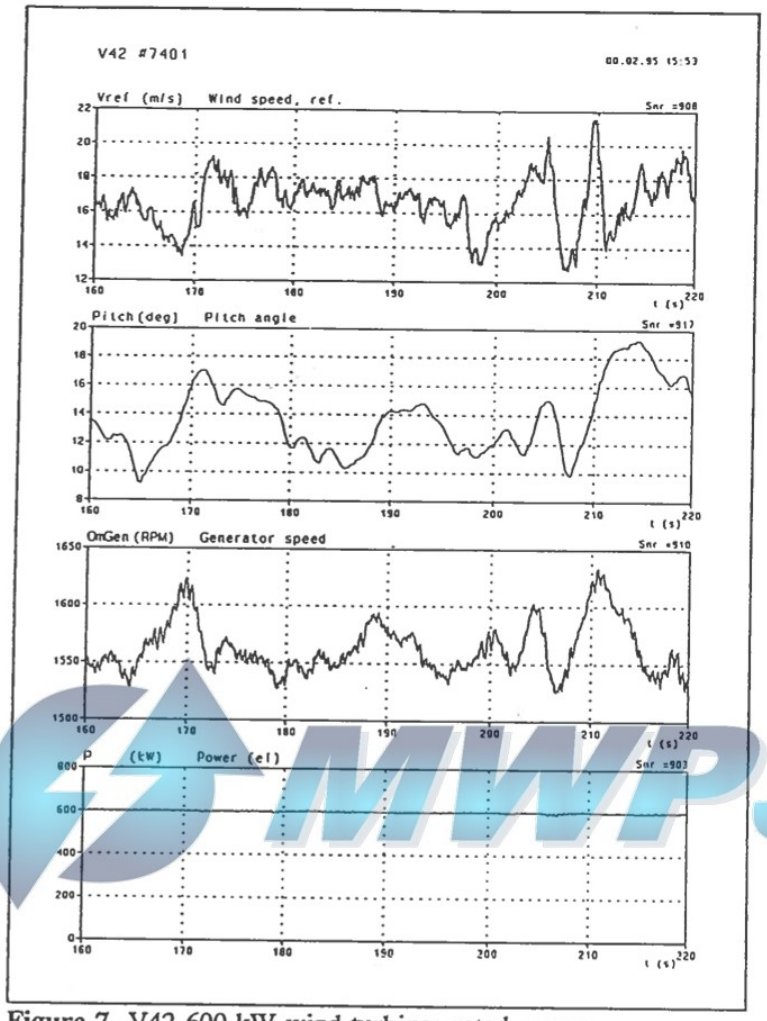

Figure 7 V42-600 kW wind turbine; rated power.

The time series in figure 7 are measured where the output is at rated power. The measurements show that the RCC is able to maintain the power constant and that the large wind speed gusts result in speed variations only. It can also be seen that the speed controller will hold the generator speed within the 1-10 % slip interval by changing the blade pitch.

4.2 Influence on the grid

Cut-in current.

The following features are achieved during cut-in of the generator:

- The generator speed is controlled to be stationary around synchronous speed by adjusting the pitch.
- All the external resistors are connected in the generator.
- The generator is cut-in by means of thyristors.

These features limit the cut-in current to the rated current and minimize the torque and power peaks during the cut-in phase.

Flicker.

Fluctuations in the power output in the frequency range from approximately 0.5 to 20 Hz can cause voltage fluctuations (flicker) dependent on the impedance of the grid.

The power output from the turbines with OptiSlip® are smoothed (see figure 6 and 7). This means that the flicker level is kept low.

Harmonics.

The possible source for creating harmonic currents during normal operation is the switching of power electronics in the generator. But the fact that this switching takes place on the rotor side and at a relative high frequency means that the content of harmonics transmitted to the grid will not be significant.