Wind Turbine Description

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1. Design of the wind turbine

The Vestas V39/V42/V44-600 kW, V47-660 kW and V47-660/200kW wind turbine is a pitch controlled upwind turbine with active yaw and a rotor with three blades.

The pitch control means that the blades can pivot upon their own longitudinal axis. The pitch control is used for speed control, optimization of power production and to start and stop the turbine.

The blades are made from glass fibre. The shells are made in a light sandwich construction and mounted on a supporting closed beam of prepreg. Through a bonded aluminium root-insert the blades are bolted to the blade bearing. The blade bearing is bolted to the blade hub.

The mechanical power from the rotor is transmitted through the mainshaft to the gearbox. The gearbox is a combined planet and helical gearbox.

From the gearbox the power is transmitted through a cardan shaft to the generator.
For 500 kW the generator is designed with constant slip of 2-3% (depending of type of generator).
The 600 and 660 kW generator is designed with integrated electronics. Then it is able to operate with a variable slip between 1 % and 10 %.

V47-660/200kW is equipped with two generators with nominel effekt at 660 kW and 200 kW. Each generator has individual gearing and outlet at the gearbox.

All functions of the turbine are monitored and controlled by a microprocessor based control unit, VMP-controller (Vestas Multi Processor controller).

The wind turbine has OptiSlip® and OptiTip® features as standard. This is described later in this chapter. (Except of 500 kW).

In the operating state EMERGENCY STOP the turbine is by full-feathering of the blades (aerodynamic brake).
The EMERGENCY STOP BUTTON (manual emergency) activates both the aerodynamics brake and the hydraulic disc brake, which is placed at the high speed shaft of the gearbox.

The pitch control is performed by activating a hydraulic/mechanical system. The hydraulic system is also used for the disc brake system.

Yawing is done by two electrical yaw gear motors, which mesh with a toothed wheel mounted on top of the tower. The bearing system is a slide system with built-in friction.

The nacelle is fully enclosed in a glass fibre reinforced polyester cover. Access to the nacelle is inside the tower.
The nacelle can be opened to the back and with the crane it is possible to bring up and down tools, spareparts etc.

The installations in the nacelle is shown in fig.1. A V47 with two generators is shown, but the installation is similar for all types of turbines, described in this manual, except of the small generator and the generatorselection box.

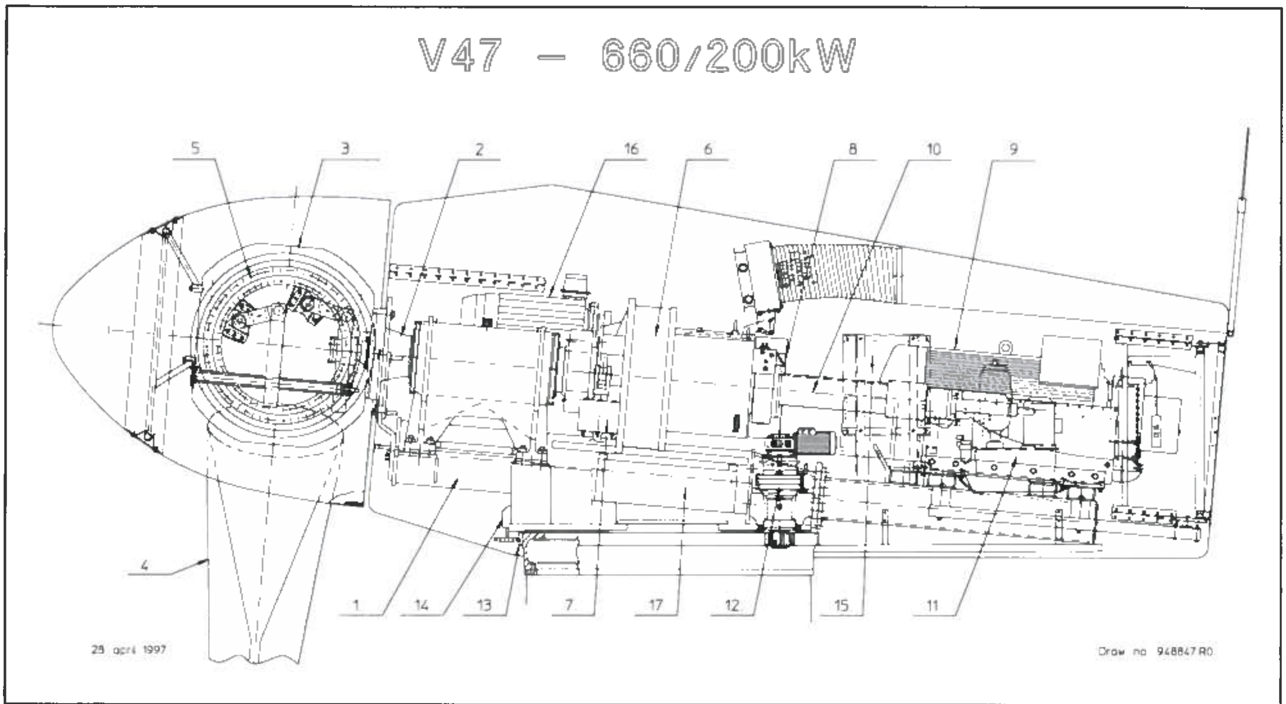


Figure 1 Structure of V47-660/200 kW.
Only difference to V39/V42/V44-600kW, V47-660 kW : no. 16 and 17 is not present.

1. Base frame
2. Main shaft
3. Blade hub
4. Blade
5. Blade bearing
6. Gearbox
7. Gear tie rod
8. Disc brake
9. Generator (Gen1)
10. Cardan shaft
11. Hydraulic power station
12. Yaw gear motor
13. Yaw ring
14. Yaw control
15. VMP top control unit
16. Small generator (Gen2)
17. Generator shift box

2. Description of main electrical components

2.1 Generator

An important part of the turbine is the asynchronous generator. It converts the mechanical energy from the gearbox to electrical energy. The generator is connected to the grid, which transfers the electrical energy to the consumer.

The public supply system is either 50 Hz or 60 Hz. The generators rotational speed depends on the frequency.

Therefore the gearbox have different gear ratios at grid with 50 Hz and 60 Hz, to obtain the same rotor speed.

The correlation between frequency, gearratio and rotation speed is:

Type of turbine	Frequency	Gearration	Synchronous generator speed	Rotor speed
V39	50	1:45.7	1500	32.8
V39	60	1:54.8	1800	32.8
V42	50	1:50.6	1500	29.6
V42	60	1:60.7	1800	29.7
V44	50	1:52.7	1500	28.5
V44	60	1:63.2	1800	28.5
V47-660kW	50	1:52.7	1500	28.5
V47-660kW	60	1:63.2	1800	28.5
V47-660/200kW	50	1:58.0/75.7	1500/1500	25.9/19.8
V47-660/200kW	60	1:69.3/90.4	1800/1800	25.9/19.8

The generator in V39/V42/V44-600 kW and V47-660 kW is a special asynchronous generator which is able to run with variable slip (1-10 %) and keeping the power constant simultaneously. This feature is achieved by a rotor current controller (RCC/VRCC) which is integrated with the rotor at the non drive end of the generator. The RCC/VRCC consists of a microprocessor unit, power electronics and variable resistors. When the VMP controller sends a request on a certain power reference, the RCC/VRCC will adjust the rotor resistance to obtain the wanted power output.

The V47-660/200 kW turbine is furthermore equipped with a 200 kW generator (without RCC/VRCC) that is used connected in low wind with lower rotor RPM (19.8 RPM).
It is mounted at an extra output at the front of the gearbox. Which generator that is connected to grid is selected by the VMP-controller via the generator selection box.

2.2 Power factor correction

An asynchronous generator contains no permanent magnets and is not separately excited. That means, that an asynchronous generator has to get the exciting current from the grid, and the magnetic field is only established, when the generator is connected to the grid.

When the generator gets exciting current from the grid, the generator consumes reactive power from the grid. The current in the cable to the generator will consist of two parts:

- Active current corresponding to the active power production (unit: kW)
- Reactive current corresponding to the reactive power consumption (unit: kVAr).

Because of the exciting current, there is a phase shift between the current and the voltage. The current is delayed compared to the voltage by an angle ϕ. A term of the phase shift is the power factor: cos ϕ.

A part of the generator's exciting current/reactive power is delivered from capacitors, which are called power factor correction. The capacitors are connected to the grid a little later than the generator and are disconnected before the generator is disconnected from the grid.

The advantage of the power factor correction is, that the loss in the grid decreases, because the grid current decreases. At no-load the grid current is about 0 A, because the generator's no-load current (only reactive current) is delivered from the capacitors.

2.3 Thyristor cut-in

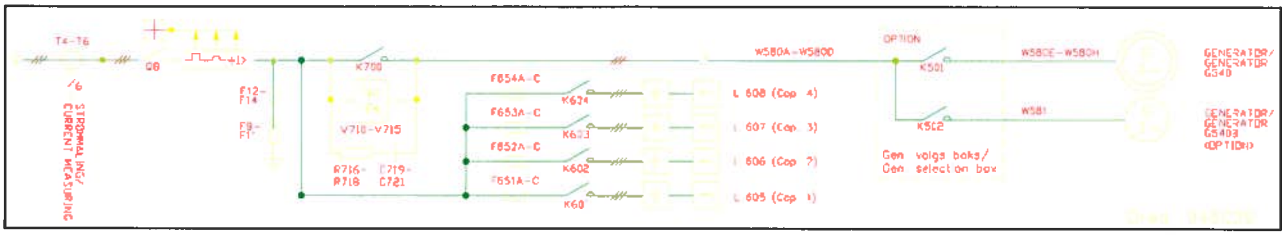


Figure 2. Circuit for generatorconnection.

When an asynchronous generator is connected directly to the grid, there will be a large cut-in current. The cut-in current can be up to 7-8 times the rated current. This cut-in current can cause disturbances on the grid.

To avoid these disturbances the generator is cut-in at synchronous speed through thyristors (V710-V715). Thyristor cut-in means that the thyristors slowly open up for the current, which takes approximately 1.5 sec.

When the thyristors are completely open, a bypasscontactor (K700) is closed, so that the thyristors are by-passed, see the above figure.

When disconnecting the generator from the grid, the thyristors are completely opened before disconnecting the by-pass contactor.
The thyristors are then trigged down (80 ms), until the current is zero, and then the generator is disconnected. In this way the contactor does not have to break any current, and there will be no arc inside the contactor.
This result in a more smooth connecting/disconnect to grid and increases the lifetime of the contactor.

3. Wind turbine controller

The name of the controller for the wind turbine is the VMP-controller, which is an abbreviation of Vestas Multi Processor controller.

The controller monitors and controls all functions in the turbine, in order to ensure that the performance of the turbine is optimal at any wind speed.
The controller will stop the turbine if a supervision detects an error.
At a operator panel, it displays data of the current operation.

The controller is designed to allow remote monitoring and control in case these features are required.

3.1 Layout of the VMP-controller

The VMP-controller includes a ground controller and a top controller. see fig. 3.
They are connected together with a supply/signal wire and an optical fiber for communication.

The ground controller is divided into 5 sections:

- Processor section, where the ground processor and the operating panel are located (or a socket for the service panel).
- Fuse section, where all the automatic fuses are located.
- Capacitor section, where the capacitors for the power factor correction are located.
- Bus-bar section, where by-pass contactor and circuit breaker are placed. The cables from the generator are connected in top of the bus-bar section.
- Grid connection section, where the grid cables are connected.

The top- and ground processors have different tasks.
The top processor takes care of the tasks in the nacelle, e.g. speed, pitch- and power control, yawing and internal temperature control.
The ground processor takes care of cut-in and cut-out of the generator and the capacitors and of current- and voltage measuring.

3.2 Operating panel

When an operator wants to look at data from the turbine, or he wants to start or stop the turbine, he can use the operating panel in the ground controller or connect a service panel to the top controller. The two panels display the same pictures but only one panel can be used at the same time. For security reasons use of servicepanel in the top can only be given away from this panel.

3.3 Data collection

The VMP-controller collects continously data about the performance of the turbine e.g.:

- Rotor and generator speed
- Wind speed
- Hydraulic pressure
- Temperatures
- Power and energy production
- Pitch

If some irregularities or errors arise, the data is stored in a LOG and/or an ALARM LOG, making it possible to analyse errors in the turbine.

3.4 System of parameters

The software to the VMP-controller system is basicly constructed so all variables can be set individually with socalled parameters.
Examples of parameters is powerreference, various alarmlimits, calibration values for anemometer etc.
To every type of turbines and variants a set of parameters is present, which is selected by start-up of the turbine.

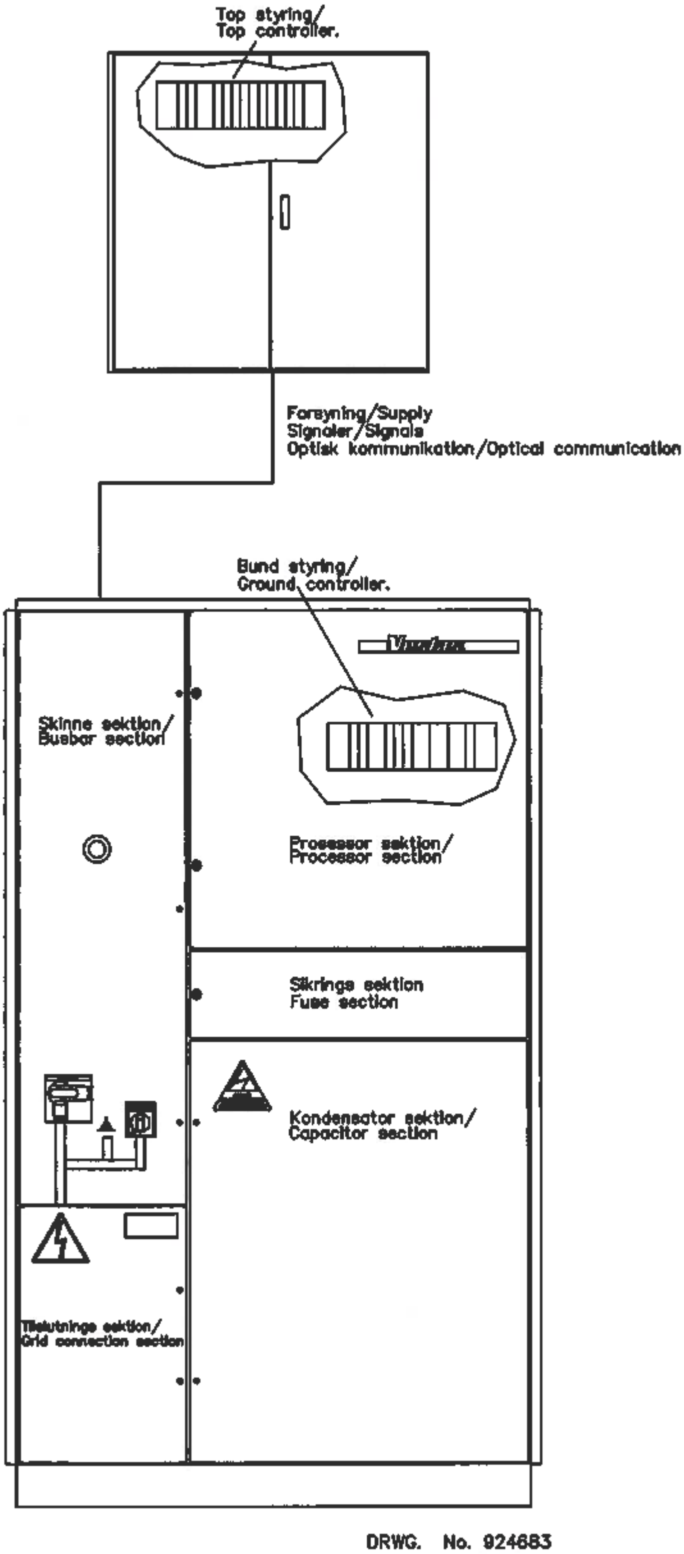


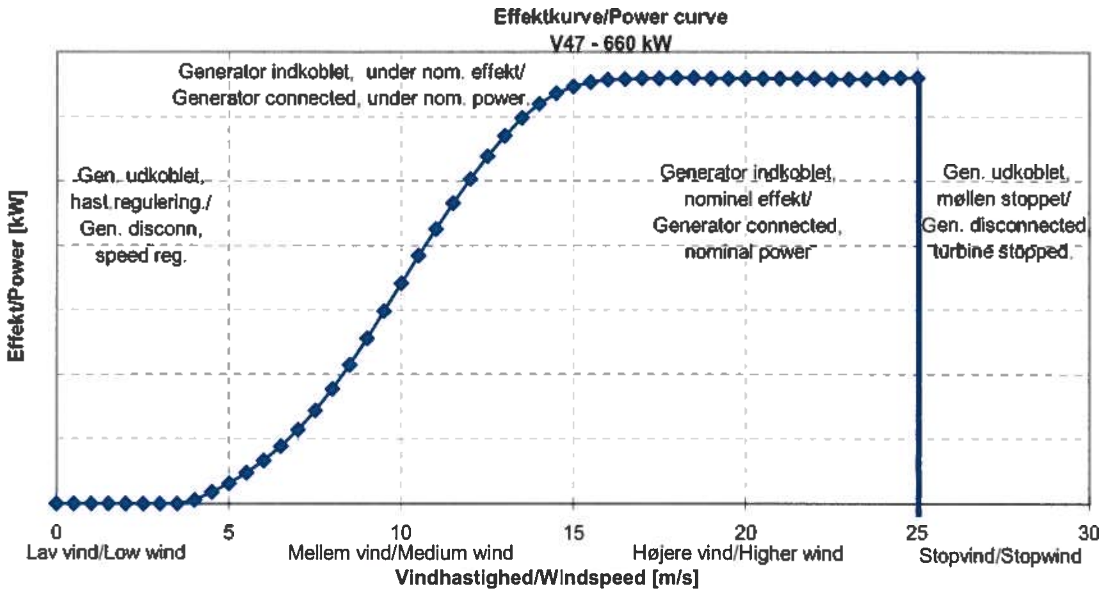
Figure 3 Layout of the VMP-controller.

3.5 Turbine control with OptiTip® and OptiSlip®

When the turbine is stopped (PAUSE, STOP or EMERGENCY STOP), the blades will be present in a pitch angel of 90° (out of the wind), see fig. 5.
When the turbine is in RUN-mode, it is able to produce electrical energy, but the momentary wind conditions are determining for how much.
This is controlled by the OptiTip® and OptiSlip® controlsystems by the VMP-controller.

The momentary wind conditions can be devided into four categories, shown by the powercurve in fig.4:

1. Low wind, the generator is not connected to grid.
2. Medium wind, the generator is connected, but does not produce nominal power.
3. Higher wind, the generator is connected and produces nominal power.
4. Stop wind, the generator is disconnected and the turbine is stopped.



Figur 4. Sketch of powercurve.

re 1. When the wind is very low and the rotor does not rotate or rotate with a very low speed the pitchangel will be approx. 45°. This will give maximum start moment to rotor which gives a quick start, when the wind increases.
The VMP-controller will then pitch the blades to 0° (into the wind), the rotatingspeed for the rotor and the generator will increase towards the nominal, which the VMP-controller will try to keep (speedcontrol).

The same situation is actual with connected generator and the wind decreases and the produced power becomes negative, the generator will be disconnected from the grid and the VMP-controller will control the speed. If the wind decreases even more the rotating speed will decrease below nominal value and the rotor will run freely.

re 2. By medium windspeed the rotating speed is regulated to the nominal value and if the pitchangel can be kept at 5° (which says that there would be enough energy in the wind) the generator is connected to the grid.

With the generator connected, but not enough energy in the wind to produce nominal power the pitch angel is regulated as a function of the windspeed.
This function is very precisely calculated, simulated and evaluated by measurements. It is called OptiTip®.
This is implemented in Vestas turbines to optimize the aerodynamics of the blades which will optimize energy production.

When the generator is producing power it courses a torque, contra to the mechanical torque of the rotor.
The VMP-controller controls the produced power so the rotor speed is kept constant within a narrow band witch is called "slip", which is the procentual relation between actual and synchronous rotating speed. In this area of control the slip is kept at 2%.

The VMP-controller in the V47-660/200 kW turbine is selecting which generator would be most optimal to connect by given criterias and is setting the rotating speed to this.

re 3. If the windspeed increases and the produced power reaches nominal value, the power will be kept constant by two control systems.
A relatively slowly system that controls the pitchangel, to keep the generator speed constant so the slip should be approx 4%.
The power will be kept constant at the nominal value as long the slip varies between 1% and 10 %.
If the windspeed increases the rotor and generator speed will increase too.
The VMP-controller will pitch the blades towards 90°, so the speed will decrease to the reference again.

If the windspeed decreases the rotor and generator speed will decrease too.
The RCC/VRCC controls quickly the rotorcurrent of the generator to keep the slip at 4% by connecting/disconnecting variable resistance.

re 4. If the windspeed increases above an upper limit the generator will be disconnected and the turbine will stop with blades pitched to approx. 90°. The VMP-controller waits until the wind speed has decreased a little below the limet and will then start up again.

This regulation system which controls the power and rotating speed as well as the variable slip generator is called OptiSlip®.

The OptiSlip® function has three conspicuous advantages:

- Minimizing the loads and shocks to the mechanical parts in the turbine.
- To improve the quality of delievered electrical energy to the grid without great fluctuations.
- Generally optimize the production of energy.

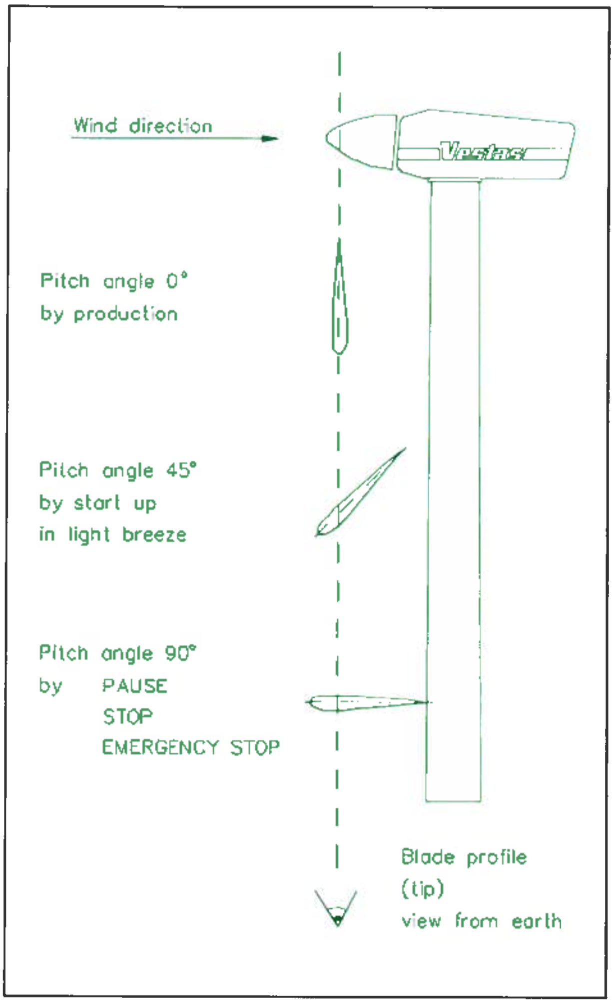


Figure 5 Pitch setting at different operating states.