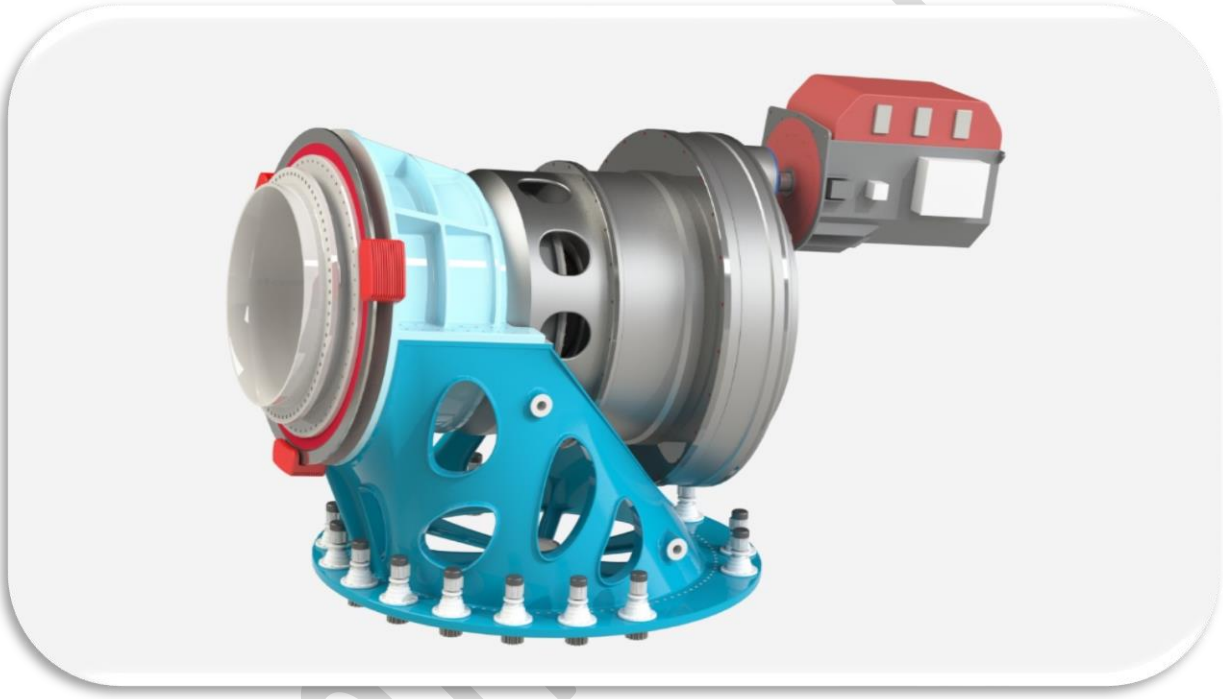
MergedGear

Technology



VerVent

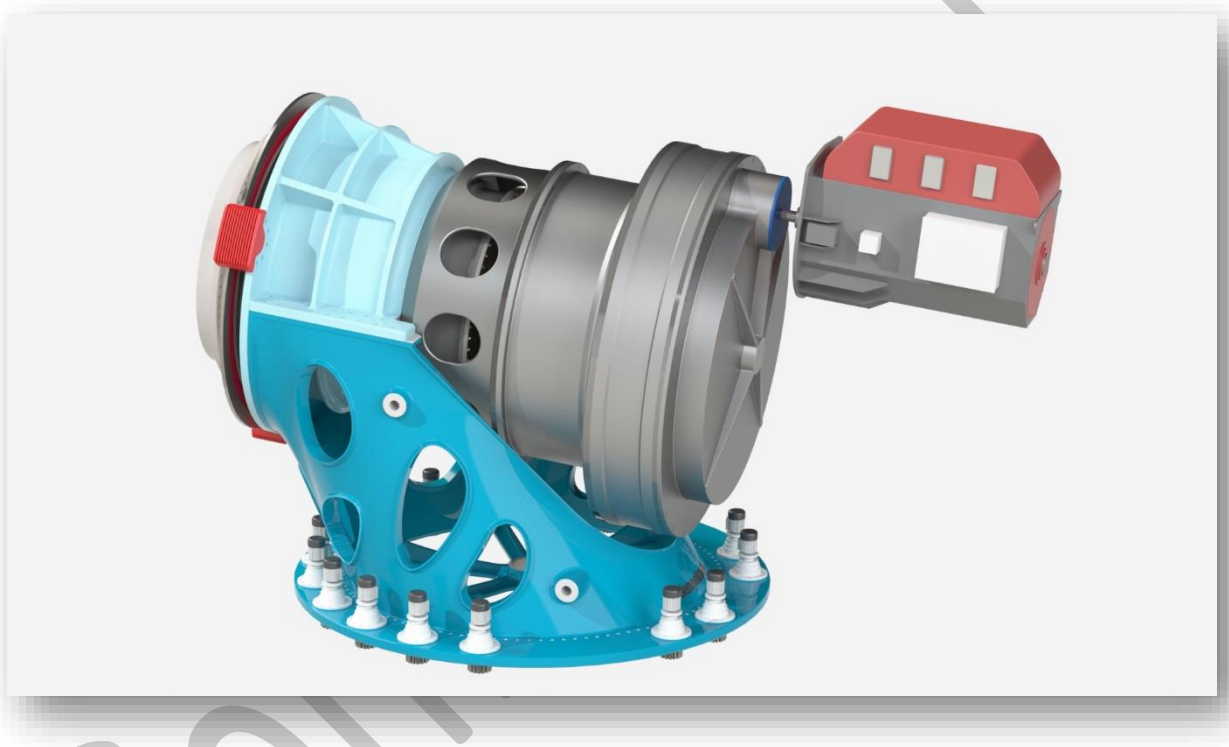
Schagen
October 2022

Introduction

VerVent's MergedGear and the Megatorque 20 gearbox concepts are based on a VerVent development, which has led to patents with at least twelve patented functions.

MergedGear is a highly innovative and compact fully integrated gearbox design, which connects 1-to-1 to the current (gearbox -) generator (combinations) used in wind turbine drive trains.

MergedGear can be easily adapted and used by today's manufacturers and can be combined with standard medium-speed generators.



The MergedGear gearbox can be divided into two parts: the first part is the innovative stepped planetary gearbox, the second a parallel step connected to the generator.

The first planetary step minimizes the negative impact of deflections and deformations, dampens axial and radial vibrations and protects the gearbox and generator from damage, breakdown and frequent maintenance.

VerVent is confident that MergedGear will be a welcome addition to today's manufacturers, also because it can be easily scaled to capacities more than 20 MW.

Why this gearbox

The nominal capacities of wind turbines are increasing and with it the technical challenges to operate these turbines without problems. The current major manufacturers produce turbines with a gearbox (Vestas) or direct drive turbines (GE, Siemens Gamesa).

VerVent has developed an innovative concept that fits within the expected upscaling and is an addition to the current possibilities.

The data table *VerVent MergedGear 20* gives an overview of the calculations of the torque.

Starting Points for Calculations							
Reference wind speed (input)	*m/sec*	11,5					
Power Coefficient		7,5					
CP (Betz table) aerodynamic efficiency	*%*	48,0%					
Specification Wind Turbine		**12MW**	**12 MW**	**14 MW**	**16 MW**	**18 MW**	**20 MW**
Diameter rotor incl. blades	*m1*	215	220	230	250	260	270
Rated GrossPower	*MW*	14	15	16	19	20	22
Rotational Speed Rotor (nominal)	*rpm*	7,7	7,5	7,2	6,6	6,3	6,1
Power at reference wind speed	*kW(h)*	16.233	16.997	18.577	21.949	23.740	25.601
Torque at reference wind speed	*kNm*	17.402	18.644	21.304	27.358	30.775	34.464
Assumed total system losses Nacelle	*%*	14%	14%	14%	14%	14%	14%

The MergedGear Innovations

Description
The MergedGear (VerVent) gearbox design focuses at meeting the huge input torque demands linked to next-generation 12 – 20 MW+ wind turbines with matching 215 – 270 m[1] rotor diameters. It incorporates that type of bearings whenever possible and feasible, that works best in that place, which is a key contributing factor to achieve a compact gearbox design with competitive torque density (Nm/kg). The gearbox input (rotor) side therefore has six planet gears for absorbing the corresponding 16 – 24MNm+ range incoming torque levels.

The Merged Gear gearbox is a derivative of the Megatorque Drive Train. The advantages of this concept also apply to MergedGear. We give an overview of these benefits.

The name MergedGear indicates what the innovation is: gears and bearings brought close together. It seems simple and it is. The Megatorque 20 concept with an especially important innovation, the central carrier, is a solid base.

The challenge for VerVent is to create a compact gearbox design with as few rotating parts as possible and therefore as few bearings as possible. The total weight is to the opinion of VerVent in line with the gearboxes already on the market for the same rated power.

These power classes will soon be on the market (> 15 MW). The MergedGear gearbox concept can scale up to capacities greater than 20 MW of nominal power without major changes in geometry and/or weight.

The ratio of the actual gearboxes is 1:50 (medium speed) or 1:160 (high(-er) speed; MergedGear allows these ratios too.

In addition, the MergedGear design can connect to a medium speed permanent magnet generator, such as are used as standard by means of a flange connection. So, a smaller chance of bearing failures .

The output of the gearbox can be connected to a standard medium speed generator that runs about 500 rpm.

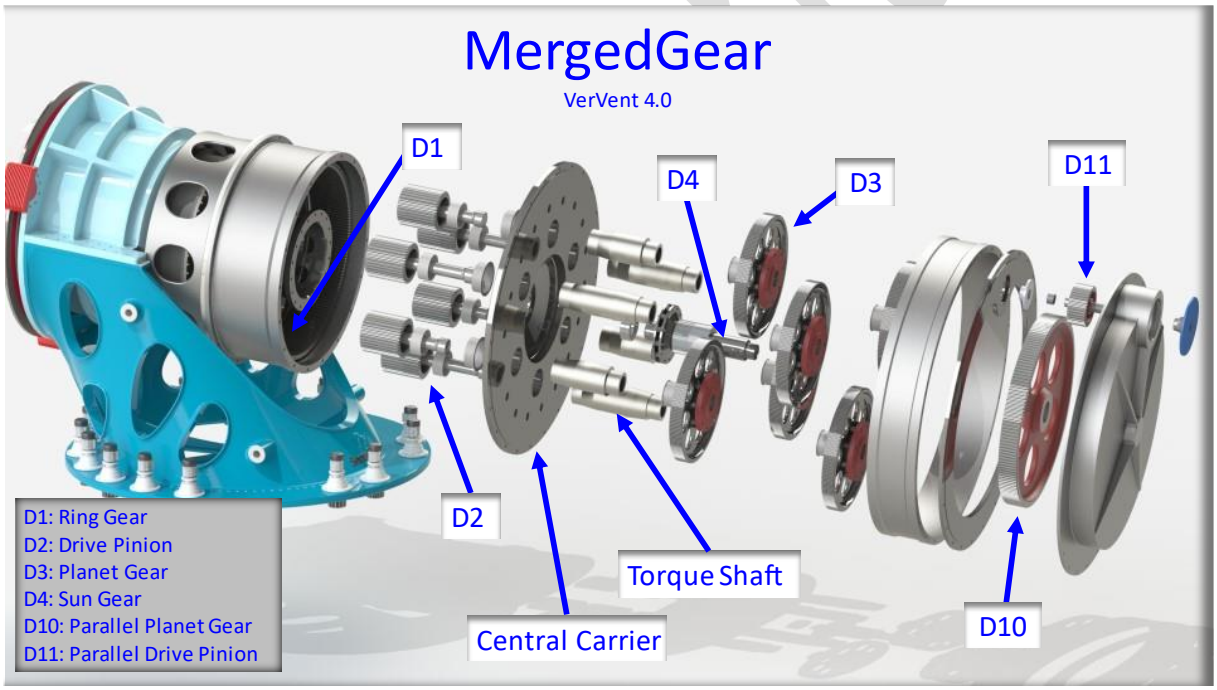
Technical advantages briefly[1]

The MergedGear Gearbox consists of two parts: 1. the innovative stepped planetary transmission, and 2. the parallel gear transmission.

The patented VerVent innovation concerns the first part of the gearbox and will be extensively explained. The second part, parallel gear transmission, has been used for many years in gearboxes for wind turbines purposes and has proven to be able to manage the torque and non-torque loads.

.

The design layout with six planets rotating in a gear with internal teeth (D1), casing outer diameter 4,100 mm, provides a step-up ratio of ~1:4.93. The second set of six drive pinions, each with bevel or bevel teeth, are individually attached to a split drive shaft with a matching planetary gear train. All six gears are divided into two separate sets of three wheels each. These gear sets rotate in a separate plane and all six wheels together drive the sun gear, and it represents the final stage of the stepped planetary gearbox. This second step ratio in the reference stepped gearbox design is ~1:3.73.
This provides an overall step ratio of 1:18.37, a good first compromise between controlling ring gear cost as a major factor in gearbox cost and a parallel goal of maximizing step ratio.



The picture gives an overview of the gearbox that leads to an overall ratio of 1 : 80. A ratio of 1 : 50 can easily be achieved by changing the parallel step in the gearbox, about the same planet, smaller pinion (driving the generator.

[1] The part of the "Megatorque planetary gearbox design features and benefits" are based on a by Eize de Vries (revised) document (version V1, d.d. 06 of January 2020) there after edited and incorporated for the purpose of this document.

As described the gearbox has a compact central 'tool' carrier, a structurally stiff element to which other main load-bearing elements are attached. This superstructure is the basis for the whole gearbox and ensures that the influence of non-torque loads are minimal and are reduced, the rotating parts such as gears and bearings are relieved. This extends the life of the gearbox and minimizes maintenance.

This *First Part of the Gearbox* contains at least *nine* innovative, features offering multiple benefits: the stepped planetary gearbox.

1. 1. The *first* and foremost innovative gearbox feature is a compact central "tool carrier", a structurally rigid element to which other main load-bearing elements are attached. These elements include six stationary coupling shafts with individual drive pinions (D2) and outer planet gears (D3), a hollow mandrel with bearing that carries the rotating ring gear (sprocket with internal teeth) and the built-in bevel gear drive shaft at the rear of the bearing housing.

2. *Second* feature is the ring gear carrier bearing support at the spaciously designed mandrel, which is structurally stiff. However, the vertical disc-shape carrier interface element has some built-in design flexibility for promoting optimal load transfer between rotating ring gear and planets.

3. A *third* main feature is the central 'tool' carrier principle and layout, which enables vertical gearbox to split. The first split is between the outer housing left part and the carrier structure, and the second split between the right housing part incorporating the bevel gear unit and secondary planetary gearbox. The central carrier itself can also be individually removed and reassembled. The gearbox-splitting feature further enables 'uncomplicated' vertical gearbox assembly and up-tower repairs during the operational period without needing an expensive jack-up or other installation vessel.

   The 'tool carrier' principle also offers a compact integrated gearbox system solution that minimizes negative gearbox and drivetrain interface impacts due to deflections and deformations. The latter are critical factors when designing large-scale mechanical drivetrains for turbines from about >10MW ratings. One crucial interface-related benefit of the innovative design is the near elimination of loads induced in the outer housing causes deflections and deformations being passed on to critical gearbox internals.

   This is enabled by the fact that within the innovative design parameters the outer housing and central carrier are linked only at the outer housing mounting ring. The mandrel attached to the central carrier directly supports the rotating ring gear, offering a structurally stiff and strong overall solution. The left part of the new gearbox housing remains linked to the MBU but via a shortened intermediate connection at a large radius for optimized load transfer.

4. *Fourth* innovative element is the six stationary shafts supporting six drive pinions (D2) and six planet gears, together with six separate torque shafts connecting each matching planet and outer gear pair. The stationary shafts (three short, and three longer) are

firmly pressed inside the central carrier creating a structurally strong and stiff interface connection.

Essential part of this solution is further that it splits the planet support and torque transfer functions through applying a separate torque shaft for each drive pinion & planet gear assembly. The torque shafts in turn provide a mechanical linkage between the drive pinion and the planet gears. This is achieved with the planets via a crimp connection. The shaft-outer-gear mechanical linkage is via an intermediate flange supplemented by a shrink fit element in between flange and planet gear. A stationary support shaft & torque shaft combined solution further offers favourable low materials fatigue performance compared to a rotating shaft absorbing both bending moments and torque transfer loading.

5. Fifth innovative feature is that the stationary shaft plus *central-carrier-support-solution* eliminates the negative impact of otherwise unavoidable anti-clockwise shaft-gear torques. These moments arise from the gear transmission (sprocket wheel, drive pinion, planet gears and sun gear, D1, D2, D3, D4) and is an inherent but not always recognized phenomenon for stepped planetary gearboxes. The problem itself is not easy to solve, especially for alternative solutions with rotating shafts and bearings between the gears. If not addressed, it can compromise the integrity and life of the gearbox.

6. *Sixth* innovative element is the double row of gears in two rotational planes at the stepped gearbox output side. This feature allows higher step-up ratios compared to an equivalent size stepped planetary gearbox but with a single row of output gears and again six planets. One main contributing reason is here that for a given ring gear pitch circle the maximum achievable step-up ratio goes down with increasing planets number. Another main contributing factor putting a limit to the maximum step-up ratio of ‘conventional’ stepped planetary gearboxes is that the outer gear circles could either touch or overlap each other, both functionally impossible.

7. *Seventh* feature is flexible linkage of each individual drive shaft with a matching outer gear. This innovative arrangement allows slight movement of these gears out of their plane of rotation.

8. The eighth additional feature involves a hollow sun gear that fits loosely over the tapered parallel planet. This dual function arrangement serves both as a support shaft for the parallel planet and sun gear, and as a drive shaft that transmits the output torque from the sun gear to the input side of the planet. The sun gear has a flexible mechanical connection to the axle, and the overall arrangement eliminates the need for 'own' sun gear bearing(s). A mutually important advantage is that it creates a 'floating' sun gear through controlled coupling flexibility. This flexibility characteristic here means torsional stiffness for optimum torque transfer, plus only minimal allowed axial movement, and finally some angular and parallel movements are allowed as essential..

9. The ninth additional feature relates to the opposite spiral shape when using helical teeth, for the two rows of planetary gear and the sun gear (on the sun gear, two planets rotate in succession, so the sun gear axis is longer). This measure ensures optimal

interaction and load distribution within this complex dynamic subsystem, where six gears move simultaneously in two planes on the sun gear. At the same time, it is intended to minimize axial movements due to balancing axial loads on the sun gear.

10. The overall solution *ten,* a combination of *Seven*, *Eight*, and *Nine* is essential for optimal load transfer within this dynamic sub system

11. *Eleven and final*, The mass of the gearbox to an estimated ~ 90 tons (+ or – 15%).

The MergedGear concept fits into the current value chain, as is usual for the (offshore) wind industry. The design is based on an accumulation of state-of-the-art proven technologies from tier-one supply chain partners combined with one new key element, the MergedGear gearbox.. With MergedGear, the total powertrain solution for the future MMW turbines (12MW +) remains very compact, competitive in mass and highly scalable.

This unique innovative drivetrain encompasses all criteria of a successful innovation. It includes one key innovation limiting supply chain cost and risk. All other individual components and system solutions incorporated are known and/or already deployed in the wind industry.

The configuration offers excellent scalability capabilities for facilitating expected future scaling trends towards 16 - 20MW+ name plate capacities with matching rotor sizes.

MergedGear Gears, Rotation and Torque

VerVent 4.0 MergedGear			
Specification Wind Turbine		**12MW**	**20 MW**
Reference wind speed (input)	*m/sec*	11,5	11,5
Power Coefficient	0	7,5	7,5
CP (Betz table) aerodynamic efficiency	%	48%	48%
Assumed total system losses Nacelle	%	14%	14%
Diameter rotor incl. blades	*m1*	215	270
Rated GrossPower	*MW*	14	22
Rotational Speed Rotor (nominal)	*rpm*	7,7	6,1
Power at reference wind speed	*kW(h)*	16.233	25.601
Torque at reference wind speed	*kNm*	17.402	34.464
Assumed total system losses Nacelle	*%*	14%	14%
Stage 1 Gearbox		**12MW**	**20MW**
Ring gear (sprocket with internal teeth)	*D1*	3.640	4.368
Drive Pinion (rondsel)	*D2*	740	888
Ratio step 1		4,92	4,92
Rotation step 1	*rpm*	33,4	30,0
Planet gear	*D3*	2.280	2.736
Sun gear	*D4*	612	736
Torque Sun Gear		950	1.885
Ratio 1 * Ratio 2		18,33	18,29
Rotation step 2	*rpm*	125	112
Second Stage Gearbox, Parallel			
Planet gear	*D10*	2.127	2.731
Number of teeth gearing		162	169
Pinion (input for Generator)	*D11*	486	614
Number of teeth gearing		37	38
Tip Diameter	*mm*	519	655
Ratio step 3		4,4	4,4
Rotation Generator	*rpm*	546	496
Torque Generator	*kNm*	217	424
Overall ratio of the Gearbox		80	81

MergedGear Gears and Bearings

First Part: stepped planetary of the Gearbox

D1: The Ring gear (sprocket internal teeth)

- S- shape teeth
- Bearing 1: tapered roller bearing, double row, SKF or equivalent

D2: Drive Pinion

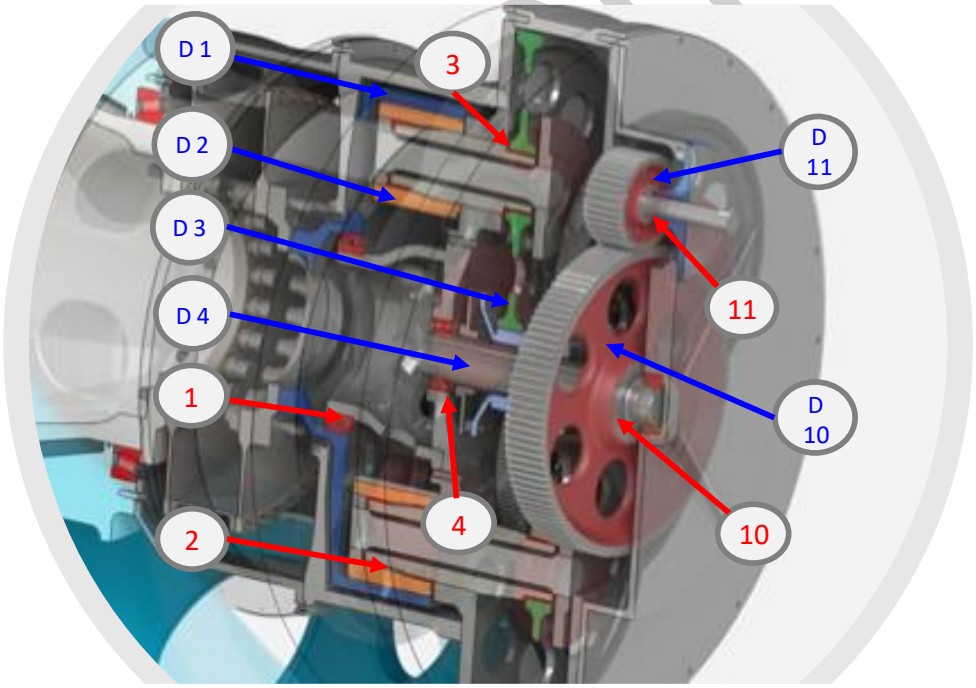
- S- shape Teeth
- Bearing 2: journal bearings

D3: Planet gear

- S- shape teeth
- Bearing 3: journal bearing for absorbing axial and radial forces

D4: Sun gear

- The sun gear has two bearings. Choices must be made from two types of bearings: “adjustable” journal bearings and / or asymmetrical spherical roller bearings
  - Bearing 4: asymmetrical spherical roller bearing to support the rear bevel gear shaft, Schaeffler Technologies, Standard 24072 or equivalent.
  - Bearing 10: adjustable journal bearing



Second Part: parallel step of the gearbox

D10: Planet Wheel

- S-Shape teeth
- Bearing 10: same as Bearing 10 Sun gear

D11: Drive Pinion

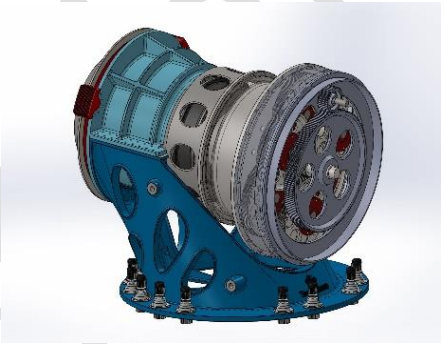
- S-Shape teeth
- Bearing 11: adjustable journal bearing

MergedGear “As it Is”

MergedGear is based on the VerVent Patent P100381PC00 (pending). That is also the base of VerVent’s Megatorque 20, inventor for VerVent: Mr. Eize de Vries. Concept development and design of MergedGear: VerVent, Mr. Edzo de Vries and Mr. Hans Bais.

VerVent performed the product development of the MergedGear, a Horizontal Axis Wind Turbine Drivetrain concept suitable for power capacity configurations up to 20MW+ as complete and as accurate as possible, based on literature research, market references and the expertise of the people who have worked on this development, and who are associated with this development process.

All Information provided in the VerVent documentation, during meetings, both in oral and written, is provided “as is” and the provided Information does not grant any warranty, guarantee, or representation with respect to any Information disclosed prior and during commercial processes, whether with respect to the accuracy, adequacy, or suitability for any particular purpose, either expressed or implied, of such Information.



The HAWT / Megatorque and MergedGear patents

The designs of the MegaTorque and MergedGear 20 concepts are the intellectual property of VerVent B.V. The design, technical specification and innovation are described in three patents.

The first patent is the VerVent bevel gear transmission.

The two other patent concern:

A change in the layout of the drivetrain and optimization of the protection of the gearbox.

An extensive new compact lightweight design with at least 12 patentable features and a new integration of the planetary and bevel gearbox. This innovation makes the high-speed generator possible.

The designs of the Megatorque and MergedGear 20 concepts are proprietary intellectual property of VerVent B.V. The design, technical specifications and innovation are described in three patents. The first of these is EP 3 027 902 B1: Wind Turbine VerVent 1.0, where the innovation and main claim is the bevel gearbox. Second, there are P100349PC00: Wind Turbine VerVent 3.0 and P100381PC00: Wind Turbine Vervent 3.1.

Contact

If you have any questions, comments, or remarks about the gearbox or the points we have mentioned, please do not hesitate to contact us.

VerVent is a subsidiary of Sustainable Business Investment BV and part of the not-for-profit company Stichting ATO.

www.vervent.nl
www.megatorque.eu
www.ato.nl (in Dutch)

VerVent BV
P.O. Box 16
1740 AA Schagen
The Netherlands
info@vervent.nl

Associate Partner USA
Lockwood Hill Associates
Jan Willem van der Werff
+1 513 312 3638
jw@lockwoodhillassociates.com