Forschungsbedarf für die Optimierung der Energiedichte und die weitere Erhöhung der Zuverlässigkeit von WEA-Antriebssträngen

Dezember 2013 / Matthias Deicke
1. **Company Profile**  
   Facts and figures

2. **LCoE**  
   Design Drivers

3. **HybridDrive Design**  
   Concept

4. **HybridDrive Project**  
   How we address LCoE

5. **Prototype HybridDrive**  
   Prototype testing

6. **Prototype HybridDrive**  
   Field measurement

7. **Summary**  
   Outlook and Questions
Winergy At a Glance

Mission

“winergy will maintain its position to be the leading supplier of reliable wind drive train components. This will be accomplished through long term partnership with our customers”

Market Position

- Global market leader for drive train components
- More than 70,000 gear units delivered
- Every 3rd wind turbine is equipped with winergy components

Customer Base

Trustful partnership with all major wind turbine OEMs since 1981

Global Footprint

winergy runs production and service facilities in all major markets globally.
## Winergy's History

### Great Achievements for the Wind Industry

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td>First installation of the HybridDrive</td>
</tr>
<tr>
<td>2013</td>
<td>First installation of a journal bearing gearbox</td>
</tr>
<tr>
<td>2012</td>
<td>70,000 gearboxes globally supplied</td>
</tr>
<tr>
<td>2011</td>
<td>Introduction of HybridDrive</td>
</tr>
<tr>
<td>2010</td>
<td>Introduction of Multi Duored gearbox</td>
</tr>
<tr>
<td>2009</td>
<td>Commissioning of new plant in Elgin, IL, USA</td>
</tr>
<tr>
<td>2007</td>
<td>Commissioning of 14 MW test bench</td>
</tr>
<tr>
<td>2006</td>
<td>Foundation of <strong>Wine</strong>rgy Drive Systems Ltd. (Tianjin, China)</td>
</tr>
<tr>
<td>2005</td>
<td>Foundation of <strong>Wine</strong>rgy Drive Systems Ltd. (Chennai, India)</td>
</tr>
<tr>
<td>2003</td>
<td>Introduction of 5 MW gearbox prototype</td>
</tr>
<tr>
<td>2001</td>
<td>Foundation of <strong>Wine</strong>rgy AG</td>
</tr>
<tr>
<td></td>
<td>Foundation of <strong>Wine</strong>rgy Drive Systems Corp. Elgin, IL, USA</td>
</tr>
<tr>
<td>1991</td>
<td>First offshore wind park with <strong>Wine</strong>rgy components</td>
</tr>
<tr>
<td>1981</td>
<td>Delivery of first specially designed wind turbine gearboxes</td>
</tr>
</tbody>
</table>
Our Customers are Supported by our Global Presence

- Voerde, Germany
- Tianjin, China
- Elgin, IL, USA
- Chennai, India

Production
Service
### Drive train concept

<table>
<thead>
<tr>
<th>Drive train concept</th>
<th>Technical facts</th>
<th>Facts of interest</th>
</tr>
</thead>
</table>
| Planetary stages drive train | Two-/three-stage gearboxes  
Winergy set standards in wind industry  
500 kW – 7.5 MW  
i = 90 … 110  
Average: 1.5 – 2.5 MW | Proven technology  
Highest market share  
Extensive track record (>70,000 gearboxes supplied) |
| Multi Duored | High power density  
Great serviceability  
Up-tower service and maintenance  
Two generators for variable output power and speed  
8-fold power splitting  
i = >>100  
5 MW – 12 MW | First installation of two prototypes in Bard wind turbines  
Duored technology known for many years in industry |
| HybridDrive | Highest overall drive train efficiency  
Modular set-up for easiest serviceability  
Super compact for flexible concepts  
3 MW – 7.5 MW  
i = 35 … 42 | First two prototypes with Fuhrländer/ W2E Wind to Energy GmbH  
3.0 MW prototype installed in a wind turbine in Sep. 2013 |
Winergy's
Most Powerful 14 MW Test Bench
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**LCoE formula:**

\[
LCoE = \frac{\sum_{t=0}^{n} Investments_t}{(1 + WACC)^{t}} + \frac{\sum_{t=0}^{n} O & M \_Costs_t}{(1 + WACC)^{t}} + \frac{\sum_{t=0}^{n} Fuel & CO2 \_Costs_t}{(1 + WACC)^{t}} + \frac{\sum_{t=0}^{n} Energy \_Output_t}{(1 + WACC)^{t}}
\]

LCoE considers costs and electricity generation over the whole lifetime of a power plant.

WACC: Weighted Average Capital Cost  
O&M: Operation and Maintenance  
\( n \): lifetime of power plant
LCoE formula (simplified):

\[
LCoE = \frac{\sum_{t=0}^{n} Investments_t}{(1+WACC)^t} + \frac{\sum_{t=0}^{n} O & M \_ Costs_t}{(1+WACC)^t} + \frac{\sum_{t=0}^{n} Fuel \& CO2 \_ Costs_t}{(1+WACC)^t} \\
= \frac{\sum_{t=0}^{n} Energy \_ Output_t}{(1+WACC)^t}
\]

For renewables **NO** costs of Fuel have to be considered.
LCoE formula (simplified):

\[
LCoE = \frac{\sum_{t=0}^{n} Investments_t}{(1+WACC)^t} + \frac{\sum_{t=0}^{n} O\&M\ Costs_t}{(1+WACC)^t}
\]

\[
- \frac{\sum_{t=0}^{n} Energy\ Output_t}{(1+WACC)^t}
\]
Scaling Rules/Driver for Development

- \( T \sim D^3 \)
- \( \text{Mass} \sim T \)
- \( \text{Investment} \sim \text{mass} \)
- \( \text{Earnings} \sim \text{kWh} \)

\[ \text{Earnings/investment} = \text{ROI} \sim 1/D \]

- \( P \sim D^2 \)
- \( \text{kWh} \sim P \)

axle mass:

\[ m = m_0 \cdot \left( \frac{D}{D_0} \right)^3 \]

Power output:

\[ P = P_0 \cdot \left( \frac{D}{D_0} \right)^2 \]

Source: Andreas Mascioni / Vensys Energy AG / VDI Konferenz 2010 / Entwicklung der getriebelosen Windenergieanlagen
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## HybridDrive Drive Train Matrix

<table>
<thead>
<tr>
<th>Speed</th>
<th>Fixed speed</th>
<th>Variable speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>High speed</td>
<td><a href="#">Asynchronous</a></td>
<td><a href="#">Asynchronous</a></td>
</tr>
<tr>
<td>700 – 2000</td>
<td><a href="#">Squirrel cage</a></td>
<td><a href="#">Squirrel cage and converter</a></td>
</tr>
<tr>
<td></td>
<td><a href="#">Pole changing</a></td>
<td><a href="#">DFIG and converter</a></td>
</tr>
<tr>
<td></td>
<td><a href="#">DFIG and resistor in rotor circuit</a></td>
<td></td>
</tr>
<tr>
<td>Intermediate</td>
<td><a href="#">Asynchronous</a></td>
<td><a href="#">Synchronous</a></td>
</tr>
<tr>
<td>speed</td>
<td><a href="#">Electrically excited generator and converter</a></td>
<td></td>
</tr>
<tr>
<td>100 – 700</td>
<td><a href="#">Squirrel cage</a></td>
<td></td>
</tr>
<tr>
<td>Low speed</td>
<td><a href="#">Asynchronous</a></td>
<td><a href="#">PEM generator and converter</a></td>
</tr>
<tr>
<td>10 – 100</td>
<td><a href="#">Squirrel cage</a></td>
<td></td>
</tr>
<tr>
<td></td>
<td><a href="#">Electrically excited generator and converter</a></td>
<td></td>
</tr>
<tr>
<td></td>
<td><a href="#">PEM generator and converter</a></td>
<td></td>
</tr>
</tbody>
</table>
HybridDrive Concept

© Siemens AG 2013. All Rights Reserved
HybridDrive Concept
HybridDrive
Concept

[Image of HybridDrive Concept]
HybridDrive General Concepts

- 2-stage gear technology
- PMG or EESG medium speed generator

= Winergy HybridDrive

- Low weight
- High efficiency
- Serviceability
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HybridDrive
Installation
Great Serviceability through a Modular Design

- A design comprising three modules allows the individual elements to be simply removed/installed:
  - 1st gear stage
  - 2nd gear stage
  - generator
- The internal service crane of the nacelle can be used to transport these modules instead of employing an external crane.

Benefits

Reduction of service complexity and costs for service work
HybridDrive
Rolling Bearings or Journal Bearings

or

Gearbox with journal bearings

• in operation
• promising results
• customer benefits
• field test running
Drive Train Efficiency

Efficiency

Wind speed / [m/s]

- Geared DFIG
- Directdrive
- Geared PM
- HybridDrive
Annual Energy Yield

 *) specific assumptions are made
HybridDrive Development Process

Wind turbine requirements/specification

V-model

product

OEM prototype test

Prototype AND serial test

e.g. generator test IEC 34

e.g. bearing test

e.g. mainbearing

IDS: integrated Drive System

*) main component or sub system

IDS

nacelle

HybridDrive

nacelle

IDS

system design

system integration

component wind

load calculation

component C

material

material tests

IDS

component*)

part

e.g. Gbx, Gen

e.g. steel

*) main component or sub system

IDS: integrated Drive System
**HybridDrive**
**First Prototype/Facts**

- Project name: T10x
- Type: W2E-120/3fc
- Design: IEC 61400-12 IEC 2a
- Power: 3MW
- Rotor diameter: 120 m
- Tower: Steel 100 m
  Concrete hybrid 140 m
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- Certification guideline GL2010
- Component Certification
- Type test before Sep. 2012

INVERTER NOT WINERGY‘s SCOPE of SUPPLY
Full system test:
- 2 HybridDrives
- Back-to-Back
- Full Load
- Heat Run
- Vibration
- Noise
- Functional Test
- Start-Up Procedure
- Different load points
- All temperatures below specified limits
- System efficiency @ rated point >96 %
- Very high efficiency @ part load
HybridDrive
Vibration Test/T1-T4/Acceleration [m/s²]

<1 m/s² in all conditions

TEST passed
HybridDrive
Noise Measurement

LESS noise than other systems

Rotor speed (vs. Torque)

Torque [kNm]

Characteristic curve P<Pnenn
Characteristic curve P=Pnenn

< 92dB(A)
< 93,1dB(A)
< 93,6dB(A)
< 92,0dB(A)
< 91,8dB(A)
< 91,8dB(A)
< 83,7dB(A)

TEST passed
HybridDrive
Noise Measurement

Schallintensitaetsspektrum
Sound intensity spectrum

1/3 Oktave

max. Value  
72.3 dB(A) by 2500 Hz

next Value  
68.4 dB(A) by 3150 Hz

<table>
<thead>
<tr>
<th>Spektrum Analysis</th>
<th>LWA</th>
<th>LsIm</th>
<th>LWA</th>
<th>Messabstand</th>
<th>Hohe</th>
<th>Breite</th>
<th>Tiefe</th>
</tr>
</thead>
<tbody>
<tr>
<td>L SM +</td>
<td>76.8 dB(A)</td>
<td>91.4 dB(A)</td>
<td>14.6 dB(A)</td>
<td>18.6 dB(A)</td>
<td>0.10 m</td>
<td>2.08 m</td>
<td>1.98 m</td>
</tr>
<tr>
<td>LWA</td>
<td>91.4 dB(A)</td>
<td>72.8 dB(A)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Betriebszustand bei der Messung  
(State of operation at time of measurement)

<table>
<thead>
<tr>
<th>n1 = 12.76 min^-1</th>
<th>Ölviskosität (Oil viscosity)</th>
<th>320 VG</th>
<th>Drehrichtung D1</th>
<th>links (cw)</th>
</tr>
</thead>
<tbody>
<tr>
<td>n2 = 453.30 min^-1</td>
<td>Belastung (Load)</td>
<td>2987.0 kW</td>
<td></td>
<td>rechts (cw)</td>
</tr>
</tbody>
</table>

TEST passed

LESS noise than other systems
Conclusion:

- HybridDrive tests finalized
- Test results as expected or slightly better
  - Heat run test ➔ o.k., as calculated
  - Efficiency ➔ slightly better than calculated
  - Noise ➔ better than calculated
  - Vibration ➔ better than expected

- HybridDrive system test successfully completed.
- First prototype has been installed and commissioned.
- Field measurements have been started.
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HybridDrive
Design Verification

blade sensor
pitch
bearing
DMS
Gbx
Gen
OSS
ESM
yaw
WTC
FC
transformer
wind speed

temperature

LVRT/HVRT
Experience in field measurements:
- Remote control
- six measurement systems available
- 0.1 Hz – 19.2 kHz sample rate
- „all“ kind of sensors
## HybridDrive

### Design Verification

<table>
<thead>
<tr>
<th>Signal</th>
<th>Short name</th>
<th>No.</th>
<th>Sample time</th>
<th>Device</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vibrations</td>
<td>LSS MP1V</td>
<td>1</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
</tr>
<tr>
<td></td>
<td>LSS MP1A</td>
<td>2</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
</tr>
<tr>
<td></td>
<td>LSS MP1H</td>
<td>3</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
</tr>
<tr>
<td></td>
<td>LSS 1H</td>
<td>4</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
</tr>
<tr>
<td></td>
<td>TA MP3V</td>
<td>5</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
</tr>
<tr>
<td></td>
<td>TA MP3A</td>
<td>6</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
</tr>
<tr>
<td></td>
<td>TA MP3H</td>
<td>7</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
</tr>
<tr>
<td></td>
<td>TA 3H</td>
<td>8</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
</tr>
<tr>
<td></td>
<td>IMS Flange MP2V</td>
<td>9</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
</tr>
<tr>
<td></td>
<td>IMS Flange MP2A</td>
<td>10</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
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<tr>
<td></td>
<td>IMS Flange MP2H</td>
<td>11</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
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<td></td>
<td>Geno R MP4V</td>
<td>12</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
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<tr>
<td></td>
<td>Geno R MP4A</td>
<td>13</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
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<tr>
<td></td>
<td>Geno R MP4H</td>
<td>14</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
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<tr>
<td></td>
<td>Genofuss MP5V</td>
<td>15</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
</tr>
<tr>
<td></td>
<td>Genofuss MP5A</td>
<td>16</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
</tr>
<tr>
<td></td>
<td>Genofuss MP5H</td>
<td>17</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
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<tr>
<td>Vibrations</td>
<td>TA MP3V</td>
<td>18</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
</tr>
<tr>
<td></td>
<td>TA MP3A</td>
<td>19</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
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<tr>
<td></td>
<td>TA MP3H</td>
<td>20</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
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<tr>
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<td>TA Zug V</td>
<td>21</td>
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<td>Piezoelectric Accelerometer</td>
</tr>
<tr>
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<td>TA Zug A</td>
<td>22</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
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<tr>
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<td>TA Zug H</td>
<td>23</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
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<tr>
<td></td>
<td>TA Druck V</td>
<td>24</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
</tr>
<tr>
<td></td>
<td>TA Druck A</td>
<td>25</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
</tr>
<tr>
<td></td>
<td>TA Druck H</td>
<td>26</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
</tr>
<tr>
<td></td>
<td>Geno R MP4V</td>
<td>27</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
</tr>
<tr>
<td></td>
<td>Geno R MP4A</td>
<td>28</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
</tr>
<tr>
<td></td>
<td>Geno R MP4H</td>
<td>29</td>
<td>8,92kHz</td>
<td>Piezoelectric Accelerometer</td>
</tr>
</tbody>
</table>

### Signals/standard:
- gearbox torque (LSS)
- gearbox torque (HSS)
- speed/rpm
- WTC:
  - electric power
  - wind speed
  - status generator
  - status brake
  - pitch angle
  - yaw angle
  - ambient
- Temperatures
- Oil pressure
- Vibration

### Option:
- e.g. displacements
HybridDrive
Design Verification / Inhouse and Uptower

Uptower verification of parameters

- Input torque
- Electric power
- Efficiency
- Vibration/noise
- Temperatures
- Displacement

Remote system has been installed / Verification is on-going.
HybridDrive
Design Verification

Uptower verification of parameters

- Input torque
- Electric power
- Efficiency
- Vibration/noise
- Temperatures
- Displacement
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HybridDrive
Drive Train Matrix

**Fixed speed**
- Asynchronous
- Squirrel cage
- Squirrel cage
- Pole changing

**Variable speed**
- Asynchronous
- Squirrel cage and converter
- DFIG and converter
- DFIG and resistor in rotor circuit
- Synchronous
- Electrically excited generator and converter
- PEM generator and converter

**High speed** 700 – 2000

**Intermediate speed** 100 – 700

**Low speed** 10 – 100

Electrically excited generator and converter
PEM generator and converter
PEM generator and converter
HybridDrive
Mechanical Advantages

Without gearbox

with gearbox

Source: Andreas Mascioni / Vensys Energy AG / VDI Konferenz 2010 / Entwicklung der getriebelosen Windenergieanlagen
HybridDrive
First Prototype / T10x / 3 MW / 120 m
Source: W2E Wind to Energy
HybridDrive
Project Review

2009
Start of internal R&D project / ENTSO-E Network Code

2011
First Order: 3 MW customer Fuhrländer
Market introduction on Hanover Fair

2011
First IQPC presentation
Inhouse prototype testing

2012
Delivery of first prototype

2013
Turbine installation (September)
Component Certificate
Husum Wind Fair: Ready for delivery
Fuhrländer bankruptcy
EESG as alternative
Journal bearings
Commissioning (October)

2013
Field Tests (ongoing)

2014
0-Series

2014
2015
Series

11. Dezember 2013 | Page 55
First Winergy HybridDrive for Customer Fuhrländer on Hanover Fair, April 2012
(from left to right: E. Wen Jibao, Angela Merkel und Joachim Fuhrländer)
First prototype installed in September 2013

First kWh produced in October 2013

Source: w2e Wind to Energy
Winergy HybridDrive: Gearbox – Generator System

Test show Promising Results

- HybridDrive test (Gbx and Gen) completed successfully
- Test results as expected or slightly better:
  - Heat run test → o.k., as calculated
  - Efficiency → slightly better than calculated
  - Noise → better than calculated
  - Vibration → better than expected

**Next steps:**
- Journal bearing
- Different types of generators
Winergy HybridDrive:
System Features and Benefits

Outline
(new, with integrated oil tank)

Features / Customer benefit

**HybridDrive:** Torque in -> Electricity out
incl.: Gbx, Gen, OSS, Sensors

**Main data:**
- Torque: 2688 kNm
- Electric power: 3590 kW @ 720 V
- Length: 2935 mm
- Weight: ~ 34 tons (79 Nm / kg)
- Efficiency: >96.5% @ rated power

**Benefits:**
- Completely tested
- System responsibility
- Improved logistic concepts possible
Thank you for your Attention!

Matthias Deicke
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