VGB-Standard

Wind Turbines (WT)

– Definitions and Indicators –

VGB-S-002-05-2015-10-EN

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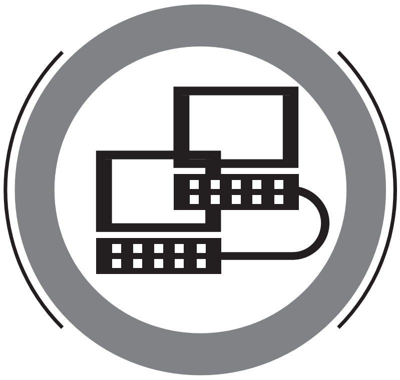

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Change index

VGB Standard	Date of change	Chapter	Description
1st edition 2015, last updated October 2015			Original

Preliminary remarks

People started using wind energy over 3000 years ago. In the time between the middle ages and the 19th century, wind energy use had its first peak. The energy converters were either wind mills, which powered grinding plants etc., or, above all in the USA, so-called western windmills, which were primarily used for pumping water.

High-speed systems with aerodynamically designed blades were first developed in the 1950s. These systems enabled the supply of electrical energy to the public network for the first time.

In recent decades, great progress has been made in the development of high-performance wind turbines. In high-wind areas (coastal areas, high plains and low mountain ranges) plants are now operated from a commercial perspective.

Worldwide, particular importance is attached to wind energy usage for sustainable energy supply, above all due to climate change and its effects. For example, the expansion of wind energy plants has boomed in Germany since 2011, with the result that, at the end of 2014, almost 40 GW of wind power was installed in on and off-shore plants in Germany.

While wind turbines, providing only a small share of the total energy generated in energy supply systems, have up to now primarily been operated around yield and depending exclusively on wind levels, with an increasing share, sustainable operation must in future take into account the technical requirements of the supply system as well as the market and network load requirements. On top of this, as with the previous conventional thermal power plants, maintenance optimisation, amongst other things, is necessary in order to achieve the longest possible service life under optimum operating conditions and therefore to allow the maximum yield from the wind power.

This publication provides the basic definitions and parameters for describing conditions and ensures their consistent usage and therefore their clarity. The basis for this are the publications already issued in the VGB standards series of publications on Basic Terms of the Electric Utility Industry (VGB-S-002-T01), Thermal Power Plants (VGB-S-002-03), Hydropower Plants (VGB-S-002-02) and Photovoltaics (VWEW ISBN 3802206223) in addition to the specific standards and definitions for the wind energy sector.

Essen, October 2015

VGB PowerTech e.V.

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Contents

1 Units

The following units* are used

Term	Unit				
Capacity					
Effective capacity	W	kW[1)]	MW $=10^3$ kW	GW $=10^6$kW	TW $=10^9$ kW
Apparent capacity	VA	kVA	MVA	GVA	TVA
Reactive capacity	var	kvar	Mvar	Gvar	Tvar
Energy					
Active energy	Ws (= J)	kWh[1)] (= 3.6 MJ)	MWh $=10^3$ kWh	GWh $=10^6$ kWh	TWh $=10^9$ kWh
Apparent energy	VAh	kVAh	MVAh	GVAh	TVAh
Reactive energy	varh	kvarh	Mvarh	Gvarh	Tvarh

Prefixes for describing decimal multiples of units.

Prefix	**Abbreviation**	**Factor**	**Numerical value****
Nano	n	10^{-9}	Billionth
Micro	µ	10^{-6}	Millionth
Milli	m	10^{-3}	Thousandth
Centi	c	10^{-2}	Hundredth
Deci	d	10^{-1}	Tenth
Deca	da	10	Ten
Hecto	h	10^{2}	Hundred
Kilo	k	10^{3}	Thousand
Mega	M	10^{6}	Million
Giga	G	10^{9}	Billion
Tera	T	10^{12}	Trillion
Peta	P	10^{15}	Quadrillion
Exa	E	10^{18}	Quintillion

* Comprehensive descriptions of units used in the energy sector can be found in:

- DIN 1301 Units, Part 1 (Dec 85), Part 2 (Feb 1978), Part 3 (Oct 79)
- List of the recommended units of measurement for the power plant sector,
- VGB power plant technology, publication 6/1981, as well as special edition
- Units in the gas and water sector. German Technical and Scientific Association for Gas and Water [DVGW: Deutscher Verein des Gas- und Wasserfaches e.V.], leaflet GW 110, December 1976.
- Thermodynamic tables. K. Raznjevic, VDI-Verlag 1977.

** In the USA 10^9 is referred to as billion and 10^{12} as a trillion.

1) Note:
In accordance with common language usage, “kilowatt” (kW) and “kilowatt hour” (kWh) are also used as units of measurement in this VGB-Standard for radiation energy, amongst other things. In this respect, these units are not electrotechnical units.

Alphabetical index of abbreviations

Symbol	Designation	Chapter
f_W	Energy returned on energy invested	7.3.4
k_b	Usability	7.1.3
k_t	Time availability	7.1.1
k_W	Energy availability	7.1.2
n_t	Time utilisation	7.3.1
n_W	Energy utilisation	7.3.2
n_{We}	Energy utilisation	7.4
P_b	Utilisable capacity	5.17
P_B	Operating capacity	5.6
P_D	Resource supply capacity	5.3
P_m	Average capacity	5.7
P_N	Nominal capacity	5.2
P_{nb}	Non-utilisable capacity	5.18
P_{ng}	Available unused capacity	5.12
P_{ns}	Available unusable capacity	5.13
P_{Nutz}	Plant power	3.3
P_{nvD}	Unavailable resource supply capacity	5.10
$P_{nv\ p}$	Planned unavailable capacity	5.15
$P_{nv\ u}$	Unplanned unavailable capacity	5.16
P_{nvT}	Technically unavailable capacity	5.14
PR	Yield (performance ratio)	7.3.3
P_R	Technical readiness capacity	5.5
P_v	Available capacity	5.8
P_{vT}	Technically available capacity	5.11
P_{vD}	Available resource supply capacity	5.9
t	Time	4.1
t_B	Operating time	4.7
t_D	Effective time	4.3
t_N	Reference period	4.2
t_{nb}	Non-utilisable time	4.13

Symbol	Designation	Chapter
t_{ng}	Available non-usage time	4.9
t_{ns}	Available non-usable time	4.12
t_{nv}	Unavailable time	4.10
$t_{nv\ u}$	Unplanned unavailability time	4.11
$t_{nv\ p}$	Planned unavailable time	4.10.1
$t_{nv\ pp}$	Planned proactive unavailability time	4.10.2
$t_{nv\ pr}$	Planned reactive unavailability time	4.10.3
$t_{nv\ p}$	Planned unavailable time	4.10.1
t_P	Peak time	4.4
t_R	Technical stand-by time	4.8
t_v	Available time	4.5
t_{vD}	Effective available time	4.6
t_{vnD}	Non-effective available time	4.6.1
t_{Vbh}	Full load utilisation hours	4.14
W_B	Operating energy (production)	6.3
W_{Ebr}	Gross energy yield (free energy yield)	6.8
W_{Ene}	Net energy yield (wind farm energy yield)	6.9
W_{Eref}	Reference yield	6.10
W_H	Energy capacity, energy resource supply	6.1
W_{HN}	Energy not utilised	6.4
W_{HR}	Standard energy capacity	6.2
W_{nvT}	Technically unavailable energy	6.7
W_R	Degree of WT plant utilisation	6.13
W_v	Available energy (meteorologi-cally available energy)	6.5
W_{vT}	Technically available energy	6.6
η_a	Degree of utilisation	7.6
η_A	Degree of WT plant utilisation	6.13
η_{AM}	Yield (performance ratio)	7.3.3

2 Wind energy

2.1 The formation of wind

Changes in solar radiation around the world cause changes in global air temperatures and therefore create air pressure differences. High pressure areas form where radiation levels are high and low pressure areas form where radiation levels are low. These large-scale air pressure differences lead to compensatory movements in the air, which we refer to as wind. The diverting force of the earth's rotation - the Coriolis force - also plays a role, this however will not be described in further detail here.

Due to the roughness of the earth's surface and the resulting friction, the wind speed near to the ground is generally lower than in higher layers of air. The influence of the ground roughness extends to a boundary layer with a thickness of between 300 m and 600 m. The development of the speed in this boundary layer can be calculated from the speed at a height of 10 m (v_{10}) using a relatively simply formula.

$$v_h = v_{10}\left(\frac{h}{10}\right)^{g^*} \qquad \frac{m}{s} \qquad \text{Equation 2.1}$$

The boundary layer exponent g* is given various values for various ground surface roughness levels.

Description of the terrain	Exponent g*
Open land with few and minor obstacles, for example, flat grassland and farming land with few trees, prairies, coasts, flat islands, inland lakes, deserts.	0.16
Land with evenly distributed obstacles between 10 and 15 m in height, for example, residential areas, small towns, woodland, shrubbery, small fields with bushes, trees and hedgerows.	0.28
Land with large and unevenly distributed obstacles, for example, city centres, very uneven terrain with a lot of tall obstacles such as trees etc.	0.40

When the boundary layer exponent has been established, the accuracy of equation 1.1 is sufficient for the altitudes useful for technical wind energy usage.

For the installation of wind converters, turbulence caused by obstacles in the vicinity and height must be taken into account. Turbulence can affect the efficiency of a wind converter.

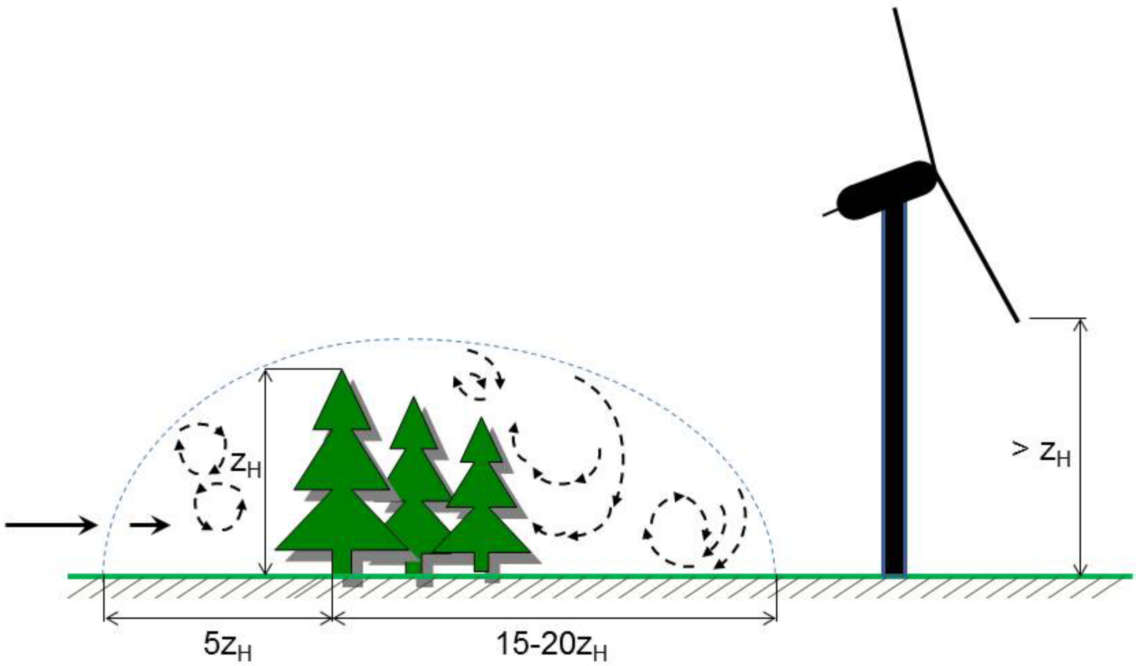

Fig. 1: Area of influence of obstacles at a height of Z_H

2.2 Wind energy

The kinetic energy from the air flow is an indirect form of solar energy, it is therefore a form of renewable energy.

The power contained in the wind P_{Wind} is viewed as kinetic energy

$$\dot{E} = \frac{1}{2} \cdot \dot{m} \cdot v^2 \qquad \text{equation 2.2.1}$$

from the air mass, which flows through surface A within a unit of time.

$$\dot{m} = A \cdot \rho \cdot v \qquad \text{equation 2.2.2}$$

The wind power is therefore calculated as

$$P_{Wind} = \dot{E} = \frac{1}{2} \cdot \dot{m} \cdot v^2 = \frac{1}{2} \cdot A \cdot \rho \cdot v^3 \qquad \text{equation 2.2.3}$$

whereby ρ is the air density.

3 Technology

3.1 Wind energy usage

Today, the energy from the wind is almost exclusively used via wind turbines (WT, also referred to as wind converters). A WT is a system that converts the kinetic energy from the wind into electrical energy [9]. The air flow causes a rotor to turn, which in turn drives an electricity generator through a rotary axis. The use of wind energy has boomed in recent years, particularly in coastal and highland areas. On the one hand this is due to the political focus placed on wind energy as a CO_2-free technology and is now, alongside water power (hydropower utilisation), able to compete with conventional methods of generating electricity. However, wind energy usage is also not an unproblematic form of energy production: the negative impact on the landscape, the acoustic and visual disturbance caused by the movement of the rotors and the impact of the wind turbines and its infrastructure on plants and animals must be accepted. This is often reflected in authorisation conditions.

3.2 Construction forms

The key system components of wind turbines include:

- Rotor
- Drive train (generator, rotor shaft, rotor bearing, brake and, if applicable, gearbox)
- Tower
- Foundation
- Control electronics
- Cabling
- Yaw system
- Wind measurement sensors
- Lightning protection
- Cut-off device
- Speed regulation
- Other safety systems

The turbine types available on the market are differentiated by axis direction between horizontal and vertical axes.

Horizontal axis turbines with horizontal main shafts are more efficient than vertical axis turbines with vertical main shafts. With the help of a yaw wind vane (passive yaw system) the horizontal axis turbines position themselves at an ideal angle to the wind. In comparison to horizontal axis systems, vertical axis turbines run more smoothly, meaning noise emissions can be reduced. For this reason, they are particularly suitable for areas close to residential developments.

Nonetheless, many locations within residential areas are simply not suitable for small wind turbines, because there is no free and even flow of wind through them due to the building developments. These unfavourable wind conditions, i.e. low wind speeds alongside increased turbulence, result in low electricity yields. A further important criterion which is often an obstacle to operating a plant in built-up areas is noise protection, as small-scale wind turbines can often exceed the prescribed noise levels in spite of their small size.

3.3 Plant power

The mechanical power which a plant can, at most, generate from the wind energy is derived from Betz's law:

$$P_{Nutz} = \frac{\rho}{2} \cdot A \cdot v^3 \cdot 0{,}593 \qquad \text{equation 3.3.1}$$

P_{Nutz} is the mechanical power that a rotor can supply to the downstream components such as gears or the generator.

ρ is the air density through which the rotor turns. The air density shows the mass contained in a certain volume. The air density itself depends on the factors air pressure, temperature and air humidity. The air is most dense at ground level. The decreases as the altitude increases. The air density fluctuates between 1.0 kg/m³ and 1.4 kg/m³ in the area from 0 m to 1,000 m. The standard air density is 1.225 kg/m³.

A is the area the air flows through. With a conventional wind turbine, as well as with the high-efficiency wind turbine, there is circular area which is calculated as follows:

$A = \pi \cdot \frac{d^2}{4}$, where d is the diameter (DW) of the circular area. equation 3.3.2

v is the wind speed. It should be noted that the wind speed is entered into the formula to the power of 3.

0.593 is the Betz coefficient. This states that no more than 59.3% if the wind energy can be utilised. If one were to attempt to utilise all of the wind's energy, the wind speed behind the rotor would be 0, and the wind would accumulate in front of the turbine and avoid the rotor.

The value 0.593 is only achieved with completely lossless power utilisation and is thus only a theoretical value. Power coefficients are lower in practice, for systems with good blade profiles they are between 0.2 and 0.5.

The mechanical power is, however, not the same as the electrical power.

Friction losses in the gearbox and in the generator are converted into heat and dissipated into the environment. We talk of the degree of efficiency η which is calculated as follows:

$$\eta = \frac{P_{ab}}{P_{zu}}$$

P_{zu} is the supplied power; therefore P_{Nutz}.

P_{ab} is the discharged power; therefore the electrical power.

The degree of efficiency η is approximately 0.9 and therefore reduces the maximum possible yield by around 10%.

3.4 Reference WT

Alongside the factors plant power and degree of efficiency, determining wind potential (6.11) and energy yields (6.8ff) for wind turbines in a location forms the basis for the planning, project development and financing of wind energy projects. In this context, the reference WT is an existing WT whose operating results can be used as reference data for determining energy yield in order to verify the calculation method.

4 Time related terms

Time is generally understood as a time period T. The time period (reporting, reference and observation time period) is a time period with a factual relation, which can be composed of several partial time periods which must not necessarily follow on from one another directly. The respective time period under observation must always be clearly marked.

Designation	Symbol	Definition
4.1 Time	t	The time is a period of time which represents the duration of a process.
4.2 Reference period	t_N	The reference period is the total reporting period, without any interruption (calendar time, e.g. day, month, quarter, year). The reference period can be divided up into several time periods such as effective time, non-effective time, peak time, off-peak time.
4.3 Effective time	t_D	The effective time is the sum of all time within a time period under observation during which energy production using the natural supply of renewable energy was possible or could be made possible with the WT under observation.
4.4 Peak time	t_P	The time with the highest demand and therefore the highest network load is referred to as the peak time. Detailed are given in the VGB-Standard VGB-S-002-T-01.
4.5 Available time	t_v	The available time is the time period during which a plant or part of a plant can or could convert or transmit energy on the basis of its technical condition, regardless of the level of power that can be attained. This is the difference between the reference period and the unavailable time. $t_V = t_N - t_{nv}$
4.6 Effective available time	t_{vD}	The effective available time is made up of the available time periods during which the natural supply of renewable energy was possible or could be made possible with the WT under observation. $t_{vD} = t_v - t_{vnD}$ or $t_{vD} = t_N - t_{nv} - t_{vnD}$

Designation	Symbol	Definition
4.6.1 Non-effective available time	t_{vnD}	The available time without available resource supply is the portion of the available time during which energy production is not or would not be possible due to an unplanned natural supply of renewable energy. This portion of time can be determined for WTs for: - The portions of time during which the available resource supply does not or would not facilitate energy production are determined from the wind levels at the location of the WT under observation - For these portions of time, times during which the WT is technically unavailable (unavailable time) must be excluded.
4.7 Operating time	t_B	The operating time is the time period during which the plant or a part of a plant converts or transmits energy. The operating time begins with the plant or part of the plant being connected to the network and ends with it being disconnected. In this respect, start-up and shut-down times for energy conversion systems without useful energy output do not count towards the operating time.
4.8 Technical stand-by time	t_R	The technical stand-by time is the period of time in which a plant or part of a plant is, in technical terms, ready for operation regardless of the available supply, but is not in operation. Note: During the technical stand-by time, it must be possible to start up the plant in accordance with the manufacturer's or operator's specifications. In this respect, start-up and shut-down times up to synchronisation count as operational availability times.

Designation	Symbol	Definition
4.9 Available non-usage time	t_{ng}	The available non-usage time is the time period during which a plant or part of a plant is available but not in use and/or cannot be used due to exterior influences (see Appendix 1). $t_{ng} = t_V - t_B$ $= t_R + t_{ns}$
4.10 Unavailable time	t_{nv}	The unavailable time is the time period during which a plant or part of a plant cannot be operated due to the technical condition of the plant or plant part for reasons within the plant or reasons which cannot be influenced by the operational management. $t_{nv} = t_N - t_V$ The technically unavailable capacity is composed of a planned and an unplanned part. The first of these is divided into a proactive (which can be influenced by the operator) and a reactive (which cannot or can only partially be influenced by the operator) part. $t_{nv} = t_{nv\ p} + t_{nv\ u}$
4.10.1 Planned unavailable time	$t_{nv\ p}$	The planned unavailability time is the time period in which a plant cannot be operated for technical reasons due to an event in the future.
4.10.2 Planned proactive unavailability time	$t_{nv\ pp}$	The planned proactive unavailability time is the part of the planned unavailability time that can be postponed by more than 12 hours.

Designation	Symbol	Definition
4.10.3 Planned reactive unavailability time	$t_{nv\ pr}$	The planned reactive unavailability time is the part of the planned unavailability time that cannot be postponed or can only be postponed by up to 12 hours.
4.11 Unplanned unavailability time	$t_{nv\ u}$	The unplanned unavailability time is the time period in which a plant cannot be operated due to an unexpected event.
4.12 Available non-usable time	t_{ns}	The available non-usable time is the time period during which a plant or part of a plant cannot be used due to outside influenced although the plant itself is functional ("outside influence time").
4.13 Non-utilisable time	t_{nb}	The non-utilisable time is the sum or the non-available time (4.104.10) and the available non-usable time (4.12). $t_{nb} = t_{nv} + t_{ns}$
4.14 Full load utilisation hours	t_{Vbh}	The full load utilisation hours are calculated as a quotient from the energy in a certain time period and the nominal capacity in the same time period. $t_{Vbh} = \frac{W}{P_N}$

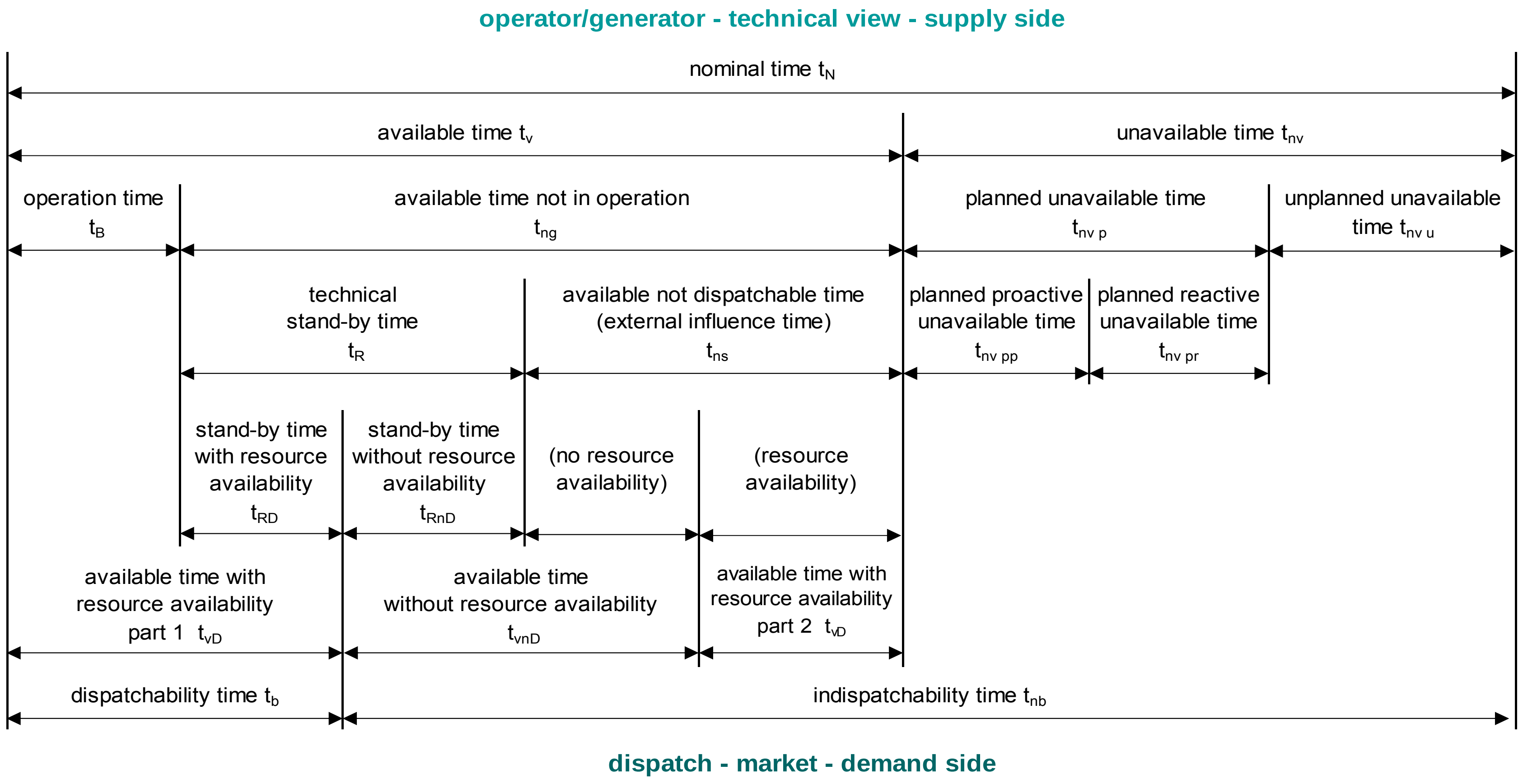

Fig. 2: Diagram to illustrate time related terms

5 Capacity related terms

The capacity is the energy produced per time unit. If there is no option to take a direct performance measurement, the performance P is calculated from the energy W and the time t.

$$P = \frac{W}{t} \qquad \text{Equation 5.1}$$

In the following, capacity refers to the effective electrical capacity.

5.1 Power curve

The power curve shows the relationship between the electrical power supplied (effective capacity) and the wind speed. This can be calculated from the technical data or can be determined through measurements in the actual wind field.

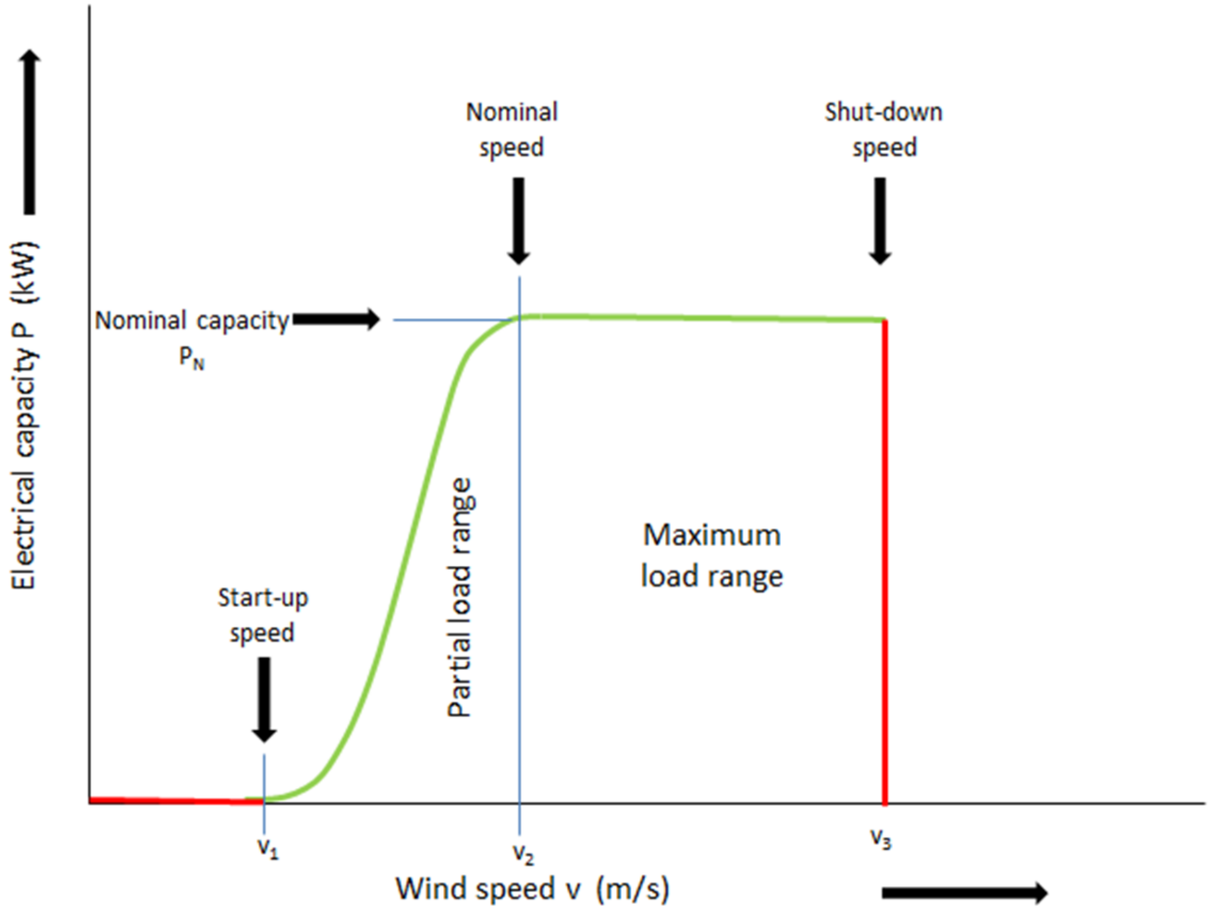

Fig. 3: Power curve of a WT

v_1 When the start-up wind speed is reached, the WT's nacelle is turned towards the wind and the rotor begins to turn. When the synchronisation speed has been reached stably, the WT is connected to the network.

v_2 The nominal wind speed is the speed at which the nominal electrical power is reached.

v_3 When the shut-down wind speed is reached the WT is shut down, the rotary blades are turned away from the wind.

Between v_1 and v_3 the wind supply is therefore at a level that allows for electricity production using the WT. The available resource supply time, available resource supply capacity and available resource supply energy relate to these wind speeds.

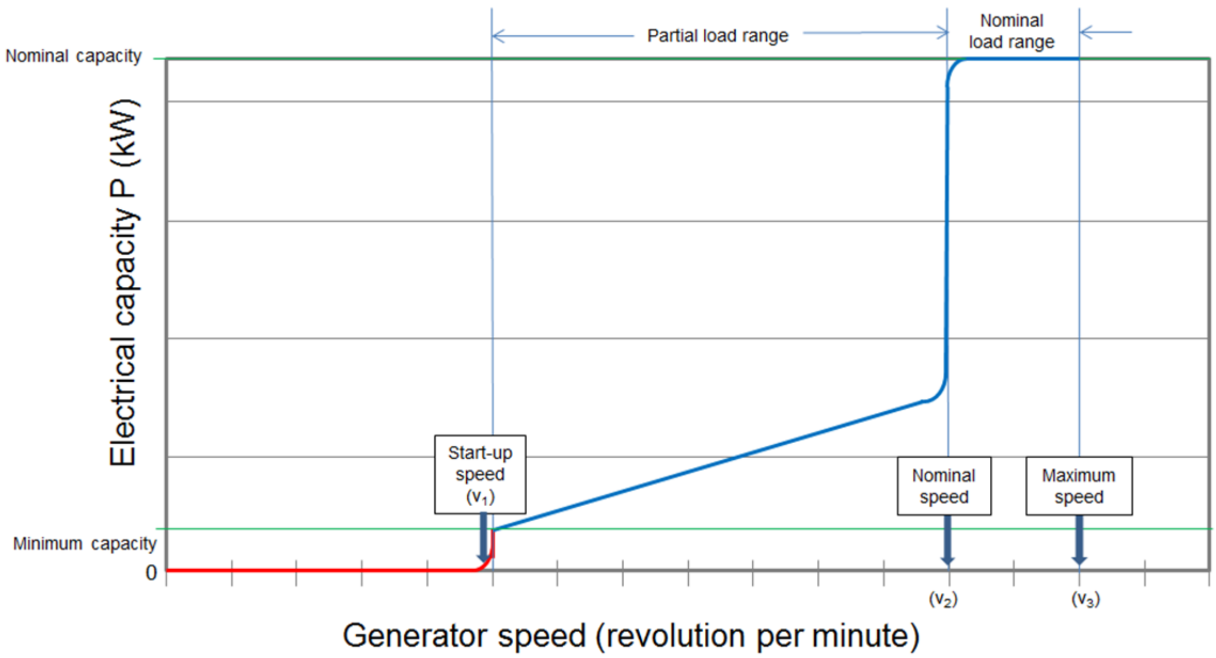

Fig. 4: Generator speed characteristic curve for a WT

Designation	Symbol	Definition
5.2 Nominal capacity	P_N	In principle, the nominal capacity is defined in the VGB-Standard VGB-S-002-01. The nominal capacity of a WT refers to the maximum permanent capacity to be supplied. This is achieved when the nominal speed is reached. From the equation 3.3.1. $P_{Nutz} = \frac{\rho}{2} \cdot A \cdot v^3 \cdot 0.593$ the influence of air density ρ results from the WT's capacity. As, alongside the influencing factors air pressure and air humidity, the air density also depends on air temperature, there can be significant differences in the operating capacity for summer and winter.
5.3 Resource supply capacity	P_D	The resource supply capacity is the planned capacity that can be achieved at a wind speed in the power curve in accordance with figure 8.
5.4 Minimum capacity		The minimum capacity for a WT (Fig. 4) is the capacity upon reaching the start-up speed. The rotor begins to turn and when the synchronisation speed has been reached stably, the WT is connected to the network. The start-up speed is 3 to 4 m/s.
5.5 Technical readiness capacity	P_R	The technical readiness capacity is the capacity available at a given time beyond the operating capacity, and which is not required to cover the load in the electrical network from network or power plant operators. It is calculated as the difference between the available supply capacity and the operating capacity, or as the difference between the supply and the sum of the operating capacity and the unavailable resource supply capacity. $P_R = P_{vD} - P_B = P_D - (P_B + P_{vnD})$

Designation	Symbol	Definition
5.6 Operating capacity	P_B	The operating capacity of a WT is the actual operated capacity at a given time and can be lower than the resource supply capacity.
5.7 Average capacity	P_m	The average capacity of a WT is the quotient from the operational energy W_B within a time period under observation and the corresponding reference period. $$P_m = \frac{W_B}{t_N}$$ The average capacity of a WT can also be calculated as a quotient from the energy capacity W_H and a time period under observation.
5.8 Available capacity	P_v	The available capacity is the capacity that can be achieved on the basis of the plant's technical and operational condition. The available capacity is the sum of the operational capacity and the unused capacity or the difference between the nominal capacity and the unavailable capacity. $$\begin{aligned} P_V &= P_B + P_{ng} \\ &= P_N - P_{nv} \end{aligned}$$
5.9 Available resource supply capacity	P_{vD}	The available resource supply capacity of a WT is the capacity that can be achieved at a given time under the applicable meteorological conditions (wind supply/temperature/air density), minus the capacity restrictions caused by technical unavailability. This corresponds to the resource supply capacity, as long as the available capacity is higher. Otherwise it is the same as the available capacity.

Designation	Symbol	Definition
5.10 Unavailable resource supply capacity	P_{nvD}	The unavailable resource supply capacity is calculated from the difference between the available capacity and resource supply capacity.
5.11 Technically available capacity	P_{vT}	The technically available capacity of a WT is the capacity that can be achieved at a given time under the given technical conditions, independently of the wind resource supply. The is equal to the nominal capacity (maximum capacity) or lower by the amount corresponding to the breakdown of plant parts at a certain time.
5.12 Available unused capacity	P_{ng}	The available unused capacity of an energy production unit is the portion of the available resource supply capacity which is not in operation. $P_{ng} = P_V - P_B$
5.13 Available unusable capacity	P_{ns}	The available unusable capacity is calculated from the difference between the unused and the readiness capacity. $P_{ns} = P_{ng} - P_R$
5.14 Technically unavailable capacity	P_{nvT}	The technically unavailable capacity (current value, time must be given) is the difference between the nominal capacity (maximum capacity) and the technically available capacity. $P_{nvT} = P_e - P_{vT}$ The technically unavailable capacity is composed of a planned and an unplanned part.

Designation	Symbol	Definition
5.15 Planned unavailable capacity	$P_{nv\ p}$	The planned unavailable capacity is the capacity or the proportion of capacity which is not available at a given time due to future action to be taken. This is divided into a proactive and a reactive part in accordance with the time related terms.
5.16 Unplanned unavailable capacity	$P_{nv\ u}$	The unplanned unavailable capacity is the capacity unavailable at a given time due to disruptions, damage or other unexpected events.
5.17 Utilisable capacity	P_b	The utilisable capacity of an energy production unit is the sum of the operating capacity and the operational readiness capacity. $P_b = P_B + P_R$
5.18 Non-utilisable capacity	P_{nb}	The non-utilisable capacity of an energy production unit is the sum of the unavailable capacity and the unusable capacity. $P_{nb} = P_{nv} + P_{ns}$
5.19 Reactive capacity		The reactive capacity is the electrical capacity which is needed to develop magnetic fields (e.g. in engines and transformers) or electrical fields (e.g. in capacitors, cables, wires) and which does not contribute to the usable energy.
5.20 Apparent capacity		The apparent capacity is the geometric sum of effective capacity and reactive capacity. It is decisive for the design of electrical systems, amongst other things.

6 Energy related terms and coefficients

The energy related terms refer to the values measured at the generator terminals. The gross energy is measured here during operation. The net energy is calculated by subtracting the auxiliary capacity requirements including the generator transformer losses.

The description “gross” or “net” should always be given.

A range of energy related terms from the electricity industry are listed in VGB-S-002-T-01;2012-04.DE [3]. For WTs the following terms in particular apply, whereby it must be noted that there is not always a corresponding commonly used energy related terms for all capacity related terms. Corresponding definitions are therefore not given. The nominal energy W_N defined in VGB-S-002-T-01;2012-04.DE [3], amongst others, is only applicable to a limited degree for WTs due to the operating mode's dependency on the available resource supply (meteorological influence). For this reason only a selection of relevant terms is given here.

Designation	Symbol	Definition
6.1 Energy capacity, energy resource supply	W_H	The energy capacity for a WT is the electrical energy that can be generated with the respective given meteorological capacity P_{vD} within a time period t. $W_H = \int P_{vH} \cdot dt$ The energy capacity indicates how much capacity a power plant actually supplies from its installed nominal capacity on average over the year. This it primarily dependent upon - The fluctuating wind resource supply - The location of the TW (topology) - The state of the art of the WT Relevant influential factors are in particular: - The capacity coefficient - The rotor diameter - The average wind speed - The roughness of the terrain Example: Onshore WTs in Germany have an average energy capacity of around 14%. This means that a wind turbine in Germany with a 2 megawatt nominal capacity would in reality only supply 14% of this nominal capacity on average over a year, but with fluctuations of 0 to nearly 2 MW. This means the WT produces as much electricity as a 0.28 megawatt generator that produces electricity constantly. Note: The energy capacity is usually determined for a reporting period (e.g. months, half years, years). For wind parks, the meteorologically available capacity of a WT is influenced by the wind shadow effect from other WTs.

Designation	**Symbol**	**Definition**
6.2 Standard energy capacity	W_{HR}	The standard energy capacity (SAC) of a WT is the energy capacity in a normal year. Note: In simple terms the standard energy capacity can be calculated as an average production value from a long series of operating years - possibly also as a moving average. Here it must be noted that technical failures lasting a long time can result in unusable values for the standard energy capacity.
6.3 Operating energy (production)	W_B	The operating energy or production is the electrical energy actually generated within a time period (meter readings). $W_B = \int P_B \cdot dt$
6.4 Energy not utilised	W_{HN}	The energy not utilised of a WT is the difference between the energy capacity and production (operating energy). $W_{HN} = W_H - W_B$ Note: The energy not utilised of a WT can, amongst other things, be caused by a technical defect in the WT or through outside influences, in particular authorisation conditions.

Designation	Symbol	Definition
6.5 Available energy (meteorologically available energy)	W_v	The available energy of a WT is the energy which can be generated on the basis of the available capacity P_v (5.8). $$W_V = \int P_V \cdot dt$$ Note: For WTs connected to the grid, the available energy and the operating energy are practically identical. A difference between the operating energy and the available energy can only occur through a temporary power failure in the time period under observation.
6.6 Technically available energy	W_{vT}	The technically available energy is the energy that could possibly be generated on the basis of the technically available capacity P_{vT} (5.11). $$W_{vT} = \int P_{vT} \cdot dt$$
6.7 Technically unavailable energy	W_{nvT}	The technically unavailable energy is the energy that it would not be possible to generate on the basis of the technically unavailable capacity P_{nvT} (5.14). $$W_{nvT} = \int P_{nvT} \cdot dt$$
6.8 Gross energy yield (free energy yield)	W_{Ebr}	The gross energy yield is the average energy production expected within a year from one or more WTs, which is calculated on the basis of the wind potential detected at the hub height with a specific power curve and without any reductions.

Designation	Symbol	Definition
6.9 Net energy yield (wind farm energy yield)	W_{Ene}	The gross energy yield is the average energy production expected in a year from one or more WTs, which is calculated on the basis of the wind potential detected at the hub height with a specific power curve and without any reductions.
6.10 Reference yield	W_{Eref}	The reference yield is the amount of electricity for each WT type, taking into account the respective hub height, which this type would yield in five operating years when erected at the reference locatione.g. within the meaning of the German Renewable Energy Act [EEG: Erneuerbare-Energien-Gesetz] by way of calculation on the basis of a measured power curve.
6.11 Wind potential		The wind potential is the primary energy supply and is calculated from the wind conditions at the location which are indicated through wind field parameters (wind speed, wind power density, wind speed frequency distribution and wind direction) in relation to a height above ground (hub height).
6.12 Wind potential study		A wind potential study serves to provide an initial estimate of a potential wind turbine location. Reference locations and publicly available information from weather stations serve as a basis. In the same way as any available site wind measurements, these allow the wind potential and energy yield projections to be determined.

Designation	Symbol	Definition
6.13 Degree of WT plant utilisation	η_A	The degree of WT plant utilisation is the quotient from the energy (operating energy) generated by the WT within a certain period of time (day, month, half-year, year) and the energy determined from the average wind speed for the reference plant in the same period of time. $\eta_A = \frac{W_B}{W_R}$

7 Availability and utilisation

In general, availability is a measure of a plant's capacity to perform an operational function. For wind turbines, availability is the measure of the ability to produce electrical (effective) capacity. The ability is independent of the actual application.

For comparative or further evaluations it is advisable to establish a boundary line between the WT and the electrical supply system in accordance with their respective responsibilities during operation. The wind farm's boundary line is therefore set at the transition point to the public power network.

Differing definitions of a WT have been established, which, depending on the issue at hand, either take into account or discount influences on the energy production ability. There are various technical terms for these perspectives, of which "availability" is the umbrella term. In the original meaning of the word, availability served the evaluation of the technical quality of a WT. In a broader view, limitations caused by so-called exterior influences which limit the maximum possible power supply are also taken into account (e.g. authorisation conditions, network disruptions), see Appendix 1. Regardless of these technical limitations, it is, in contrast, the volatile wind resource supply that facilitates the operation and therefore also the usability of the WT.

Utilisation is a measure of the actual usage of the WT.

The terms availability and utilisation are quantified through the development of ratios for time, capacity and energy values. In order to avoid misunderstanding, they must always be used with the relevant additional term "time", "capacity" or "energy".

The standard VGB-RV 808 [2] contains a comprehensive presentation of the determination of availability and utilisation parameters for thermal power plants. This system can be adjusted and expanded correspondingly for WTs in order to take into consideration and demonstrate the features that may in part be different.

The following contains a list of selected parameters which take the particular conditions for wind turbines into account.

Designation	Symbol	Definition
7.1 Availability		Availability is the umbrella term for various parameters for quantifying a WT's capacity to generate electrical energy. Distinctions are made between time availability, energy availability and usability. Identification of "availability" is necessary in order to avoid confusion.
7.1.1 Time availability	k_t	The time availability of a WT is the quotient from the availability time and the reference period. $k_t = \frac{t_v}{t_N} = \frac{t_B + t_{ng}}{t_N}$ In the case of limitations, only limitations with 100% of the reference capacity are taken into account.
7.1.2 Energy availability	k_W	The energy availability is calculated as a quotient from the available energy in a time period and the nominal energy in the same time period. $k_W = \frac{W_v}{W_N}$ The energy availability is the comprehensive parameter for overall evaluation of the availability of a WT and facilitates a long-term quality comparison. This takes all plant-related capacity limitations into account.
7.1.3 Usability	k_b	The usability is the quotient from the usable energy and the nominal energy. $k_b = \frac{W_b}{W_N} = \frac{W_N - W_{nv} - W_{ns}}{W_N}$ The (energy) usability is a measure of the energy that the WT can generate on the basis of its technical and operational condition, as well as its condition as affected by external influences including wind.

Designation	Symbol	Definition
7.2 Unavailability		The unavailability is the supplementary value for each "availability" so that the total is calculated from both parts 1. Identification of each "availability" is necessary in order to avoid confusion.
7.3 Utilisation		Utilisation is a measure of the energy that a plant has actually generated.
7.3.1 Time utilisation	n_t	The time utilisation is the quotient from the operating time and the reference period. $n_t = \frac{t_B}{t_N}$
7.3.2 Energy utilisation	n_W	The energy utilisation is also described as the specific energy capacity or energy resource supply. It is the quotient from the production and the theoretical maximum possible energy during uninterrupted operation with nominal capacity, see VGB-RV 808 [2]. Alternatively, it can also be determined as the quotient from the energy capacity of the WT (6.1) and its nominal energy. $n_W = \frac{W_B}{P_N \cdot t_N}$
7.3.3 Yield (performance ratio)	PR	The yield (performance ratio) of a WT is the quotient from the degree of plant utilisation during a time period and the degree of efficiency. $PR = \frac{\eta_A}{\eta_M}$ Note: The yield of a WT is a comprehensive measure of the design, the quality of the main components and the installation of the WT.

Designation	Symbol	Definition
7.3.4 Energy returned on energy invested	f_W	The energy returned on energy invested of a WT indicates how many multiples of the energy used to operate the plant can be generated by the WT during its entire service life (useful life). It is therefore a measure of the unit's profitability.
7.4 Energy utilisation	n_{We}	The energy utilisation is the quotient from the production and the energy capacity of the WT. It can be calculated as the quotient from the energy utilisation parameters and specific energy capacity. $n_{We} = \frac{W_B}{W_H}$
7.5 Availability of a wind farm		The availability of a wind farm is calculated in the same way as the individual availability parameters. Instead of an individual term, the sum of all WT's involved should be used. Alternatively, the parameters for the individual WTs can be used by weighting these with their nominal capacity. This is presented below for the time availability. The nominal capacity values are cancelled out if all of the WTs have the same nominal capacity. $k_t = \frac{\sum P_{N,i} \cdot (t_{B,i} + t_{R,i})}{\sum P_{N,i} * t_N} = \frac{\sum t_{B,i} + t_{R,i}}{\sum t_N}$
7.6 Degree of utilisation	η_a	The degree of utilisation of an energy conversion system is the quotient from the full load utilisation hours and the reference period. $\eta_a = \frac{t_{Vbh}}{t_N}$ Note: A factor that is thematically related to the duration of utilisation is the percentage value of energy utilisation. In contrast to the calculation of availabilities, for the duration of utilisation the excess energy is included.

Appendix 1 External influences[1]

External influences are all external occurrences that affect a wind turbine or wind farm in a way that influences the provision of power/the availability. The plant operator has no influence on the occurrences (e.g. climate, operating conditions).

Limitations to the performance of a WT due to exterior influences, on which the operational management has little or no influence, do not reduce the availability. The capacity limitations caused by exterior influences are defined as available unusable capacity, provided the cause for the loss of performance is one of the events listed below, or a comparable event, and does not involve any technical damage or disruption to the plant (regardless of whether this is available or unavailable).

If external influences cause technical damage or a disruption to the plant, this is unavailability.

Climate	Capacity/energy limitations caused by extraordinary environmental influences, e.g. hurricane (>= wind speed 12)/still air, wind shear, landslide, rough seas (extreme wave heights), lighting (Network/IT failure, fire), snow and ice.
Approval	- Operating conditions due to negative acoustic or visual impact caused by the rotor blades. - Operating condition to protect, for example, birds, bats, fish and whales, etc.

[1] External influence is defined in VGB-RV 808 [13]. The extract reproduced is specific to wind power.

Network restrictions	The wind turbines or the wind farm are distinguished from the grid at the transition point to the public power network. All events which result in the impairment of energy transmission into the power lines, connection points etc. should be classified as exterior influences. – Measures which do not allow the energy to be conducted outside of the area of responsibility of the plant operator (e.g. maintenance works/disruptions in the substations or transmission lines and insufficient transmission capacity) – Measures for the safety or reliability of the electrical supply system, which are initiated by the network operator e.g. TSO redispatch (intraday change of use by the network operator) – Protection trip in the transmission network e.g. due to lightning strike
Lack of staff	Lack of operational readiness due to strike, pandemic, blockades, staffing of the central control room
Other	– Terror attack, police investigation, naval or aviation disaster, earthquake, vandalism, *force majeure* – Open day/public relations work – Additional regulatory conditions with existing operating permit, e.g. increased (impermissible) noise levels, air traffic control – Sabotage, e.g. hacker attack on IT/control

Appendix 2 Event Characteristic Key (EMS)

In recording operating events, depending on the objective, various identification and key systems for event characterisation are used by operators, manufacturers and institutions. The VGB PowerTech Event Characteristic Key System EMS was introduced in 2003 and is intended to replace all national and international event description key systems. The ECK system prevents events being recorded twice or multiple times and therefore also prevents differing evaluations. This ensures there is a clear codification system for analysis.

The EMS system is described in detail in the VGB standards "Technical and commercial parameters for power plants" [2] and "EMS - event characteristic key system (application and key part)" [5].

With regard to WTs, there is in particular a change to the EMS 1 code D2 (external influence without damage) in accordance with the information given in Appendix 1 as a difference.

Appendix 3 RDS-PP

The plant identification system was further developed on the basis of the Identification System for Power Stations (KKS) in the form of the now internationally applicable RDS-PP Reference Designation System for Power Plants and in its initial application phase was specifically specified for wind turbines. The RDS-PP® application guideline developed in this context was created by a VGB PowerTech project group from the work group "Plant identification and documentation" in close collaboration with manufacturers, operators, research institutions and maintenance technicians from the wind energy sector.

The application explanations contain specific recommendations for the use of the reference designation system for identifying technical objects within a system or plant in the wind turbine sector. They must be applied in conjunction with the relevant basic and technical standards, the VGB-Standard B101 and the specialist VGB application explanations B116 D2 and, as of February 2014, VGB-S-823-32-201403.

The application explanations apply to new plants as well as for the subsequent identification of existing wind turbines. They also cover the plant-related infrastructure and transformer stations. They apply to all technical areas across the entire useful life of the plants, from planning through to demolition. It is recommended that they also be used in approval procedures.

The VGB-Standard VGBS-823-32-2014-03-EN-DE is available for use in the following forms:

- Basic (print edition or eBook as a single-user version including Annex 3 and 4 as a pdf file; combined offer: print and eBook) [6]
- Basic package (combined offer: print edition and eBook as single-user version including Annex 3 and 4 as an Excel file) [7]
- Company package (combined offer: print edition, Word file and CL eBook including Annex 3 and 4 as an Excel file) [8]

Evaluations for the unavailability analysis require the previous codification with this RDS-PP plant identification system.

List of abbreviations

BDEW	German Association of the Energy and Water Industries (Bundesverband der Energie- und Wasserwirtschaft)
BGW	German Association of the Gas and Water Industries (Bundesverband der deutschen Gas- und Wasserwirtschaft e.V.)
CO_2	Carbon dioxide
DIN	German Institute for Standardisation
ESHA	The European Small Hydropower Association
IEC	International Electrotechnical Commission
ISO	International Organization for Standardization
MW	Megawatt
ÖNORM	Austrian standard (Österreichische Norm)
TSO	Transmission system operator
VDEW	Association of the Electricity Industry (Verband der Elektrizitätswirtschaft e. V.)
VGB	VGB PowerTech e. V.
WT	Wind turbine

List of illustrations

List of references

[1] DIN 55302
Statistische Auswertungsverfahren, Ausgabe 1970

[2] VGB-S-002-03-2014-06-DE; (previously VGB-RV 808)
VGB-Standard Technische und kommerzielle Kennzahlen für Kraftwerksanlagen

VGB-RV 808
Begriffe der Versorgungswirtschaft, Teil B Elektrizität und Fernwärme, Heft 3 Grundlagen und Systematik der Verfügbarkeitsermittlung für Wärmekraftwerke, Ausgabe 03/2008

[3] VGB-S-002-01;2015-10-DE
Elektrizitätswirtschaftliche Grundbegriffe

[4] Gesetz über Einheiten im Messwesen vom 2. Juli 1969
letzte Ausführungsverordnung: 2. Verordnung zur Änderung der Ausführungsverordnung zum Gesetz über Einheiten im Messwesen vom 12. Dezember 1977, Bundesgesetzblatt Jahrgang 1977, Teil I, Seite 2537

[5] EMS Ereignis-Merkmal-Schlüsselsystem (Anwendung und Schlüsselteil) – eBook, ISBN: 978-3-86875-444-5

[6] RDS-PP – Anwendungsrichtlinie, Teil 32: Windkraftwerke (Grundwerk: eBook, inkl. Annex 3 und 4 als PDF-Datei); ISBN: 978-3-86875-744-6

[7] Referenzkennzeichensystem für Kraftwerke RDS-PP - Anwendungserläuterungen für Windkraftwerke – eBook; ISBN: 978-3-86875-446-9

[8] Reference Designation System for Power Plants RDS-PP - Application Explanations for Wind Power Plants – eBook; ISBN: 978-3-86875-447-6

[9] DIN EN 61400-1
Windenergieanlagen, Teil 1: Auslegungsanforderungen

Alphabetical index of designations

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Technically unavailable energy	W_{nvT}	6.7
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Technically available energy	W_{vT}	6.6
Technically available capacity	P_{vT}	5.11
Technical readiness capacity	P_R	5.5
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Available capacity	P_v	5.8
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