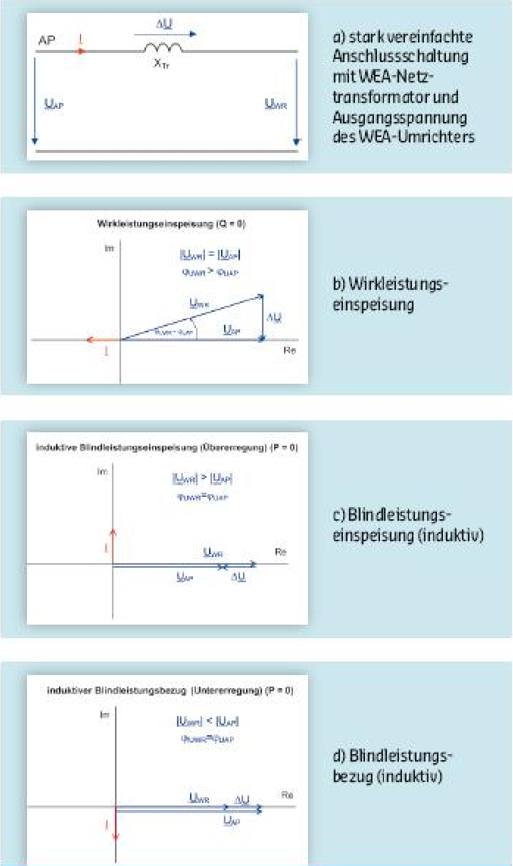
Working like a power plant

The P-Q behaviour of wind power stations has to meet the grid connection rules

Dr. –Ing. Steffen Prinz
Prof. Dr.-Ing. habil. Dietrich Stade



a) stark vereinfachte Anschlussschaltung mit WEA-Netztransformator und Ausgangsspannung des WEA-Umrichters

b) Wirkleistungseinspeisung

c) Blindleistungseinspeisung (induktiv)

d) Blindleistungsbezug (induktiv)

Bild 2: Leistungs-und Spannungsverhältnisse am Anschlusspunkt AP der WEA.

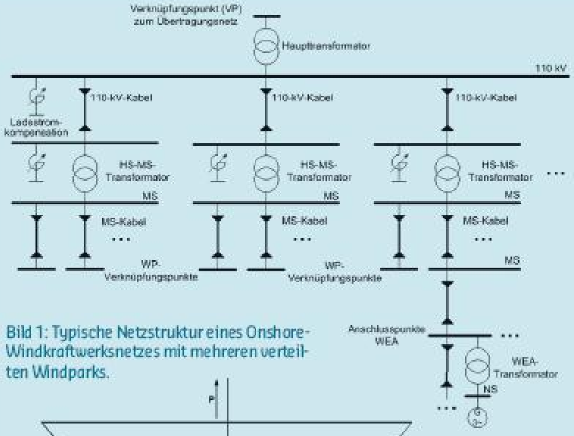


Bild 1: Typische Netzstruktur eines Onshore-Windkraftwerksnetzes mit mehreren verteilten Windparks.

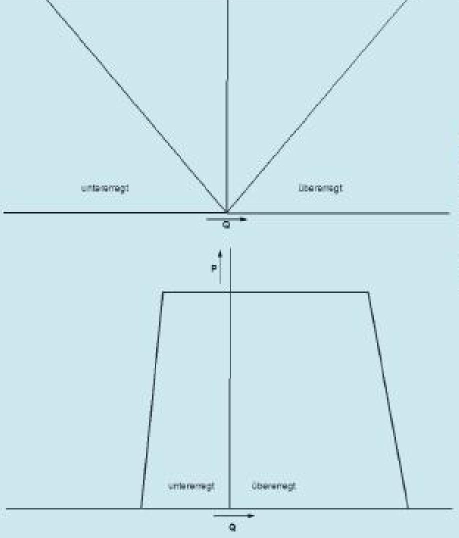


Bild 3: Idealisierte P-Q-Diagramme
a) WEA mit Umrichterspeisung (cos φ-Regelung)

b) Synchrongenerator

1. Introduction

In wind power stations, the electricity is mainly produced with rotating electrical machines. The choice is largely between asynchronous and synchronous generators with

- direct connection to the grid or
- an AC/AC converter as input.

While the practice of previous years was often to employ generator systems which took their excitation power or their reactive power from the mains supply, and which thus, as they fed active power, only had a supportive function for the mains, a gradual change has been made. Now wind power stations compose a grid of their own and have the ability to regulate voltage and reactive power in themselves.

Large on-shore wind energy parks are currently being tested and offer power of several hundred MW, with each individual unit (IPU) producing up to 6 MW, and these require similar operations and fault management as would be the case for conventional power plants producing electrical energy.

Large wind energy parks (also known as wind power stations) will in future make a highly significant contribution to the general electricity supply. They are covered by grid connection regulations [1, 2, 3] which require them to make a contribution to the stability of the mains, supporting the mains grid in case of interruptions such as those caused by a short circuit. Fault ride through will be essential, as switching off the wind power stations when a mains fault occurs would in many cases lead to an inacceptable drop in the level of power produced.

New control strategies coupled with provision of reactive power now make it possible to fulfil the requirements of grid operation under all operative conditions, quite independently of the type of generator in the IPUs and how they are connected to the grid (whether as converter fed synchronous generator or as double fed asynchronous generators).

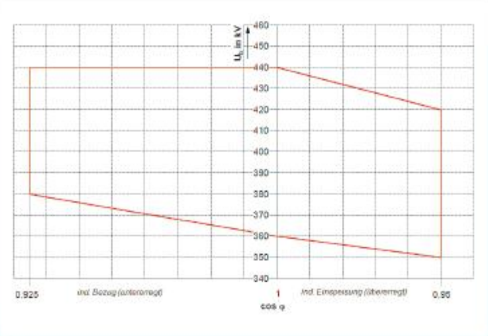


Bild 4: Grundanforderung an die netzseitige Blindlastbereitstellung von Erzeugereinheiten für das Netz. [1]

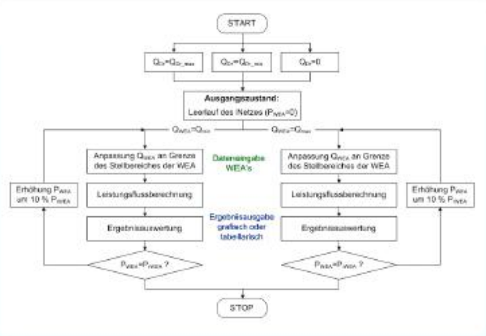


Bild 5: Ablaufplan zur Ermittlung des Netto-Leistungsdiagramms eines Windkraftwerkes.

2. Technical Requirements of the Wind Power stations

The behaviour of the whole system of electricity supply networks is considerably influenced by the stationary and dynamic behaviour of modern wind turbines in wind energy parks which have a total power output of up to and above 100 MW and are directly coupled to the high voltage electricity grids.

At times, wind power stations are now replacing conventional power plants on the principle of power station use in “merit order”. There is no alternative to the option of allowing wind power stations in all cases (normal operation and faults in the electrical grid) to contribute to grid stability and continued functioning of the grid protection system by guaranteeing maintenance of frequency and voltage levels for the grid. The guidelines issued by the grid operators [1, 2, 3, 4, 5] therefore impose the following main requirements on the IPUs and their grid performance.

- Participation in the primary and secondary control system and in the minute reserve system,
- Provision of variable reactive power on the basis of the standard figures for reactive power Q, the displacement factor cos φ and the grid voltage U_N.
- Black start capability,
- No separation of the IPUs from the grid if voltage drops or interrupts appear (for example, as a consequence of automatic restart) within prescribed time and voltage limits, and
- Provision of short-circuit current contribution if there is a short circuit. Also the IPUs must have the ability to raise the stability of the grid under dynamic conditions and to maintain voltage.

The electrical “power-plant-like” behaviour of the wind park which is thus required by the grid operators is to be seen as a system service and is remunerated accordingly.

3. Reactive Power Management in the Wind Power Station Grid

There follows a closer explanation of the basic configuration used in reactive power management of an on-shore wind farm grid, using a typical grid structure. The grid combines a number of wind farms at different sites and with different power, linking them by a 110 kV cable network, and they feed into the transmission supply via one main transformer. Single IPUs usually supply electricity to 30 kV cable networks which are coupled to the 110-kV cable network via a High Voltage to Medium Voltage transformer station.

When drawing up the balance sheet for the reactive power budget of the wind farm grid, the following considerations must be the starting point:

- The voltage dependent reactive load power Q'_C of the 110-kV PVC cable (cross-section 1200 mm, operating capacity 0.26 μF/km) is approximately 1 MVAr/km.
- The current-dependent inductive power requirement of the cables and transformers comes out as $Q_L = 3 \cdot I^2 \cdot \omega L$ and is, for example, in the case of a 380/110-kV main transformer with S_r = 200 MVA and u_k = 14 %, approximately 28 MVAr at rated current.
- Load current chokes are necessary in the 110-kV cable network (see Fig. 1) and at least one of these must be settable or switchable. They

will serve to compensate the reactive power and maintain voltage in the 110-kV network.

- It is also necessary, of course, for the IPUs to offer variable reactive power provision (either inductive consumption or inductive supply) in accordance with their power curve and for this to be used in preserving the supply balance. Converter coupled IPUs will facilitate provision of variable reactive power because this is the way they operate in electrical terms. The DC-AC inverter on the grid side of the converter will set a modifiable voltage $\underline{U}_{WR}$ (variable in magnitude and phase) at the terminals on the low-voltage side of the IPU transformer. The change in magnitude of this voltage in relation to the mains voltage $\underline{U}_{AP}$ results either in consumption or supply of inductive power. The range of possible reactive power is defined by the design of the converter (Fig. 2).

The idealised P-Q diagrams shown in Fig. 3 present possible control strategies. The IPU curve with input converter (Fig. 3 a) enables cos φ to be controlled within defined limits. The reactive power versus voltage behaviour cannot be brought about by this method, or at least can only be achieved in dependence on the active net power being passed on. The characteristic curves for the synchronous generator (Fig. 3 b) and a converter fed IPU will make flexible control of both cos φ and the Q-U relation possible.

4. EXEMPLARY CASE

The point of this exercise is to determine the real net active power diagram for the Point of Coupling (PC) of a wind farm, firstly so that the transmission grid operator [1, 2] can be assured that the connection regulations are being fulfilled as shown in Fig. 3 and secondly to enable any necessary complementary measures to be taken for this purpose. The IPUs in the wind farm must be able to respond to grid management requirements, providing values for reactive power or cos φ within the range covered by the graph in Fig. 4, in dependence on the operating voltage U_b of the 380-kV grid.

Calculations of the stationary power flow in the wind farm are necessary if the net power diagram is to be produced for a wind farm grid as in Fig. 1. These calculations must include reference to the demands made by the above-mentioned reactive power balance issues. The investigations here described were carried with the ELEKTRA program [6], developed by KEMA-IEV GmbH, Dresden. The calculations reveal that the following important conditions must be taken into account.

- In the wind farm grid, automatic voltage control takes place in accordance with the ranges set at the stage-setting mechanisms at the transformers.
- The utilisation to which the electrical equipment such as transformers, cables and chokes can be fully exploited is limited by their rated values.

- Voltage maintenance on the grid takes place in accordance with the usual grid requirements.

Fig. 5 gives as an example a schedule for the determination for the net active power diagram for a wind farm grid which has settable load current compensation. The graph can be produced with the computation software mentioned in [6] or a comparable program. The grid calculations for the stages of the schedule in Fig. 5 must be reiterated for various operational voltages across the prescribed voltage range within the 380-kV grid. In every individual calculation, all the conditions listed above must be checked. In addition the settability or switchability of the load current chokes and the P-Q behaviour of the IPUs as shown in the power diagram must be taken into account. Fig. 6 shows an example of the results of such a calculation, reflecting U_b = 410 kV and presenting the net active power diagram for the wind farm. The reference value for the power unit schema in Fig. 6 is the rated power S_r of the main transformer in the 380/110-kV transforming station. The idealised power diagram as shown in Fig. 3 a was taken as the basis for the P-Q behaviour. In each case, the load current choke was a settable version.

The limits to the power range for the wind farm P-Q behaviour requirements assumed in the case here examined were set by the characteristic curves shown in grey in Fig. 6 (cos φ = 0.925 for the inductive consumption and 0.95 for the inductive supply). It is clear that the possible settings of the wind farm up to net active power production of approximately 0.75 power units are well enough rated to allow variable reactive power within the prescribed cos φ limits. Where the P is to be greater than 0.75 power units, the inductive longitudinal elements of electrical equipments in the grid will require so much reactive power that when the load current chokes are switched off there is not enough reactive power at the 380-kV coupling point to fulfil the requirement cos φ = 0.95 (inductive).

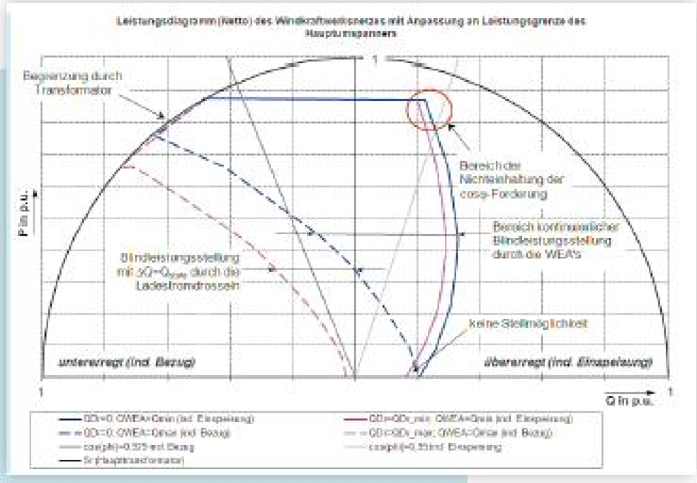


Bild 6: Netto-Leistungsdiagramm des Windkraftwerkes (Betriebsspannung des Netzes U_b = 410 kV).

In several cases an extra reactive power of approximately 0.05 power units will be required to cover the range prescribed for cos φ in all possible states of the wind farm supply system.

The power diagram thus becomes a useful aid as evidence of reactive load provision in accordance with the grid usage rules of the grid operator [1 … 3].

5. Abstract

It has become apparent in investigations of the stationary P-Q behaviour of wind farms, here presented, that it is certainly possible to integrate high-performance sources of renewable energy into high and very high voltage grids without infringing system requirements. The careful analysis of the reactive power circumstances during normal operation of the wind farm in association with effective methods of power flow calculation permit reliable estimation of the power conditions in all normal operating states of the wind farm.

6. Bibliography

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Symbols used in formulae, abbreviations

P	Active power
P_r	Rated active power
Q	Reactive power
Q_C	Reactive Load power (capacitative)
Q_L	Longitudinal reactive power (inductive)
Q_{DR}	Reactive power of a choke
S	Apparent power
S_r	Rated apparent power
I	Current
U	Voltage
U_N	Mains voltage
U_b	Operating voltage
U_{AP}	Voltage at coupling point
U_{WR}	Voltage at the rectifier
ΔU	Drop in voltage
X_{TR}	Reactance of transformer
$\cos \varphi$	Displacement factor
φ_u	Phase angle between 2 voltage vectors
IPU	Individual power unit
CP	Coupling point