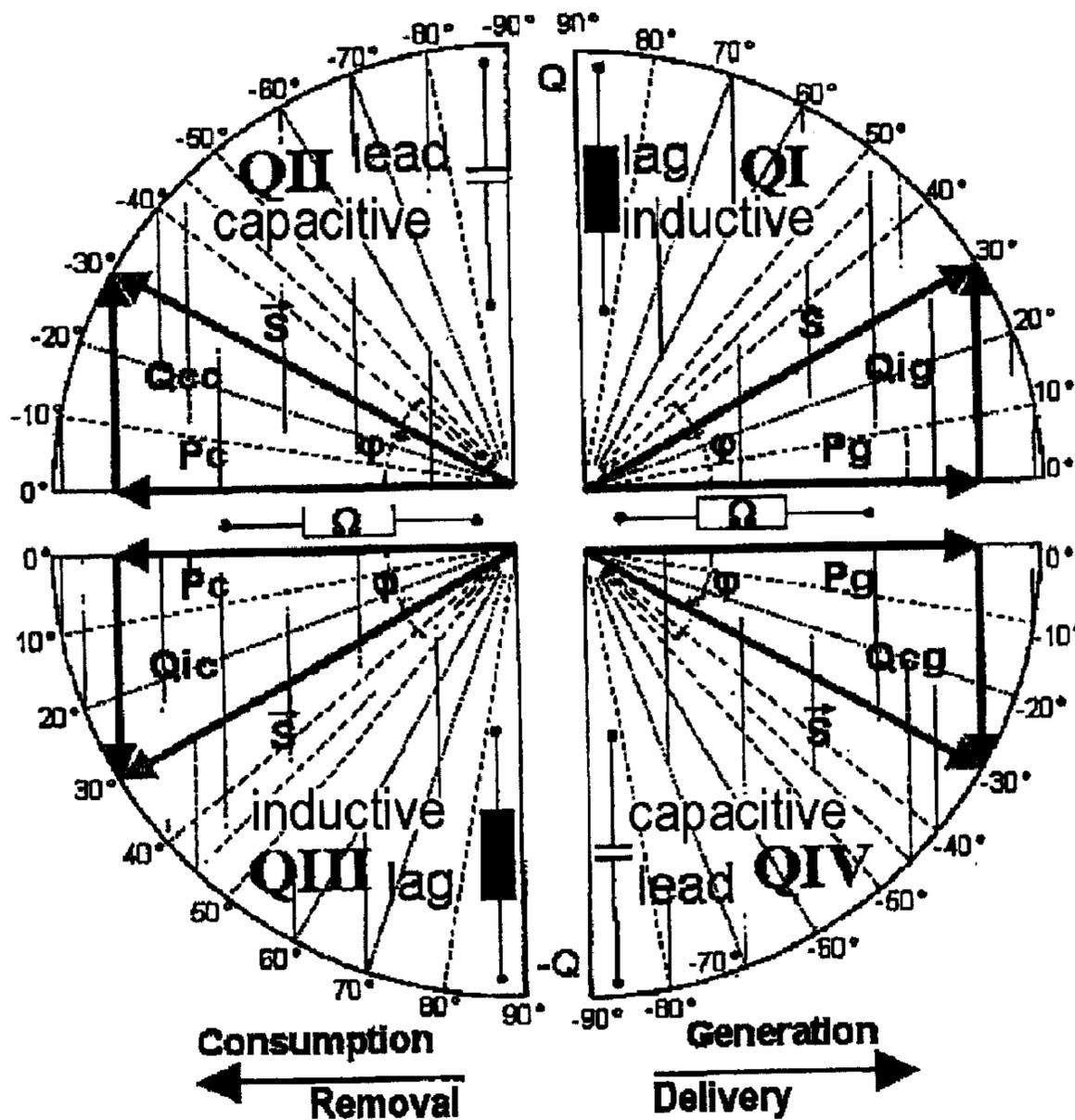




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(54) **Titre : PROCÉDE PERMETTANT DE FAIRE FONCTIONNER UNE EOLIENNE**  
 (54) **Title: METHOD FOR OPERATING A WIND TURBINE**



(57) **Abrégé/Abstract:**

The invention relates to a method for controlling at least one wind turbine (100), wherein the at least one wind turbine (100) is set up to feed electrical power into an electrical power grid (120), and, depending on a supply of power in the electrical power grid

**(57) Abrégé(suite)/Abstract(continued):**

(120), electrical active power is fed into the electrical power grid (120) or electrical active power is removed from the electrical power grid (120) and is supplied to at least one electrical consumer of the at least one wind turbine (100), and, depending on a further state variable of the electrical power grid (120), electrical reactive power is fed into the electrical power grid (120) or electrical reactive power is removed from the electrical power grid (120).

Abstract

The invention relates to a method for controlling at least one wind turbine (100), wherein the at least one wind turbine (100) is set up to feed electrical power into an electrical power grid (120), and, depending on a supply of power in the electrical power grid (120),  
5 electrical active power is fed into the electrical power grid (120) or electrical active power is removed from the electrical power grid (120) and is supplied to at least one electrical consumer of the at least one wind turbine (100), and, depending on a further state variable of the electrical power grid (120), electrical reactive power is fed into the electrical power grid (120) or electrical reactive power is removed from the electrical power grid  
10 (120).

Figure 3

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Method for operating a wind turbine

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The present invention relates to a method for operating at least one wind turbine. In addition, the present invention relates to a wind turbine and also relates to a wind farm comprising a number of wind turbines.

5 Wind turbines are generally known. They produce electrical energy from wind and feed this into an electric power grid. In addition, it was already proposed many years ago for wind turbines to feed into the electrical power grid such that they also support the electrical power grid beyond the pure provision of energy.

10 By way of example, US 6,784,564 describes a method in which the fed active power is reduced in accordance with the grid voltage. A method that concerns a power regulation dependent on the grid frequency can be inferred from US 6,891,281. The setting of a phase angle in accordance with the grid voltage is described in US 6,965,174.

15 Such measures are important and, in particular in decentralized grids, may help improve the grid quality and sometimes even enable for the first time a stable operation of the electrical power grid or at least a portion thereof or ensure this permanently. Nowadays, however, at least in the Federal Republic of Germany, which will surely be followed by many other countries, the proportion of wind turbines in the grid is increasing. A great, and in all likelihood growing, responsibility will thus also be bestowed in the future upon wind turbines for the stabilization of electrical power grids. The ability of wind turbines to support the grid must therefore be developed and improved further where possible.

20 The object of the present invention is therefore to address at least one of the above-mentioned problems. In particular, a solution is to be proposed that helps to further improve the support of an electrical power grid by wind turbines. At the very least, a solution alternative to known methods or systems is to be proposed.

25 The German Patent and Trademark Office has performed a search of the following prior art for the priority application relating to the present PCT application: DE 10 2005 041 927 B4, DE 10 2005 049 426 B4, DE 10 2008 037 449 B4, DE 10 2011 007 037 A1 and WO 2003/ 058 063 A1.

In accordance with the invention, a method according to Claim 1 is proposed. This controls at least one wind turbine, which is set up to feed electrical power into an electrical power grid. Where technically expedient, explanations in conjunction with an individual wind turbine also apply to a number of wind turbines as well as a wind farm comprising a number of wind turbines, even without this being mentioned together with each individual feature and in each individual advantage. This is then true in particular when it is clear from the explanation that this is also applicable for wind turbines or a wind farm.

It is thus proposed for the at least one wind turbine to feed electrical active power into the electrical power grid or to remove electrical active power from the electrical power grid in a manner dependent on a supply of power in the electrical power grid. In particular, in “normal operation”, electrical active power is fed into the electrical power grid, but, in the case of an excess supply of power in the grid, electrical active power is removed from the grid by the at least one wind turbine. This removed active power is then fed to at least one electrical consumer, which is present in the at least one wind turbine or a wind farm. This consumer does not necessarily have to be arranged physically in the wind turbine, although this is often the case. Here, it is proposed in particular to use existing consumers.

In addition, electrical reactive power is fed into or removed from the electrical power grid depending on a further state variable of the electrical power grid, such as the grid frequency or the grid voltage of the electrical power grid.

A “4-quadrant operation” is thus proposed, therefore specifically both the fed active power and the fed reactive power can be positive or negative independently of one another. The proposed method thus expressly also includes the two quadrants in which electrical active power is removed from the electrical power grid and reactive power is fed in, which constitutes one quadrant, and in which electrical active power is removed from the electrical power grid and reactive power is likewise removed, which constitutes a further quadrant.

At least one of the electrical consumers preferably has no electrical resistor banks. Thus, at least one consumer is preferably used that is not provided exclusively as a resistor bank or the like in order to destroy electrical energy, that is to say, expressed technically correctly, in order to convert electrical energy into thermal energy without further purpose. Rather, it is proposed to use consumers that are provided anyway in a wind turbine or a

wind farm. Thus, progress can be achieved already by the proposed method alone for operating at least one wind turbine, without the need to provide additional apparatuses.

The electrical consumer(s) used to take up the electrical power which in one case is removed from the electrical power grid may comprise, for example, a blade heater for heating a rotor blade. Likewise, a generator heater for heating a generator can be used. As a further example, a nacelle heater is mentioned, which can heat the interior of a nacelle of a wind turbine. Furthermore, a tower heater for heating a wind turbine tower is conceivable. Particularly, the use of existing heaters or heating devices enables the conversion of a not insignificant quantity of electrical energy into thermal energy, which can be radiated to the surrounding environment.

Nonetheless, however, other consumers are also considered, such as the generator of the respective wind turbine, which can be operated in motor operation. Some of the energy could thus be converted into air movement. In principle, however, it is also conceivable here to operate the generator such that it heats up and in this regard is used as a further consumer in order to convert electrical energy into thermal energy. Nonetheless, this must be performed carefully accordingly so as not to damage the generator.

In particular, it is proposed for the consumers to then be operated when there is a need for a power decrease. The aforementioned consumers, which are also to be used here, are each provided in order to perform a certain function, specifically the consumer function associated therewith respectively. In the case of the blade heater, this is the function of heating the blade. In the case of the generator heater, this is the function of heating the generator and also thus drying the generator where applicable. This respective consumer function is usually performed only on specific occasions, that is to say a blade heater is then operated particularly when icing has been identified and the ice is to be thawed. Here, however, it is proposed to operate the corresponding consumer independently of the need for such a consumer function, that is to say for example to also operate the blade heater at the height of summer.

Accordingly, it is also proposed in accordance with one embodiment to use the electrical power removed from the electrical power grid to operate at least one de-icing device, in particular a blade heater, independently of whether there is a need for de-icing. In particular, independently of whether icing is present, is expected or is even possible. The de-icing device is thus also operated at the height of summer. Wind turbines are preferably

equipped with a de-icing device even for locations in which icing is never expected *per se*.

In addition or alternatively, it is proposed to use the removed power or a portion thereof to operate at least one drying device for drying a generator or for drying another functional unit of the wind turbine, independently of whether there is a need for drying. A generator heater provided anyway or other drying arrangement can thus be used as a consumer in this case of power removal from the electrical power grid.

The supply of power in the electrical power grid can be considered as a state variable of the electrical power grid. The further state variables, in accordance with which reactive power is fed or removed, preferably include the grid frequency of the electrical power grid and/or the grid voltage of the electrical power grid. In accordance with these embodiments, the feed or removal of electrical active power is thus set depending on the supply of power, and the feed or removal of reactive power is performed depending on grid frequency and/or grid voltage. Here, the grid-frequency-dependent and/or grid-voltage-dependent feed or removal of reactive power can depend both qualitatively and quantitatively on the aforementioned state variables. Both the level of reactive power and a dynamic rise or drop can be dependent on the aforementioned grid state variables.

Likewise, the level and/or the behaviour of the grid state variables can be considered as criteria.

The method preferably uses a frequency inverter in order to feed or remove the active power and the reactive power into/from the electrical power grid. It is hereby possible to decouple this feed or removal operation completely from the functioning of the wind turbine, in particular of the generator. Any plant controller, with adapted specifications, can initially continue to be operated in an unchanged manner. Of course, the controller then adapts the operation of the wind turbine, where applicable, when less power is required or when the power is even negative. However, the immediate response when feeding or removing active power and/or reactive power can be implemented initially independently of the frequency converter.

The wind turbine or all concerned wind turbines is/are preferably operated in what is known as full converter operation. In the case of this full converter operation, in order to explain this for the normal generation operation, the total energy of the generator removed by said generator from the wind is rectified and transferred into a corresponding

DC intermediate circuit. From this DC intermediate circuit, the frequency inverter or a number of frequency inverters cooperating accordingly produces/produce the power to be fed, that is to say the current to be fed, in accordance with frequency, phase and amplitude.

5 During operation of the power removal, this frequency inverter, which is also referred to just as an inverter for simplification, can introduce power or energy from the electrical power grid into the DC intermediate circuit. Appropriate energy can then be removed from the relevant consumers by this DC intermediate circuit. Indeed, there is advantageously a command signal for removing such power at relevant consumers from a central point in  
10 the wind turbine or even in the wind farm, however the subsequent implementation is performed by the respective consumer. Lastly, the relevant consumer also otherwise operates independently, specifically when it is not used for power consumption, but for regular operation of the consumer function thereof.

In the case of the proposed method, a number of wind turbines are preferably used,  
15 which form a wind farm and feed into the electrical power grid via a grid point of common coupling. The aforementioned effects and the aforementioned behaviour can be combined as a result. Such a wind farm, which feeds into the grid point of common coupling, thus also regularly has a significant quantity in terms of the amount of feedable and removable power (both reactive power and active power) compared with an individual  
20 wind turbine. Such a wind farm is thus preferably operated in the described 4-quadrant operation and thus constitutes a significant quantity from the viewpoint of the electrical power grid, not only for the provision of energy, but also for the potential of the controllability. It can cater in a significant measure to the supply of power, inclusive of the usual power demand. *Inter alia*, it can thus also favourably influence situations in which, in the  
25 past, payment of a sum would have been necessary in order to remove power in certain cases.

A wind turbine is preferably proposed which is set up to use a method according to at least one of the above-described embodiments.

More preferably, a wind farm is proposed that uses a number of wind turbines and is set  
30 up to use a method according to at least one above-described embodiment.

Such a wind farm preferably has a central controller for controlling the wind turbines, which also controls the described 4-quadrant operation, such that the wind farm can act at the grid coupling point as an efficient feed and control unit.

The invention will be explained in greater detail hereinafter by way of example with reference to the accompanying figures.

Figure 1 schematically shows a wind turbine in a perspective view.

Figure 2 schematically shows a wind farm.

Figure 3 illustrates the proposed 4-quadrant operation on the basis of a symbolic diagram.

Figure 1 shows a wind turbine 100 with a tower 102 and a nacelle 104. A rotor 106 having three rotor blades 108 and a spinner 110 is arranged on the nacelle 104. During operation, the rotor 106 is set in a rotary motion by the wind and thus drives a generator in the nacelle 104.

Figure 2 shows a wind farm 112 comprising, by way of example, three wind turbines 100, which may be the same or different. The three wind turbines 100 are thus representative of, in principle, any number of wind turbines of a wind farm 112. The wind turbines 100 provide their power, specifically in particular the produced current, via an electrical farm grid 114. Here, the produced currents or powers of the individual wind turbines 100 are added and a transformer 116 is usually provided, which performs an upward transformation of the voltage in the farm so as to then feed this into the power grid 120 at the feed point 118, which is also referred to generally as the grid point of common coupling or PCC for short. Figure 2 is merely a simplified illustration of a wind farm 112, which for example does not show any controller, although a controller is of course provided. By way of example, the farm grid 114 can also be formed differently, in which for example a transformer is also provided at the output of each wind turbine 100, so as to specify just one other exemplary embodiment.

Figure 3 illustrates the proposed 4-quadrant drive in accordance with an illustration in the form of a diagram in the complex plane, which specifically represents active power in the abscissa direction and reactive power  $Q$  in the ordinate direction. In this diagram, the angle  $\varphi$  is thus also plotted, which in this regard represents the phase angle between fed

current and voltage. Here, the four regions each showing one quadrant are graphically shown separately from this diagram of the complex plane for the purpose of illustration, since a spacing is plotted in the region of the coordinate system. The diagram thus shows the four quadrants, which are denoted by QI to QIV. The four quadrants are named thus  
 5 in this context, wherein Q otherwise denotes the reactive power.

The first quadrant QI according to Figure 3 shows the case in which active power and reactive power are fed. The fed reactive power is referred to as  $P_g$  (generated power) and the reactive power is referred to as  $Q_{ig}$  (generated inductive reactive power). The fed active power  $P_g$  and the fed inductive reactive power  $Q_{ig}$  give the apparent power  $\vec{S}$ .

10 This first quadrant may also represent the normal feed case. So as to further illustrate that inductive reactive power is fed, which leads precisely to the vector diagram of  $P_g$ ,  $Q_{ig}$  and  $\vec{S}$ , the symbol of an inductance is also shown in the first quadrant. Due to the term "lag" used by a person skilled in the art, which means the same as running behind, it is additionally indicated that in this operation the fed current lags behind the voltage,  
 15 specifically precisely by the shown angle  $\varphi$ .

In the second quadrant QII, active power is removed from the electrical power grid, that is to say is consumed and not generated, which is indicated by the symbol  $P_c$  (power consumed). The reactive power component  $Q_{cc}$  is positively illustrated. Since, however, active power is removed, the reactive power is also referred to here as removed (con-  
 20 sumed), however is used as capacitive reactive power, which is why the naming  $Q_{cc}$  is used. The current here runs ahead of the voltage, which is referred to here as "lead" and is illustrated by the symbol of the capacitance (of the capacitor) in the second quadrant QII.

The removed capacitive reactive power  $Q_{cc}$  could at least theoretically also be referred to  
 25 as produced inductive reactive power  $Q_{ig}$ , which from a technical viewpoint however would be confusing, at least in accordance with the selected illustration, because the leading current and accordingly the shown angle  $\varphi$  denotes capacitive reactive power.

For the rest, two resistors are indicated parallel to the abscissa and thus symbolize the actual axis of this complex illustration.

In the third quadrant QIII, active power  $P_c$  is also removed, that is to say consumed. However, the proportion of reactive power  $Q_{ic}$  is negative here. Inductive reactive power is thus consumed and the current runs behind the voltage (lag), which is why the symbol of the shown inductance is also used again here.

5 The fourth quadrant QIV lastly shows the case that active power  $P_g$  is fed and (inductive) reactive power  $Q_{cg}$  is removed, which corresponds to the feed (generation) of capacitive reactive power  $Q_{cg}$ , such that the naming  $Q_{cg}$  is selected, because here the current again runs ahead of the voltage. This is also illustrated here by the capacitance.

10 A solution is thus created that proposes a 4-quadrant operation of a wind turbine or of a wind farm and this behaviour is illustrated by Figure 3.

Here, the underlying reasoning is that, in the case of the energy revolution in Germany, wind energy is one of the central pillars, if not the central pillar. In terms of technical content, the proposals of course are not limited to Germany. By means of the solution presented here, topics such as direct marketing, control reserve and minute reserve are also taken into consideration and form components for constructing what are known as green power plants. It is proposed for the provided energy to be organized such that conventional power plants, in particular nuclear power plants, can be switched off. Nevertheless, it must be possible to create and operate a stable grid without these large and partially leading and grid-stabilizing power plants. It has been identified that a key point here is the load flow control in the distributor grid and also at a higher level in the transmission grid, which both form parts of the electrical power grid. This load flow control is a parameter for stability of the electric power grid.

25 A conventional power plant is generally designed to provide energy. The system service powers of such a conventional power plant are limited only to the provision of the required energy, supply of reactive power for voltage preservation and control of the load flow in the electric power grid. Such a power plant provides this service only during production operation (also referred to as "generation operation"), that is to say with the delivery of energy.

30 In the case of the specific proposed 4-quadrant power plant, that is to say in the case of the wind turbine or the wind farm which can be operated in 4-quadrant operation, it is also possible to provide system services during consuming operation ("consumption opera-

tion”), that is to say also when energy is drawn from the electrical power grid. To this end, the possibility of load flow control by the consumption of energy is proposed.

In addition to the feed reduction to 0, power can also be removed from the electrical power grid.

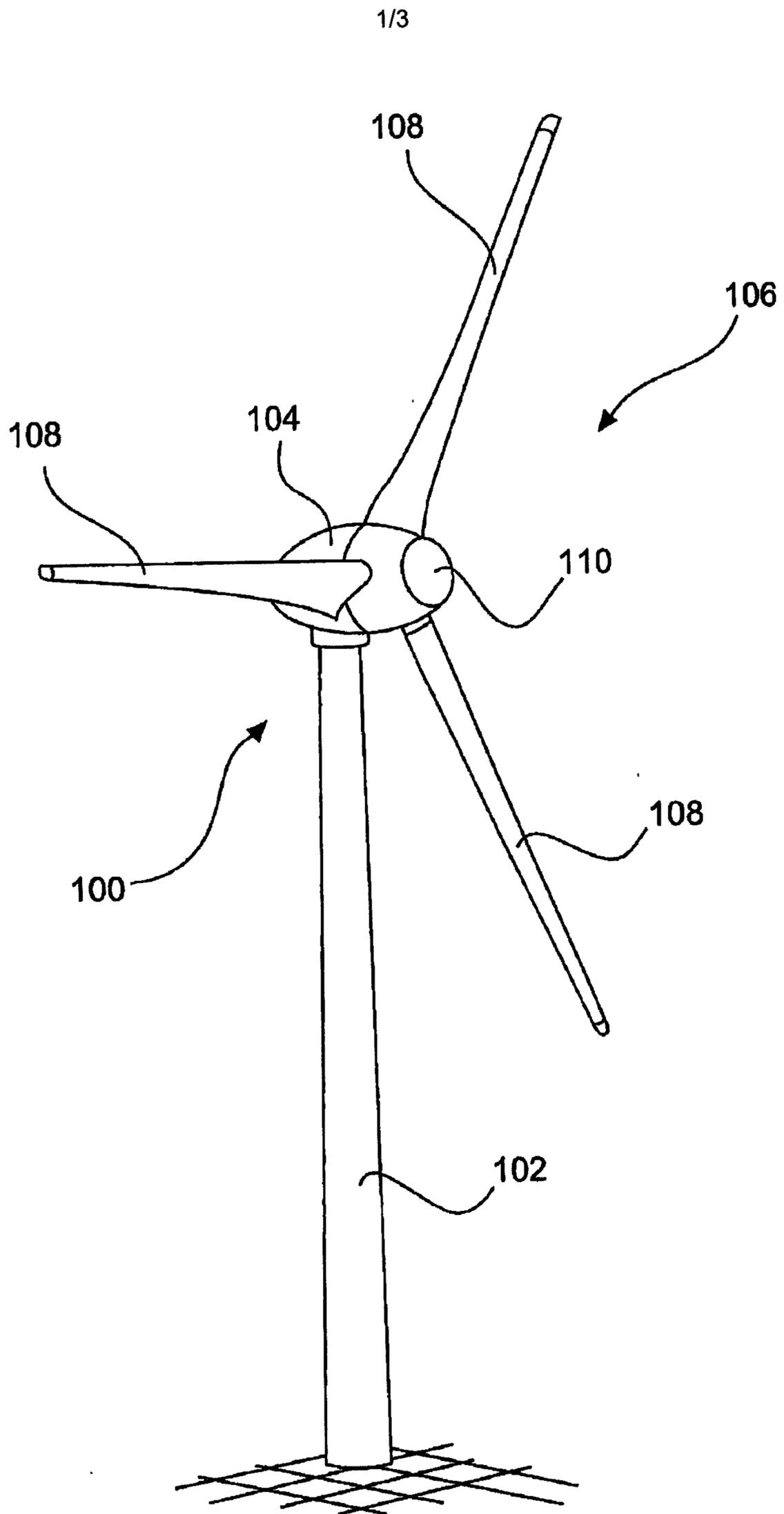
5 So as to name one example, reference is made to the fact that the North of Germany is very windy and therefore a lot of wind energy is provided in order to be fed into the electrical power grid, and therefore specifically also into the European integrated network. An excess supply hereby produced would significantly increase the load flow from North to South Germany, which could lead to problems in the integrated network. In order to  
10 control the load flow in the integrated network such that no problems can occur, numerous large consumers (for example thermal consumers) are connected in a controlled manner into the numerous distributed wind turbines in Germany. The consumers could be generator heaters, blade heaters and generators operated in motor operation. Besides the regulated reference power, services such as reactive power for load flow control can  
15 also be introduced. This method may indeed have advantages in terms of a global energy balance, but also has an advantage in the numerous widely distributed actuators, specifically wind turbines, which can be activated and deactivated at relatively short notice. Processes in the grid can thus be responded to quickly, wherein the present invention additionally proposes this for the described 4-quadrant operation.

20 As a further example for illustration, reference is made to the fact that energy is traded on the spot market. There are times at which the current price can fall up to minus 3,000 euros/MWh. This regional excess supply of energy and the resultant negative price can now be controlled by reducing or even completely destroying in the regional wind turbines the excess energy responsible for such a described price behaviour by switching on the  
25 large consumers, in particular thermal consumers.

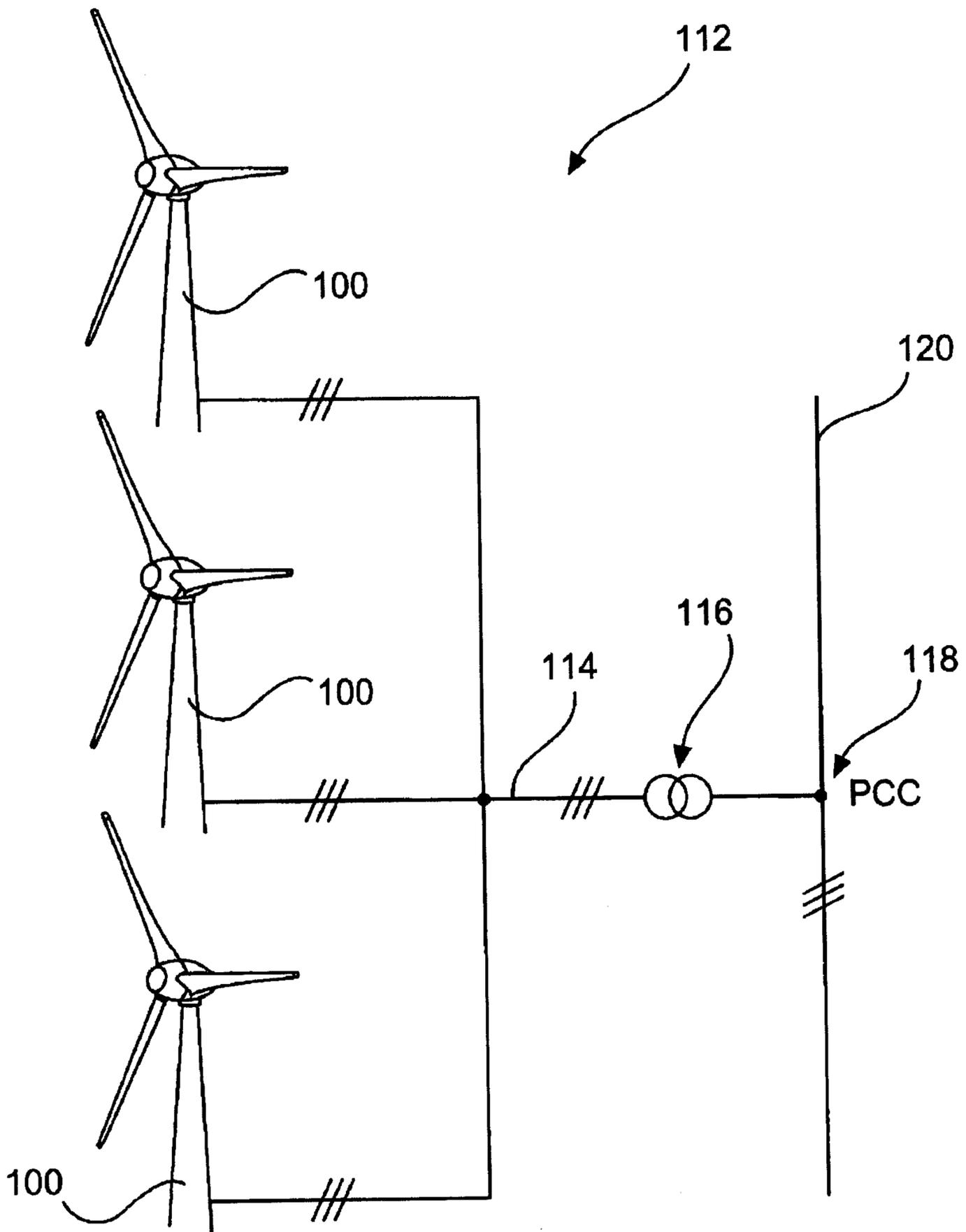
Claims

1. Method for controlling at least one wind turbine (100), wherein  
the at least one wind turbine (100) is set up to feed electrical power into an electrical power grid (120), and,  
5       - if in the electrical power grid (120) additional supply of electrical power is needed, then electrical active power is fed into the electrical power grid (120)  
          and  
      - if in the electrical power grid there is an excess supply of electrical power then electrical active power is removed from the electrical power grid (120)  
10       and is supplied to at least one electrical consumer of the at least one wind turbine (100), and,  
      depending on a further state variable of the electrical power grid (120),  
      - electrical reactive power is fed into the electrical power grid (120) or  
      - electrical reactive power is removed from the electrical power grid (120),  
15       characterized in that  
      the feed or removal of electrical active power and the feed or removal of electrical reactive power is performed by means of at least one frequency inverter.
  
2. Method according to Claim 1,  
wherein at least one of the electrical consumers is selected from the group comprising:  
20       - a blade heater for heating a rotor blade (108),  
      - a generator heater for heating a generator,  
      - a nacelle heater for heating a nacelle (104),  
      - a tower heater for heating a wind turbine tower (102) or a portion thereof,  
25       and  
      - a generator of the respective wind turbine (100) in motor operation.
  
3. Method according to Claim 1 or 2,  
characterized in that  
30       - the at least one consumer is intended to perform a consumer function and  
      - the electrical power removed from the electrical power grid (120) is used to operate the respective at least one electrical consumer independently of whether at the time there is a current demand for the consumer function of the consumer.

4. Method according to one of Claims 1 to 3,  
characterized in that  
the electrical power removed from the electrical power grid (120) is used
- to operate at least one de-icing device, independently of whether a need for  
5 de-icing is present, is expected or is even possible, and/or
  - to operate at least one drying arrangement for drying a generator or for dry-  
ing another functional unit of the wind turbine (100), independently of wheth-  
er there is a need for drying.
5. Method according to one of Claims 1 to 4,  
10 characterized in that  
the further state variable comprises a variable from the group
- grid frequency of the electrical power grid (120) and
  - grid voltage of the electrical power grid (120).
6. Method according to one of Claims 1 to 5,  
15 characterized in that  
a number of wind turbines (100) are provided, which form a wind farm (112) and  
feed into the electrical power grid (120) via a grid point of common coupling (PCC).
7. Wind turbine (100), comprising an electrical consumer and a frequency inverter  
20 adapted for feeding or removing electrical active power and for feeding or removing  
electrical reactive power, wherein the wind turbine is set up to use a method ac-  
cording to one of Claims 1 to 5.
8. Wind farm (112), comprising a number of wind turbines (100), each one of which  
25 comprises an electrical consumer and a frequency inverter adapted for feeding or  
removing electrical active power and for feeding or removing electrical reactive  
power, wherein the wind turbines feed into the electrical power grid (120) via a grid  
point of common coupling (PCC), and are set up to use a method according to one  
of Claims 1 to 6.
9. Wind farm (112) according to Claim 8,  
30 characterized in that a central controller for controlling the at least one wind turbine  
(100) is provided.



**Fig. 1**



**Fig. 2**

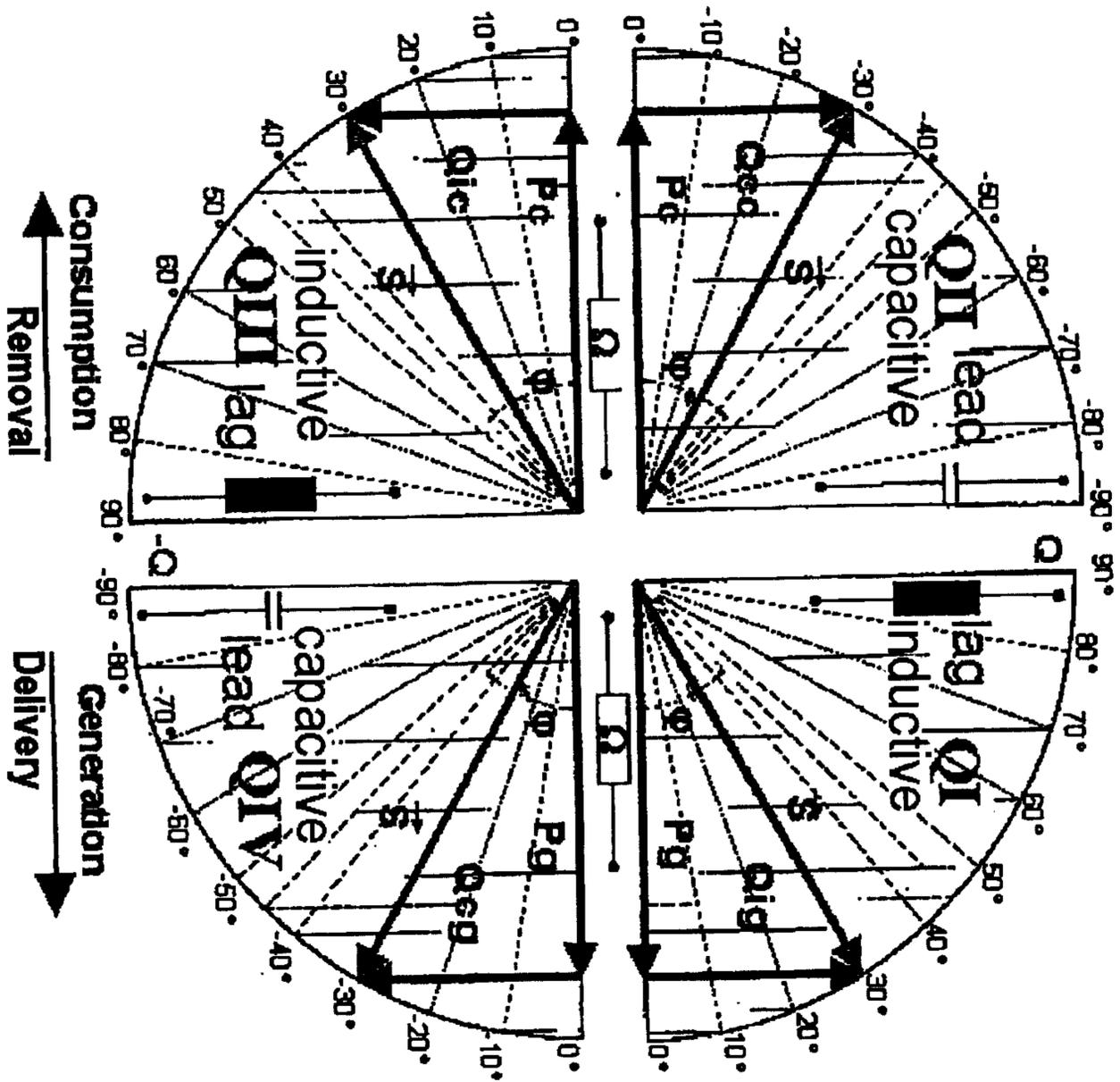
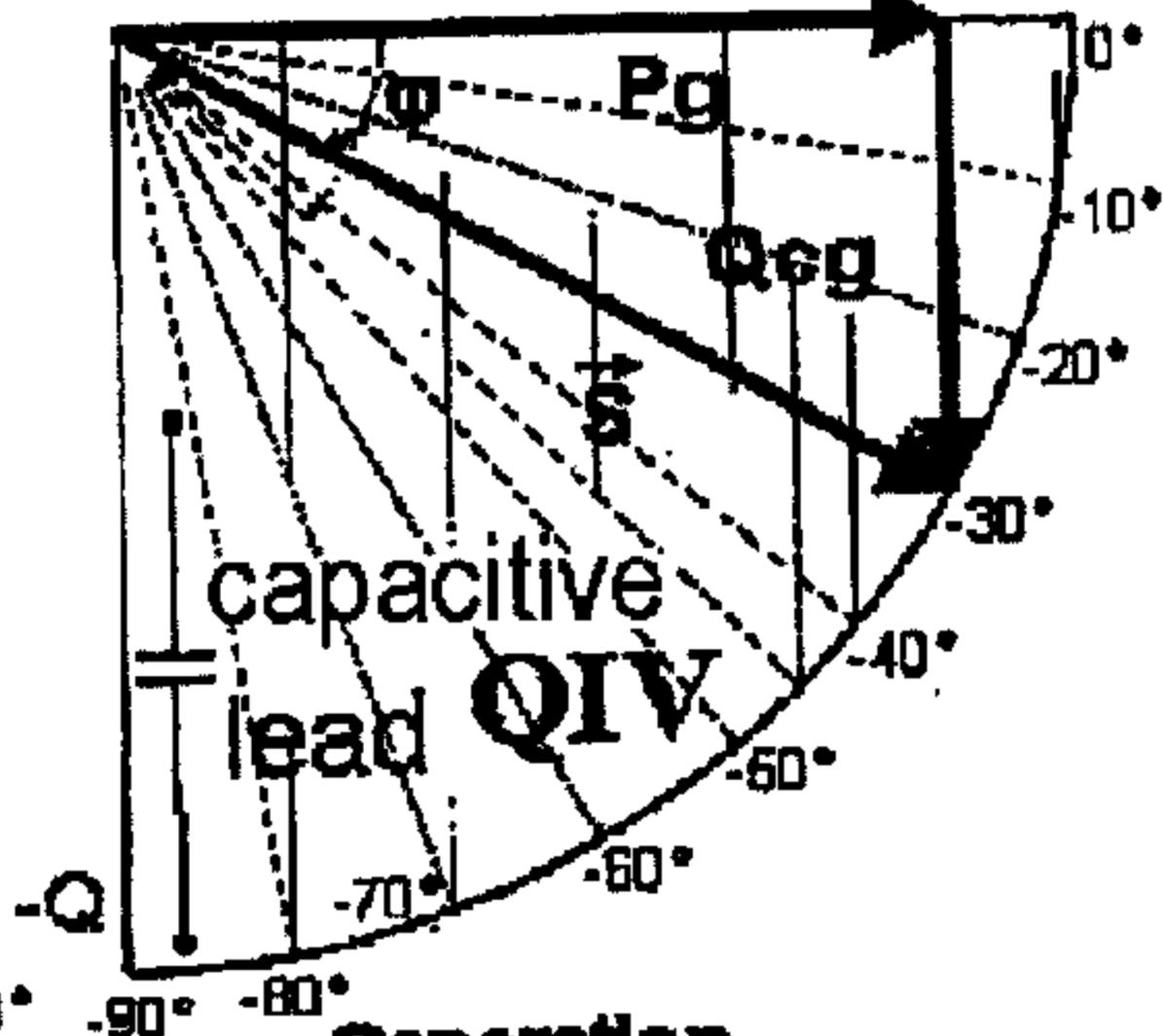
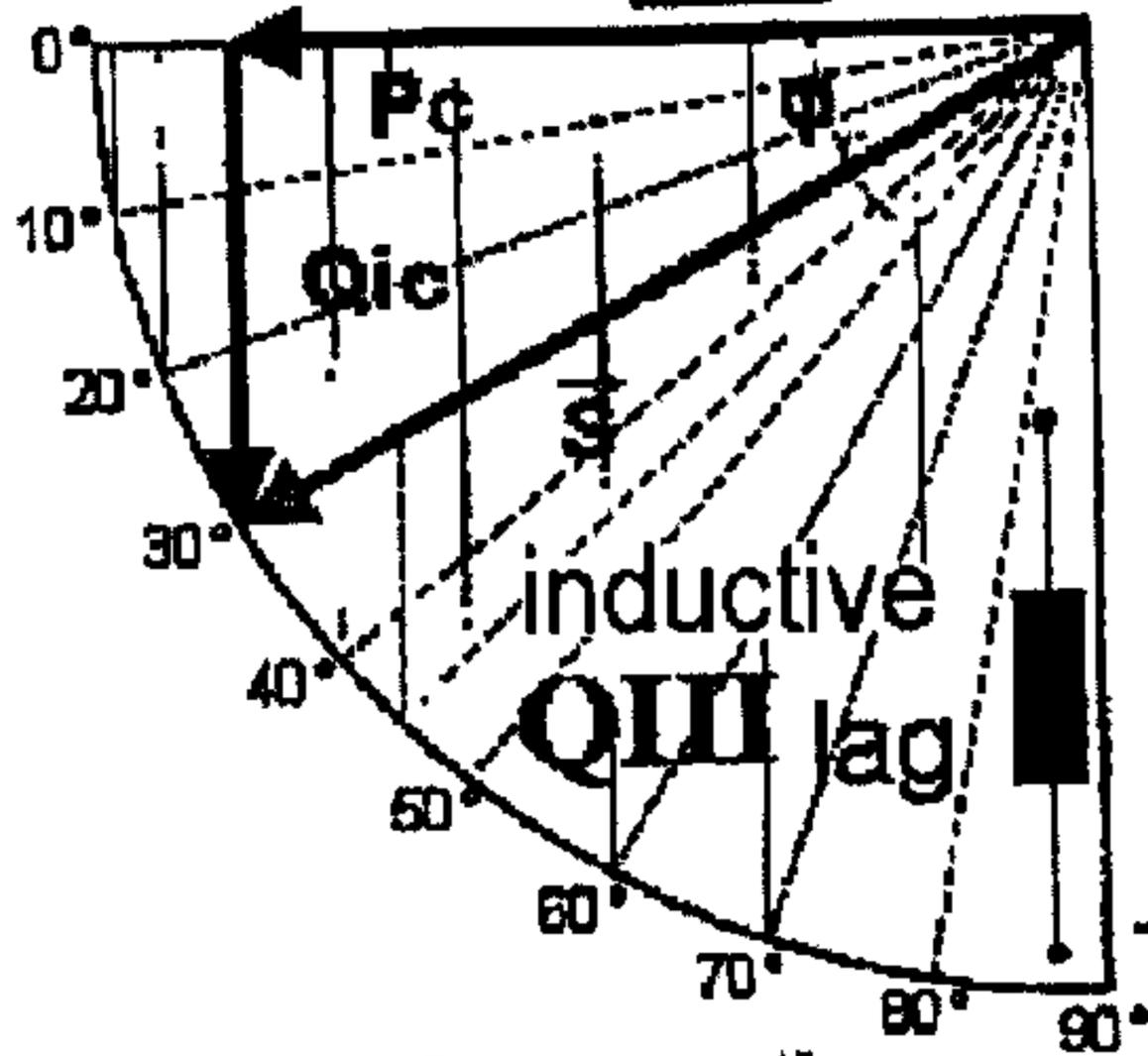
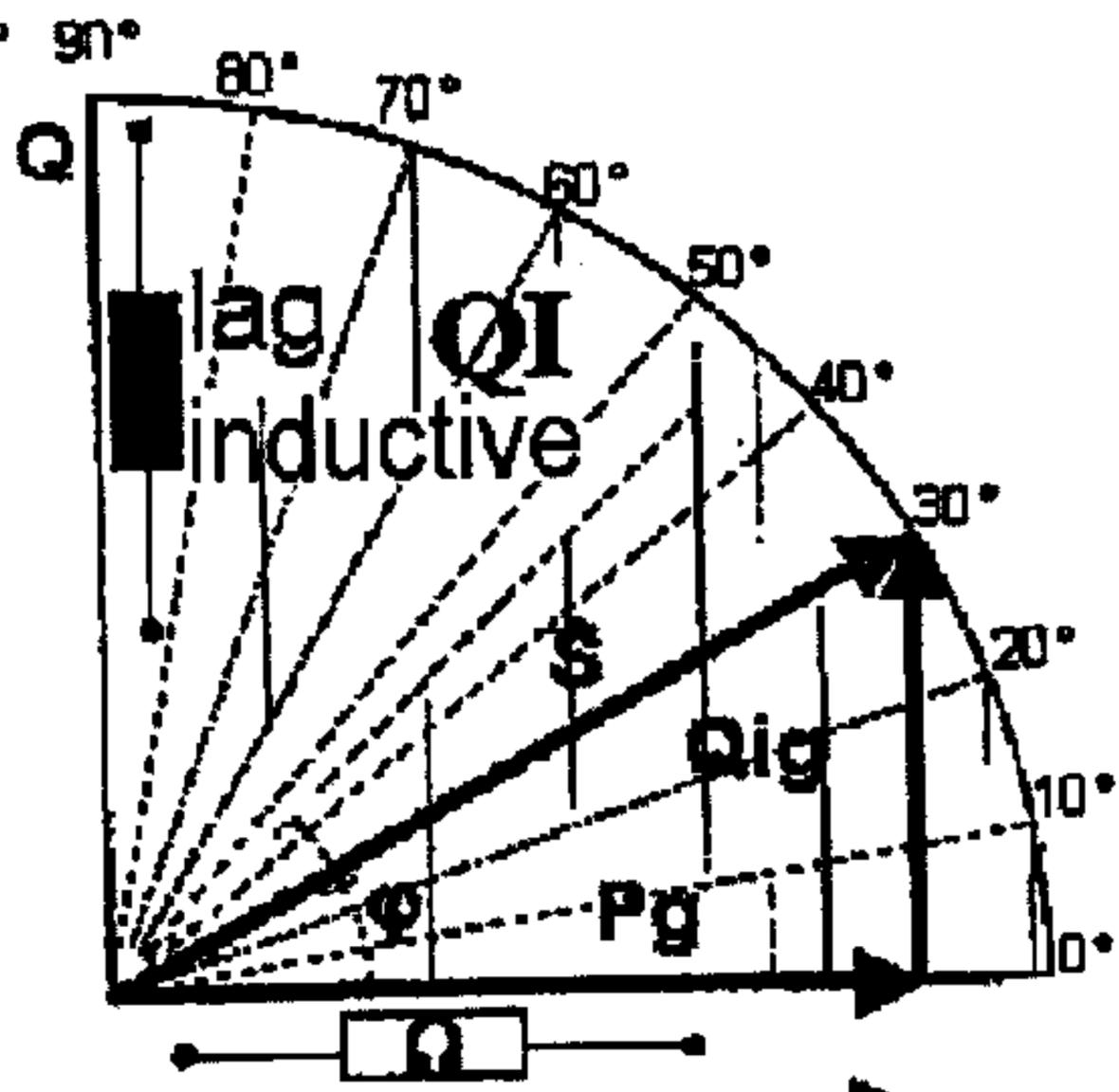
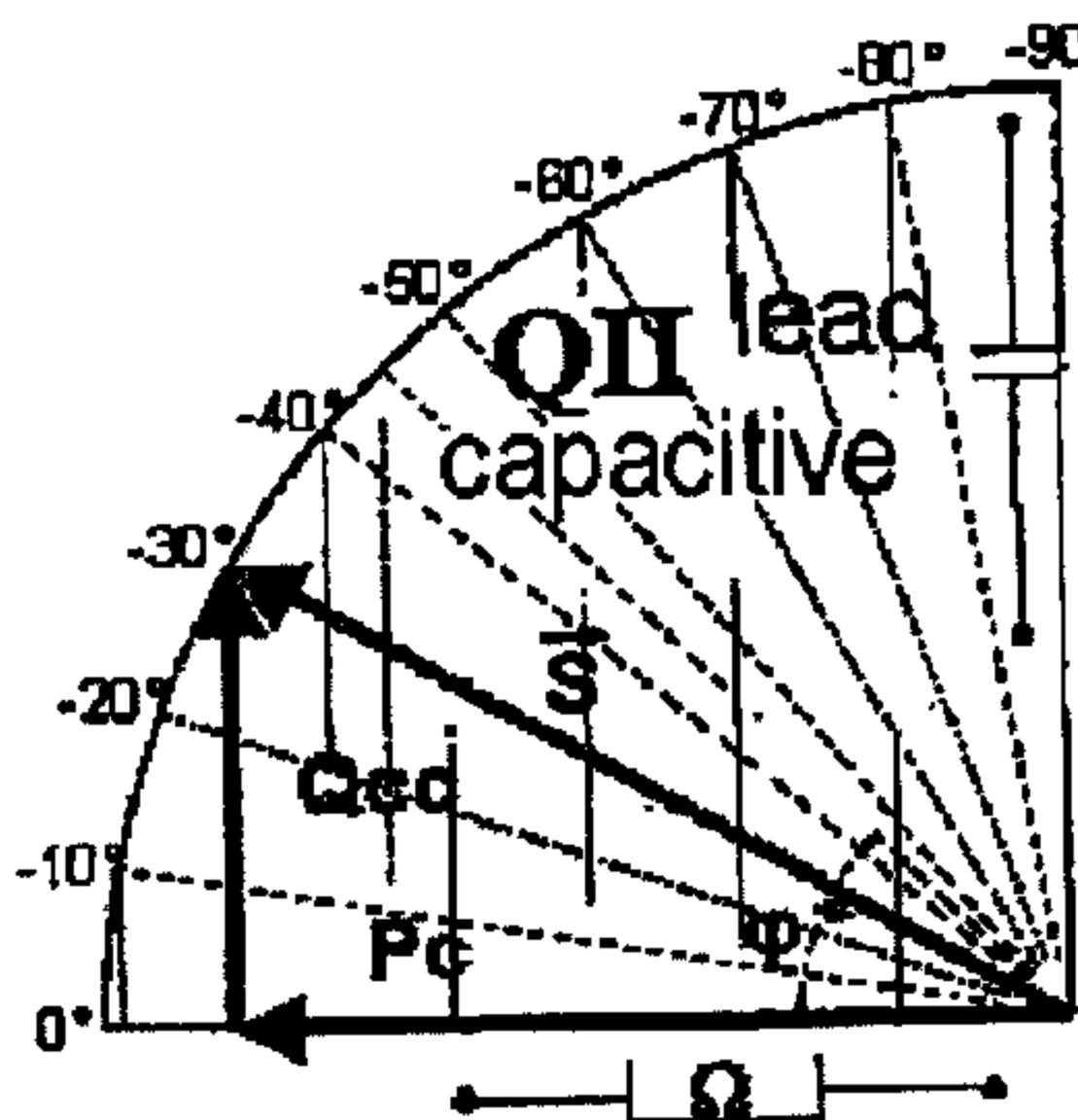


Fig. 3



Consumption  
Removal

Generation  
Delivery