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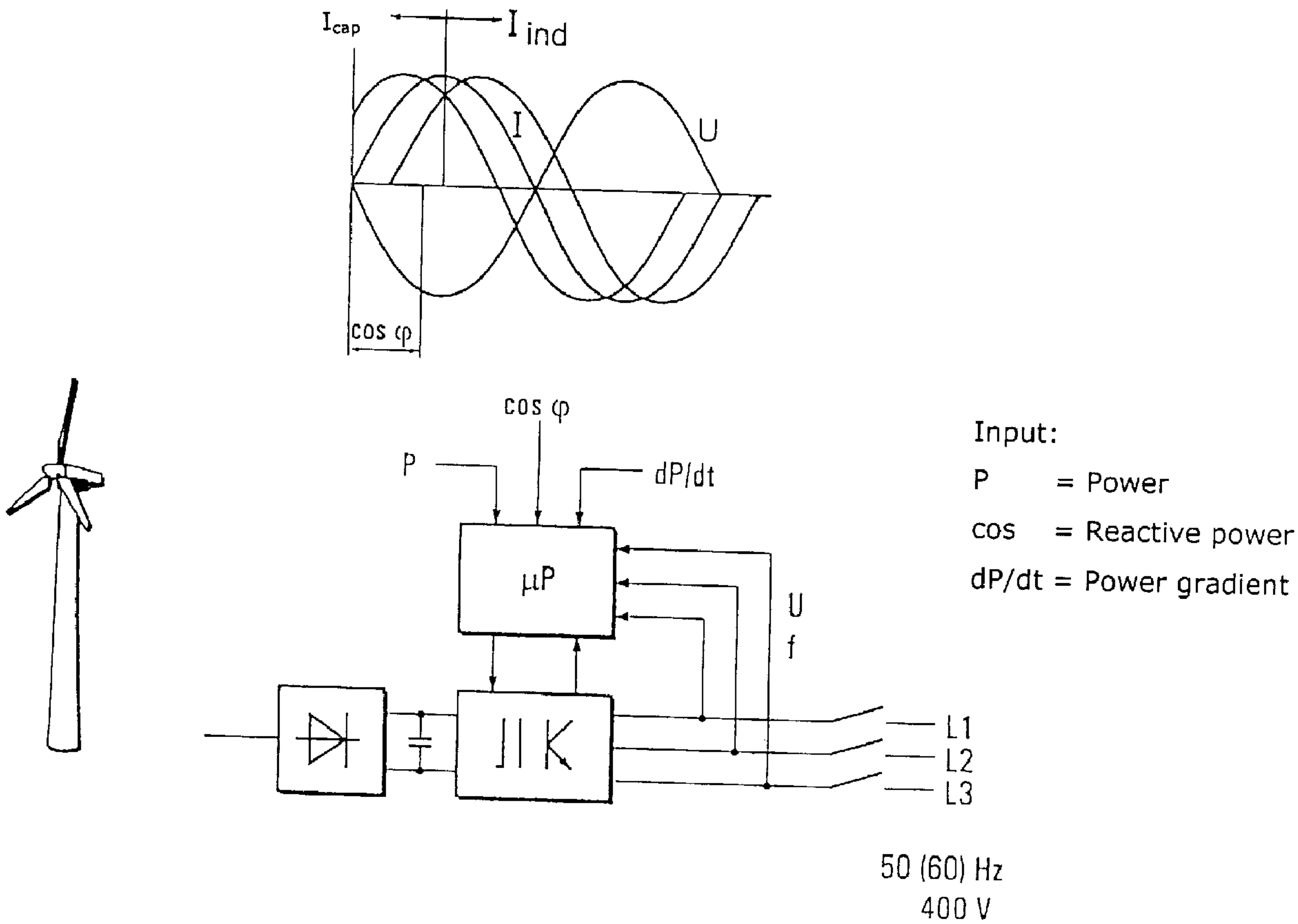


(57) **Abrégé/Abstract:**
Wind power installations were initially always erected in the form of individual units and it is only in recent years that, caused also by administrative and building regulations, wind power installations are frequently installed in wind parks. In that respect a wind park in

(57) Abrégé(suite)/Abstract(continued):
its smallest unit is an arrangement of at least two wind power installations, but frequently markedly more. By way of example mention may be made of the wind park at Holtriem (East Frisia) where more than 50 wind power installations are set up in an array. It is to be expected that the number of units and also the installed power of the wind power installations will also increase greatly in the forthcoming years. In most cases the wind potential is at its greatest in regions of the power supply networks with a low level of short-circuit power and low population density. It is precisely there that the technical connection limits are quickly reached by the wind power installations, with the result that it is then no longer possible for further wind power installations to be set up at such sites. A method of operating a wind park comprising a plurality of wind power installations, wherein the wind park is connected to an electrical power supply network into which the electrical power produced by the wind park is fed and the wind park and/or at least one of the wind power installations of the wind park has a control input, by means of which the electrical power of the wind park or one or more individual wind power installation or installations can be set in a range of between 0 and 100% of the respective power to be made available, in particular the nominal power, and that there is provided a data processing apparatus which is connected to the control input and by means of which the setting value is set in the range of between 0 and 100%, depending on how great is the power that the overall wind park provides at its output for feeding into the energy network and wherein the operator (PSU) of the electrical supply network to which the wind park is connected can adjust the power delivered by the wind park by way of the control input.

Abstract

Method of operating a wind park.

Wind power installations were initially always erected in the form of individual units and it is only in recent years that, caused also by administrative and building regulations, wind power installations are frequently installed in wind parks. In that respect a wind park in its smallest unit is an arrangement of at least two wind power installations, but frequently markedly more. By way of example mention may be made of the wind park at Holtriem (East Frisia) where more than 50 wind power installations are set up in an array. It is to be expected that the number of units and also the installed power of the wind power installations will also increase greatly in the forthcoming years. In most cases the wind potential is at its greatest in regions of the power supply networks with a low level of short-circuit power and low population density. It is precisely there that the technical connection limits are quickly reached by the wind power installations, with the result that it is then no longer possible for further wind power installations to be set up at such sites.

A method of operating a wind park comprising a plurality of wind power installations, wherein the wind park is connected to an electrical power supply network into which the electrical power produced by the wind park is fed and the wind park and/or at least one of the wind power installations of the wind park has a control input, by means of which the electrical power of the wind park or one or more individual wind power installation or installations can be set in a range of between 0 and 100% of the respective power to be made available, in particular the nominal power, and that there is provided a data processing apparatus which is connected to the control input and by means of which the setting value is set in the range of between 0 and 100%, depending on how great is the power that the overall wind park provides at its output for feeding into the energy network and wherein the operator (PSU) of the electrical supply network to which the wind park is connected can adjust the power delivered by the wind park by way of the control input.

(Figure 1)

METHOD OF OPERATING A WIND PARK

The invention concerns a method of operating a wind park and also a wind park as such.

Wind power installations were initially always erected in the form of individual units and it is only in recent years that, caused also by administrative and building regulations, wind power installations are frequently installed in wind parks. In that respect a wind park in its smallest unit is an arrangement of at least two wind power installations, but frequently markedly more. By way of example mention may be made of the wind park at Holtriem (East Frisia) where more than 50 wind power installations are set up in an array. It is to be expected that the number of units and also the installed power of the wind power installations will also increase greatly in the forthcoming years. In most cases the wind potential is at its greatest in regions of the power supply networks with a low level of short-circuit power and low population density. It is precisely there that the technical connection limits are quickly reached by the wind power installations, with the result that it is then no longer possible for further wind power installations to be set up at such sites.

A conventional wind park which is connected by way of example to a 50 MW transformer substation can therefore have at a maximum only 50 MW total power, that is to say for example 50 wind power installations each with 1 MW nominal power.

Bearing in mind that wind power installations are not constantly operated in the nominal mode and thus the overall wind park also does not constantly reach its maximum power (nominal power), it can be found that the wind park is not put to optimum use if the nominal power of the wind park corresponds to the maximum possible total power which can be fed in.

The invention accordingly proposes a solution in which the wind park has a total power output which is higher than the maximum possible network feed-in power. When applied to the above-indicated example the power can be raised to a value of over 50 MW, for example 53 MW. As soon as the wind speeds are sufficiently high to produce the limit power of 50 MW the wind park regulating system according to the invention comes into play and regulates individual or all installations down when the overall maximum power output is exceeded in such a way that it is always observed. This means that, at wind speeds above the nominal wind (wind speed at which a wind power installation reaches its nominal power), at least one or all installations are operated with a (slightly) throttled power output (for example at a power level of 940 kW instead of 1 MW).

The advantages of the invention are apparent. Overall the network components of the feed network (network components are for example the transformer and the lines) can be put to optimum use or can have their loads balanced in the optimum fashion (utilisation thereof up to the thermal limit is also a possibility). In that way existing wind park areas can be better utilised, by virtue of setting up a maximum possible number of wind power installations. The number is then no longer (so severely) limited by the existing network capacity.

For controlling/regulating a wind power installation it is desirable if it has a data input, by means of/by way of the electrical power can be set in a range of between 0 and 100% (with respect to the nominal power). If for example a reference value of 350 kW is applied to that data input, then the maximum power output of that wind power installation will not exceed the reference value of 350 kW. Any value from 0 to the nominal power (for example from 0 to 1 MW) is possible as a reference value.

That data input can be used directly for power limitation purposes.

It is however also possible by means of a regulator to regulate the generator power output in dependence on the network voltage (in the wind park network or in the feed-in network).

A further important function will be discussed hereinafter on the basis of wind park regulation. It will be assumed for example that a wind park comprises 10 wind power installations which each have a nominal power output of 600 kW. By virtue of the capacitances of the network components (line capacitances) or the limited capacitances in the transformer substation it will further be assumed that the maximum power to be delivered (limit power) is limited to 5200 kW.

There is now the possibility of limiting all wind power installations to a maximum power of 520 kW by means of the reference value (data input). That provides that the requirement for limiting the power to be delivered is always met.

Another possibility involves not allowing the maximum power as the sum of all installations to be exceeded, but at the same time producing a maximum amount of energy (kW-hours (work)).

In that respect it should be recognised that, at low to moderate wind speeds within the wind park, it frequently happens that the wind power installations at the advantageous (good) sites (these are the sites which the wind first encounters within the wind park) receive a great deal of wind. If now all wind power installations are simultaneously controlled down to their throttled value (for example all to 520 kW), that produced power is admittedly attained by some wind power installations arranged at good sites, while some other wind power installations which however are in the 'wind shadow' of the well-located wind power installations (in the second and third rows) have less wind and as a result operate for example only at 460 kW power and do not reach the value of the maximum throttled power of 520 kW. The overall power output from the wind park is accordingly therefore substantially below the allowed limit power output of 5200 kW.

The wind park power regulation according to the invention in that case regulates the individual installations in such a way that the maximum possible energy yield is set. This means in specific terms that for example the installations in the first row (that is to say at good sites) are regulated to a higher power (for example to the nominal power (therefore no throttling action). Therefore the overall electrical power in the wind park rises. Park regulation however regulates each individual installation in such a way that the maximum allowed electrical connection power is not exceeded while at the same time the work produced (kWh) reaches a maximum value.

Wind park management in accordance with the invention can be easily adapted to the respective situations which arise. Thus for example it is very simple to effect different throttling in respect of the power of individual installations if an individual one or a plurality of installations of a wind park are (or have to be) taken from the network, if for maintenance reasons or other reasons an individual installation or a plurality of installations have to be temporarily stopped.

For controlling/regulating the wind park or the individual installations it is possible to use a data/control processing apparatus which is connected to the data inputs of the installations and which, from the wind speed data which are ascertained (by each installation), ascertains the respective most advantageous power throttling value for an individual installation or for the entire wind park.

In the accompanying drawings:
Figure 1 is a block circuit diagram depicting control of a wind power installation;
Figure 2 schematically depicts a wind park comprising three wind power installations;
Figure 3 is a frequency/power timegraph of a wind power installation;
Figure 4 is a side view of a wind power installation;
Figure 5 is an electric circuit diagram of a microprocessor-controlled inverter for a wind power installation;
Figure 6 is an electric circuit diagram of a wind power installation regulating apparatus;
Figure 7 schematically depicts coupling of a wind power installation to an electrical network;
Figure 8 is an electric circuit diagram alternative to that of Figure 6;
Figure 9 is a simplified schematic depiction of a wind power installation feeding into a network;
Figure 10 depicts a regulating device for the operation of a wind power installation;
Figure 11 graphically depicts a relationship between network voltage and phase angle;
Figure 12 schematically depicts components of a regulating device for the Figure 9 embodiment; and
Figure 13 is a simplified schematic depiction of regulation of a plurality of wind power installations.

Figure 1 is a block circuit diagram showing the control of a wind power installation by means of a microprocessor P connected to an inverter apparatus (PWR), by means of which multi-phase alternating current can be fed into the power supply network. The microprocessor has a power input P, an input for inputting a power factor (cos phi) and an input for inputting the power gradient (dP/dt).

The inverter apparatus comprising a rectifier, a rectifier intermediate circuit and an inverter is connected to the generator of a wind power installation and receives therefrom the energy produced by the generator, in rotary speed-variable fashion, that is to say, in dependence on the rotary speed of the rotor of the wind power installation.

The design illustrated in the Figure serves to illustrate how the power delivered by a wind power installation can be limited in its amount to a maximum possible network feed-in value.

Figure 2 is a view showing the principle of a wind park comprising for example three wind power installations 1, 2 and 3 of which - as viewed from the direction of the wind - two are disposed in side-by-side relationship and the third is positioned behind the first two. As each of the individual wind power installations has a power input for setting the power of the respective installation (Figure 1), the power levels of an individual wind power installation can be set to a desired value by means of a data processing apparatus, by means of which the entire wind park is controlled. In Figure 2 the advantageous sites for the wind power installations are those which the wind first encounters, that is to say the installations 1 and 2.

The present invention also concerns a method of operating a wind park having at least one wind power installation with an electrical generator drivable by a rotor for delivering electrical power to an electrical network to which the wind power installation is connected. The invention further concerns a wind power installation comprising a rotor and an electrical generator coupled to the rotor for delivering electrical power to an electrical consumer, in particular an electrical network.

In the case of low-power electrical (island) networks the network frequency rises very quickly (abruptly) if a relatively large consumer is separated from the electrical network. The drive machines such as for example diesel engines, water wheels and the like require some time in order then to reduce their (mechanical and electrical) power. During that period of time those generators produce more energy than is taken from the electrical network. That energy is then consumed for accelerating the generators. That means that the rotary speed and thus also the network frequency rises.

As many electrical devices, for example computers, electric motors and the like, which are connected to the electrical network, are however not designed for fluctuating network frequencies or abrupt changes therein, that can result in damage to electrical machines, even going as far as destruction thereof.

The object of the present invention is to eliminate the above-described problems when wind power installations (a wind park) are connected to the electrical network.

According to the invention that object is attained by a method having the features set forth in claim 7 and a wind power installation having the feature set forth in claim 10. Advantageous developments are correspondingly described in the appendant claims.

It is proposed in accordance with the invention, if wind power installations are operated on such low-power networks, that their (mechanical and) electrical power is to be controlled in dependence on the rising network frequency. That is intended to prevent a further increase in the network frequency or to provide for a reduction in the network frequency.

That aspect of the invention is described in greater detail hereinafter by means of an embodiment.

Figure 3 shows the demand on a wind power installation (of a wind park) to reduce its output power P in dependence on the electrical frequency f of the network. In this case the value of 100% represents the reference or target frequency (50 Hz, 60Hz) of the electrical network. The values 100.6% and 102% respectively are correspondingly higher values of the network frequency f.

The electrical power of the wind power installation (of the wind park) is not yet reduced for example when there is a rise in the network frequency by 0.6% (that is to say to 100.6%). If thereafter the network frequency rises still further, then the electrical power of the wind power installation is reduced. In the illustrated example the electrical power of the wind power installation is reduced to zero power when there is a rise in the network frequency to 102%.

Figure 5 shows an embodiment of a wind power installation which satisfies that requirement. The wind power installation has adjustable rotor blades (pitch regulation of the rotor blades) so that the mechanical power of the wind power installation can be reduced. If for example the angle of incidence of the rotor blades relative to the wind is adjusted, the force on the rotor blades can also be reduced to a desired value. The electrical alternating current from the generator (not shown) which is connected to the rotor which carries the rotor blades is rectified by means of a rectifier 2 and smoothed by means of a capacitor 3. The inverter 4 then converts the dc voltage into an alternating current which is delivered to the network L1, L2, L3. The frequency of that output current is predetermined by the network. The regulating apparatus 5 comprising a microprocessor measures the network frequency and controls the power switches of the inverter in such a way that the output frequency corresponds to the network voltage (network frequency). If - as described above - the network frequency rises, the electrical power is reduced, as shown in Figure 3.

Figure 6 shows the regulating apparatus according to the invention. The diagrammatically illustrated rotor 4 of the wind power installation is coupled to a generator G which provides an electrical power which is dependent on the wind speed and thus the wind power. The ac voltage produced by the generator G is firstly rectified by means of the inverter and then converted into an ac voltage which is of a frequency corresponding to the network frequency. The network voltage at the network feed-in point of the network is ascertained by means of the network frequency detector. As soon as the network frequency exceeds a predetermined value - see Figure 3 - , the electrical power output is reduced in order to counteract a further increase in the network frequency. Accordingly, by means of the regulating apparatus, the network frequency of the network is regulated to a desired network frequency value, or at least a further rise therein is prevented.

Regulating the feed in that way of the power delivered by the wind power installation makes it possible to avoid or considerably reduce network frequency fluctuations.

Figure 7 shows the coupling of a wind power installation to an electrical network, wherein the electrical power produced by the wind power installation is delivered at the network feed-in point into the network. A plurality of consumers, in the illustrated example diagrammatically shown in the form of houses, are connected to the electrical network.

Figure 8 shows essential components of the control-regulating apparatus in a somewhat different view from Figure 6. The control and regulating arrangement has a rectifier, in which the ac voltage produced in the generator is rectified. A frequency converter connected to the rectifier converts the dc voltage which is initially rectified in the intermediate circuit, into an ac voltage which is fed into the network in the form of a three-phase ac voltage by way of the lines L1, L2, and L3. The frequency converter is controlled by means of the microcomputer which is part of the overall regulating apparatus. For that purpose the microprocessor is coupled to the frequency converter. The input parameters for regulation of the voltage, with which the electrical power made available by the wind power installation 2 is fed into the network, are the currently prevailing network voltage, the network frequency f, the electrical power P of the generator, the reactive power factor cos _ as well as the power gradient dP/dt. The microprocessor embodies the regulation according to the invention in respect of the voltage to be fed in, at its desired network frequency.

The present invention further concerns a method of operating a wind park comprising at least one wind power installation having an electrical generator drivable by a rotor for delivering electrical power to an electrical network and in particular to the connected consumers thereof.

The present invention also concerns a wind power installation (wind park), in particular for carrying out such a method, comprising a rotor and an electrical generator coupled to the rotor for delivering electrical power to an electrical network, and a wind park having at least two wind power installations.

In the known wind power installations for producing electrical energy from wind energy, the generator is operated in parallel mode with an electrical consumer, frequently an electrical network. During operation of the wind power installation the electrical active power produced by the generator can vary in dependence on the currently prevailing wind speed. The consequence of this is that the network voltage (magnitude and/or phase) can also be variable, for example at the feed-in point, in dependence on the currently prevailing wind speed. The same also applies for the current to be fed in.

In a situation involving feeding the electrical power produced into an electrical network, for example a public power mains however fluctuations in the network voltage can occur. However, such fluctuations are permissible only within very close limits, in the interests of reliable operation of connected consumers.

Relatively large deviations from the reference value in respect of the network voltage in the power supply network, in particular at the medium-voltage level, can be compensated for example by actuating switching devices such as step transformers, insofar as they are actuated when the values exceed or fall below predetermined limit values. In that way the network voltage is kept substantially constant within predetermined tolerance limits.

The object of the present invention is to provide a method of operating a wind power installation as well as a wind power installation or wind park, which, even with a fluctuating active power delivery, are in a position to reduce or at least not significantly increase the unwanted fluctuations in the voltage at a predetermined point in the network in comparison with the situation without a wind power installation or installations.

The invention (claims 15 ff) attains that object, in a method of the kind set forth in the opening part of this specification, in that the phase angle of the electrical power produced by the wind power installation or installations is varied in dependence on at least one voltage detected in the network.

In a wind power installation of the kind set forth in the opening part of this specification, that object is attained by an apparatus which is capable of carrying out the method according to the invention.

In a wind park of the kind set forth in the opening part of this specification that object is attained by at least one respective apparatus which is suitable for carrying out the method according to the invention, and a respective voltage detection device, for each separately regulatable part of the wind park.

The invention avoids unwanted fluctuations in the voltage applied at the consumer, in particular the electrical voltage prevailing in a network, by the phase angle of the delivered power being varied in dependence on the voltage of the consumer or the network. That compensates for unwanted fluctuations in voltage, which arise out of changes in the active power delivered by the wind power installation or installations and/or the power taken from the network by the consumers.

In a particularly preferred feature the phase angle is altered in such a way that the voltage at at least one predetermined point in the network remains substantially constant. In that situation to obtain the required regulating parameter the voltage at at least one point in the network is detected.

In particular that point can be a point other than the feed-in point. That detection of the magnitude of the voltage and a suitable change in the phase angle of the electrical power delivered by the wind power installation or installations can provide a quickly reacting and effective regulating system.

In a particularly preferred embodiment the values to be set for the phase angle are derived from predetermined characteristic values. Those characteristic values can preferably be provided in the form of a table in which a previously determined family of characteristic curves is represented in the form of discrete values, this making it possible to deduce the phase angle to be set.

In a preferred development of the invention the regulation system can directly or indirectly provide that, if the voltage fluctuations have exceeded the predetermined limit values, the voltage is brought back into the tolerance range again by the actuation of a switching device in the network, for example a step transformer. At the same time or in relation thereto the phase angle is set for a predetermined period of time to a constant value - preferably a mean value, for example zero, in order once again to be able to compensate for subsequently occurring voltage fluctuations, by a suitable change in the phase angle.

In a particularly preferred development of the invention suitable voltage detection procedures and setting operations in respect of the phase angle can also be implemented separately in electrically separate portions of the network, in order to regulate each portion in such a way that the voltage in each of the portions remains substantially constant.

A further development of the wind power installation according to the invention advantageously provides a regulating device having a microprocessor as in that way it is possible to implement digital regulation.

A preferred development of the wind park set forth in the opening part of this specification provides that there are a respective apparatus which is suitable for carrying out the method according to the invention and a respective voltage detection device for each separately regulatable part of the wind park so that electrically separate portions of the network can also be separately regulated in such a way that the voltage in each portion of the network remains substantially constant.

The invention is described hereinafter by means of an embodiment of a method of operating a wind power installation, with reference to Figures 9-13.

A wind power installation 2 diagrammatically shown in Figure 9, having a rotor 4, is connected to an electrical network 6 which for example can be a public mains network. A plurality of electrical consumers 8 are connected to the network. The electrical generator (not shown in Figure 9) of the wind power installation 2 is coupled to an electrical control and regulating apparatus 10 which firstly rectifies the alternating current produced in the generator and then converts it into an alternating current at a frequency which corresponds to the network frequency. The control and regulating apparatus 10 has a regulating device according to the invention.

A voltage detection device 22 can be provided at any point 22 in the network 6, the voltage detection device measuring (besides the phase) in particular the magnitude of the network voltage and returning the measured value to the regulating device 10 as a suitable regulating parameter.

Figure 10 illustrates the regulating device according to the invention. The diagrammatically illustrated rotor 4 is coupled to a generator 12 which produces electrical power which can depend on the wind speed. The ac voltage produced in the generator 12 can firstly be rectified and then converted into an ac voltage of a frequency corresponding to the network frequency.

The network voltage is measured at a location 22 in the network 6 by means of a voltage detector (not shown). In dependence on the ascertained network voltage - possibly by means of a microprocessor shown in Figure 12 - an optimum phase angle   is calculated. The network voltage U is then regulated to the desired value Uref by means of the regulating device.

The electrical power delivered by the generator 12 to the network 6 is regulated by the change in the phase angle.

The view shown in Figure 11 illustrates the relationship between the voltage in the network and the phase angle. If the voltage deviates from its reference value Uref which is between the voltage values Umin and Umax then, corresponding to the characteristic curve in the graph, the phase angle   is altered in such a way that, depending on the sign of the deviation, either inductive or capacitive reactive power is fed into the network in order in that way to stabilise the voltage at the voltage detection point (at 22 in Figure 9).

Figure 12 shows essential components of the control and regulating apparatus 10 illustrated in Figure 9. The control and regulating apparatus 10 has a rectifier 16 in which the alternating current produced in the generator is rectified. A frequency converter 18 connected to the rectifier 16 converts the initially rectified direct current into an alternating current which is fed into the network 6 in the form of a three-phase alternating current by way of the lines L1, L2 and L3.

The frequency converter 18 is controlled by means of a microprocessor 20 which is part of the overall regulating device. For that purpose the microprocessor 20 is coupled to the frequency converter 18. The input parameters for the microprocessor 20 are the currently prevailing network voltage U, the electrical power P of the generator, the reference value of the network voltage Uref and the power gradient dP/dt. The change according to the invention in the power which is to be fed in is implemented in the microprocessor 20.

Figure 13 shows two wind power installations 2, as an example of a wind park. A regulating apparatus 10 is associated with each of those wind power installations 2 which naturally can also symbolically stand for a respective plurality of wind power installations. The regulating apparatus 10 detects the voltage at predetermined points 22, 27 in the network 6, 7 and transmits the voltage by way of lines 25, 26 to the respectively associated regulating apparatus 10.

The portions 6, 7 of the network can be connected together or separated from each other, by way of a switching device 23. Provided in parallel with the switching device 23 is a switching device 24 which makes it possible for the two regulating apparatuses 10 to be connected together or separated from each other, according to the switching condition of the switching device 23.

If therefore the two portions 6, 7 of the network are connected together, then the two regulating apparatuses 10 are also connected to each other so that the entire network is considered as a unit and is supplied by the entire wind park as a unit, wherein the wind park is again regulated in unitary fashion in dependence on the voltage at the detection point 22, 27.

If the two portions 6, 7 are separated by the switching device 23, the regulating apparatuses 10 are also separated from each other in such a way that a part of the wind park is monitored by a detection point 22 by way of a line 25 by the regulating apparatus 10 and the associated part of the wind park can be correspondingly regulated, while the other portion of the network 7 is monitored by a detection point 27 by way of a line 26 by means of the regulating apparatus 10 which correspondingly regulates the other part of the wind park to stabilise the voltage in the portion 7 of the network.

It will be appreciated that this division does not have to be limited to two portions. That division can be taken as far as associating an individual installation with a portion of the network.

Central regulation of a wind park, in accordance with the invention, essentially aims to provide that the wind park not only feeds electrical energy into a public power supply network but also at the same time can be controlled in such a way as to support the network, preferably by the operator of the public network (power supply utility). Insofar as reference is made to a wind park in the present application, that is also intended to denote an individual wind power installation and not only always a plurality of wind power installations, in which respect it is preferably precisely a plurality of wind power installations that always forms a wind park.

For the central control of the wind park, in accordance with the invention, the operator of the public power supply network not only has a control access by means of a suitable control line (bus system) to the wind park/to the wind power installation, but he also receives from the wind park/wind power installation data, such as for example measured wind data, data about the status of the wind park, and also for example data about the available power (currently prevailing power) (active power)) of the wind park.

Such a central control can also mean for example that the wind park is entirely taken off the network in certain circumstances, for example if the network connection rules which are preset by the operator of the public supply network cannot be observed on the part of the wind park.

If for example the voltage in the network falls below a given predetermined value, for example to a value of between 70 and 90% of the network voltage, the wind park must be separated from the network within a predetermined time, for example between two and six seconds.

Finally it is necessary to provide that the change in power (dP) of the wind park is not only predetermined by the wind but can also still alter at entire given time intervals. That power parameter is therefore also referred to as the power gradient and specifies by how many percent the respective available power may alter within a predetermined time (for example per minute). Thus for example it can be provided that the power gradient of the wind park may be at a maximum between 5 and 15%, preferably 10% of the network connection capacity per minute.

Such regulation of the wind park can be effected for example by all wind power installations of a park simultaneously or uniformly increasing their power delivery in the predetermined power gradient. It will be appreciated that alternatively it is also possible to envisage that, in the case of a wind park of for example between 10 and 20 installations, firstly one or two installations (at the respective order of magnitude of the power gradient) initially feed into the network at full power and then in accordance with the respective predetermined power gradient further installations are cut in, within a predetermined time, until all of the available power of the wind park can be fed into the network.

A further aspect of the wind park regulation according to the invention is the provision of the reserve power at the level of a percentage, for example 10%, of the currently available power of the wind park, or a fixed value, for example between 500 kW and 1 MW or more per wind park. That reserve power is not to be confused with a park power which exceeds the network connection power of the wind park. The reserve power decisively involves a power reserve (this concerns both active power and also reactive power) which it does not exceed in the range of the network connection power. That reserve power can be prescribed by the operator of the public supply network. That is to say, if therefore sufficient wind is available to feed the network connection power from the wind park into the network, the power supply utility, by virtue of the prescribed control intervention into the wind park, can provide that this theoretically possible power is not completely fed into the network, but a part of that power remains available as reserve power. A particular aspect of that reserve power is that, in the event of an unexpected failure of power station power (at other locations at which power is fed into the network), the network can be stabilised by way of calling up the corresponding reserve power.

Accordingly, with the above-indicated central control of the wind park, the power fed into the network is under normal circumstances therefore less than the power to be made available by the wind park (maximum available power), in dependence on the respective power requirement in the network.

So that this above-described power control procedure can be implemented the network operator also requires the prescribed data such as wind speed, installation status of the wind park (how many installations are in operation, how many are out of operation or damaged) and preferably also the maximum possible active power delivery. In that respect, in regard to the maximum possible active power delivery, the limitation can apply that this has to be provided in the form of data only when it cannot be determined from the wind speed and the installation status.

A normal bus system for example also a standardised bus system, can be used for control of the wind park and also for data supply for the power supply utility. There are already standardised interfaces for such standardised bus systems, for example a Profibus system, so that central wind park control can also be implemented by means of suitably standardised control commands.

Supplemental to the foregoing, it can also be provided that the wind park, as from a pre-designed power, that is to say at a total power output of more than 50 MW, is treated as a large-scale power station and then must also satisfy the conditions for large-scale power stations.

Finally it can also be provided that the wind park is so regulated that the network connection value (the network connection capacity) is not exceeded.

Finally when switching on/cutting in the wind park it is also necessary to provide that unwanted network retroactions do not occur. For example, when switching on/cutting in a wind park, the current may not be higher than a predetermined value in respect of the nominal current which corresponds to the connection capacity. Such a value can be for example in the range of between 1.0 and 1.4.

If the frequency in the public power supply network rises then - as already described - it should be provided that, from a given frequency value, for example from 50.25 Hz (with a nominal frequency of 50 Hz), the delivered active power of the wind park is automatically reduced until the network frequency is again stabilised at a value as described above.

Therefore it must also always be possible to operate the wind park at a reduced level of power delivery in order to be able to observe the network requirements. That power regulation also means that the power delivery (in particular active power) can be reduced to any desired value in any operating condition and from any operating point.

Thus for example it is possible to implement limitation of the feed-in power below the available feed-in power if there are dangers in regard to safe reliable system operation, bottlenecks or a risk of overloading in up-stream-disposed networks are to be fixed, there is the danger of the formation of an island network, static or dynamic stabilities are endangered, the frequency rise can endanger the entire network system, and for example repair operations or other operational-governed stoppages also have to take place at the power supply utility.

Besides the active power delivery which has already been described above and which is to be afforded if necessary, it must also be possible to provide a given reactive power, in which case it can also be set as wished by the power supply utility, more specifically both in the inductive and also in the capacitive range, that is to say underexcited and overexcited, in which respect the respective values can be predetermined for that purpose by the power supply utility.

In that connection, the reference value in respect of reactive power provision can be set variably, wherein the reference value presetting is effected at the network connection nodes for the power factor (cos phi) or a voltage magnitude. It is also possible to predetermine a fixed reference value.

As already described hereinbefore the power delivery is reduced and/or the wind park is completely taken off the network if frequency values in the network exceed/fall below certain levels. Thus for example the wind park can be taken off the network when the network falls below a network frequency of about 48 Hz (with a 50 Hz network frequency) or at 51 to 52 Hz. In that respect, at values below the intended range, it is still possible to provide within limits of the range that only a part of the current available power is fed into the network, for example between about 80 and 95% of the current available power.

If for example the network voltage should also fall below a predetermined value, the same also applies here, as in the case of the deviating network frequency. In other words, when the voltage falls below or exceeds a predetermined network voltage in the given voltage, firstly a reduced power delivery takes place and, when the network voltage falls below or exceeds given limit values, the installations are completely taken off the network or at least the power fed into the network is set at zero.

Finally it can also be provided that, when given network voltage and/or network frequency values are reached, tried-and-tested shut-down of the wind park is effected, without a power delivery which has already been reduced being implemented beforehand.

That however also means at the same time that, with given frequency deviations/voltage deviations within a predetermined range around the network frequency/network voltage, automatic separation of the wind park from the network is not admissible.

Finally, for network protection purposes, it can also be provided that the shut-down time when the voltage value is exceeded is markedly shorter (for example between 50 and 200 milliseconds) than in the case of voltage reduction protection (shut-down time of more than 1 second, preferably between about 2 and 6 seconds). In that respect, the shut-down time when the value of the upper frequency or lower frequency exceeds or falls below the predetermined, still just admissible limit value is approximately in the region of the shut-down time when the voltage is in excess (above a predetermined voltage value).

Finally in the event of a fault in the network, for example in a short-circuit situation, automatic separation of the wind park from the network should not always occur straightaway, but rather the wind park can also be controlled in such a way that, depending on the respective network connection, it still feeds into the network a contribution to the short-circuit power as apparent power in order in that way still to be able to afford network support to a certain degree. This means that the wind park, at least for a certain time for the duration of a short circuit but at a maximum only a few seconds, has to deliver the highest possible apparent current (apparent power) which however corresponds for example to once or up to 1.5 times the current which corresponds to the network connection capacity.

The above-described behaviour can also be made dependent on the level of the nominal voltage, for example if it exceeds a predetermined value of for example more than 50 kV.

So that the above-described shut-down procedures can take place in good time, for example a protective relay (distance protective relay) is to be installed for the implementation thereof at the network connection node.

Finally means should also be provided which, upon start-up of a wind park, synchronise the voltage in the network and that of the wind park because, when the wind park is started up again, asynchronous voltages sensitively disturb the network and can cause it to shut down.

Insofar as in accordance with the present invention the power is regulated below a value of the power which is to be currently made available by a wind park, that can be implemented by various measures.

Thus for example the power can overall be reduced for each individual installation so that the entire wind park assumes the desired reduced power value. As an alternative thereto however it can also be provided that only individual installations are reduced in respect of their power feed-in value so that the total feed-in power value of the wind park again assumes the desired value.

Finally it can also be provided that for example a given power made available by the wind park is put into intermediate storage in so-called dump loads (resistors) or other energy storage means or is converted into another form of energy, such that the feed-in value of the wind park assumes the desired value.

The reduction in power output can also be afforded by a procedure whereby one wind power installation or given wind power installations are entirely removed from the network so that then once again the overall power of the wind park (in particular the active power thereof) can be set to the desired value and/or drops below the desired value.

For data transmission of the data in respect of the wind park (wind data, status data, power data etc) or for control of the wind park, it is also possible to provide a wireless communication arrangement so that the control data or information data can be wirelessly transmitted and processed.

In the case of the above-mentioned wind park regulation, it is also to be provided that, within the wind park, the procedure also involves ascertaining the value which can be made available as maximum energy and also then further ascertaining what amount of energy is fed into the network so that, taking the difference amount which is substantially due to control of the wind park on the part of the power supply utility, it is possible to calculate a feed-in recompense amount which if necessary is reimbursed.

As already described it is not only possible for the power supply utility which operates the power supply network to have the possibility of limiting or restricting the power output of the wind park or individual wind power installations with the access by way of a control line, for various reasons (network protection, servo power), but it is also possible for the operator of the public power supply network, at the same time, to obtain data relating to the status of the wind park, for example data relating to the maximum available power, wind speed and so forth. As, when the power is restricted to below the currently available power, the wind park or the wind power installations of a wind park are not put to optimum use, that results in feed-in losses on the part of the wind power installation operators. Therefore here too the invention proposes the provision of a virtual current meter which detects the difference in respect of that which is not taken off by the intervention on the part of the power supply undertaking into the regulation system and thus the limitation in respect of the wind park or wind power installation power output. Such a 'virtual current meter' can on the one hand ascertain from the wind speed the power which is to be available and, if at the same time the power supply undertaking or anyone else reduces the power output of individual wind power installations or an entire wind park below the power output which can be made available, then by an integration operation it is possible to ascertain (count) the amount of energy which is not fed into the network. The virtual current meter makes it possible for the operator of the wind power installation to obtain remuneration also for the 'virtual current', that is to say the current which is not fed into the network by virtue of the interventions in regulation of the power supply. The 'virtual current meter' can be installed both at the operator of the wind power installation, in the wind power installations themselves within the wind park, at the power supply undertaking or also at the manufacturer of the wind power installations.

Insofar as the present application uses the term wind power installation, that is synonymous with the term wind park. Insofar as the present application describes various aspects of the invention they can be embodied together with the wind power installations or the control thereof. It is however also possible for the different approaches according to the invention to be implemented and claimed singularly without the further aspects of the invention, even if the present application usually describes various aspects of the invention together. It will be clear to the man skilled in the art however that various aspects of the invention can also be implemented and claimed differently and the common description thereof is thus not equivalent to them always having to be implemented and claimed together.

WHAT IS CLAIMED IS:

1. A method of operating a wind park having a plurality of wind power installations and a control input, said wind park producing electrical power and connected to feed at least a portion of that power into an electrical power supply network, the method comprising:

setting a limit electrical power of said wind park in a range of between 0 and 100% of a nominal electrical power thereof by the control input,

changing the phase angle between the current and the voltage of the electrical power fed into the electrical power supply network according to a voltage of the electrical power supply network to reduce the electrical power fed into the electrical power supply network when one or more of:

at least one of the network frequencies in the electrical power supply network exceeds a first given value;

at least one of the network frequencies in the electrical power supply network falls below a second given value;

the voltage of the electrical power supply network exceeds a first given voltage; and

the voltage of the electrical power supply network falls below a second given voltage,

wherein an external operator system (PSU) of the electrical power supply network can adjust the electrical power fed into the electrical power supply network by way of the control input.

2. A method according to claim 1, wherein the first given value and the second given value define a range of at least ±3% about a reference network frequency value.

3. A method according to claim 1, wherein the first given value and the second given value define a range of at least $\pm 6\%$ about a reference network frequency value.

4. A method according to any one of claims 1 to 3, comprising measuring the voltage of the electrical power supply network at least at one location in the electrical power supply network and wherein the change in phase angle depends on the measured voltage value.

5. A method according to claim 4, wherein the phase angle is changed in such a way that the voltage at at least one predetermined point in the network remains substantially unchanged.

6. A method according to claim 5, wherein the voltage of the electrical power supply network is measured at the at least one predetermined point in the electrical power supply network.

7. A method according to any one of claims 4 to 6, wherein the voltage of the electrical power supply network is measured at a different point than the feed-in point.

8. A method according to any one of claims 1 to 7 comprising actuating a switching device in the electrical power supply network when a fluctuation of the voltage of the electrical power supply network exceeds a predetermined limit.

9. A method according to claim 8 wherein the phase angle between the current and the voltage fed into the electrical power supply network

is set for a predetermined period of time to a constant value when the switching device is actuated.

10. A method according to any one of claims 4 to 9, wherein said wind park is connected to feed electrical power to electrically separate portions of the electrical power supply network, and wherein the steps of:

changing the phase angle between the current and the voltage fed into the electrical power supply network to reduce the electrical power fed into the electrical power supply network; and

measuring the voltage of the electrical power supply network, are performed separately for the electrically separate portions of the electrical power supply network.

11. A wind park connected to feed electrical power into an electrical power supply network, said wind park comprising:

a plurality of wind power installations;

a control input for setting a limit electrical power of at least one of the wind power installations in a range of between 0 and 100% of a nominal electrical power thereof;

a regulating apparatus connected to the control input, the regulating apparatus configured to:

limit the electrical power fed into the electrical power supply network to a limit electrical power of said wind park, the limit electrical power of said wind park based at least in part on the limit electrical power of the at least one of the wind power installations; and

throttle the electrical power fed into the electrical power supply network by causing the phase angle between the current and the voltage of the electrical power fed into the electrical power supply network to be changed according to a voltage of the electrical power supply network when one or more of:

at least one of the network frequencies in the electrical power supply network exceeds a first given value;

at least one of the network frequencies in the electrical power supply network falls below a second given value;

the voltage of the electrical power supply network exceeds a first given voltage; and

the voltage of the electrical power supply network falls below a second given voltage,

wherein an external operator system (PSU) of the electrical supply network can adjust the electrical power fed into the electrical power supply network by way of the control input.

12. A wind park according to claim 11, wherein said wind park has a nominal electrical power greater than a maximum network feed-in power of the electrical power supply network.

13. A wind park according to any one of claims 11 and 12, wherein the power produced by at least one wind power installation is throttled to be less than a nominal electrical power thereof when the electrical power fed into the electrical power supply network is equal to the limit electrical power of said wind park.

14. A wind park according to claim 13, wherein the throttling of the power produced by each of the plurality of wind power installations is of the same magnitude.

15. A wind park according to claims 13, wherein the throttling of the power produced by one of the plurality of wind power installations is of a magnitude different from a magnitude of the throttling of the power produced by at least one other of the plurality of wind power installations.

16. A wind park according to any one of claims 11 to 15, wherein the limit electrical power of said wind park is lower than the nominal electrical power thereof, and wherein the limit electrical power is determined based at least in part by the power capacity of electrical power supply network and by the power capacity of the power transmission unit through which the electrical power produced by said wind park is fed into the electrical power supply network.

17. A wind park according to any one of claims 11 to 16, wherein the limit electrical power of a first wind power installation is greater than the limit electrical power of a second wind power installation which in the wind direction is behind the first wind power installation.

18. A wind park according to any one of claims 11 to 17, wherein the regulating apparatus comprises a frequency detector for measuring the frequency of the voltage of the electric power fed into the electrical power supply network.

19. A wind power installation according to claim 18, wherein the regulating apparatus comprises a microprocessor coupled to receive a frequency measurement generated by the frequency detector.

20. A wind power installation according to claim 19, wherein the regulating apparatus comprises an inverter coupled to the microprocessor.

21. A wind park according to any one of claims 11 to 20, wherein at least one of the wind power installations comprises adjustable rotor blades.

22. A wind park according to any one of claims 11 to 21, wherein at least one the wind power installations does not deliver any electrical power to the electrical power supply network if a network frequency of the electrical power supply network exceeds a first given value.

23. A wind park according to claim 22, wherein the first given value is at least 2% greater than a reference frequency value.

24. A wind park according to any one of claims 18 to 22, wherein at least one the wind power installations does not deliver any electrical power to the electrical power supply network if a network frequency of the electrical power supply network falls below a second given value.

25. A wind park according to claim 24, wherein the second given value is at least 2% less than a reference frequency value.

26. A wind park according to any one of claims 11 to 25, wherein said wind park is connected to feed electrical power to a plurality of electrically separate portions of the electrical power supply network, said wind park comprising a voltage detection device for each electrically separate portion of said wind park.

27. A wind park according to any one of claims 11 to 26, wherein said wind park is electrically separated from the electrical power supply network within a predetermined period of time of the voltage of the power supply network falling below a disconnect threshold in the range of between 70% and 90% of a nominal voltage of the electrical power supply network.

28. A wind park according to claim 27 wherein the predetermined period of time is in the range of between two and six seconds.

29. A wind park according to any one of claims 11 to 28, wherein the power gradient of the electrical power of said wind park is limited to a value of between 5 and 15% of the network connection capacity of said wind park per minute.

30. A wind park according to any one of claims 11 to 29 wherein the power gradient of the electrical power of said wind park is limited to 10% of the network connection capacity of said wind park per minute.

31. A method of operating a wind park having a plurality of wind power installations and a control input, said wind park producing electrical

power and connected to feed at least a portion of that power into an electrical power supply network, the method comprising:

setting a limit electrical power of said wind park in a range of between 0 and 100% of a nominal electrical power thereof by the control input,

reducing the electrical power fed into the electrical power supply network when one or more of:

at least one of the network frequencies in the electrical power supply network exceeds a first given value; and

at least one of the network frequencies in the electrical power supply network falls below a second given value;

wherein an external operator system (PSU) of the electrical power supply network can adjust the electrical power fed into the electrical power supply network by way of the control input.

32. A method according to claim 31, wherein the first given value and the second given value define a range of at least ±3% about a reference network frequency value.

33. A method according to claim 31, wherein the first given value and the second given value define a range of at least ±6% about a reference network frequency value.

34. A wind park connected to feed electrical power into an electrical power supply network, said wind park comprising:

a plurality of wind power installations;

a control input for setting a limit electrical power of at least one of the wind power installations in a range of between 0 and 100% of a nominal electrical power thereof;

a regulating apparatus connected to the control input, the regulating apparatus configured to:

limit the electrical power fed into the electrical power supply network to a limit electrical power of said wind park, the limit electrical power of said wind park based at least in part on the limit electrical power of the at least one of the wind power installations; and

throttle the electrical power fed into the electrical power supply network when one or more of:

at least one of the network frequencies in the electrical power supply network exceeds a first given value; and

at least one of the network frequencies in the electrical power supply network falls below a second given value;

wherein an external operator system (PSU) of the electrical supply network can adjust the electrical power fed into the electrical power supply network by way of the control input.

35. A wind park according to claim 34, wherein said wind park has a nominal electrical power greater than a maximum network feed-in power of the electrical power supply network.

36. A wind park according to any one of claims 34 and 35, wherein the power produced by at least one wind power installation is throttled to be less than a nominal electrical power thereof when the electrical power fed into the electrical power supply network is equal to the limit electrical power of said wind park.

37. A wind park according to claim 36, wherein the throttling of the power produced by each of the plurality of wind power installations is of the same magnitude.

38. A wind park according to claims 36, wherein the throttling of the power produced by one of the plurality of wind power installations is of a magnitude different from a magnitude of the throttling of the power produced by at least one other of the plurality of wind power installations.

39. A wind park according to any one of claims 34 to 38, wherein the limit electrical power of said wind park is lower than the nominal electrical power thereof, and wherein the limit electrical power is determined based at least in part by the power capacity of electrical power supply network and by the power capacity of the power transmission unit through which the electrical power produced by said wind park is fed into the electrical power supply network.

40. A wind park according to any one of claims 34 to 39, wherein the limit electrical power of a first wind power installation is greater than the limit electrical power of a second wind power installation which in the wind direction is behind the first wind power installation.

41. A wind park according to any one of claims 34 to 40, wherein the regulating apparatus comprises a frequency detector for measuring the frequency of the voltage of the electric power fed into the electrical power supply network.

42. A wind power installation according to claim 41, wherein the regulating apparatus comprises a microprocessor coupled to receive a frequency measurement generated by the frequency detector.

43. A wind power installation according to claim 42, wherein the regulating apparatus comprises an inverter coupled to the microprocessor.

44. A wind park according to any one of claims 34 to 43, wherein at least one of the wind power installations comprises adjustable rotor blades.

45. A wind park according to any one of claims 34 to 44, wherein at least one the wind power installations does not deliver any electrical power to the electrical power supply network if a network frequency of the electrical power supply network exceeds a first given value.

46. A wind park according to claim 45, wherein the first given value is at least 2% greater than a reference frequency value.

47. A wind park according to any one of claims 41 to 45, wherein at least one the wind power installations does not deliver any electrical power to the electrical power supply network if a network frequency of the electrical power supply network falls below a second given value.

48. A wind park according to claim 47, wherein the second given value is at least 2% less than a reference frequency value.

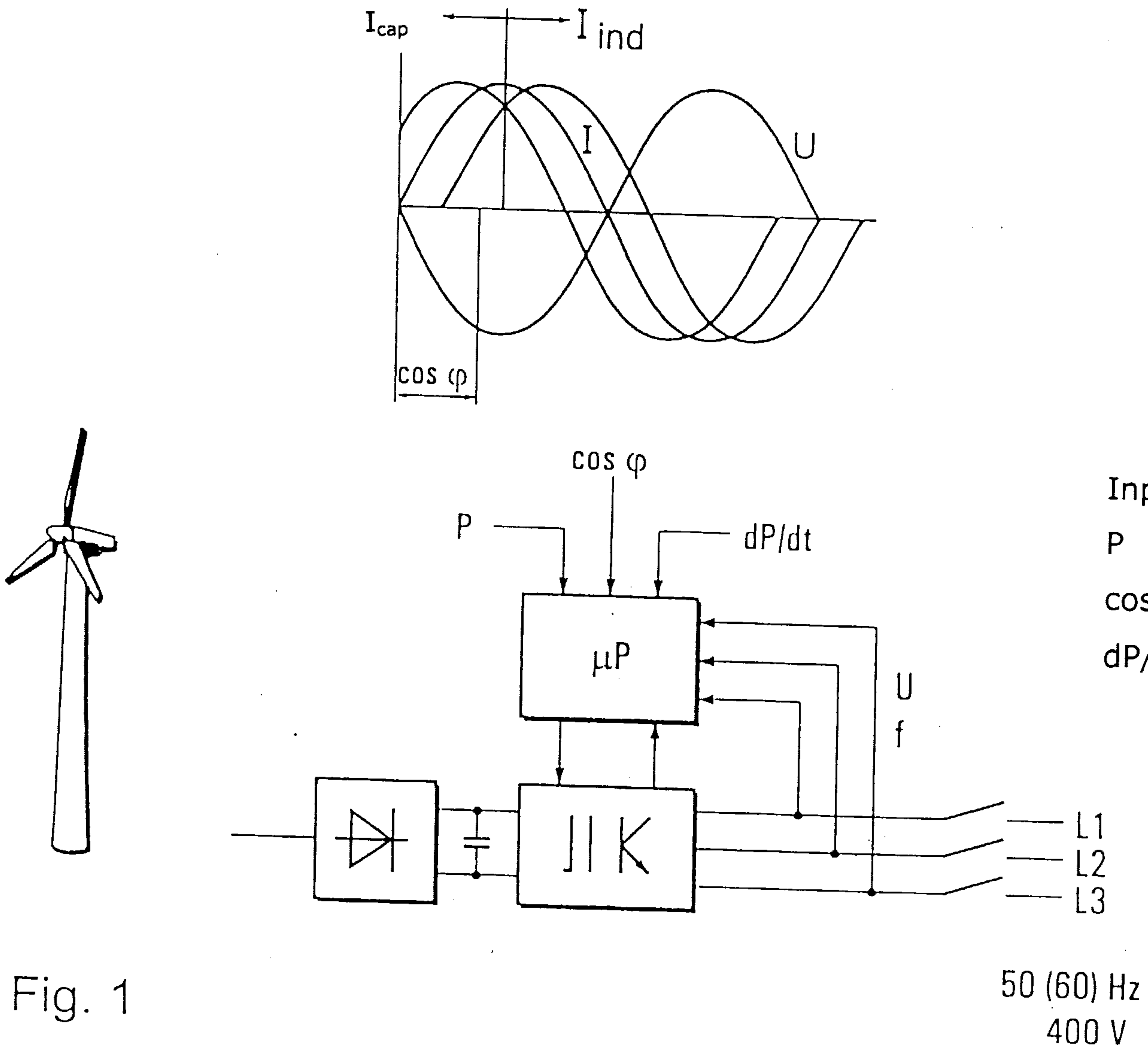
49. A wind park according to any one of claims 34 to 48, wherein said wind park is connected to feed electrical power to a plurality of electrically separate portions of the electrical power supply network, said wind park comprising a voltage detection device for each electrically separate portion of said wind park.

50. A wind park according to any one of claims 34 to 49, wherein said wind park is electrically separated from the electrical power supply network within a predetermined period of time of the voltage of the power supply network falling below a disconnect threshold in the range of between 70% and 90% of a nominal voltage of the electrical power supply network.

51. A wind park according to claim 50 wherein the predetermined period of time is in the range of between two and six seconds.

52. A wind park according to any one of claims 34 to 51, wherein the power gradient of the electrical power of said wind park is limited to a value of between 5 and 15% of the network connection capacity of said wind park per minute.

53. A wind park according to any one of claims 34 to 52 wherein the power gradient of the electrical power of said wind park is limited to 10% of the network connection capacity of said wind park per minute.



Input:

P = Power

cos = Reactive power

dP/dt = Power gradient

Fig. 1

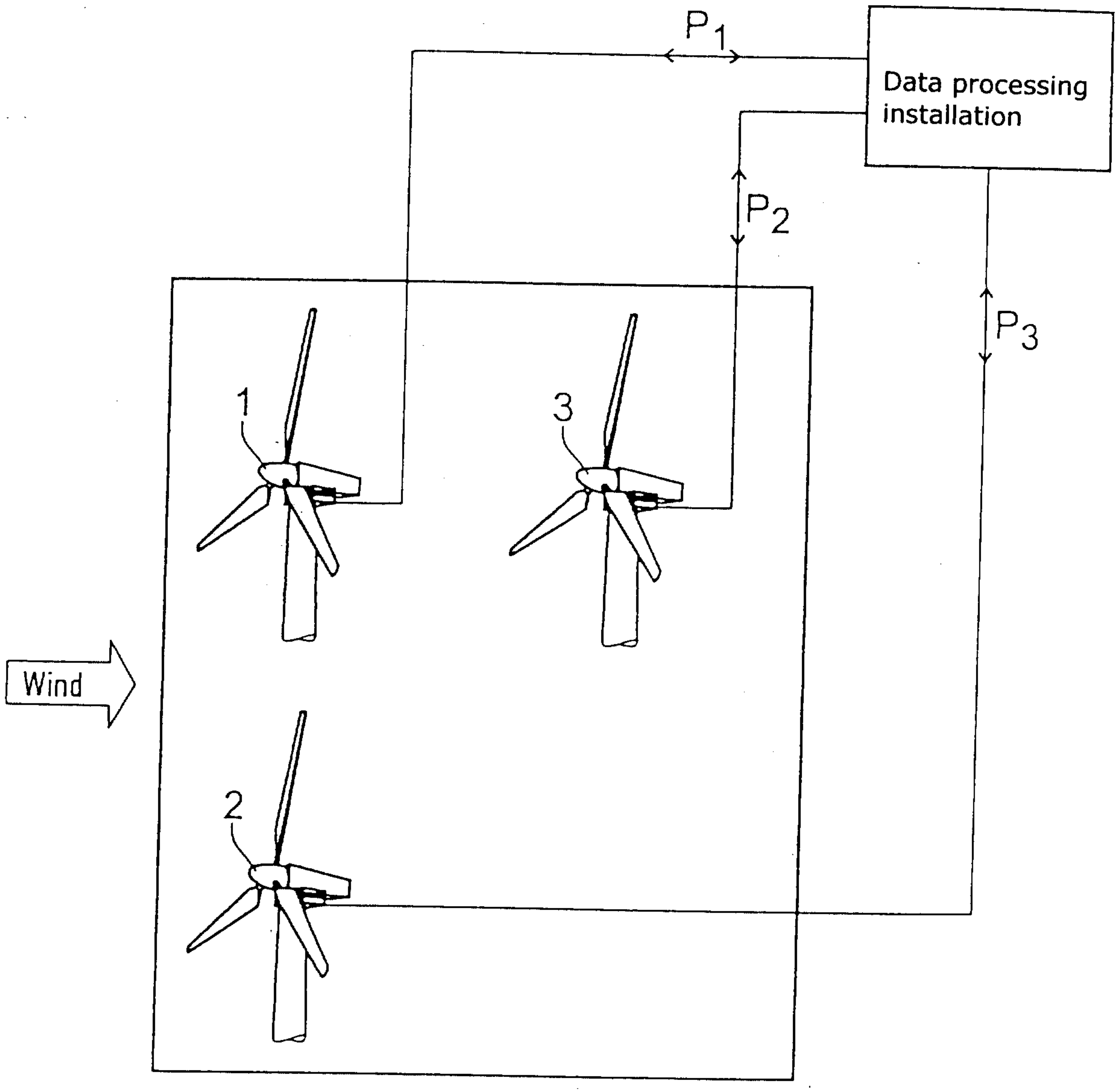


Fig. 2

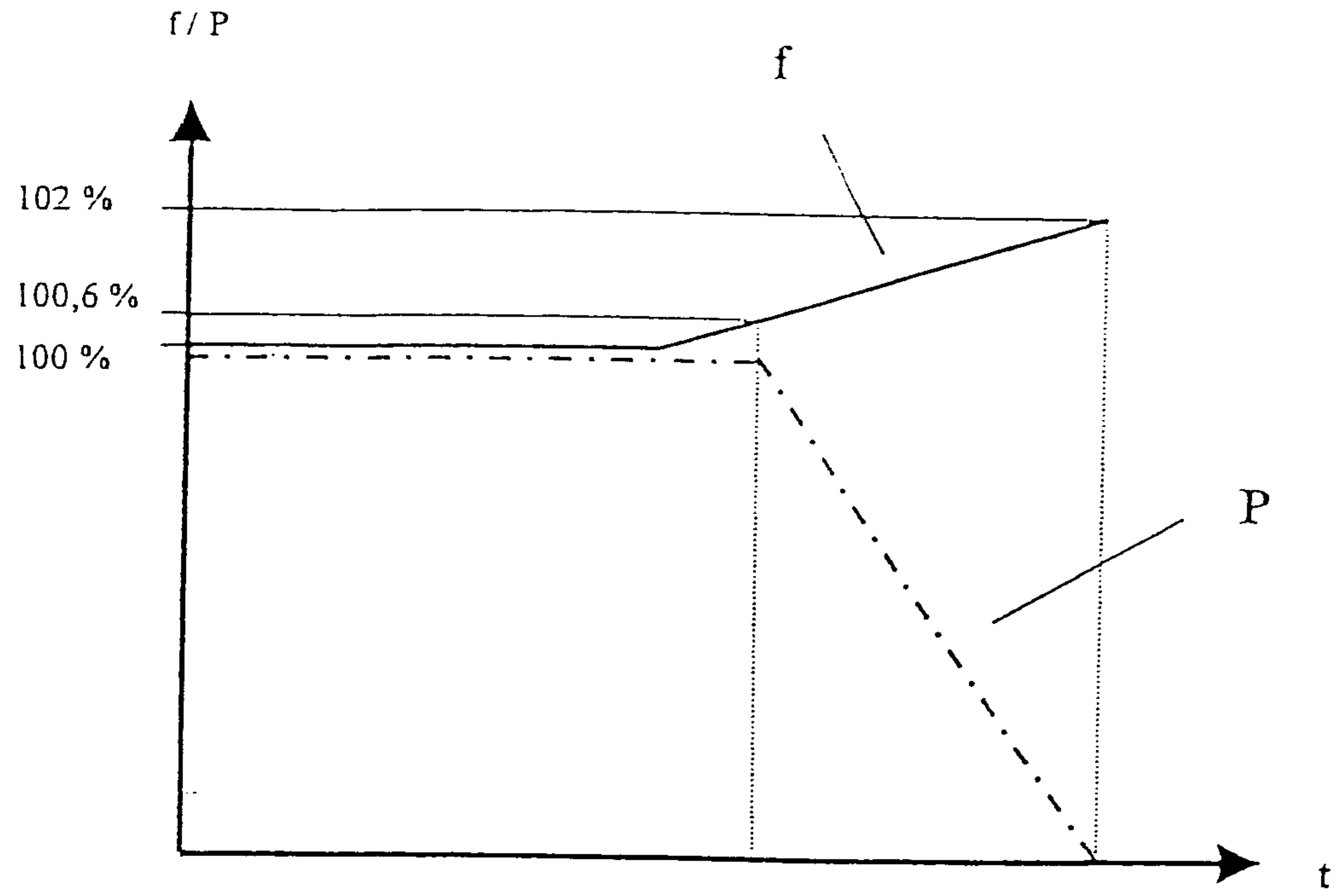


Fig. 3

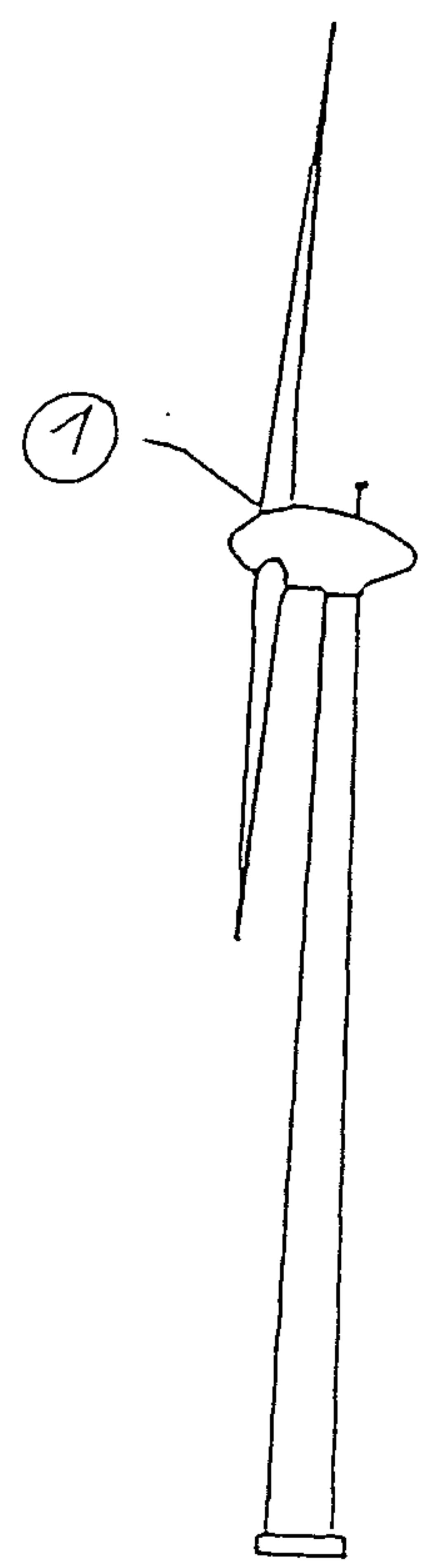


Fig. 4

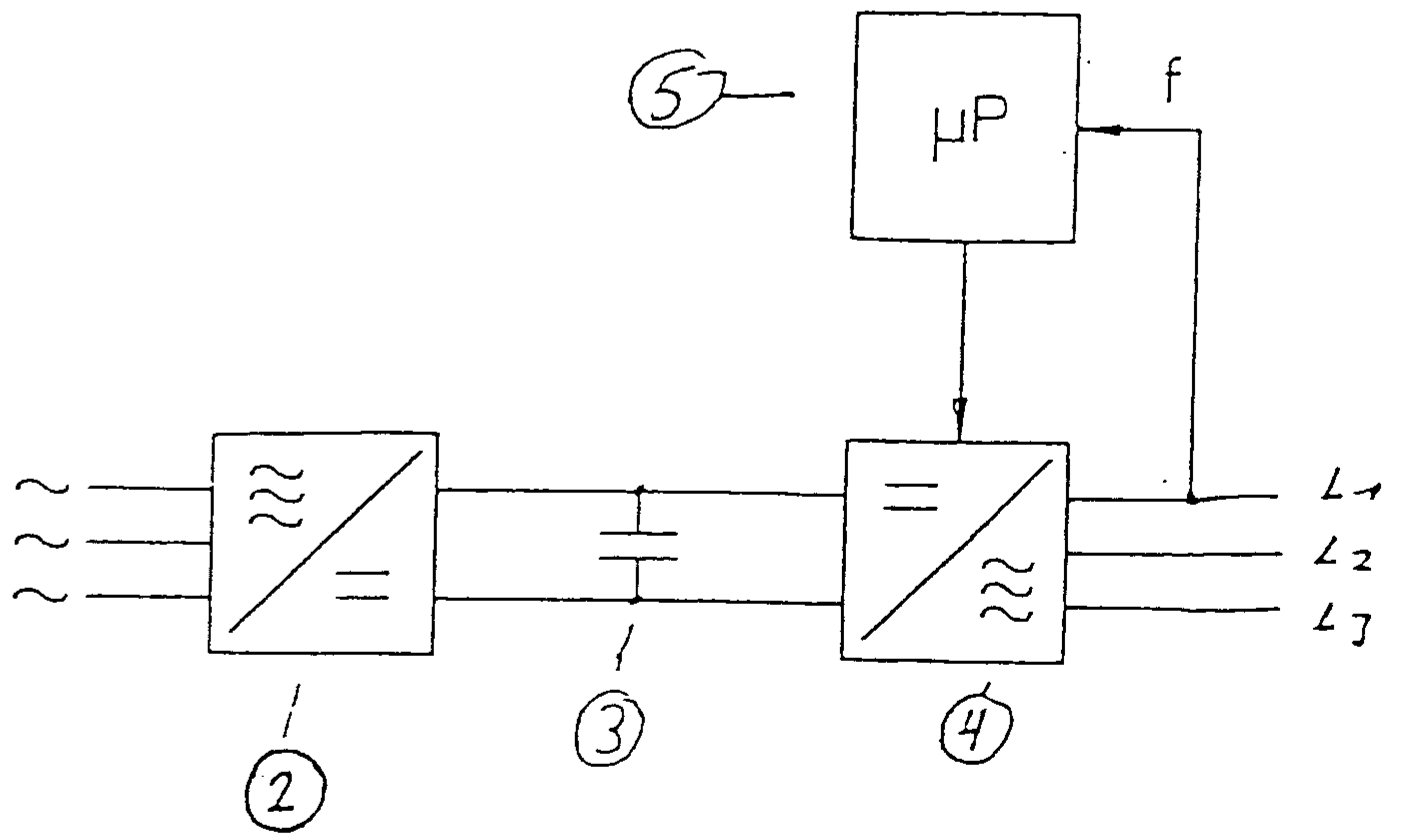


Fig. 5

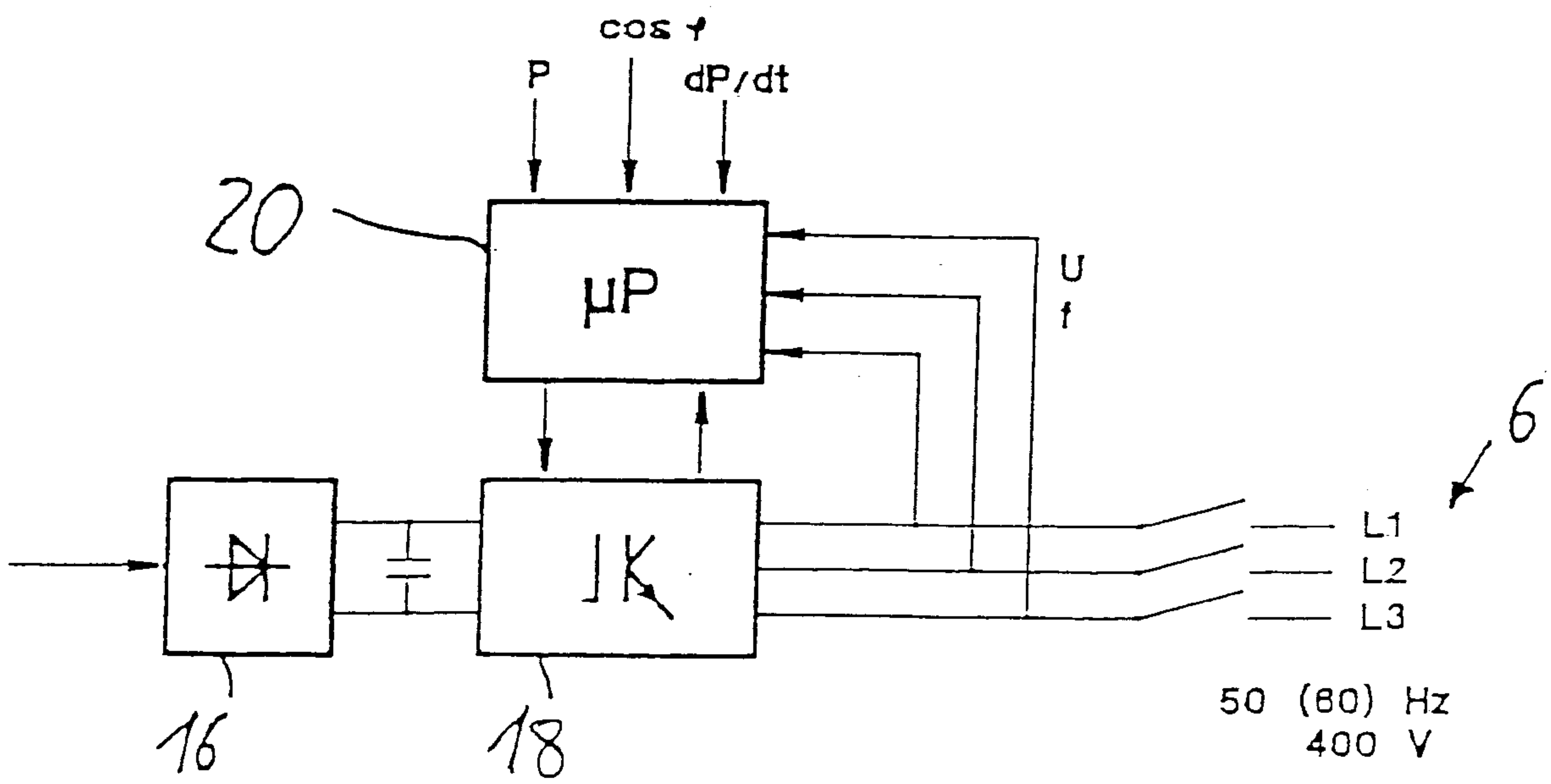


Fig. 6

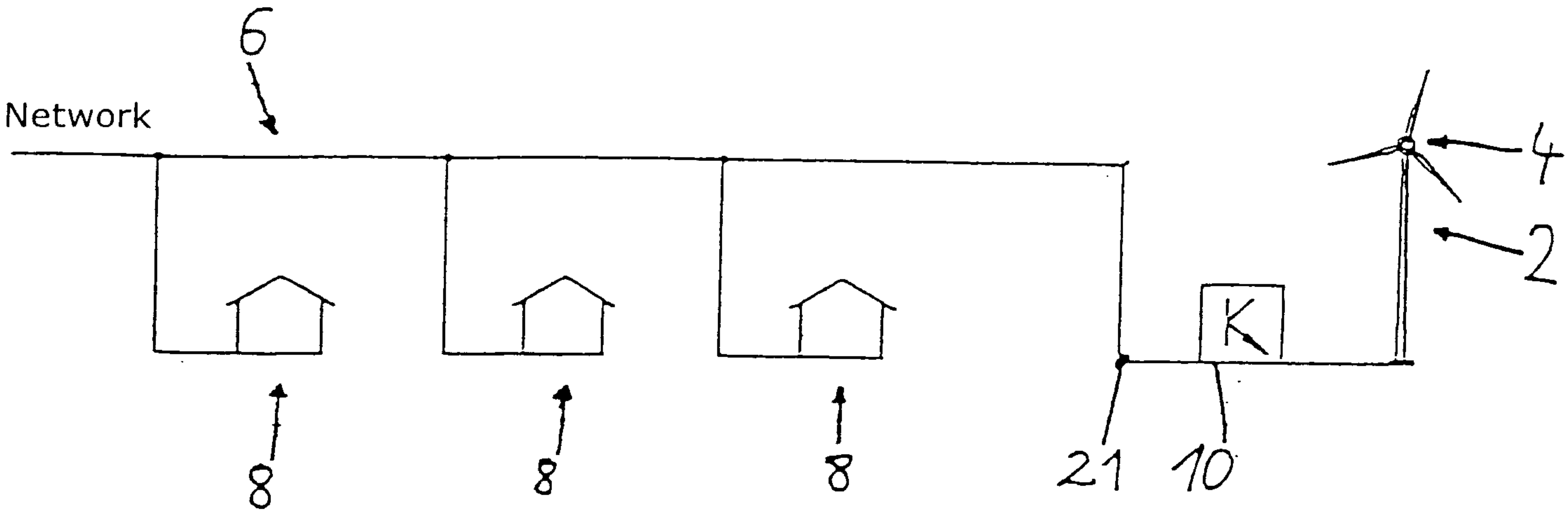


Fig. 7

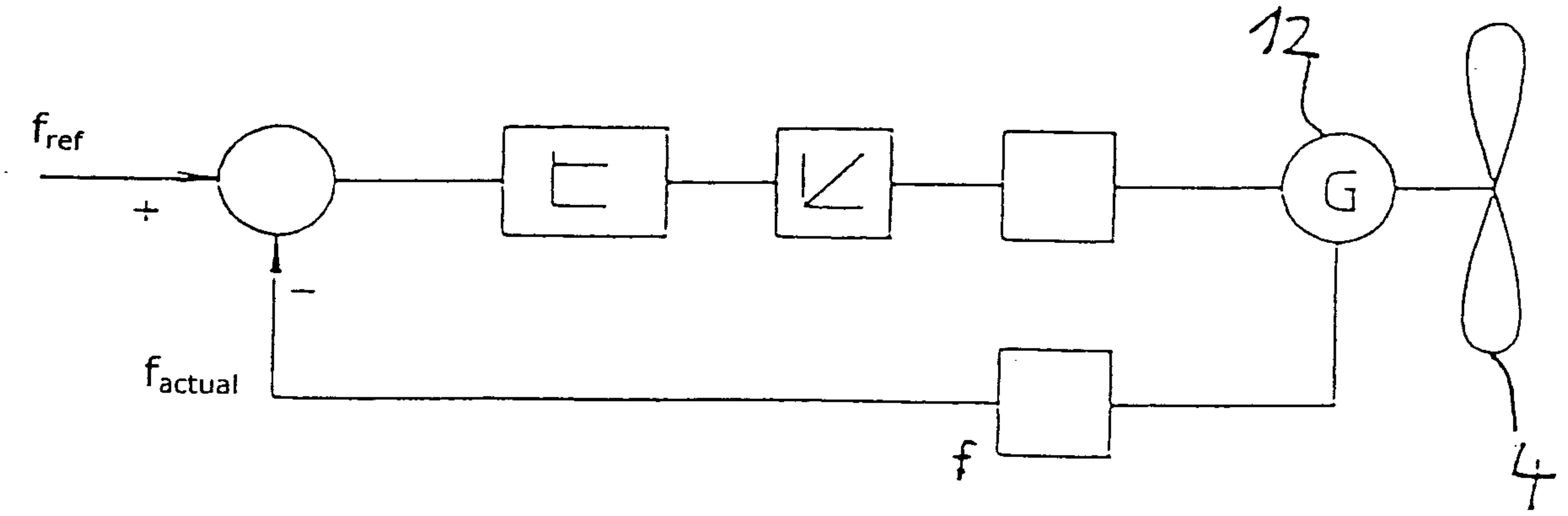


Fig. 8

Fig. 9

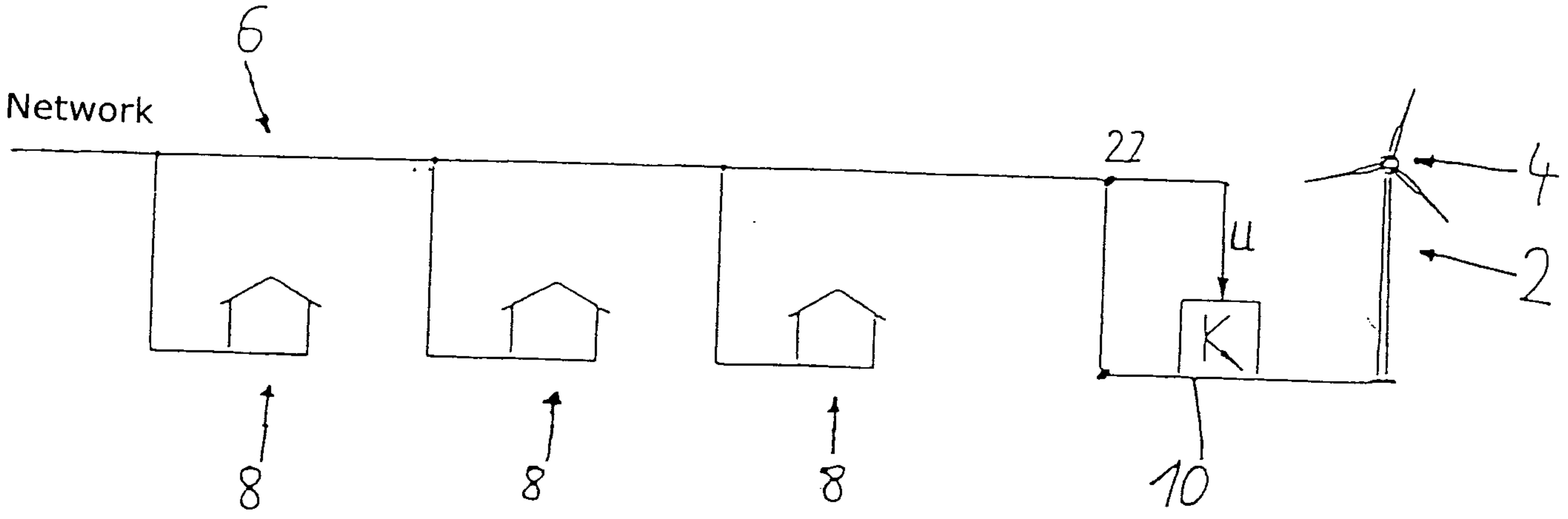


Fig. 10

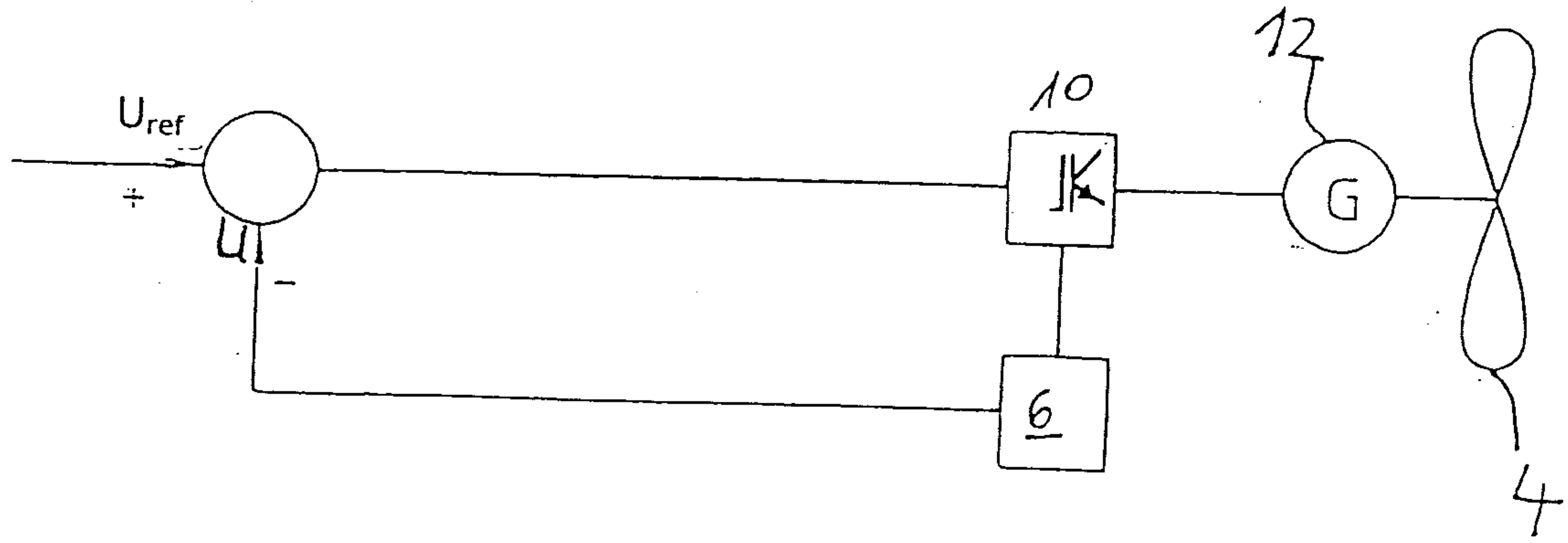
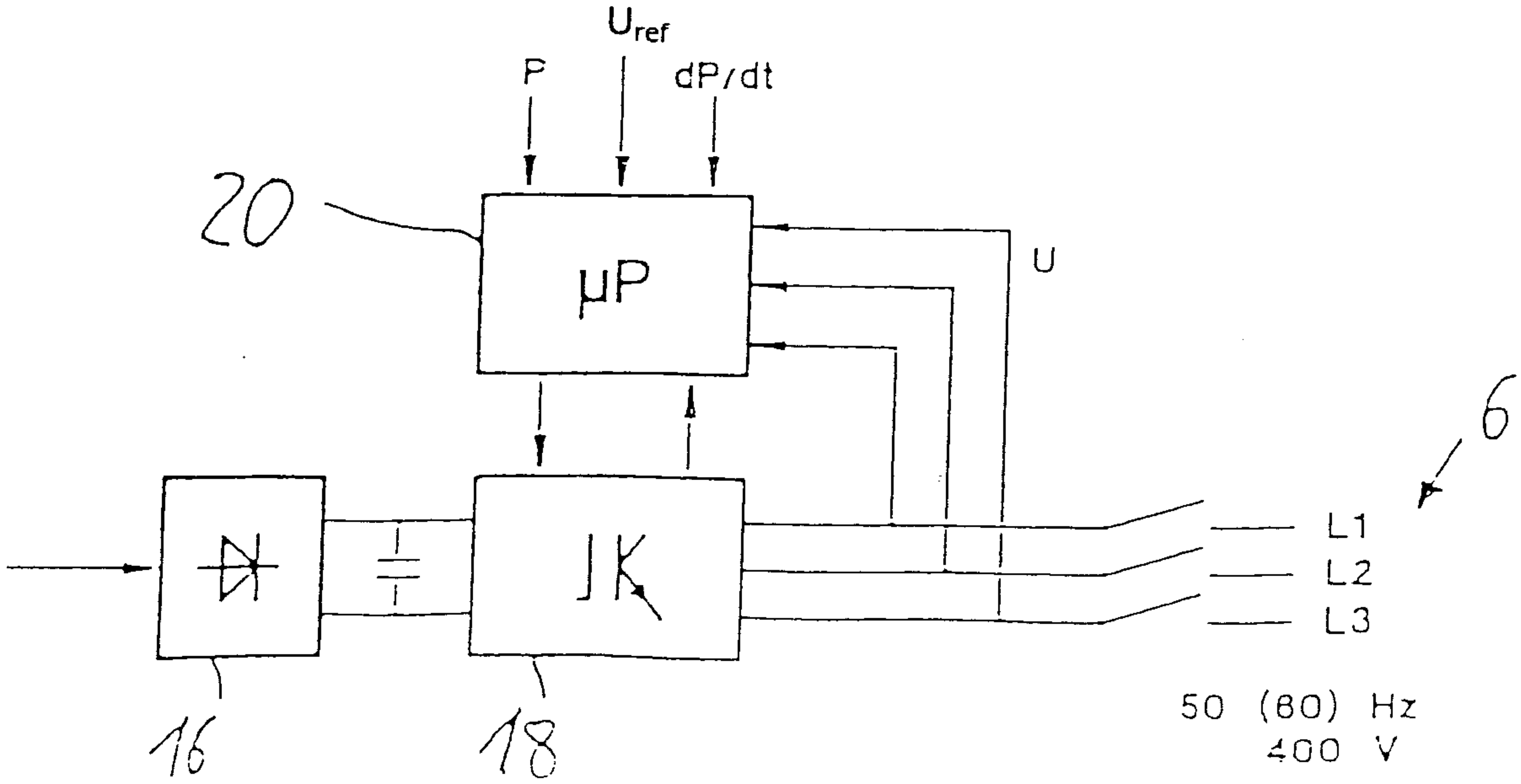


Fig. 12



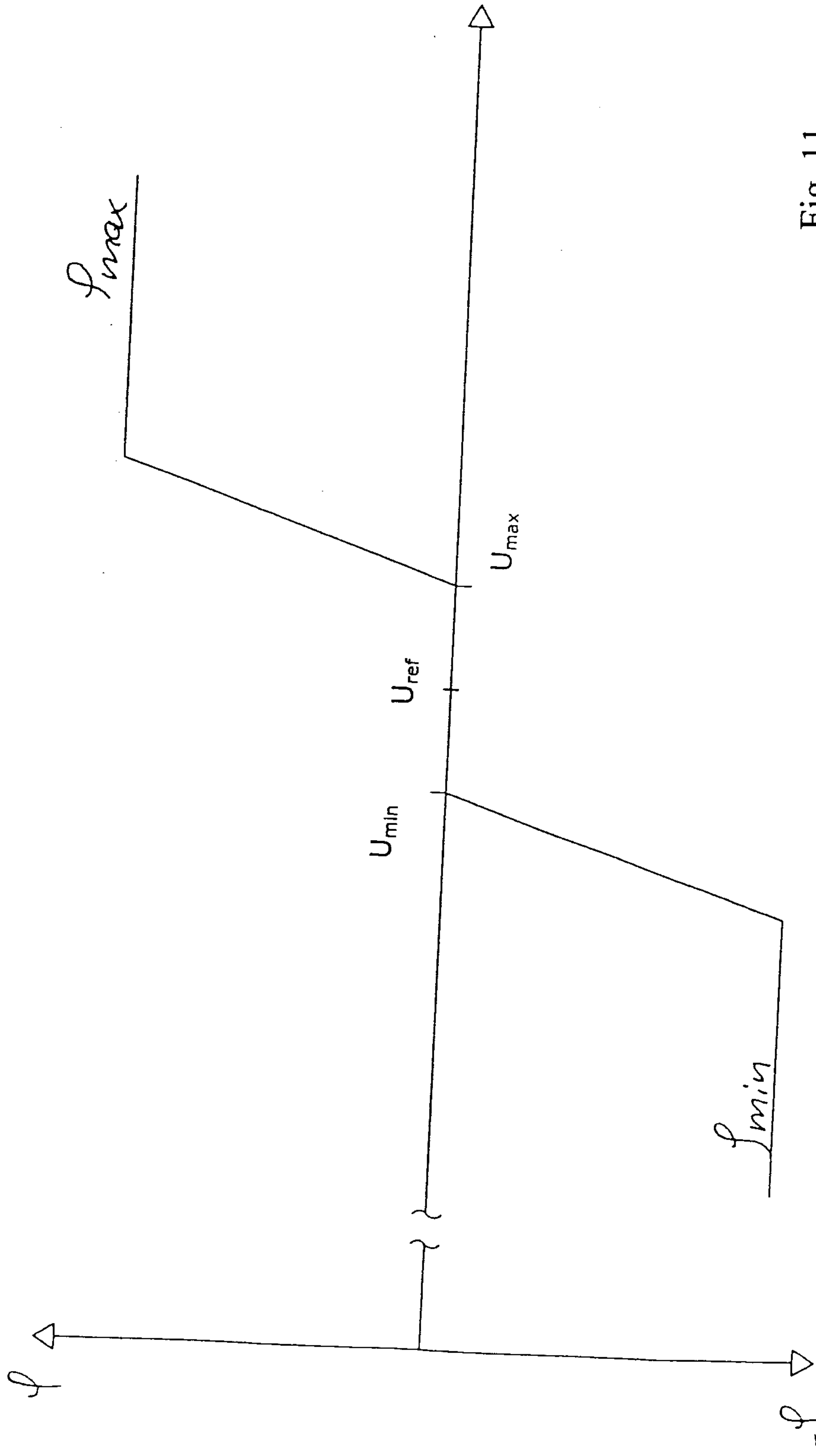


Fig. 11

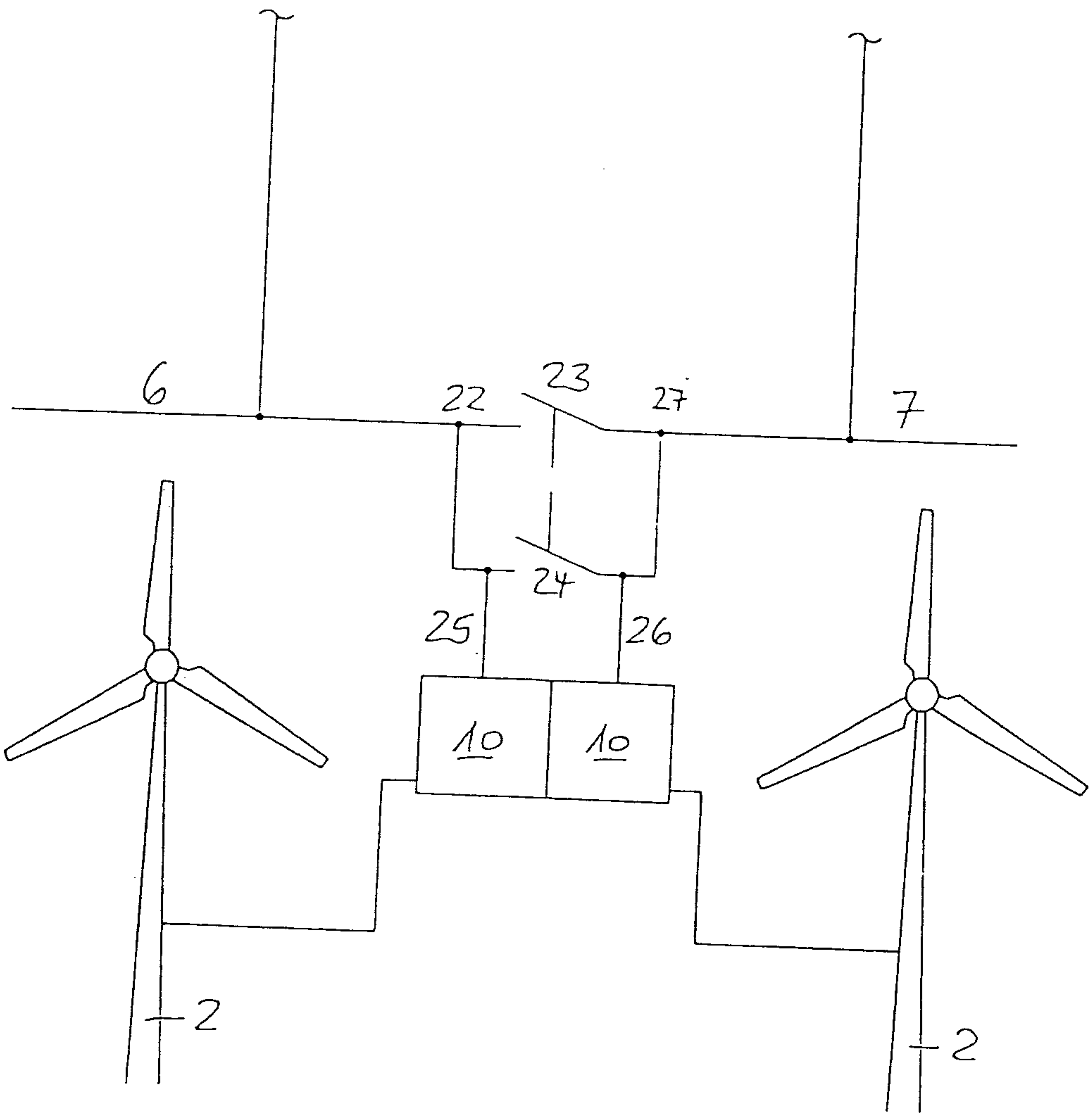
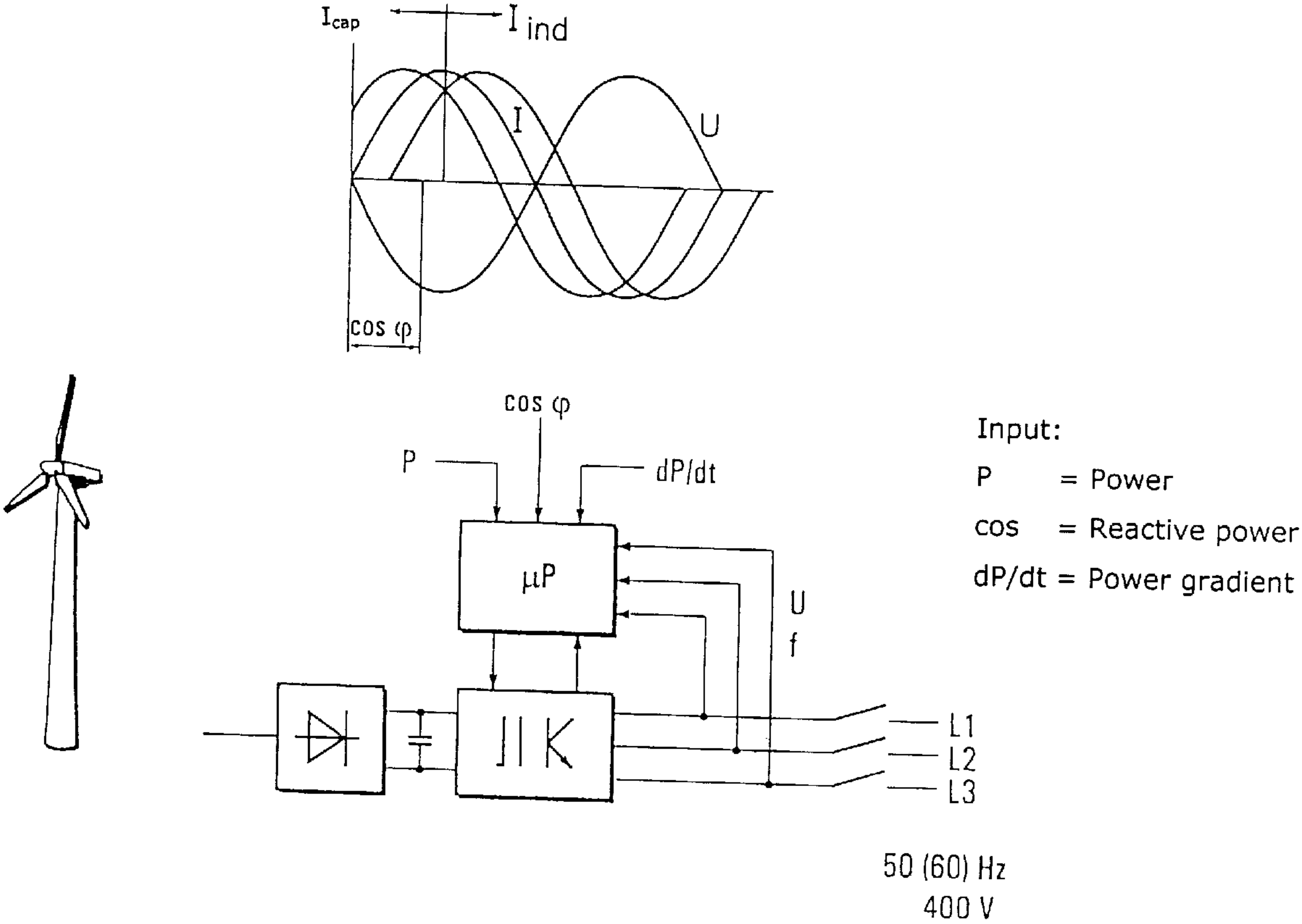


Fig. 13


I_{cap}
I_{ind}
I
U
cos φ
cos φ
P
dP/dt
μP
U
f
L1
L2
L3
Input:
P = Power
cos = Reactive power
dP/dt = Power gradient
50 (60) Hz
400 V