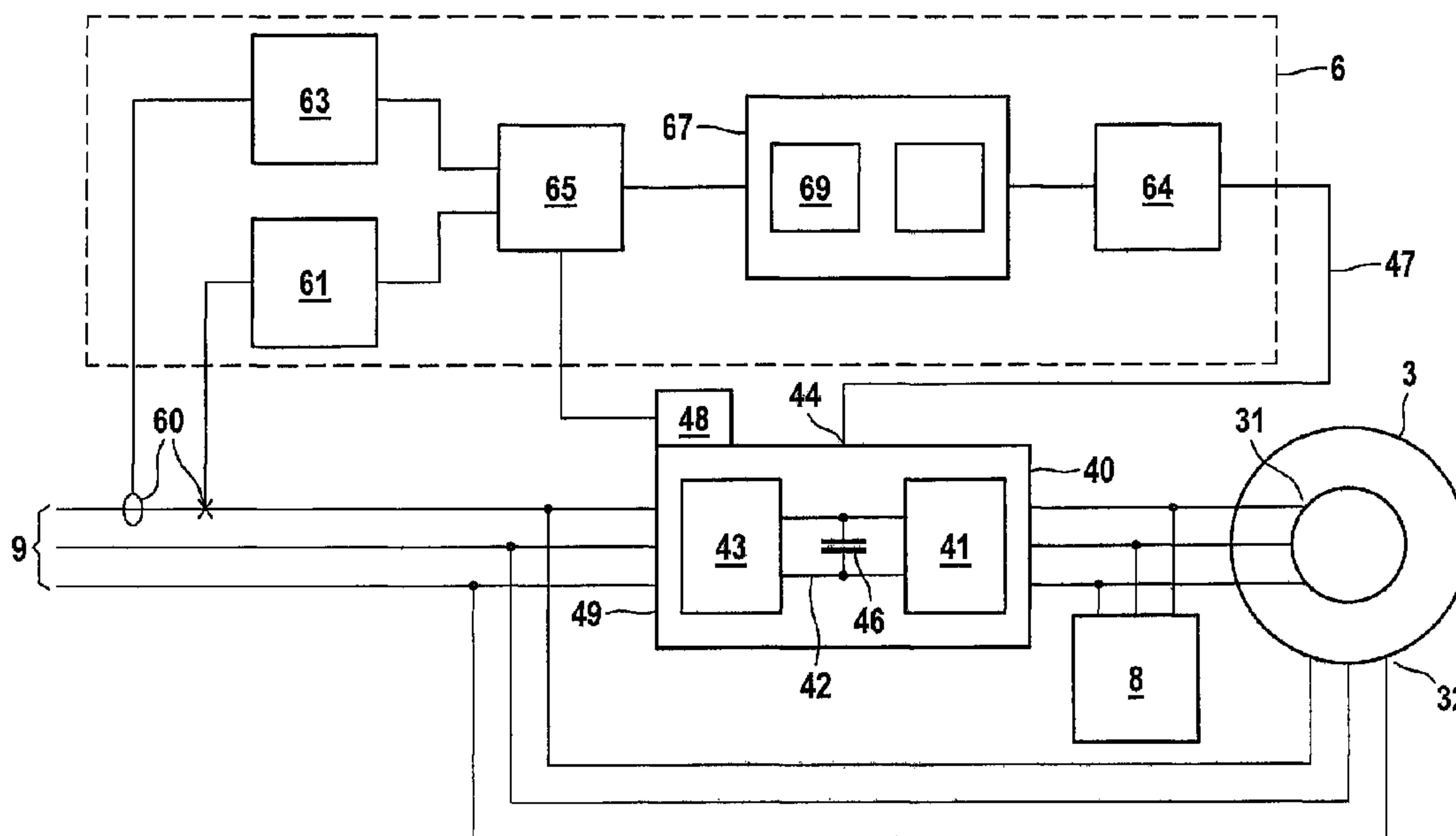




(86) Date de dépôt PCT/PCT Filing Date: 2007/10/17  
 (87) Date publication PCT/PCT Publication Date: 2008/05/02  
 (45) Date de délivrance/Issue Date: 2014/06/03  
 (85) Entrée phase nationale/National Entry: 2009/04/22  
 (86) N° demande PCT/PCT Application No.: EP 2007/009005  
 (87) N° publication PCT/PCT Publication No.: 2008/049541  
 (30) Priorité/Priority: 2006/10/24 (DE10 2006 050 077.6)

(51) Cl.Int./Int.Cl. *H02J 3/40* (2006.01)  
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(54) Titre : CONVERTISSEUR A ANGLE DE PHASE COMMANDABLE  
 (54) Title: CONTROLLABLE PHASE-ANGLE CONVERTER



(57) **Abrégé/Abstract:**

The invention relates to a converter (4), in particular for wind energy installations, having a generator (3) which is driven by a wind rotor (2) in order to feed electrical power into a power supply system (9), with the converter (4) having a control input (44) for the phase angle of the electrical power emitted to the power supply system. The invention provides a phase control device (6), which has a power supply system fault detector (63), a phase angle detector (61) and a signal processing module (67). When a power supply system fault with a determined phase error is detected, a signal for a default angle of the converter (4) is applied to the control input (44) of the converter. As a result, the phase change which occurs at the end of the power supply system disturbance does not lead to an undesirable sudden surge in the power output.



## (12) NACH DEM VERTRAG ÜBER DIE INTERNATIONALE ZUSAMMENARBEIT AUF DEM GEBIET DES PATENTWESENS (PCT) VERÖFFENTLICHTE INTERNATIONALE ANMELDUNG

(19) Weltorganisation für geistiges Eigentum  
Internationales Büro(43) Internationales Veröffentlichungsdatum  
2. Mai 2008 (02.05.2008)

PCT

(10) Internationale Veröffentlichungsnummer  
**WO 2008/049541 A1**(51) Internationale Patentklassifikation:  
H02J 3/40 (2006.01)

(21) Internationales Aktenzeichen: PCT/EP2007/009005

(22) Internationales Anmeldedatum:  
17. Oktober 2007 (17.10.2007)

(25) Einreichungssprache: Deutsch

(26) Veröffentlichungssprache: Deutsch

(30) Angaben zur Priorität:  
10 2006 050 077.6  
24. Oktober 2006 (24.10.2006) DE

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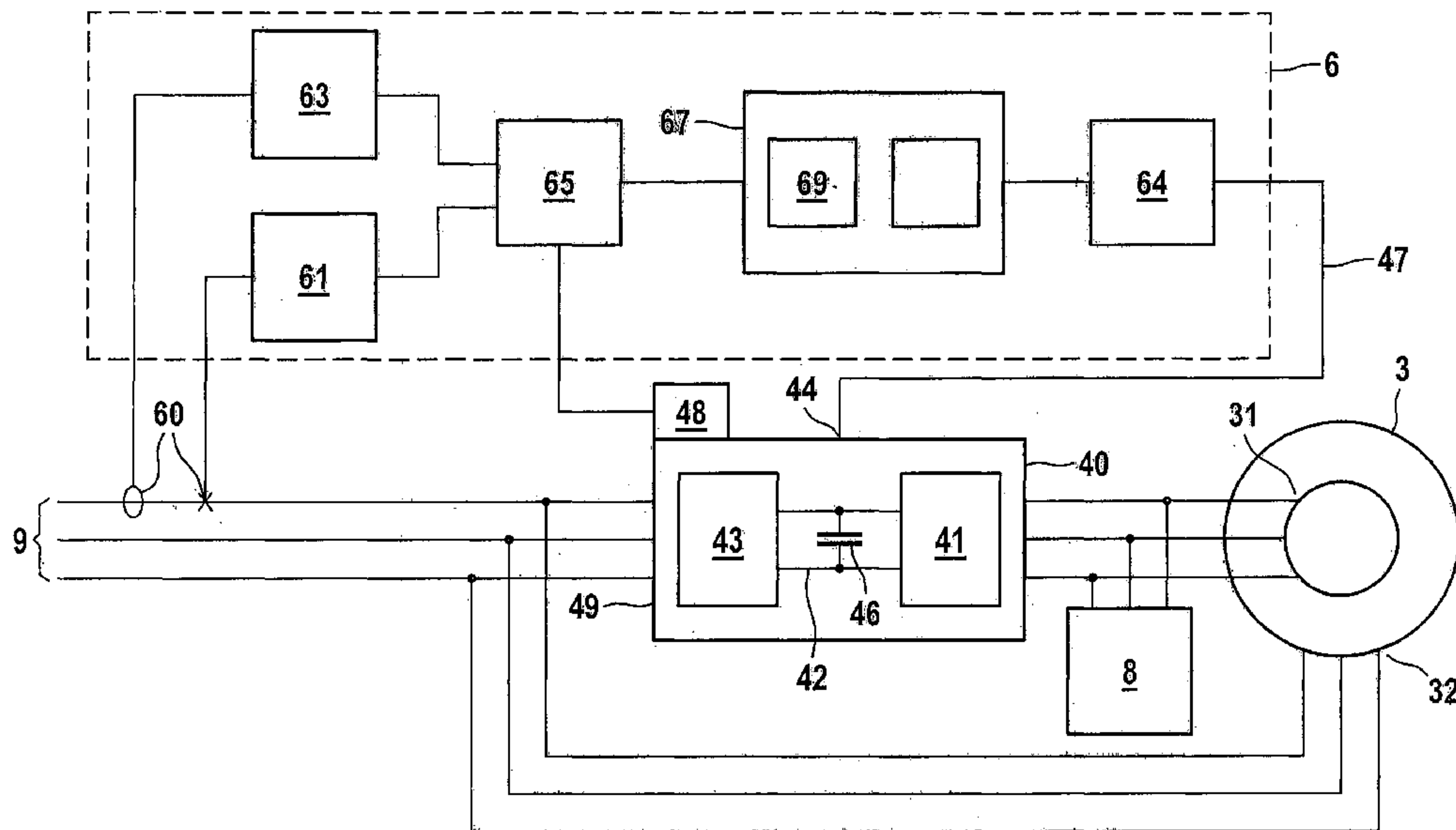
(81) Bestimmungsstaaten (soweit nicht anders angegeben, für jede verfügbare nationale Schutzrechtsart): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Bestimmungsstaaten (soweit nicht anders angegeben, für jede verfügbare regionale Schutzrechtsart): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), eurasisches (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), europäisches (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF,

[Fortsetzung auf der nächsten Seite]

(54) Title: CONTROLLABLE PHASE-ANGLE CONVERTER

(54) Bezeichnung: UMRICHTER MIT STEUERBAREM PHASENWINKEL



(57) Abstract: The invention relates to a converter (4), in particular for wind energy installations, having a generator (3) which is driven by a wind rotor (2) in order to feed electrical power into a power supply system (9), with the converter (4) having a control input (44) for the phase angle of the electrical power emitted to the power supply system. The invention provides a phase control device (6), which has a power supply system fault detector (63), a phase angle detector (61) and a signal processing module (67). When a power supply system fault with a determined phase error is detected, a signal for a default angle of the converter (4) is applied to the control input (44) of the converter. As a result, the phase change which occurs at the end of the power supply system disturbance does not lead to an undesirable sudden surge in the power output.

[Fortsetzung auf der nächsten Seite]

**WO 2008/049541 A1**

CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG). — *Erfindererklärung (Regel 4.17 Ziffer iv)*

**Erklärungen gemäß Regel 4.17:**

- *hinsichtlich der Identität des Erfinders (Regel 4.17 Ziffer i)*
- *hinsichtlich der Berechtigung des Anmelders, ein Patent zu beantragen und zu erhalten (Regel 4.17 Ziffer ii)*

**Veröffentlicht:**

- *mit internationalem Recherchenbericht*
- *vor Ablauf der für Änderungen der Ansprüche geltenden Frist; Veröffentlichung wird wiederholt, falls Änderungen eintreffen*

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**(57) Zusammenfassung:** Die Erfindung betrifft einen Umrichter (4), insbesondere für Windenergieanlagen, mit einem über einen Windrotor (2) angetriebenen Generator (3), zum Einspeisen elektrischer Leistung in ein Netz (9), wobei der Umrichter (4) einen Steuereingang (44) für einen Phasenwinkel der an das Netz abgegebenen elektrischen Leistung aufweist. Die Erfindung sieht eine Phasenstelleinrichtung (6) vor, die einen Netzfehlerdetektor (63), einen Phasenwinkeldetektor (61) und ein Signalverarbeitungsmodul (67) aufweist. Bei einem erkanntem Netzfehler mit einem ermittelten Phasenfehler wird ein Signal für einen Vorgabewinkel an den Steuereingang (44) des Umrichters angelegt. Damit wird erreicht, dass die am Ende der Netzstörung auftretende Phasenänderung nicht zu einem unerwünschten Sprung in der Wirkleistungsabgabe führt.

### Controllable phase-angle converter

The invention relates to a converter, in particular for wind energy installations having a generator which is driven via a wind rotor, for feeding electrical power into a network, with the converter having a control input for a phase angle of the electrical power which is emitted to the network.

Converters are nowadays being increasingly used to feed electrical power into a network from local feeding power stations. These converters are particularly suitable for use with variable rotation-speed generators, such as those provided for modern wind energy installations. In this case, conversion to the frequency of the fixed-frequency supply network (normally 50 Hz) is required in order to feed in the wind-frequency electrical power produced by the generator. In the event of disturbances in the network, the phase angle of the voltage can change suddenly. It has been found that sudden phase changes can have similar negative effects on converters to those of voltage dips. In the case of conventional converters, overcurrents can therefore occur in the event of a sudden phase change, thus activating protective devices for the converter, such as its crowbar circuit. The activation of the protective devices changes the braking torque of the converter and of the generator connected to it, thus leading to undesirable reactions on the mechanical part. Torque oscillations can occur at the generator and on its drive train, which can lead to increased wear or even to failure.

Attempts have been made to use special additional circuits to prevent activation of the converter protective devices. For example, a chopper can be provided in an intermediate circuit of the converter which limits  
5 overvoltages or overcurrents occurring as a result of sudden phase changes, in the intermediate circuit itself. However, the additional circuits increase the production complexity and therefore increase the price of the converter. Furthermore, their power-handling ca-  
10 pability is restricted, as a result of which they are frequently inadequate for high power levels. In addition, if the protective device is switched on frequently, reactions on the mechanical components of the wind energy installation can reduce their life.

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The invention is based on the object of specifying a converter and a wind energy installation having a converter such as this, as well as a method for operation, which achieves a better response to sudden phase  
20 changes in the network.

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The solution according to the invention lies in the features of the independent claims. Advantageous developments are the subject matter of the dependent claims.  
25  
In the case of a converter, in particular wind energy installations having a generator which is driven by a wind rotor, for feeding electrical power into a network, with the converter having a control input for a  
30 phase angle of the electrical power which is emitted to the network, the invention provides a phase control device which has a network fault detector, a phase angle detector and a nominal angle generator, with the latter having a signal processing module which is designed to

determine a signal for a preset angle for the converter from the phase error signal of the phase angle detector when a network fault occurs, which signal is applied to the control input of the converter via a control line.

5

The essence of the invention is the idea of detecting the change in the phase angle which leads to the network disturbance and using this as the basis for phase-angle control of the converter. The occurrence of the disturbance is determined by means of the network fault detector in order, when a disturbance is identified, to determine a phase error signal by means of the phase angle detector from the phase angle in the network before and after the disturbance occurs. Based on the phase difference, the signal processor module determines an angle which is preferably calculated such that, at the end of the network disturbance and when the phase suddenly changes back again, this leads to no change, or as little change as possible, to the power that is fed in. This angle is applied to the control input of the converter, as a preset angle.

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Conventionally, when a network disturbance occurs, a change in the phase is identified only after a delay, to be precise in particular when it changes suddenly. Before the change in phase is actually taken into account, the converter feeds into the network with an incorrect phase angle. In-phase current and reactive-current regulators which are provided on the converter can operate correctly, however, only when the phase angle is correct. If the phase angle is incorrect, only a small amount of in-phase current as provided can be fed into the network, and it is even possible for in-phase current to be parasitically drawn from the network

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rather than being fed into it. As a consequence of too little current being fed in (or the parasitic drawing), the energy level in the intermediate circuit of the converter rises, and this can lead to an overvoltage or  
5 an overcurrent in the intermediate circuit. These result in activation of the protective devices, such as triggering of the crowbar, with the negative effects mentioned initially on the drive train and the generator.

10

The invention has now identified the fact that the damaging effects of the phase suddenly changing back at the end of the disturbance on the converter and its control system, in particular its in-phase current control, can be minimized by deliberately presetting the  
15 phase angle. The preset angle can be chosen such that, when a sudden change back through a predetermined angle occurs, the power which is emitted remains unchanged. If, for example, a sudden phase change of +25 degrees  
20 occurs as a consequence of the network disturbance, then the preset angle of the converter is set to a value of +12.5 degrees; as a result of this, when a sudden phase change of a further 25 degrees occurs at the end of the network disturbance, the phase angle of  
25 the converter with respect to the network has a value of -12.5 degrees, and the power therefore remains constant. For this purpose, the processing module expediently has a lead module which is designed to determine a lead angle from the phase error signal.

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The lead module is expediently in the form of a divider, to be precise preferably with a divisor of 2. This is based on the knowledge that, when the phase changes back suddenly at the end of the network distur-

bance, an angular magnitude can frequently be expected which corresponds to the magnitude of the sudden phase change that occurred at the start of the disturbance. It is then expedient to choose the preset angle to be  
5 half as great as the sudden phase change which occurred initially. This can be achieved in a simple and expedient manner by a divider with a divisor of 2.

A characteristic element is preferably additionally  
10 provided, which limits the lead angle to adjustable limit values. It is therefore possible to take account of restrictions relating to the possible phase angles of the wind energy installation and its converter. In particular, it has been proven to provide as limit val-  
15 ues those angles which correspond to the maximum magnitude of the volt-amperes of the converter. It is also possible to provide for the characteristic element to be provided with a memory of permissible power and wattless-component ranges from which the limit values can  
20 be called up dynamically as a function of the respective power. This makes it possible to match the respective limit values to the instantaneous power situation of the converter and/or of its wind energy installation.

25

The phase angle detector can be provided with a pattern wave generator which is synchronized to the network frequency. This makes it possible to obtain a clean phase curve even when the network frequency is noisy,  
30 on the basis of which phase curve the sudden phase change can be determined more accurately. The accuracy and the speed of determination of the phase error signal are thus increased. It is expedient for the pattern wave generator to be in the form of a PLL circuit. This

allows cleaner detection even when the network frequency is varying in a quasi-steady-state form.

According to one particularly advantageous embodiment,  
5 which may be used for independent protection, the network fault detector has a device for identification of the return of the network voltage and a switching device, which is connected to the control input of the converter and is designed to apply a reference frequency  
10 signal to the control input when the voltage returns. This makes it possible, when the network voltage returns, to once again set on the converter a phase angle that is the same as that before the occurrence of the disturbance. This means that the correct phase angle  
15 is available immediately when the voltage returns in all those situations in which the network phase once again assumes the original value before the disturbance at the end of the disturbance. This is also applicable when the phase does not suddenly change back again exactly,  
20 but a small phase error remains. The converter can then feed the maximum power into the network without any further delay.

The reference frequency signal is generally synchronized to the original network voltage. However, it is  
25 possible for the reference frequency signal to differ from this. This applies in particular to the phase. For example, the phase of the reference frequency signal may have an offset in the inductive sense. Since the  
30 phase angle is frequently inductive when the voltage returns, this makes it easier to connect the converter when the voltage returns.

The converter preferably has a protection unit which is designed to determine the phase angle difference be-

tween the network and the network-side inverter before and after a network voltage returns, and to switch off the network-side inverter when the phase angle difference rises. This is achieved in that the network-side inverter of the converter can be switched off when the phase difference of the network-side inverter increases when the network voltage returns. This results in maximum protection for the components of the converter even when the disturbance profile is poor.

10

A PLL circuit with a freewheeling device is preferably provided as the generator for the reference frequency signal, which is connected to the network frequency and is decoupled by means of the freewheeling device when a network fault occurs. This allows the reference frequency signal to be generated from the network frequency in a simple manner, and to also be maintained over the time duration of a network fault.

20 The invention also relates to a wind energy installation having a converter as described above for feeding electrical power into a network. The invention furthermore relates to a corresponding method for operation of the converter. Reference is made to the above statements for a more detailed explanation.

The invention will be described in the following text with reference to the attached drawing, which illustrates advantageous exemplary embodiments, and in which:

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Figure 1 shows a schematic overview illustration of a wind energy installation connected to an electrical supply network;

Figure 2 shows a circuit diagram of a converter according to a first exemplary embodiment of the wind energy installation illustrated in Figure 1;

Figure 3 shows a partial circuit diagram of one variation for a second exemplary embodiment;

Figure 4 shows a graph illustrating the phase angle during a network disturbance;

Figure 5 shows a graph with angle errors during the network disturbance shown in Figure 4; and

Figure 6 shows a power diagram with a real component and a wattless component.

A wind energy installation which has a converter designed according to the invention is illustrated schematically in Figure 1, and is provided in its totality with the reference number 1. In a manner known per se, which will not be explained in any more detail, the wind energy installation has a pod 11 which is arranged such that it can rotate on a tower 10. A wind rotor 2 is arranged on its end face, such that it can rotate. The wind rotor 2 drives a generator 3 via a rotor shaft. This generator 3 may, in particular, be in the form of a synchronous machine, an asynchronous machine (in each case coupled to the network via a converter), but preferably a double-fed asynchronous machine. A stator of the generator 3 is connected directly or via a transformer (not illustrated) to a three-phase connecting line to a network 9 of the wind power installa-

tion 1. A rotor (not illustrated) of the generator 3 is connected to a generator-side end of a converter 4, whose other, network-side end is connected to the network 9. A controller 5 is also provided for operation of the converter 4.

The design and method of operation of the converter 4 will be explained with reference to the example of the wind energy installation. The invention can also be used for other types of electrical-energy generators which provide a converter for feeding the electrical power into the network. The converter 4 is primarily used to convert wild-frequency electrical power generated by the generator 3, which is driven at a variable rotation speed, such that the electrical power can be emitted at a frequency which matches that of a fixed-frequency supply network 9. Figure 2 illustrates the application in which the converter 4 is connected to a double-fed asynchronous generator 3. A rotor 31 of the double-fed asynchronous generator 3 is connected to a generator-side end 40 of the converter 4. The supply network 9 is connected to a network-side end 49. The stator 32 of the generator 3 is connected directly to the electrical supply network.

25

The main components of the converter 4 comprise a generator-side inverter which is operated as a rectifier 41, a network-side inverter 43 and an intermediate circuit 42, which is arranged between them, as a connection. The rotor 31 of the generator 3 is connected to the generator-side inverter 41. A so-called crowbar circuit 8 can be arranged at this point, for overload protection. The crowbar circuit 8 is designed to short the rotor 31 and thus to prevent the occurrence of a

damaging overvoltage. The design and method of operation of the crowbar circuit 8 are known from the prior art and therefore do not need to be explained in any more detail. The generator-side inverter 41 provides  
5 full-wave rectification for the three-phase current fed in from the rotor 31. The intermediate circuit 42 is in the form of a DC-voltage intermediate circuit and has a capacity 46 as an energy store. The network-side inverter 43 has six controllable switching elements,  
10 preferably IGBTs, in a full-bridge arrangement. The IGBTs are operated in a manner known per se by the controller 5 of the converter such that a three-phase current is produced at a variable frequency and a variable phase angle. The frequency and phase angle are in this  
15 case predetermined by the controller 5 such that they match those of the supply network 9. In addition, a control input 44 is provided for externally presetting the phase angle, via a control line 47.

20 The supply network 9 is connected to the output connection 49 of the converter 4, to be precise directly or via a transformer (not illustrated), with the output connection 49 being fed from the network-side inverter 43. Electrical energy which is generated by the rotor  
25 31 of the generator 3 is therefore fed into the supply network 9 via the converter 4 (depending on the operating point of the generator 3, the power flow may also be reversed).

30 A sensor pair 60 for the phase angle of the voltage and current in the supply network 9 are arranged on the electrical supply network. The sensor pair 60 is illustrated on only one phase, for clarity reasons; the other phases are correspondingly equipped. The sensor

pair 60 produces an input signal for a phase control device 6, which will be explained in more detail in the following text. The phase control device 6 comprises a phase angle detector 61, a network fault detector 63,  
5 an angle calculation unit 65 and a signal processing module 67, at whose output a preset value for the phase angle of the converter 4 is emitted. The output is connected via a control line 47 to the control input 44 of the converter 4. The signal processing module 67 con-  
10 tains a lead module which is in the form of a divider 69. The divider 69 is designed to halve the angle value produced by the angle error module 65, and to emit this as a lead angle via the control line 47.

15 The method of operation will be explained in more detail in the following text with additional reference to Figures 4 and 5. It is assumed that a network disturbance occurs as a result of a change in the phase angle of the voltage. It is assumed that the disturbance oc-  
20 curs at the time  $t = t_0 = 0.2$  s. At this time, the phase angle suddenly changes by an amount of about 17 degrees in the inductive sense. The onset of the disturbance is determined by the network fault detector 63, and the absolute sudden phase change is determined at the same  
25 time by the phase angle detector 61. Taking account of the instantaneous network frequency, the angle error module 65 corrects the angle data, as determined by the phase angle detector 61, with the network frequency, and sets the initial angle to 0 degrees. This results  
30 in a representation of the network angle which is illustrated in Figure 5 and can be evaluated for the subsequent signal processing module 67. As can easily be seen from the illustration in Figure 5, the phase angle error, corrected to the network frequency, is

17 degrees. This value is applied as the phase error signal to the signal processing module 67. The divider 69 determines a lead angle of 8.5 degrees from this. This lead angle is emitted at the output of the signal processing module 67 and is applied, via a characteristic element 64 for magnitude limiting and the control line 47 to the control input 44 of the converter 4. This sets a control angle of 8.5 degrees inductive at the converter. This results in an operating point which lies on the straight line illustrated by dashed lines in Figure 6. This setting of the converter 4 is optimum in the sense that, when the phase suddenly changes back at the end of the network disturbance (see  $t = 3.8$  s in Figures 4 and 5) this results in an angle change at the converter amounting to 17 degrees in the capacitive direction, which, on the basis of the said phase error of 8.5 degrees inductive, leads to a new phase angle of 8.5 degrees capacitive, as is illustrated by the dashed-dotted line in Figure 6. The power output, which is symbolized by the horizontal solid line in Figure 6, does not change, because the phase angle changes symmetrically with respect to the power axis. The power output of the converter 4 to the network 9 therefore remains unchanged, and the voltage in the intermediate circuit 42 of the converter in consequence also remains stable. This therefore makes it possible to avoid the derailment of the power control which frequently occurs in this situation in converters according to the prior art. This therefore also prevents triggering of the crowbar 8 in order to provide protection against a damaging overvoltage in the intermediate circuit 42. Thanks to the invention, when the network voltage returns, the converter 4 still feeds power into the network without any disturbance or interruption. The op-

eration of the wind energy installation can be continued without any reactions occurring on the generator 3 and its drive train as a result of undesirable triggering of the crowbar 8.

5

A protection unit 48 is expediently provided on the converter and is used to detect the profile of the phase angle difference when the network voltage returns, using the angle data determined by the phase control device 6. The protection unit 48 acts on the network-side inverter 43 and can switch this off when a fault situation is identified. The protection unit 48 is designed to switch the network-side inverter 43 off when the phase difference between the network-side inverter 43 and the network 9 does not decrease, but increases, when the network voltage returns. This therefore provides maximum protection for the components even in extraordinary situations.

20 A second exemplary embodiment is based on the first exemplary embodiment and has components as illustrated in Figure 3 added to it. Corresponding elements are provided with the same reference symbols. Reference is made to the above explanation, in order to avoid explaining them again. In the second exemplary embodiment 25 a reference frequency generator is also provided, and is in the form of a follow-up synchronization circuit (phase locked loop - PLL circuit) 66. A measured value for the phase of the network 9 is applied to its input. 30 The reference angle determined by the phase angle detector 61 is applied to the PLL circuit 66. When a network fault is identified, the PLL circuit 66 is decoupled via a freewheeling device 62 and continues to oscillate freely. A device 64 is also provided in order

to identify the return of the network voltage. In the exemplary embodiment, this device 64 is in the form of a threshold-value switch which emits an output signal for the return of the network when a sudden phase angle change above an adjustable threshold occurs. This output signal is applied to a control input of a switching device 68. When the switching device 68 is operated, then the network frequency signal, which is passed on from the PLL circuit 66, is passed on and is applied to the control input 44 of the converter 4. This variant operates as follows. The network angle is updated by means of the PLL circuit 66 throughout the duration of the disturbance in the network 9. When a sudden change in the phase angle occurs at the end of the disturbance in the network 9 (see the time  $t_1$  in Figure 5), then this is identified by the identification device 64. This emits a corresponding control signal to the switching device 68, as a result of which the output signal of the PLL circuit 66 is applied as a control signal to the converter 4. This ensures that the converter 4 can immediately orient itself again with respect to the network frequency provided as a reference by the PLL circuit 66. The converter 4 can therefore be resynchronized to the network more quickly, thus considerably shortening any possible transient process. The power control of the converter 4 can therefore operate immediately again, without any delay.

**Patent Claims**

1. A converter for feeding electrical power into a network, the converter comprising:

5 a control input for a phase angle of the electrical power which is emitted to the network; and

a phase control device, which has:

a network fault detector;

10 a phase angle detector that interacts with the network fault detector such that a phase error signal is generated based on a comparison between the phase angle before and after onset of a network fault; and

15 a signal processing module designed to determine a signal for a preset angle from the phase error signal determined by the phase angle detector, the signal for a preset signal being applied via a control line to the control input of the converter.

20 2. The converter as claimed in claim 1, wherein signal the processing module has a lead module which is in the form of a divider.

3. The converter as claimed in claim 2, wherein the lead module is a divisor of 2.

25 4. The converter as claimed in claim 2 or 3, wherein a characteristic element is additionally provided, and limits the lead angle to adjustable limit values.

5. The converter as claimed in claim 4, wherein the characteristic element is provided with a memory for permissible power and wattless-component ranges, from which

the limit values can be called up dynamically as a function of the respective power.

6. The converter as claimed in any one of claims 1 to 5, wherein the phase angle detector is provided with a pattern  
5 wave generator which is synchronized to the network frequency.

7. The converter as claimed in claim 1, wherein the network fault detector interacts with a device for identification of network voltage return, and a switching device is provided, which is designed to apply a reference frequency signal to the  
10 control input of the converter when the network returns.

8. The converter as claimed in claim 7, wherein the reference frequency signal is designed to map the network frequency.

9. The converter as claimed in claim 7 or 8, wherein a PLL  
15 circuit is provided in order to form the reference frequency signal.

10. The converter as claimed in claim 9, wherein a freewheeling device is provided for the PLL circuit, and is driven by the network fault detector.

20 11. The converter as claimed in one of claims 7 to 10, wherein a protection unit is provided and is designed to determine the phase angle difference between the network and the network-side inverter before and after the network voltage returns, and to switch off the network-side inverter if the  
25 phase angle difference increases.

12. A wind energy installation comprising:

a generator which is driven via a wind rotor; and

a converter for feeding electrical power into a network,  
with the converter having:

a control input for a phase angle of the electrical  
power which is emitted to the network; and

5 a phase control device, which has:

a network fault detector;

10 a phase angle detector that interacts with the  
network fault detector such that a phase error  
signal is generated based on a comparison  
between the phase angle before and after onset  
of a network fault; and

15 a signal processing module designed to  
determine a signal for a preset angle from the  
phase error signal determined by the phase  
angle detector, the signal for a preset angle  
being applied via a control line to the control  
input of the converter.

13. A method for operation of a converter, in particular for  
wind energy installations having a generator which is driven  
20 via a wind rotor, for feeding electrical power into a network,  
with a control signal for a phase angle of the electrical  
power which is to be emitted to the network being applied to a  
control input of the converter, and an identification of a  
network fault being performed, the method comprising:

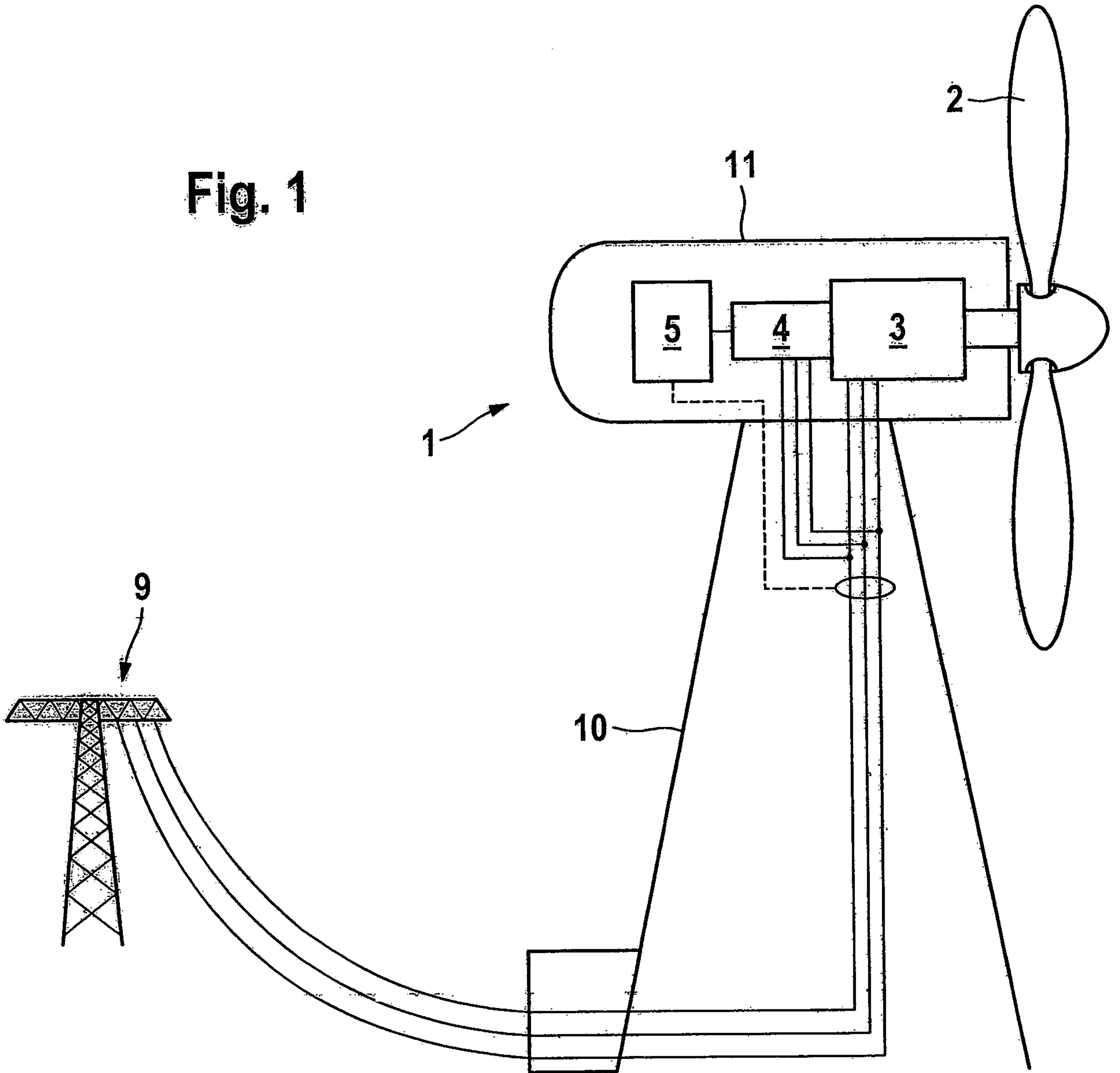
25 comparing the phase angle before and after onset of a  
network fault;

determining a phase error signal based on the comparing;

determining a preset signal from the determined phase error signal; and

applying the preset angle as a signal to the control input of the converter.

Fig. 1



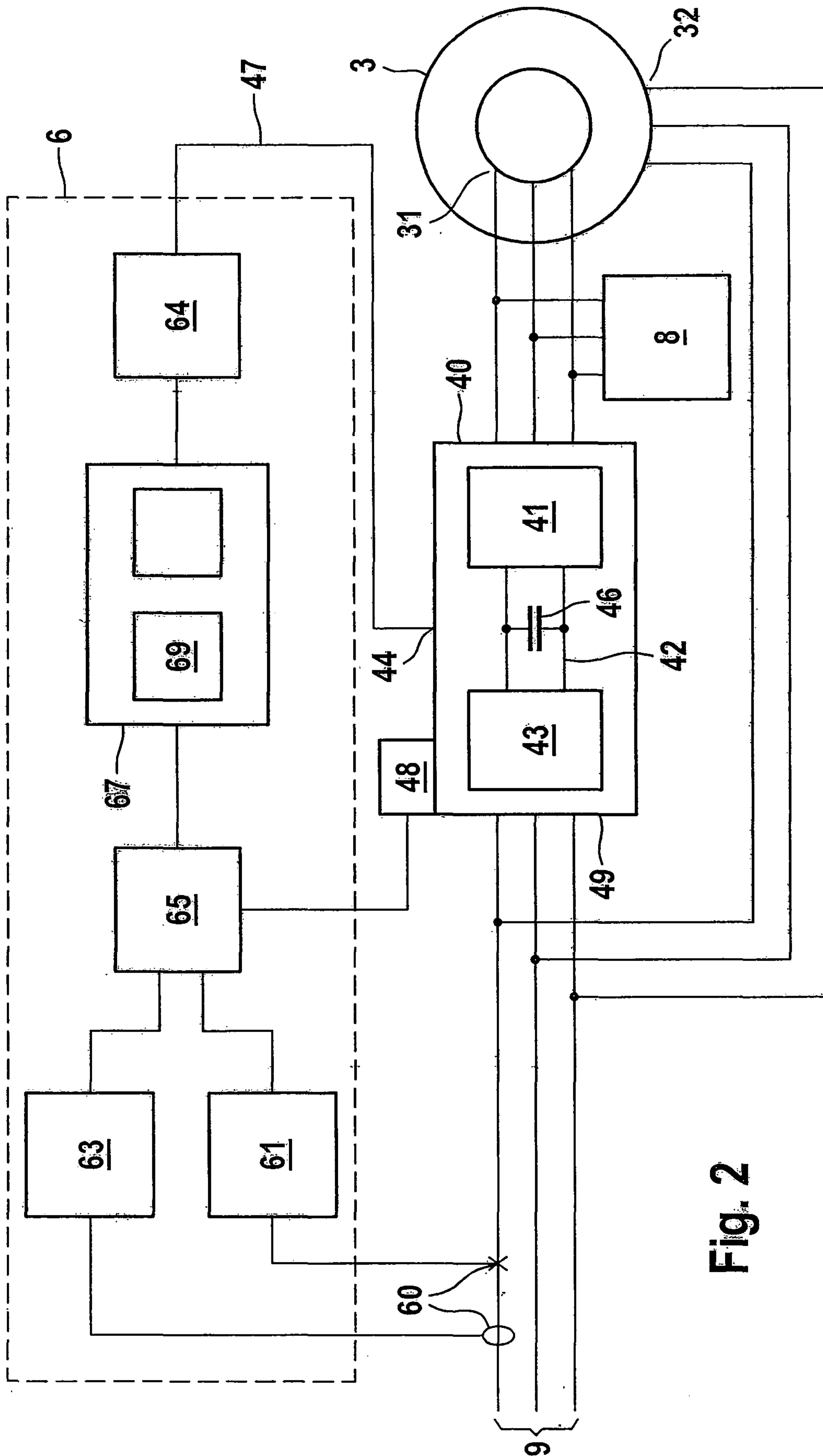


Fig. 2

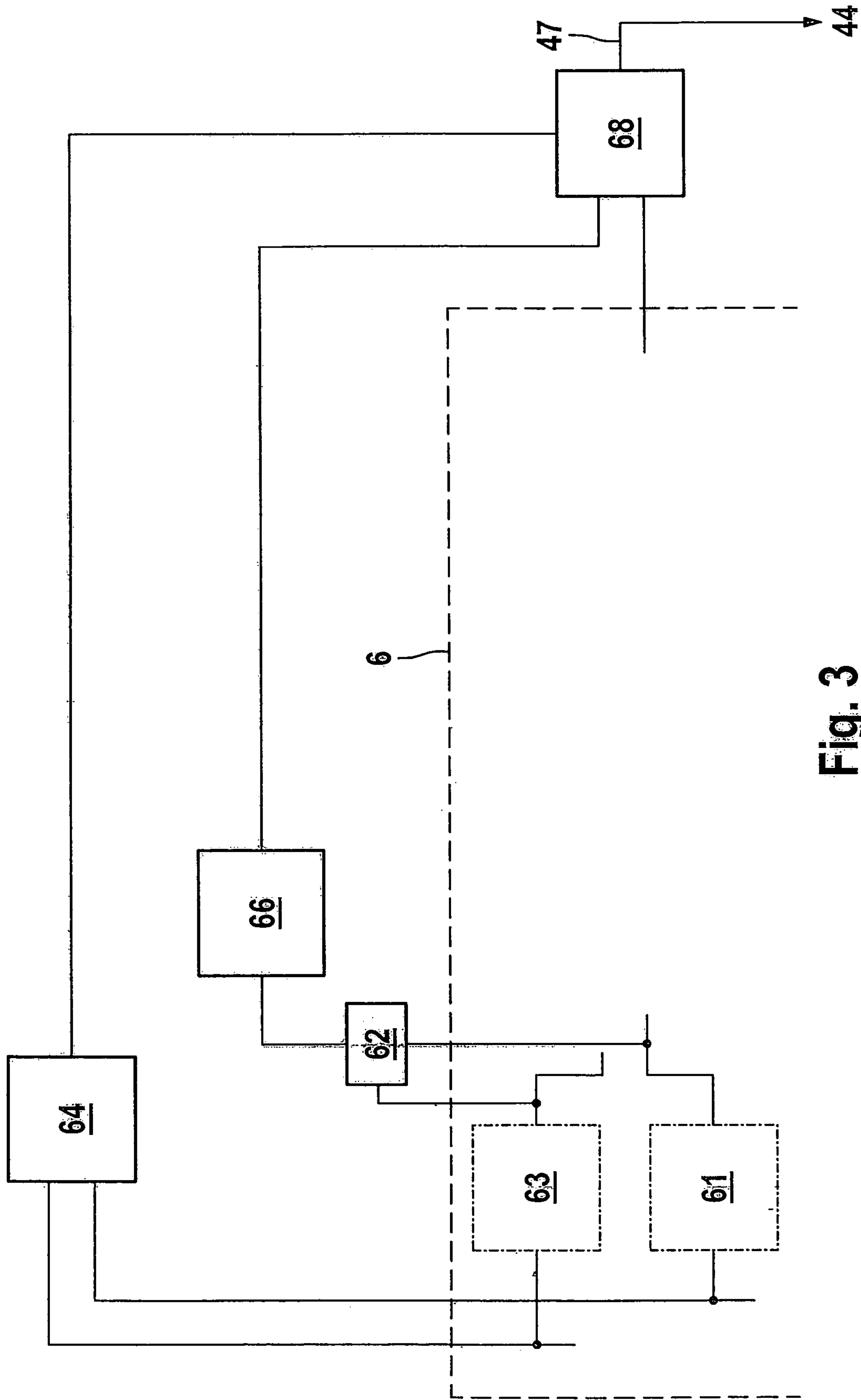
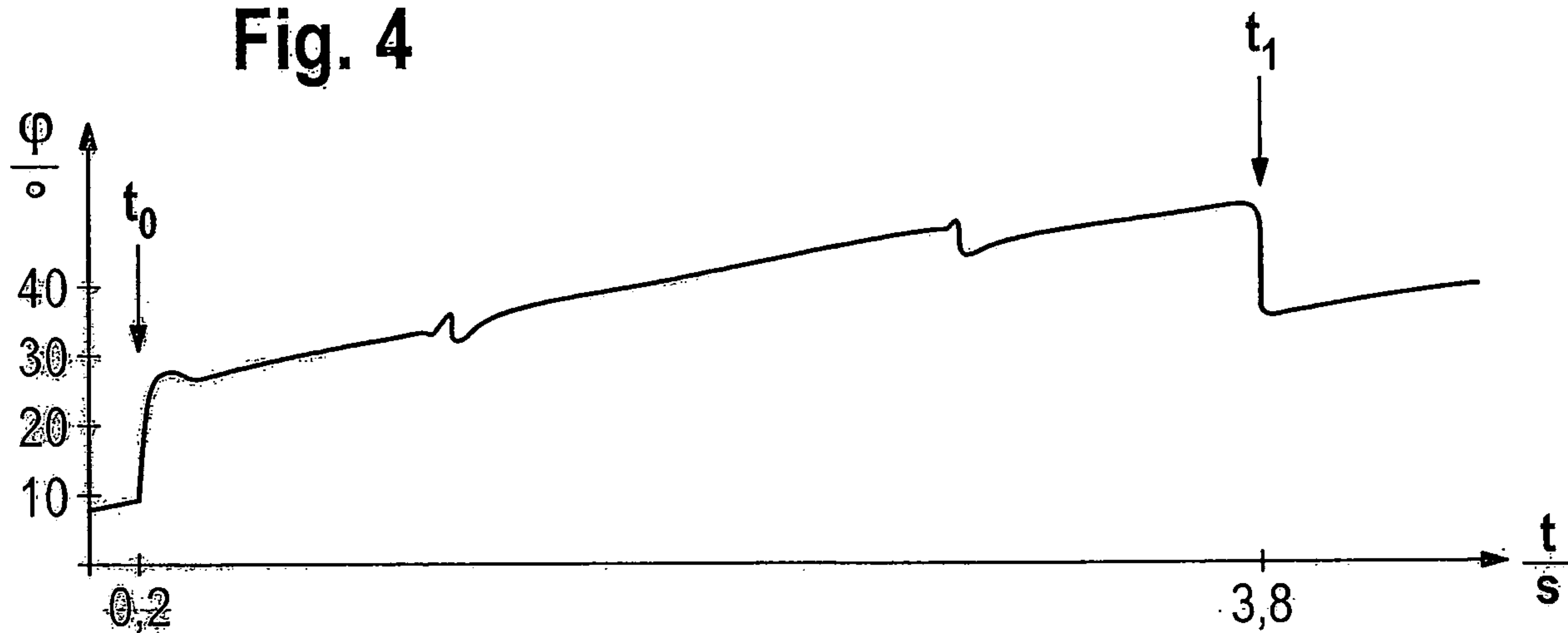
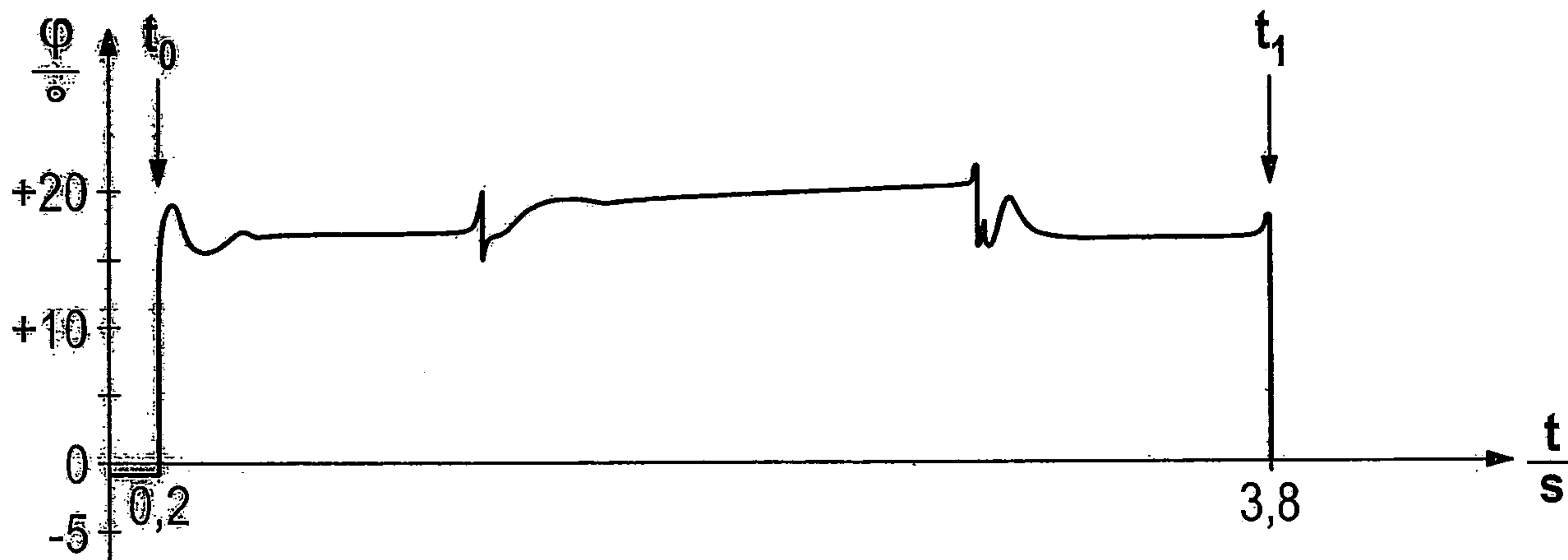


Fig. 3

**Fig. 4**



**Fig. 5**



**Fig. 6**

