DESCRIPTION

Title of Invention: METHOD FOR MONITORING AND DIAGNOSING DETERIORATION OF INVERTER

Technical Field

[0001] The present invention is related to a method for monitoring and diagnosing deterioration of an inverter, in which deterioration of an inverter that supplies a driving current to a motor is detected by measuring and analyzing current signals (a current waveform) on the output side (the secondary side) of the inverter while the inverter is being in operation.

Background Art

[0002] With regard to an inverter that supplies a driving current to a motor, it has been conventionally unable to monitor and diagnose the progress of deterioration while the inverter is being in operation. This makes it requires the inverter, the motor, and electrical equipment driven by the motor to be paused when diagnosing, and it is not only time-consuming to do the work, but also it leads to a drop in operating rate of the electrical equipment. To cope with this, there is disclosed, e.g., in patent literature 1, an apparatus for diagnosing abnormality and deterioration of electrical equipment, in which an abnormality and deterioration diagnosis for electrical equipment including an induction motor and an inverter is conducted while the electrical equipment is kept in operation without pausing

the electrical equipment or stopping the same to decompose it. Also, patent literature 2 is an invention regarding a method for diagnosing a rotary mechanical system abnormality, in which a rotary mechanical system abnormality is diagnosed by comparing the states of a current at a normal time and a current in operation (i.e. at inspection) of a motor, and patent literature 2 contains that the single harmonic ratio and the total harmonic ratio of higher harmonic components and a power-supply frequency component of current signals of the motor in operation, and the unbalance rate of inter-phase currents of the motor in operation are calculated, and that an abnormality is diagnosed to be occurring in the power-supply quality or in the inverter when even one of them becomes equal to or more than the criterial value.

Citation List

Patent Literature

[0003]

Patent Literature 1: Japanese Unexamined Patent Application Publication No. 2003-156547

Patent Literature 2: Japanese Patent No. 5733913

Summary of Invention

Technical Problem

[0004] The diagnosing apparatus for electrical equipment in patent literature 1 specifies, based on the

size of content rate of each order of the higher harmonics contained in the equipment current flowing through the electrical equipment, the extent of the abnormality and deterioration of the electrical equipment, and the cause and the location of the abnormality and deterioration. In other words, patent literature 1 explains that causes of deterioration and locations of deterioration (i.e. a part where the deterioration has occurred) correspond one by one to the orders of the higher harmonics on the input side and output side of the inverter, and that it is possible to avoid replacing the whole equipment and to fix or replace only the part where the deterioration has occurred. However, since it is considered that the content rate of each order of the higher harmonics contained in the equipment current changes if the parts composition of the inverter or the properties of each part differ, there is a possibility that the cause and the location of the deterioration cannot be accurately specified. Also, it is common to replace the circuit board when deterioration (failure) occurs in an inverter, and it is not realistic to fix or replace only the part where the deterioration has occurred. Therefore, when diagnosing whether or not there is deterioration (abnormality) in an inverter, it is not needed to specify the cause and the location of the abnormality and deterioration, and what is required is a simple method for monitoring and diagnosing deterioration.

Also, patent literature 2 mentions an abnormality

diagnosis for an inverter as well; however, what are used as the parameters are only the single harmonic ratio and the total harmonic ratio of the higher harmonic components and the power-supply frequency component of the current signals of the motor in operation and the unbalance rate of the inter-phase currents of the motor in operation, and other changes in the current signals are not put in consideration. Thus, it is not enough as a method for monitoring the progress of deterioration of the inverter and for diagnosing whether or not there is deterioration. In addition, even if patent literature 2 can judge whether or not there is abnormality occurring in either the power-supply quality or the inverter, it cannot distinguish whether the abnormality occurs in the power-supply quality due to a cause except for an abnormality in the inverter, or deterioration (the abnormality) occurs in the inverter itself, thereby being not able to accurately detect deterioration of an inverter.

The present invention has been made in consideration of the above circumstances, and has as its object to provide a method for monitoring and diagnosing deterioration of an inverter capable of simply and accurately detecting a sign of deterioration of an inverter, of managing the progress of the deterioration, and of providing appropriate maintenance, by measuring, analyzing, and monitoring the current signals on the output side of the inverter, which supplies a driving current to a motor, while the inverter is being in operation.

Solution to Problem

[0005] In order to achieve the above object, according to the present invention, there is provided a method for monitoring and diagnosing deterioration of an inverter used to detect deterioration of an inverter supplying a driving current to a motor, including:

an inverter deterioration determination process for determining whether or not there is deterioration of the inverter, the inverter deterioration determination process measuring an output current of the inverter while the motor is in operation, and determining that the inverter is deteriorating when ~~at least one of~~ following (a) ~~to (c)~~ and/or (b) occurs: (a) a period abnormality in which a period of a current waveform acquired by the output current measurement fluctuates; ~~(b) an amplitude abnormality in which an amplitude of a current waveform acquired by the output current measurement fluctuates;~~ and ~~(c)~~(b) a higher harmonic ratio abnormality in which a ratio of higher harmonics of a power-supply frequency f_1 obtained by conducting a frequency spectrum analysis for time series data of a current waveform acquired by the output current measurement fluctuates.

In here, the motor may be a three-phase induction motor, be a single-phase induction motor, or be a permanent magnet synchronous motor (a PM motor). In cases where the inverter is a three-phase output inverter, the output current measurement may be conducted for only one phase or be conducted for all the three phases.

[0006] In the method for monitoring and diagnosing deterioration of an inverter according to the present invention, whether or not there is occurrence of the period abnormality can be judged by comparing a criterial sine-wave signal waveform and the current waveform, the criterial sine-wave signal waveform calculated based on a power-supply frequency f_1 obtained by conducting a frequency spectrum analysis for the time series data of the current waveform.

In the method for monitoring and diagnosing deterioration of an inverter according to the present invention, it is preferred that the period abnormality ~~is~~be determined to be occurring when a current period fluctuation ratio T_R, which is calculated by using an equation (1) below from: a power-supply period T_1 that is a reciprocal of the power-supply frequency f_1 ~~obtained by conducting a frequency spectrum analysis for time series data of the current waveform~~; and a maximum half period T_{max} and a minimum half period T_{min} of the current waveform, becomes equal to or more than a preset criterial value of a period fluctuation ratio or has a tendency to increase with the lapse of time.

[0007] [Math. 1]

$$T_R = \frac{2\left(T_{max} - T_{min}\right)}{T_1} \quad \cdots (1)$$

[0008] In the method for monitoring and diagnosing deterioration of an inverter according to the present invention, the inverter deterioration determination process can also determine that the inverter is deteriorating when

an amplitude abnormality in which an amplitude of the current waveform fluctuates occurs in addition to occurrence of the period abnormality and/or the higher harmonic ratio abnormality.

In the method for monitoring and diagnosing deterioration of an inverter according to the present invention, ~~the higher harmonic ratio abnormality is determined to be occurring when a specific higher harmonic ratio I_R, which is calculated by using an equation (2) below from: a current value I_1 of the power-supply frequency f_1 obtained by conducting a frequency spectrum analysis for the time series data of the current waveform acquired by the output current measurement; and a current value $I_{6i\pm1}$ of a $(6i \pm 1)$th-order higher harmonic of the power-supply frequency f_1, becomes equal to or more than a preset criterial value of a higher harmonic ratio or has a tendency to increase with the lapse of time.~~it is preferred that the amplitude abnormality be determined to be occurring when a current amplitude fluctuation ratio P_R, which is calculated by using an equation (2) or an equation (3) below from: a maximum amplitude P_{max}; a minimum amplitude P_{min}; and a current effective value I_{rms} or a current average value I_{ave} each obtained from the current waveform, becomes equal to or more than a preset criterial value of an amplitude fluctuation ratio or has a tendency to increase with the lapse of time.

[0009] ~~[Math. 2]~~In here, regarding a current waveform in an unsteady state, the amplitude (i.e. the distance from

the center of the oscillation to the maximum displacement) does not become constant but fluctuates, and thus, the maximum value of the amplitude (an absolute value) is deemed to be the maximum amplitude P_{max}, and the minimum value of the same is deemed to be the minimum amplitude P_{min}.

$$I_R = \frac{\sqrt{\sum_{i=1}^{n} I_{6i\pm1}^2}}{I_1} \quad \cdots (2)$$

[0010] ~~In here, n is a natural number of 1 or more and 8 or less, and more preferably, a natural number of 1 or more and 3 or less.~~[Math. 2]

$$P_R = \frac{P_{max} - P_{min}}{I_{rms}} \quad \cdots (2)$$

[0011] ~~In the method for monitoring and diagnosing deterioration of an inverter according to the present invention, the higher harmonic ratio abnormality is determined to be occurring when peaks of a (6i - 3)th-order higher harmonic and a (6i + 3)th-order higher harmonic of the power-supply frequency f_1 obtained by conducting a frequency spectrum analysis for the time series data of the current waveform acquired by the output current measurement, are both smaller than peaks of a (6i - 1)th-order higher harmonic and a (6i + 1)th-order higher harmonic.~~

~~In here, i is at least one of 1, 2, and 3.~~[Math. 3]

$$P_R = \frac{P_{max} - P_{min}}{I_{ave}} \quad \ldots \quad (3)$$

[0012] In the method for monitoring and diagnosing deterioration of an inverter according to the present invention, it is preferred that~~the amplitude abnormality is determined to be occurring when a current amplitude fluctuation ratio P_R, which is calculated by using an equation (3) or an equation (4) below from: a maximum amplitude P_{max}; a minimum amplitude P_{min}; and a current effective value I_{rms} or a current average value I_{ave} each obtained from the current waveform,~~ the higher harmonic ratio abnormality be determined to be occurring when a specific higher harmonic ratio I_R, which is calculated by using an equation (4) below from: a current value I_1 of the power-supply frequency f_1; and a current value $I_{6i\pm1}$ of a (6i ± 1)th-order higher harmonic of the power-supply frequency f_1, becomes equal to or more than a preset criterial value of ~~an amplitude fluctuation~~a higher harmonic ratio or has a tendency to increase with the lapse of time.

[0013] ~~In here, regarding a current waveform in an unsteady state, the amplitude (i.e. the distance from the center of the oscillation to the maximum displacement) does not become constant but fluctuates, and thus, the maximum value of the amplitude (an absolute value) is deemed to be the maximum amplitude P_{max}, and the minimum value of the same is deemed to be the minimum amplitude P_{min}.~~ [Math. 4]

$$I_R = \frac{\sqrt{\sum_{i=1}^{n} I_{6i\pm1}^2}}{I_1} \quad \cdots (4)$$

[0014] ~~[Math. 3]~~In here, n is a natural number of 1 or more and 8 or less, and more preferably, a natural number of 1 or more and 3 or less.

$$P_R = \frac{P_{max} - P_{min}}{I_{rms}} \quad \cdots (3)$$

[0015] ~~[Math. 4]~~In the method for monitoring and diagnosing deterioration of an inverter according to the present invention, the higher harmonic ratio abnormality may be determined to be occurring when peaks of a (6i − 3)th-order higher harmonic and a (6i + 3)th-order higher harmonic of the power-supply frequency f_1, are both smaller than peaks of a (6i − 1)th-order higher harmonic and a (6i + 1)th-order higher harmonic.

In here, i is at least one of 1, 2, and 3.

$$P_R = \frac{P_{max} - P_{min}}{I_{ave}} \quad \cdots (4)$$

[0016] In the method for monitoring and diagnosing deterioration of an inverter according to the present invention, it is preferred that the inverter deterioration determining process be carried out when a value of KI (Kullback-Leibler Information), which is calculated by using an equation (5) below from: a reference amplitude probability density function fr(x) obtained from a criterial sine-wave

signal waveform made based on the power-supply frequency f_1 obtained by conducting a frequency spectrum analysis for the time series data of the current waveform acquired by the output current measurement; and an at-diagnosis amplitude probability density function ft(x) obtained from the current waveform, becomes equal to or more than a preset criterial value of KI or has a tendency to increase with the lapse of time.

[0017] [Math. 5]

$$KI = \int_{-\infty}^{\infty} f_r(x) \, log \frac{f_r(x)}{f_t(x)} \, dx \quad \cdots (5)$$

Advantageous Effects of Invention

[0018] The method for monitoring and diagnosing deterioration of an inverter according to the present invention is capable of simply and reliably detecting deterioration (abnormality) of an inverter because the method analyzes a current waveform acquired by measuring an output current of an inverter and determines that the inverter is deteriorating when at least one of a period abnormality, an amplitude abnormality, and a higher harmonic ratio abnormality occurs. Therefore, the method has excellent reliability of an inverter deterioration detection and excellent maintenance efficiency of an inverter. In particular, by additionally monitoring the status (transition) of any one or more of: a period fluctuation ratio of the current waveform; an amplitude fluctuation ratio of the current waveform; and a higher harmonic ratio of a

power-supply frequency f_1 when a value of KI becomes equal to or more than a preset criterial value of KI or has a tendency to increase with the lapse of time, the work efficiency improves, and besides, this makes it possible to figure out the progress of deterioration of the inverter and to enhance the deterioration detection accuracy.

Brief Description of Drawings

[0019]

Fig. 1 is an explanatory diagram illustrating a method for monitoring and diagnosing deterioration of an inverter according to an embodiment of the present invention.

Fig. 2 is a graph illustrating a result of a frequency spectrum analysis for current signals of one phase of output currents of a three-phase output inverter in operation.

Fig. 3 is a graph comparing a criterial sine-wave signal waveform and a current waveform where a period abnormality has been occurring.

Fig. 4 is a graph comparing the criterial sine-wave signal waveform and a current waveform where an amplitude abnormality has been occurring.

Fig. 5(A) is a graph illustrating a result of a higher harmonic analysis conducted for a result of a frequency spectrum analysis conducted for time series data of the criterial sine-wave signal waveform.

Fig. 5(B) is a graph illustrating a result of a higher

harmonic analysis conducted for a result of a frequency spectrum analysis conducted for time series data of the current waveform where a higher harmonic ratio abnormality is occurring.

Description of Embodiment

[0020] An embodiment of the present invention will be explained next with reference to the accompanying drawings to provide an understanding of the present invention.

A method for monitoring and diagnosing deterioration of an inverter according to the embodiment of the present invention is, as shown in Fig. 1, used to detect deterioration of a three-phase output inverter (an example of an inverter) 11 that supplies driving currents to a three-phase induction motor (an example of a motor) 10.

As shown in Fig. 1, the input side (the primary side) of the three-phase output inverter 11 is connected to a power supply (a commercial three-phase AC power supply) 14, and the output side (the secondary side) of the same is connected to the three-phase induction motor 10. On the far side of the three-phase induction motor 10, various rotary machines such as a pump, blower, and the like (an example of load) are, not shown in the figures but, connected and driven by the three-phase induction motor 10.

At this time, if there is deterioration (abnormality) in the three-phase output inverter 11, various abnormalities occur in the output currents (i.e. the current waveforms) of

the three-phase output inverter 11. Thus, by measuring, analyzing, and monitoring the output currents of the three-phase output inverter 11 that is in operation, the deterioration of the three-phase output inverter 11 can be detected.

[0021] The output currents of the three-phase output inverter 11 can be easily measured by connecting, e.g., a clamp-type current detector 16 to each of three power lines 15 that connect the three-phase output inverter 11 and the three-phase induction motor 10 (i.e. the stators). Although a diagnosis with higher accuracy can be carried out when the currents of all the three phases are measured, a diagnosis still can be carried out even by only measuring the current of any one of the three phases. An analog current waveform (current signals) measured by the current detector 16 is converted to digital current data by an A/D converter (not shown in the figures), and processed by a processing unit (not shown in the figures). The processing unit is composed of a conventionally-known computing unit (i.e. a computer) including a RAM, a CPU, a ROM, I/O devices, and buses connecting these elements. The process by the processing unit is carried out by conducting a predetermined program with the CPU. Incidentally, transmission of the current data from the A/D converter to the processing unit can be done by using a LAN, a USB cable, or the like, and the installing place of the processing unit may be selected as appropriate. Also, the installing place and number of monitors for

displaying the diagnosis from the processing unit may be selected as appropriate, and the diagnosis also can be checked from a remote place by using the LAN. Moreover, by using a cloud environment, a plurality of workers and administrators can share the measured data and the diagnosis processed by the processing unit.

[0022] The method for monitoring and diagnosing deterioration of an inverter according to the present invention is applied in order to carry out an inverter deterioration diagnosis simply and quantitatively. The details of the method for monitoring and diagnosing deterioration of an inverter according to this embodiment will be explained below. Note that, in here, the diagnosis is carried out while focusing only on the output current of one of the three phases of the three-phase output inverter 11.

First, a power-supply frequency f_1 is obtained by once conducting a frequency spectrum analysis for time series data of a current waveform (current signals), which is acquired by measuring the output current of the three-phase output inverter 11 while the three-phase induction motor 10 is in operation by using the current detector 16, a criterial sine-wave signal waveform (a simulation waveform) calculated based on the power-supply frequency f_1 is A/D-converted and transmitted to the processing unit, and a reference amplitude probability density function fr(x) is obtained from a plurality of point data acquired within a predetermined

sampling time and is stored in a memorizing means (a RAM or a ROM) (a first step).

The frequency spectrum analysis is carried out with a conventionally-known method, and with the analysis, a current spectrum such as shown in Fig. 2 is acquired by filtering (i.e. applying a band-pass filter for, e.g., 0.5 Hz to 125 Hz to) the sampled current signals of the output current and conducting the fast Fourier transformation for the filtered current signals. Then, from the maximum peak of the current spectrum, the power-supply frequency f_1 of the output current of the three-phase output inverter 11 can be obtained, and based on the power-supply frequency f_1, a criterial sine-wave signal waveform (simulation waveform) a, such as shown in Fig. 3 and Fig. 4, is acquired.

[0023] Subsequently, a current waveform acquired by measuring the output current of the three-phase output inverter 11 at diagnosis is A/D-converted and transmitted to the processing unit, and from a plurality of point data acquired within the predetermined sampling time, an at-diagnosis amplitude probability density function ft(x) is obtained and is stored in the memorizing means (a second step).

Incidentally, the measuring time (the sampling time) of the output current in the first and second steps is, e.g., approximately 8 to 16 seconds.

An amplitude probability density function (such as the

reference amplitude probability density function and the at-diagnosis amplitude probability density function) is for obtaining the probability that a fluctuating signal exists at a specific amplitude level, and also for analyzing how much fluctuation occurs around which amplitude level.

[0024] Next, a value of KI is calculated from the reference amplitude probability density function fr(x) and the at-diagnosis amplitude probability density function ft(x) by using the aforementioned equation (5) (a third step).

[0025] Then, when the value of KI calculated by using the equation (5) becomes equal to or more than a preset criterial value of KI or has a tendency to increase with the lapse of time, it is determined that there is a possibility that deterioration of the three-phase output inverter 11 is occurring (a fourth step). At this time, it may be so made as to set a first criterial value and a second criterial value of KI in advance, to call attention when the calculated value of KI becomes equal to or more than the first criterial value of KI (e.g. 0.5), and to warn that there is a danger when the calculated value of KI becomes equal to or more than the second criterial value of KI (e.g. 1). These notifications may be displayed on the monitor or may be emailed to the administrators or the like.

[0026] Also, since the value of KI that changes with the lapse of time is revealed by doing the second and third steps repeatedly at predetermined time intervals, when the

value of KI shows a tendency to increase with the lapse of time, it can be determined that there is a possibility that deterioration of the three-phase output inverter 11 is progressing. In this case, the deterioration trend of the three-phase output inverter 11 can be figured out even before the value of KI reaches the criterial value of KI (i.e. the first or second criterial value).

[0027] When it is determined from the value of KI that there is a possibility that deterioration of the three-phase output inverter 11 is occurring as described above, additionally, the inverter deterioration determination process, which determines whether or not there is deterioration of the inverter by analyzing the current waveform and comparing it to the criterial sine-wave signal waveform, is carried out.

The details of the inverter deterioration determination process will be explained below.

First, a current period fluctuation ratio T_R is calculated by using the aforementioned equation (1) from: a power-supply period T_1 that is a reciprocal of the pre-obtained power-supply frequency f_1; and a maximum half period T_{max} and a minimum half period T_{min} of the current waveform (refer to Fig. 3). When the calculated current period fluctuation ratio T_R becomes equal to or more than a preset criterial value of a period fluctuation ratio or has a tendency to increase with the lapse of time, it is judged that a period abnormality where a period of a current

waveform fluctuates is occurring, thereby it is determined that deterioration of the three-phase output inverter 11 is occurring (a fifth step). At this time, it may be so made as to set a first criterial value and a second criterial value of the period fluctuation ratio in advance, to call attention when the calculated current period fluctuation ratio T_R becomes equal to or more than the first criterial value of the period fluctuation ratio (e.g. 0.1), and to warn that there is a danger when the calculated current period fluctuation ratio T_R becomes equal to or more than the second criterial value of the period fluctuation ratio (e.g. 0.2). These notifications may be displayed on the monitor or may be emailed to the administrators or the like.

[0028] Next, a current amplitude fluctuation ratio P_R is calculated by using the aforementioned equation (3) or (4) from: a maximum amplitude P_{max}; a minimum amplitude P_{min} (refer to Fig. 4); and a current effective value I_{rms} or a current average value I_{ave} each obtained from the current waveform. When the calculated current amplitude fluctuation ratio P_R becomes equal to or more than a preset criterial value of an amplitude fluctuation ratio or has a tendency to increase with the lapse of time, it is judged that an amplitude abnormality where an amplitude of a current waveform fluctuates is occurring, thereby it is determined that deterioration of the three-phase output inverter 11 is occurring (a sixth step). At this time, it may be so made as to set a first criterial value and a second criterial value

of the amplitude fluctuation ratio in advance, to call attention when the calculated current amplitude fluctuation ratio P_R becomes equal to or more than the first criterial value of the amplitude fluctuation ratio (e.g. 0.3), and to warn that there is a danger when the calculated current amplitude fluctuation ratio P_R becomes equal to or more than the second criterial value of the amplitude fluctuation ratio (e.g. 0.5). These notifications may be displayed on the monitor or may be emailed to the administrators or the like.

[0029] Next, when a specific higher harmonic ratio I_R, which is calculated by using the aforementioned equation (2) from: a current value I_1 of the pre-obtained power-supply frequency f_1; and a current value $I_{6i\pm1}$ of a $(6i \pm 1)$th-order higher harmonic of the power-supply frequency f_1, becomes equal to or more than a preset criterial value of a higher harmonic ratio or has a tendency to increase with the lapse of time, it is determined that a higher harmonic ratio abnormality where a ratio of higher harmonics of the power-supply frequency f_1 fluctuates is occurring. Note that n is a natural number of 1 or more and 8 or less, and more preferably, a natural number of 1 or more and 3 or less (a seventh step). At this time, it may be so made as to set a first criterial value and a second criterial value of the higher harmonic ratio in advance, to call attention when the calculated specific higher harmonic ratio I_R becomes equal to or more than the first criterial value of the higher harmonic ratio (e.g. 0.03), and to warn that there is a

danger when the calculated specific higher harmonic ratio I_R becomes equal to or more than the second criterial value of the higher harmonic ratio (e.g. 0.05). These notifications may be displayed on the monitor or may be emailed to the administrators or the like.

[0030] Instead of determining whether or not there is occurrence of a higher harmonic ratio abnormality by using the specific higher harmonic ratio I_R calculated by using the aforementioned equation (2), the higher harmonic ratio abnormality where a ratio of higher harmonics of the power-supply frequency f_1 fluctuates also can be determined to be occurring when the peaks of a (6i − 3)th-order higher harmonic and a (6i + 3)th-order higher harmonic of the pre-obtained power-supply frequency f_1 are both smaller than the peaks of a (6i − 1)th-order higher harmonic and a (6i + 1)th-order higher harmonic (provided that i is at least one of 1, 2, and 3) (an eighth step). In this case, the occurrence of the higher harmonic ratio abnormality can be detected in a simple way without doing calculations. For instance, in contrast with at a normal time shown in Fig. 5(A), in Fig. 5(B), the peaks of the 3rd-order higher harmonic and the 9th-order higher harmonic are both smaller than the peaks of the 5th-order higher harmonic and the 7th-order higher harmonic, the peaks of the 9th-order higher harmonic and the 15th-order higher harmonic are both smaller than the peaks of the 11th-order higher harmonic and the 13th-order higher harmonic, and the peaks of the 15th-order higher harmonic

and the 21st-order harmonic are both smaller than the peaks of the 17th-order higher harmonic and the 19th-order higher harmonic, and thus, it can be easily detected that a higher harmonic ratio abnormality is occurring.

[0031] The fifth to eighth steps explained above can be carried out in random order. Incidentally, it is not necessarily required to do all the fifth to eighth steps, and any one step or two or more steps of the fifth to eighth steps may be selected as appropriate. Even in cases of selecting a plurality of steps from them, it is also possible to deem that deterioration of the three-phase output inverter is occurring at a time where an abnormality is detected in any one of the steps, and to omit the remaining step(s).

In cases where the changes along the lapse of time in the value of KI, in the current period fluctuation ratio T_R, in the current amplitude fluctuation ratio P_R, and in the specific higher harmonic ratio I_R are made into a graph and displayed on the monitor, it is easy for the administrators to visually check the deterioration trend of the three-phase output inverter, thereby it is excellent in simplicity and reliability of deterioration trend management. At this time, it is not necessary to simultaneously display the transitions of all the parameters, and the transitions may be separated and displayed on several screens. Also, the number and combination of the parameters to be simultaneously displayed may be selected as appropriate.

[0032] The present invention has been described above

with reference to the embodiment. However, the present invention is not limited to the structures described in the above embodiment, and the present invention includes other embodiments and modifications conceivable within the scope of the matters described in the scope of the claims.

For example, in the above embodiment, the case of diagnosing by measuring the output current of only any one of the three phases of the three-phase output inverter has been explained. However, diagnosis also can be carried out by measuring the output currents of all the three phases and conducting the same analysis for each output current. In this case, a comprehensive evaluation including the balance among the three phases can be made, thereby the diagnosing accuracy improves. Also, the configuration of the inverter is not particularly limited. Moreover, the determination based on the value of KI (i.e. the first to fourth steps) may be omitted and the inverter deterioration determination process (i.e. the fifth to eighth steps) may be carried out from the start.

Industrial Applicability

[0033] With the method for monitoring and diagnosing deterioration of an inverter according to the present invention, a sign of deterioration of an inverter can be simply and accurately detected by measuring, analyzing, and monitoring the current signals on the output side of the inverter, which supplies a driving current to a motor, while the inverter is being in operation, and thus, appropriate

maintenance can be provided to the inverter depending on the progress of the deterioration. Therefore, the work efficiency of the maintenance improves and the work load decreases.

Reference Signs List

[0034] 10: three-phase induction motor (motor), 11: three-phase output inverter (inverter), 14: power supply, 15: power line, 16: current detector

CLAIMS

1. A method for monitoring and diagnosing deterioration of an inverter used to detect deterioration of an inverter supplying a driving current to a motor, comprising:

an inverter deterioration determination process for determining whether or not there is deterioration of the inverter, the inverter deterioration determination process measuring an output current of the inverter while the motor is in operation, and determining that the inverter is deteriorating when at least one of following (a) to (c) occurs: (a) a period abnormality in which a period of a current waveform acquired by the output current measurement fluctuates; (b) an amplitude abnormality in which an amplitude of a current waveform acquired by the output current measurement fluctuates; and (c) a higher harmonic ratio abnormality in which a ratio of higher harmonics of a power-supply frequency f_1 acquired by the output current measurement fluctuates,

wherein the inverter deterioration determination process determines that the inverter is deteriorating when the period abnormality occurs, and

wherein the period abnormality is determined to be occurring when a current period fluctuation ratio T_R, which is calculated by using an equation (1) below from: a power-supply period T_1 that is a reciprocal of the power-supply frequency f_1 obtained by conducting a frequency spectrum

analysis for time series data of the current waveform; and a maximum half period T_{max} and a minimum half period T_{min} of the current waveform, becomes equal to or more than a preset criterial value of a period fluctuation ratio or has a tendency to increase with the lapse of time.

[Math. 1]

$$T_R = \frac{2\left(T_{max} - T_{min}\right)}{T_1} \quad \cdots (1)$$

2. A method for monitoring and diagnosing deterioration of an inverter used to detect deterioration of an inverter supplying a driving current to a motor, comprising:

an inverter deterioration determination process for determining whether or not there is deterioration of the inverter, the inverter deterioration determination process measuring an output current of the inverter while the motor is in operation, and determining that the inverter is deteriorating when at least one of following (a) to (c) occurs: (a) a period abnormality in which a period of a current waveform acquired by the output current measurement fluctuates; (b) an amplitude abnormality in which an amplitude of a current waveform acquired by the output current measurement fluctuates; and (c) a higher harmonic ratio abnormality in which a ratio of higher harmonics of a power-supply frequency f_1 acquired by the output current measurement fluctuates,

wherein the inverter deterioration determination

process determines that the inverter is deteriorating when the higher harmonic ratio abnormality occurs, and

wherein the higher harmonic ratio abnormality is determined to be occurring when a specific higher harmonic ratio I_R, which is calculated by using an equation (2) below from: a current value I_1 of the power-supply frequency f_1 obtained by conducting a frequency spectrum analysis for time series data of the current waveform acquired by the output current measurement; and a current value $I_{6i\pm1}$ of a $(6i \pm 1)$th-order higher harmonic of the power-supply frequency f_1, becomes equal to or more than a preset criterial value of a higher harmonic ratio or has a tendency to increase with the lapse of time;

provided that n is a natural number of 1 or more and 8 or less.

[Math. 2]

$$I_R = \frac{\sqrt{\sum_{i=1}^{n} I_{6i\pm1}^2}}{I_1} \quad \cdots (2)$$

3. A method for monitoring and diagnosing deterioration of an inverter used to detect deterioration of an inverter supplying a driving current to a motor, comprising:

an inverter deterioration determination process for determining whether or not there is deterioration of the inverter, the inverter deterioration determination process measuring an output current of the inverter while the motor

~~is in operation, and determining that the inverter is deteriorating when at least one of following (a) to (c) occurs: (a) a period abnormality in which a period of a current waveform acquired by the output current measurement fluctuates; (b) an amplitude abnormality in which an amplitude of a current waveform acquired by the output current measurement fluctuates; and (c) a higher harmonic ratio abnormality in which a ratio of higher harmonics of a power-supply frequency f_1 acquired by the output current measurement fluctuates,~~

~~wherein the inverter deterioration determination process determines that the inverter is deteriorating when the higher harmonic ratio abnormality occurs, and~~

~~wherein the higher harmonic ratio abnormality is determined to be occurring when peaks of a (6i − 3)th-order higher harmonic and a (6i + 3)th-order higher harmonic of the power-supply frequency f_1 obtained by conducting a frequency spectrum analysis for time series data of the current waveform acquired by the output current measurement, are both smaller than peaks of a (6i − 1)th-order higher harmonic and a (6i + 1)th-order higher harmonic;~~

~~provided that i is at least one of 1, 2, and 3.~~

~~4. The method for monitoring and diagnosing deterioration of an inverter set forth in claim 1,~~

~~wherein the inverter deterioration determination process also determines that the inverter is deteriorating~~

~~when the higher harmonic ratio abnormality occurs, and~~

~~wherein the higher harmonic ratio abnormality is determined to be occurring when a specific higher harmonic ratio I_R, which is calculated by using an equation (2) below from: a current value I_1 of the power-supply frequency f_1 obtained by conducting a frequency spectrum analysis for the time series data of the current waveform acquired by the output current measurement; and a current value $I_{6i\pm1}$ of a (6i ± 1)th-order higher harmonic of the power-supply frequency f_1, becomes equal to or more than a preset criterial value of a higher harmonic ratio or has a tendency to increase with the lapse of time;~~

~~provided that n is a natural number of 1 or more and 8 or less.~~

~~[Math. 3]~~

$$I_R = \frac{\sqrt{\sum_{i=1}^{n} I_{6i\pm1}^2}}{I_1} \quad \cdots (2)$$

~~5. The method for monitoring and diagnosing deterioration of an inverter set forth in claim 1,~~

~~wherein the inverter deterioration determination process also determines that the inverter is deteriorating when the higher harmonic ratio abnormality occurs, and~~

~~wherein the higher harmonic ratio abnormality is determined to be occurring when peaks of a (6i - 3)th-order~~

~~higher harmonic and a (6i + 3)th-order higher harmonic of the power-supply frequency f_1 obtained by conducting a frequency spectrum analysis for the time series data of the current waveform acquired by the output current measurement, are both smaller than peaks of a (6i - 1)th-order higher harmonic and a (6i + 1)th-order higher harmonic;~~

~~provided that i is at least one of 1, 2, and 3.~~

~~6. The method for monitoring and diagnosing deterioration of an inverter set forth in any one of claims 1 to 5,~~

~~wherein the inverter deterioration determination process also determines that the inverter is deteriorating when the amplitude abnormality occurs, and~~

~~wherein the amplitude abnormality is judged to be occurring when a current amplitude fluctuation ratio P_R, which is calculated by using an equation (3) below from: a maximum amplitude P_{max}; a minimum amplitude P_{min}; and a current effective value I_{rms} each obtained from the current waveform, becomes equal to or more than a preset criterial value of an amplitude fluctuation ratio or has a tendency to increase with the lapse of time.~~

~~[Math. 4]~~

$$P_R = \frac{P_{max} - P_{min}}{I_{rms}} \quad \cdots (3)$$

~~7. The method for monitoring and diagnosing deterioration of an inverter set forth in any one of claims 1 to 5,~~

wherein the inverter deterioration determination process also determines that the inverter is deteriorating when the amplitude abnormality occurs, and

wherein the amplitude abnormality is judged to be occurring when a current amplitude fluctuation ratio P_R, which is calculated by using an equation (4) below from: a maximum amplitude P_{max}; a minimum amplitude P_{min}; and a current average value I_{ave} each obtained from the current waveform, becomes equal to or more than a preset criterial value of an amplitude fluctuation ratio or has a tendency to increase with the lapse of time.

[Math. 5]

$$P_R = \frac{P_{max} - P_{min}}{I_{ave}} \quad \cdots (4)$$

8. The method for monitoring and diagnosing deterioration of an inverter set forth in any one of claims 1 to 7,

wherein the inverter deterioration determination process is carried out when a value of KI, which is calculated by using an equation (5) below from: a reference amplitude probability density function fr(x) obtained from a criterial sine-wave signal waveform made based on the power-supply frequency f_1 obtained by conducting a frequency spectrum analysis for the time series data of the current waveform acquired by the output current measurement; and an at-diagnosis amplitude probability density function ft(x) obtained from the current waveform, becomes equal to or more

~~than a preset criterial value of KI or has a tendency to increase with the lapse of time.~~

~~[Math. 6]~~

$$KI = \int_{-\infty}^{\infty} f_r(x) \, log \frac{f_r(x)}{f_t(x)} \, dx \qquad \cdots (5)$$

1. A method for monitoring and diagnosing deterioration of an inverter used to detect deterioration of an inverter supplying a driving current to a motor, comprising:

an inverter deterioration determination process for determining whether or not there is deterioration of the inverter, the inverter deterioration determination process measuring an output current of the inverter while the motor is in operation, and determining that the inverter is deteriorating when following (a) and/or (b) occurs: (a) a period abnormality in which a period of a current waveform acquired by the output current measurement fluctuates; and (b) a higher harmonic ratio abnormality in which a ratio of higher harmonics of a power-supply frequency f_1 obtained by conducting a frequency spectrum analysis for time series data of a current waveform acquired by the output current measurement fluctuates.

2. The method for monitoring and diagnosing deterioration of an inverter set forth in claim 1,

wherein whether or not there is occurrence of the period abnormality is judged by comparing a criterial sine-wave signal waveform and the current waveform, the criterial

sine-wave signal waveform calculated based on a power-supply frequency f_1 obtained by conducting a frequency spectrum analysis for the time series data of the current waveform.

3. The method for monitoring and diagnosing deterioration of an inverter set forth in claim 2,

wherein the period abnormality is determined to be occurring when a current period fluctuation ratio T_R, which is calculated by using an equation (1) below from: a power-supply period T_1 that is a reciprocal of the power-supply frequency f_1; and a maximum half period T_{max} and a minimum half period T_{min} of the current waveform, becomes equal to or more than a preset criterial value of a period fluctuation ratio or has a tendency to increase with the lapse of time.

[Math. 1]

$$T_R = \frac{2\left(T_{max} - T_{min}\right)}{T_1} \quad \ldots \quad (1)$$

4. The method for monitoring and diagnosing deterioration of an inverter set forth in any one of claims 1 to 3,

wherein the inverter deterioration determination process determines that the inverter is deteriorating when an amplitude abnormality in which an amplitude of the current waveform fluctuates occurs in addition to occurrence of the period abnormality and/or the higher harmonic ratio abnormality.

5. The method for monitoring and diagnosing deterioration

of an inverter set forth in claim 4,

wherein the amplitude abnormality is judged to be occurring when a current amplitude fluctuation ratio P_R, which is calculated by using an equation (2) below from: a maximum amplitude P_{max}; a minimum amplitude P_{min}; and a current effective value I_{rms} each obtained from the current waveform, becomes equal to or more than a preset criterial value of an amplitude fluctuation ratio or has a tendency to increase with the lapse of time.

[Math. 2]

$$P_R = \frac{P_{max} - P_{min}}{I_{rms}} \quad \ldots \quad (2)$$

6. The method for monitoring and diagnosing deterioration of an inverter set forth in claim 4,

wherein the amplitude abnormality is judged to be occurring when a current amplitude fluctuation ratio P_R, which is calculated by using an equation (3) below from: a maximum amplitude P_{max}; a minimum amplitude P_{min}; and a current average value I_{ave} each obtained from the current waveform, becomes equal to or more than a preset criterial value of an amplitude fluctuation ratio or has a tendency to increase with the lapse of time.

[Math. 3]

$$P_R = \frac{P_{max} - P_{min}}{I_{ave}} \quad \ldots \quad (3)$$

7. The method for monitoring and diagnosing deterioration of an inverter set forth in any one of claims 1 to 6,

wherein the higher harmonic ratio abnormality is determined to be occurring when a specific higher harmonic ratio I_R, which is calculated by using an equation (4) below from: a current value I_1 of the power-supply frequency f_1; and a current value $I_{6i\pm1}$ of a $(6i \pm 1)$th-order higher harmonic of the power-supply frequency f_1, becomes equal to or more than a preset criterial value of a higher harmonic ratio or has a tendency to increase with the lapse of time;

provided that n is a natural number of 1 or more and 8 or less.

[Math. 4]

$$I_R = \frac{\sqrt{\sum_{i=1}^{n} I_{6i\pm1}^2}}{I_1} \quad \ldots \quad (4)$$

8. The method for monitoring and diagnosing deterioration of an inverter set forth in any one of claims 1 to 6,

wherein the higher harmonic ratio abnormality is determined to be occurring when peaks of a $(6i - 3)$th-order higher harmonic and a $(6i + 3)$th-order higher harmonic of the power-supply frequency f_1 are both smaller than peaks of a $(6i - 1)$th-order higher harmonic and a $(6i + 1)$th-order higher harmonic;

provided that i is at least one of 1, 2, and 3.

9. The method for monitoring and diagnosing deterioration of an inverter set forth in any one of claims 1 to 8,

wherein the inverter deterioration determination process is carried out when a value of KI, which is calculated by using an equation (5) below from: a reference amplitude probability density function fr(x) obtained from a criterial sine-wave signal waveform made based on a power-supply frequency f_1 obtained by conducting a frequency spectrum analysis for the time series data of the current waveform; and an at-diagnosis amplitude probability density function ft(x) obtained from the current waveform, becomes equal to or more than a preset criterial value of KI or has a tendency to increase with the lapse of time.

[Math. 5]

$$KI = \int_{-\infty}^{\infty} f_r(x) \log \frac{f_r(x)}{f_t(x)} dx \quad \cdots \quad (5)$$