IEC/TS 60034-24

Edition 1.0 2009-09

TECHNICAL SPECIFICATION

SPÉCIFICATION TECHNIQUE

Rotating electrical machines –
Part 24: Online detection and diagnosis of potential failures at the active parts of rotating electrical machines and of bearing currents – Application guide

Machines électriques tournantes –
Partie 24: Détection et diagnostic en ligne de défaillances potentielles des parties actives de machines électriques tournantes et de courants de palier – Guide d'application

IEC/TS 60034-24:2009

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

- Catalogue of IEC publications: www.iec.ch/searchpub

The IEC on-line Catalogue enables you to search by a variety of criteria (reference number, text, technical committee,…). It also gives information on projects, withdrawn and replaced publications.

- IEC Just Published: www.iec.ch/online_news/justpub

Stay up to date on all new IEC publications. Just Published details twice a month all new publications released. Available on-line and also by email.

- Electropedia: www.electropedia.org

The world's leading online dictionary of electronic and electrical terms containing more than 20 000 terms and definitions in English and French, with equivalent terms in additional languages. Also known as the International Electrotechnical Vocabulary online.

- Customer Service Centre: www.iec.ch/webstore/custserv

If you wish to give us your feedback on this publication or need further assistance, please visit the Customer Service Centre FAQ or contact us:
Email: csc@iec.ch
Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00

A propos de la CEI

La Commission Electrotechnique Internationale (CEI) est la première organisation mondiale qui élabore et publie des normes internationales pour tout ce qui a trait à l'électricité, à l'électronique et aux technologies apparentées.

A propos des publications CEI

Le contenu technique des publications de la CEI est constamment revu. Veuillez vous assurer que vous possédez l'édition la plus récente, un corrigendum ou amendement peut avoir été publié.

- Catalogue des publications de la CEI: www.iec.ch/searchpub/cur_fut-f.htm

Le Catalogue en-ligne de la CEI vous permet d'effectuer des recherches en utilisant différents critères (numéro de référence, texte, comité d'études,…). Il donne aussi des informations sur les projets et les publications retirées ou remplacées.

- Just Published CEI: www.iec.ch/online_news/justpub

Restez informé sur les nouvelles publications de la CEI. Just Published détaille deux fois par mois les nouvelles publications parues. Disponible en-ligne et aussi par email.

- Electropedia: www.electropedia.org

Le premier dictionnaire en ligne au monde de termes électroniques et électriques. Il contient plus de 20 000 termes et définitions en anglais et en français, ainsi que les termes équivalents dans les langues additionnelles. Egalement appelé Vocabulaire Electrotechnique International en ligne.

- Service Clients: www.iec.ch/webstore/custserv/custserv_entry-f.htm

Si vous désirez nous donner des commentaires sur cette publication ou si vous avez des questions, visitez le FAQ du Service clients ou contactez-nous:
Email: csc@iec.ch
Tél.: +41 22 919 02 11
Fax: +41 22 919 03 00

IEC/TS 60034-24

Edition 1.0 2009-09

TECHNICAL SPECIFICATION

SPÉCIFICATION TECHNIQUE

**Rotating electrical machines –
Part 24: Online detection and diagnosis of potential failures at the active parts of rotating electrical machines and of bearing currents – Application guide**

**Machines électriques tournantes –
Partie 24: Détection et diagnostic en ligne de défaillances potentielles des parties actives de machines électriques tournantes et de courants de palier – Guide d'application**

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

COMMISSION
ELECTROTECHNIQUE
INTERNATIONALE

PRICE CODE
CODE PRIX S

ICS 29.160 ISBN 978-2-88910-021-7

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

ROTATING ELECTRICAL MACHINES –

Part 24: Online detection and diagnosis of potential failures at the active parts of rotating electrical machines and of bearing currents – Application guide

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.

2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.

3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.

4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.

5) IEC provides no marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with an IEC Publication.

6) All users should ensure that they have the latest edition of this publication.

7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.

8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.

9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a technical specification when

- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- The subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 60034-24, which is a technical specification, has been prepared by IEC technical committee 2: Rotating machinery.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
2/1537/DTS	2/1553A/RVC

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

NOTE A table of cross-references of all IEC TC 2 publications can be found in the IEC TC 2 dashboard on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

INTRODUCTION

Progress in design and technology has resulted in an increasing reliability of rotating electrical machines, but failures could not be eliminated completely. Since the demand for a high availability is permanently increasing, it is essential to detect deficiencies at an early stage and to recognize the origin and identify the severity of the fault in order to estimate the risk of a continuation of operation.

It would be advantageous, if the signals which are obtained by the detection methods presented in this guide, were suitable to distinguish the different failures from each other. By this means, the signal analysis can be used as input data of a complete monitoring system.

The aim of this guide is to present possible tools which are available for the intended purpose and to explain their advantages and disadvantages. The minimum requirements which shall be met by the various sensors will be discussed, whereas the detailed design rules are outside the scope of this technical specification.

This guide deals with the detection of failures at the active parts of multi-phase rotating machines (all kinds of winding faults in stator and rotor, cage deficiencies, eccentricities) and of bearing currents.

ROTATING ELECTRICAL MACHINES –

Part 24: Online detection and diagnosis of potential failures at the active parts of rotating electrical machines and of bearing currents – Application guide

1 Scope

This part of IEC 60034 is applicable to the on-line detection and diagnosis of failures at the active parts of multi-phase rotating electrical machines (induction and synchronous machines) and of bearing currents. The failure analysis includes:

– interturn faults;

– phase-to-phase short-circuits;

– double earth faults and single earth faults of motors with earth connection of the star-point;

– static and dynamic eccentricities;

– cage imperfection or defects (e.g. broken bars or end-rings);

– bearing currents.

This can be achieved by tools like search coils or other magnetic sensors or partly by the analysis of the terminal voltages and currents.

The detection of the following effects is excluded from the scope:

– vibration (covered by ISO standards, e.g. ISO 10816 and ISO 7919);

– partial discharge (covered by IEC 60034-27);

– single earth-faults of motors without earth connection of the star-point;

– core imperfection.

Also excluded are special methods applicable for specific applications only (e.g. turbo generators).

2 Normative references

There are no normative references in this technical specification.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
distribution factor
the factor, related to a distributed winding, which takes into account the reduction in the generated voltage due to the phase difference between the voltages generated in the coils in different slots

[IEV 411-38-37]

3.2
chording (pitch) factor
the factor, related to a distributed winding, which takes into account the reduction in the generated voltage, when the winding pitch is not 100 %

[IEV 411-38-38]

3.3
branch factor
the factor, related to a distributed winding, which takes into account the reduction in the generated voltage due to the phase difference between the voltages generated in the series-connected branches

4 Basis of the diagnosis

The ability of electrical machines to operate is based on the existence of a magnetic field in the air-gap, which is looping in a cross-sectional area of the laminations of stator and rotor. Flux components in the end-portions of the machine outside the cores are of a parasitic nature. Therefore available signals suitable for the detection of potential faults originate from the magnetic field in the air-gap, which shall be analyzed in order to distinguish between those components which occur under regular operating conditions and those components which are attributed to a specific failure and which do not exist in a healthy machine.

Since the winding producing the magnetic field consists of coils distributed symmetrically around the circumference and since the sum of the supplying currents is usually zero, the air-gap field forms also a periodic function along the circumference. The wave of the flux density can be considered as the superposition of a sum of sinusoidally distributed waves, which are characterized by the following features:

- amplitude,
- number of pole-pairs,
- angular velocity,
- phase-angle,
- type of wave (rotating or standing).

Table 1 shows the composition of the air-gap field in the case of a three-phase cage induction motor, which is equipped with an integral slot winding. The table can easily be extended to be valid also for fractional slot windings. Similar tables can be developed for slip-ring motors and all kinds of synchronous machines.

Table 1 – Most important magnetic fields in the air-gap of a three-phase cage induction motor with an integral slot stator winding under normal operating and fault conditions

Origin of the field		Stator fields	Rotor fields	Item
Fields under normal operating conditions	winding fields (slot harmonics)	type: rotating frequency: f_1 number of pole pairs: $\nu_1 = p\,(1 + 6g_1)$ $g_1 = 0; \pm 1; \pm 2; \ldots$ (slot harmonics: $\nu_1 = p + g_1\,Q_s$)	type: rotating frequency: $f_1\left\{1+\frac{g_2 Q_r}{p}(1-s)\right\}$ $g_2 = 0; \pm 1; \pm 2; \ldots$ number of pole pairs: $\nu_2 = \nu_1 + g_2\,Q_r$	1
	saturation fields	type: rotating frequency: $3f_1$ number of pole pairs: $\nu_1 = 3p$	type: rotating frequency: $f_1\left\{3+\frac{g_2 Q_r}{p}(1-s)\right\}$ $g_2 = 0; \pm 1; \pm 2; \ldots$ number of pole pairs: $\nu_2 = 3p + g_2\,Q_r$	2
Additional fields under fault conditions	interturn faults phase-to-phase faults double earth faults	type: superposition of reverse rotating fields of different amplitude frequency: f_1 number of pole pairs: $\nu_1 = 1; 2; 3; \ldots$	type: superposition of reverse rotating fields of different amplitude frequency: $f_1\left\{\pm 1+\frac{g_2 Q_r}{p}(1-s)\right\}$ $g_2 = \pm 1; \pm 2; \ldots$ + positive-sequence fields – negative-sequence fields number of pole pairs: $\nu_2 = \nu_1 + g_2\,Q_r$	3

Origin of the field	Stator fields	Rotor fields	Item
eccentricity	type: 2 rotating fields frequency: $f_1\{1 \pm \frac{K}{p}(1-s)\}$ K = 0: static eccentricity K = 1: dynamic eccentricity number of pole pairs: $\nu_1 = p \pm 1$	type: 2 rotating fields frequency: $f_1\left\{1+\left[\pm\frac{K}{p}+\frac{g_2 Q_r}{p}\right](1-s)\right\}$ number of pole pairs: $\nu_2 = \nu_1 + g_2\ Q_r$ $g_2 = 0; \pm 1; \pm 2; \ldots$	4
rotor asymmetry		type: superposition of reverse rotating fields of the same amplitude frequency: $f_1\left\{\pm s+\frac{\nu_2}{p}(1-s)\right\}$ number of pole pairs: $\nu_2 = 1; 2; 3; \ldots$	5

Symbols:

- f_1 fundamental frequency
- p number of pole pairs, for which the motor is designed
- ν number of pole pairs in general
- Q_s number of stator slots
- Q_r number of rotor bars
- s slip

5 Kinds of electrical signal analysis

5.1 General

A valuable detection method shall be able to detect failures at an early stage. Therefore signals disclosing a rapid change in the case of small deficiencies, are optimal for the intended purpose. By contrast signals which vary only insignificantly should not be used as the basis of the diagnosis.

The signal processing needs the availability of appropriate electronic equipment. Although the resolution of modern devices is high, signals which do not need excessive precision should be preferred in this respect.

5.2 Stator current/voltage analysis

The analysis of the terminal voltages or currents of a rotating machine allows identification of

– different frequencies,

– positive-, negative-, and zero-sequence components,

– different amplitudes of the components.

In general, all waves of induction in the air-gap field can induce voltages of certain frequencies in the stator winding and can cause currents of the same frequencies. The additional current components which are generated by a specific failure are superimposed to the supply values during undisturbed operation. All details shall be taken from the relevant table, that is Table 1 in the case of three-phase cage induction motors.

Table 1 is worded for one single supply frequency f_1. However, in case of a converter supplied machine, it is valid for each voltage/frequency component, which is contained in the output spectrum of the converter.

Table 1 shows the components of the air-gap field. Whether a specific component induces a voltage in the stator winding, depends on its winding factor for the number of pole pairs under consideration. The winding factor is the product of the following terms:

– the distribution factor,

– the chording factor,

– the branch factor.

The branch factor is not generally known amongst engineers, but of fundamental importance for the problem under consideration. Each symmetrical three-phase integral slot winding consists of p (in case of a single-layer winding) or $2p$ (in case of a double-layer winding) identical coil groups (branches), which are distributed symmetrically around the circumference. They can be series-connected or connected to form parallel branches with the maximum number $a = 2p$. The connecting method considerably influences the branch factor of a specific number of pole pairs.

It can be shown that the branch factor is zero for the eccentricity fields $\nu = p + 1$ and $\nu = p - 1$ for all windings with series-connection of the coil-groups. *Consequently both types of eccentricity cannot be detected for such machines by stator current analysis.*

The branch factor of the harmonic fields according to item 1 to 4 of Table 1 depends also on the individual configuration and in addition on the number of rotor slots. The design of a given case is selected by the manufacturer of the machine for different reasons (e.g. to suppress unbalanced magnetic pull, to avoid nasty magnetic tones, etc.) and unknown to the user. *It is therefore not advisable to use the harmonic rotor fields of items 3 and 4 as the signal for a stator current analysis.*

The group of winding faults in item 3 marks the most severe deficiencies at the active parts. They all produce magnetic fields of fundamental frequency. *Thus winding faults cannot be detected by a frequency analysis of the stator currents.*

The field waves, produced by winding faults, are of elliptic nature, which means the superposition of two reverse rotating waves, having the same number of poles and the same frequency, but different amplitudes. In principle such failures can be detected by exploring the negative sequence component of the current of fundamental frequency.

Especially in case of the most dangerous failure, an interturn fault of a high-voltage machine, when the high currents flow in only one of many turns per phase, this component is very small. A negative-sequence component of the current may also be caused by an unavoidable small asymmetry of the supply voltages (a negative sequence component of the voltage results in a negative sequence component of the currents, which is 6 to 10-times higher). *Summing up, it is not recommendable to detect winding faults by means of a voltage/current analysis.*

Reliable detection of cage imperfection or defects (e.g. broken bars or end-rings) is possible by use of stator current analysis.

Another disadvantage of the stator current analysis cannot be neglected. Statistics of insurance companies manifest that most of the winding faults occur during transient phenomena such as starting of motors, short-circuits at the terminals, etc., and cause high inrush currents. It is unfeasible to detect failures by current analysis during the interval of the transients.

5.3 Induced voltages of auxiliary turns embedded into the stator slots or other magnetic sensors sensing the air-gap flux

An ideal diagnostic signal would be zero during operation of a healthy machine under steady-state and transient conditions, it would rise with the amount of the deficiency for all kinds of failures according to items 3 to 5 of Table 1 and would be able to distinguish between the failures. Solutions close to the optimum have been developed.

These solutions are based on turns made by insulated wire, the diameter of which can be selected under solely mechanical aspects. Both coil-sides are incorporated in the stator slots of the main winding, usually during manufacturing of the machine between the upper layer of the winding and the slot wedge. The assembly at a later stage is possible. The end-connections are led close to the end of the core.

The same insight into the magnetic field at specific locations at the stator bore can eventually be achieved by other kinds of magnetic sensors instead of measuring turns.

Usually several turns of the same pitch are series-connected and shifted against each other by a predetermined angle. It is aimed to get finally a system of auxiliary measuring coils, for which the resulting winding factor is zero for all air-gap fields, which exist during normal undisturbed operation, and for which the winding factor is maximum for a field with that number of pole pairs, which is intended to be used as the reference field of the diagnosis.

If a system of auxiliary coils can be found which fulfills the condition explained above for a reference field, which is amongst the fields generated by all failures of items 3 to 5, the coil system would be complete. But there is one remaining difficulty: The fields produced by a winding fault according to item 3 of Table 1, are of an elliptic nature. If one of them is chosen as reference field, the induced voltage of the coil system would vary with the location of the fault at the circumference. Such a situation is of course unacceptable.

The problem can be eliminated by use of a second identical coil system, which is shifted against the first one by the angle $\pi/(2\nu)$, when ν is the number of pole pairs of the reference field. Then both coil groups form a symmetrical two-phase system, which easily allows the