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Commission Electrotechnique Internationale
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Effets d'un système de tensions déséquilibré sur les caractéristiques de fonctionnement des moteurs asynchrones triphasés à cage

Effects of unbalanced voltages on the performance of three-phase cage induction motors

Publication
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Révision de la présente publication

Le contenu technique des publications de la CEI est constamment revu par la Commission afin d'assurer qu'il reflète bien l'état actuel de la technique.

Les renseignements relatifs à ce travail de révision, à l'établissement des éditions révisées et aux mises à jour peuvent être obtenus auprès des Comités nationaux de la CEI et en consultant les documents ci-dessous:

- **Bulletin de la CEI**
- **Annuaire de la CEI**
- **Catalogue des publications de la CEI**
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Terminologie

En ce qui concerne la terminologie générale, le lecteur se reportera à la Publication 50 de la CEI: Vocabulaire Electrotechnique International (VEI), qui est établie sous forme de chapitres séparés traitant chacun d'un sujet défini, l'Index général étant publié séparément. Des détails complets sur le VEI peuvent être obtenus sur demande.

Les termes et définitions figurant dans la présente publication ont été soit repris du VEI, soit spécifiquement approuvés aux fins de cette publication.

Symboles graphiques et littéraux

Pour les symboles graphiques, symboles littéraux et signes d'usage général approuvés par la CEI, le lecteur consultera:

- la Publication 27 de la CEI: Symboles littéraux à utiliser en électrotechnique;
- la Publication 617 de la CEI: Symboles graphiques pour schémas.

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Publications de la CEI établies par le même Comité d'Etudes

L'attention du lecteur est attirée sur le deuxième feuillet de la couverture, qui énumère les publications de la CEI préparées par le Comité d'Etudes qui a établi la présente publication.

Revision of this publication

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- **IEC Bulletin**
- **IEC Yearbook**
- **Catalogue of IEC Publications**
  Published yearly

Terminology

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The terms and definitions contained in the present publication have either been taken from the IEV or have been specifically approved for the purpose of this publication.

Graphical and letter symbols

For graphical symbols, and letter symbols and signs approved by the IEC for general use, readers are referred to:

- IEC Publication 27: Letter symbols to be used in electrical technology;
- IEC Publication 617: Graphical symbols for diagrams.

The symbols and signs contained in the present publication have either been taken from IEC Publications 27 or 617, or have been specifically approved for the purpose of this publication.

IEC publications prepared by the same Technical Committee

The attention of readers is drawn to the back cover, which lists IEC publications issued by the Technical Committee which has prepared the present publication.

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

EFFECTS OF UNBALANCED VOLTAGES ON THE PERFORMANCE OF THREE-PHASE CAGE INDUCTION MOTORS

FOREWORD

1) The formal decisions or agreements of the IEC on technical matters, prepared by Technical Committees on which all the National Committees having a special interest therein are represented, express, as nearly as possible, an international consensus of opinion on the subjects dealt with.

2) They have the form of recommendations for international use and they are accepted by the National Committees in that sense.

3) In order to promote international unification, the IEC expresses the wish that all National Committees should adopt the text of the IEC recommendation for their national rules in so far as national conditions will permit. Any divergence between the IEC recommendation and the corresponding national rules should, as far as possible, be clearly indicated in the latter.

PREFACE

This report has been prepared by IEC Technical Committee No. 2: Rotating Machinery.

This text of this report is based on the following documents:

Six Months' Rule	Report on Voting
2(CO)507	2(CO)513

Further information can be found in the Report on Voting indicated in the table above.

The following IEC publications are quoted in this report:

Publications Nos. 34-1 (1983): Rotating Electrical Machines, Part 1: Rating and Performance.

34-12 (1980): Rotating Electrical Machines, Part 12: Starting Performance of Single-speed Three-phase Cage Induction Motors for Voltages up to and including 660 V.

EFFECTS OF UNBALANCED VOLTAGES ON THE PERFORMANCE OF THREE-PHASE CAGE INDUCTION MOTORS

INTRODUCTION

When the line voltages applied to a three-phase cage induction motor are not equal, the currents in the stator windings will also be unequal. A small percentage voltage imbalance will result in a much larger percentage current imbalance.

The application of unbalanced voltages to a three-phase induction motor introduces a "negative sequence voltage", and this produces in the air gap a flux rotating against the rotation of the rotor, thus tending to produce high currents. A small negative sequence voltage may produce currents in the windings considerably in excess of those present under balanced voltage conditions. Consequently, the temperature rise of the motor operating at a particular load and percentage voltage imbalance will be greater than for the motor operating under the same conditions with balanced voltages.

1. Scope

This report is applicable to the effects of unbalanced voltages on the performance of three-phase cage induction motors.

2. Effects of unbalanced voltages on performance

The effects of unbalanced voltages on motor performance are as follows:

a) *Currents:* The currents at normal operating speed will be greatly unbalanced to the order of approximately six to ten times the voltage imbalance.

The locked-rotor currents will be unbalanced to the same degree that the voltages are unbalanced, but the locked-rotor apparent power will increase only slightly.

b) *Torques:* The locked-rotor, pull-up and breakdown torques are decreased when the voltages are unbalanced. If the voltage imbalance should be extremely severe, the torques might not be adequate for the application.

c) *Full-load speed:* The full-load speed is reduced slightly when the motor operates with unbalanced voltages.

d) *Noise and vibration:* Noise and vibration may increase with an increase in voltage (and current) imbalance. The vibration could be detrimental to the motor or to the entire drive system.

3. Calculation of percentage imbalance

The percentage voltage imbalance can easily be determined by a motor user from the voltage readings of the three phases. It is calculated by the following formula:

$$\text{Percentage voltage imbalance} = \frac{\text{maximum voltage deviation from average voltage}}{\text{average voltage}} \times 100$$

Example: With voltages of 220 V, 215 V and 210 V, the average voltage is 215 V, and the maximum voltage deviation from the average is 5 V. Therefore:

$$\text{Percentage voltage imbalance} = \frac{5}{215} \times 100 = 2.3\,\%$$

The true negative sequence voltage component may be up to 18% higher than the value obtained from the formula.

The above formula is given for the convenience of the motor user, and is only an approximation of the per cent negative sequence voltage component. A more accurate determination can be made with the aid of symmetrical components.

For voltage imbalances over 5% a study of the negative sequence component of the currents is necessary.

4. Derating of motor to prevent overheating

Voltages should preferably be virtually balanced. See Sub-clause 12.2.1 of IEC Publication 34-1: Rotating Electrical Machines, Part 1: Rating and Performance. In some applications a greater imbalance than that permitted by IEC Publication 34-1 may be unavoidable, and some derating of the motor might be necessary to reduce the possibility of damage from overheating.

Note. – Derating might not be necessary when a motor is designed to operate (under rated conditions) at temperatures lower than those in accordance with IEC Publication 34-1.

Typical values of derating of Design N, three-phase cage induction motors (see IEC Publication 34-12: Rotating Electrical Machines, Part 12: Starting Performance of Single-speed Three-phase Cage Induction Motors for Voltages up to and including 660 V), are shown in Figure 1, page 9. For other design types and for rated outputs larger than 630 kW, the derating curve may be different and the manufacturer should be consulted or operating temperature measurements should be examined.

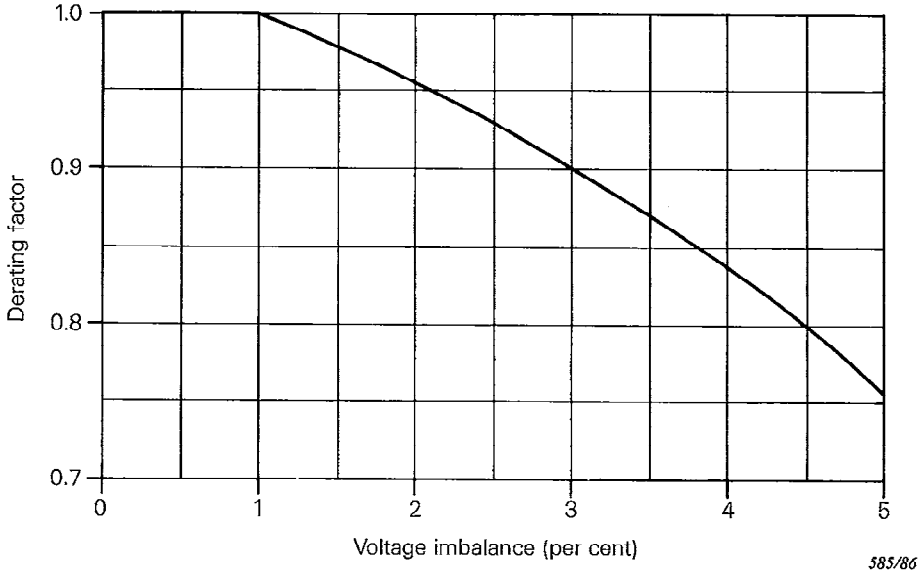

FIG. 1. – Typical derating factor due to unbalanced voltages.

5. Overload protection devices for derated motors

Where a motor is derated for operation on unbalanced voltages, the selection and setting of the overload protection device should take into account the combination of the derating factor applied to the motor and the increase in current resulting from the unbalanced voltages. This is a complex problem involving the variation in motor current as a function of load and voltage imbalance, in addition to the characteristics of the overload protection device relative to maximum current or average current.

In the absence of specific information, it is recommended that overload protection devices be selected and/or adjusted at the minimum value that does not result in tripping for the derating factor and voltage imbalance that applies.

Where unbalanced voltages are likely, it is recommended that the user install overload protection devices that are responsive to *maximum* current rather than *average* current.

Publications de la CEI préparées par le Comité d'Etudes n° 2

34: – Machines électriques tournantes.

34-1 (1983)	Première partie: Caractéristiques assignées et caractéristiques de fonctionnement. Modification n° 1 (1987).
34-2 (1972)	Deuxième partie: Méthodes pour la détermination des pertes et du rendement des machines électriques tournantes à partir d'essais (à l'exclusion des machines pour véhicules de traction).
34-2A (1974)	Premier complément: Mesure des pertes par la méthode calorimétrique.
34-3 (1968)	Troisième partie: Valeurs nominales et caractéristiques des turbo-machines triphasées à 50 Hz.
34-4 (1985)	Quatrième partie: Méthodes pour la détermination à partir d'essais des grandeurs des machines synchrones.
34-5 (1981)	Cinquième partie: Classification des degrés de protection procurés par les enveloppes des machines tournantes.
34-6 (1969)	Sixième partie: Modes de refroidissements des machines tournantes.
34-7 (1972)	Septième partie: Symboles pour les formes de construction et les dispositions de montage des machines électriques tournantes.
34-8 (1972)	Huitième partie: Marques d'extrémités et sens de rotation des machines tournantes.
34-9 (1972)	Neuvième partie: Limites du bruit.
34-10 (1975)	Dixième partie: Conventions relatives à la description des machines synchrones.
34-11 (1978)	Onzième partie: Protection thermique incorporée. Chapitre 1: Règles concernant la protection des machines électriques tournantes.
34-11-2 (1984)	Chapitre 2: Détecteurs thermiques et auxiliaires de commande utilisés dans les dispositifs de protection thermique.
34-11-3 (1984)	Chapitre 3: Règles générales concernant les protecteurs thermiques utilisés dans les dispositifs de protection thermique.
34-12 (1980)	Douzième partie: Caractéristiques de démarrage des moteurs triphasés à induction à cage à une seule vitesse pour des tensions d'alimentation inférieures ou égales à 660 V.
34-13 (1980)	Treizième partie: Spécification pour les moteurs auxiliaires pour laminoirs.
34-14 (1982)	Quatorzième partie: Vibrations mécaniques de certaines machines de hauteur d'axe supérieure ou égale à 56 mm – Mesurage, évaluation et limites de l'intensité vibratoire.
72 (1971)	Dimensions et puissances normales des machines électriques tournantes – Désignation des carcasses entre 56 et 400 et des brides entre FF55 et FF1080 et entre FT55 et FT1080. Modification n° 1 (1977). Modification n° 2 (1981).
72A(1970)	Dimensions et puissances normales des machines électriques tournantes à fixation par pattes, désignation des carcasses entre 355 et 1000.
136 (1985)	Dimensions des balais et porte-balais pour machines électriques.
276 (1968)	Definitions et nomenclature des balais de charbon, des porte-balais, des collecteurs et des bagues.
279 (1969)	Mesure de la résistance des enroulements d'une machine à courant alternatif en fonctionnement sous tension alternative.
356 (1971)	Dimensions des collecteurs et des bagues.
413 (1972)	Méthodes d'essai pour la mesure des propriétés physiques des matières de balais pour machines électriques.

(Suite au verso)

IEC publications prepared by Technical Committee No. 2

34: – Rotating electrical machines.

34-1 (1983)	Part 1: Rating and performance. Amendment No. 1 (1987).
34-2 (1972)	Part 2: Methods for determining losses and efficiency of rotating electrical machinery from tests (excluding machines for traction vehicles).
34-2A (1974)	First supplement: Measurement of losses by the calorimetric method.
34-3 (1968)	Part 3: Ratings and characteristics of three-phase, 50 Hz turbine-type machines.
34-4 (1985)	Part 4: Methods for determining synchronous machine quantities from tests.
34-5 (1981)	Part 5: Classification of degrees of protection provided by enclosures for rotating machines.
34-6 (1969)	Part 6: Methods of cooling rotating machinery.
34-7 (1972)	Part 7: Symbols for types of construction and mounting arrangements of rotating electrical machinery.
34-8 (1972)	Part 8: Terminal markings and direction of rotation of rotating machines.
34-9 (1972)	Part 9: Noise limits.
34-10 (1975)	Part 10: Conventions for description of synchronous machines.
34-11 (1978)	Part 11: Built-in thermal protection. Chapter 1: Rules for protection of rotating electrical machines.
34-11-2 (1984)	Chapter 2: Thermal detectors and control units used in thermal protection systems.
34-11-3 (1984)	Chapter 3: General rules for thermal protectors used in thermal protection systems.
34-12 (1980)	Part 12: Starting performance of single-speed three-phase cage induction motors for voltages up to and including 660 V.
34-13 (1980)	Part 13: Specification for mill auxiliary motors.
34-14 (1982)	Part 14: Mechanical vibration of certain machines with shaft heights 56 mm and higher – Measurement, evaluation and limits of the vibration severity.
72 (1971)	Dimensions and output ratings for rotating electrical machines – Frame numbers 56 to 400 and flange numbers FF55 to FF1080 and FT55 to FT1080. Amendment No. 1 (1977). Amendment No. 2 (1981).
72A(1970)	Dimensions and output ratings for foot-mounted electrical machines with frame numbers 355 to 1000.
136 (1985)	Dimensions of brushes and brush-holders for electrical machinery.
276 (1968)	Definitions and nomenclature for carbon brushes, brush-holders, commutators and slip-rings.
279 (1969)	Measurement of the winding resistance of an a.c. machine during operation at alternating voltage.
356 (1971)	Dimensions for commutators and slip-rings.
413 (1972)	Test procedures for determining physical properties of brush materials for electrical machines.

(Continued overleaf)

Publications de la CEI préparées par le Comité d'Etudes n° 2 *(suite)*

467 (1974) Méthodes d'essai pour la mesure des propriétés physiques des balais de charbon pour machines électriques.

560 (1977) Définitions et terminologie des porte-balais de machines électriques.

681: – Dimensions des moteurs de faible puissance pour applications particulières.

681-1 (1980) Première partie: Moteurs pour brûleurs à mazout.

773 (1983) Méthodes d'essai et appareils pour la mesure des propriétés opérationnelles des balais.

778 (1984) Porte-balais pour bagues groupe R – exécution RA.

892 (1987) Effets d'un système de tensions déséquilibré sur les caractéristiques de fonctionnement des moteurs asynchrones triphasés à cage.

IEC publications prepared by Technical Committee No. 2 *(continued)*

467 (1974) Test procedures for determining physical properties of carbon brushes for electrical machines.

560 (1977) Definitions and terminology of brush-holders for electrical machines.

681: – Dimensions of small power motors for definite purpose application.

681-1 (1980) Part 1: Oil burner motors.

773 (1983) Test methods and apparatus for the measurement of the operational characteristics of brushes.

778 (1984) Brush-holders for slip-rings group R – type RA.

892 (1987) Effects of unbalanced voltages on the performance of three-phase cage induction motors.

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