Philosophy of quality systems and testing of electrical machines

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SECTION 1


The quality of a product is the main consideration when making a purchase. It may be a consumer durable, an industrial product or a professional service. The quality of a product also means a reasonable cost-efficient after sales service and a consumer-friendly attitude on the part of the producer. Farsighted societies and organizations, that conceived such a philosophy long ago evolved methods to practice this meticulously and consistently. This has helped them upgrade their own methods and technologies to excel in their fields, and today they are ahead of their competitors. They recognized the disadvantages of poor quality as long ago as in 1911, as mentioned in F.W. Taylor’s book Principles of Scientific Management. Taylor laid great emphasis on inspection methods and quality control and his philosophy gained wide acceptance at the time.

It must be emphasized that a method leading to final inspection or testing of a product only when it has been manufactured is a shortsighted approach and cannot guarantee total quality requirements. This method fails to guard against improper use of inputs, inadequate product design or lack of process control etc., that may appear only after the product is put to use. An inadequate size or quality of a bolt, incorrect tightening, or any other inconsistency in quality, for instance, may not be detected during brief inspections, but may appear during use. Moreover, inspection alone cannot identify problems that may occur as a result of defective packing (the packer might damage the product while nailing the packing), poor storage (inconsistent storage facility, water seepage, rodents or any substances that may damage, rust or corrode the product), and damage during transportation.

Products for critical duties such as for defence, aviation, space or transport will need much more than a mere final inspection. Such applications can ill afford to be left to chance and this is true even with products for household and daily use. To ensure proper quality of product at every stage, therefore, it is imperative to introduce quality systems from planning to various manufacturing activities. A good quality system would identify areas such as packaging, storage and transportation methods and set norms to guarantee safe delivery of the product up to its destination.

Quality is thus a part of an organization’s policy and objectives, and is applicable to those who wish to achieve product excellence, through self-discipline and quality assurance activities. It aims at

- Better product reliability
- More customer confidence by relieving him from constant checks to ensure the required quality and timely delivery, particularly for custom-built and engineering products. In a third party order, the quality systems would also help fulfil the customer’s own contractual obligations to his client.
- Improving company’s image and goodwill.
- Enhancing competitiveness and acceptability in national and international markets, where many other brands may already be available.
- Reducing wastage and rework.
- Improving productivity, etc.

For a nation to produce a good quality product and meet the stringent quality expectations of the market, it is mandatory to meet such requirements. Quality has assumed greater significance in the changed world scenario, with the emergence of the WTO (World Trade Organization) formerly GATT (General Agreement on Tariffs and Trade), which means greater competition at the international level. Through quality, one can build international markets for products, in addition to local markets, not only to improve an image but also to serve the economy of the nation by earning foreign exchange. The Quality Systems may be applied to all activities, as noted later, that together produce a product or service.

Making of the quality systems

To put these philosophies into practice, many countries have framed guidelines and standards. The earliest standard was issued in 1959 by the US Department of Defense for large contracts (MIL-Q 9858, ‘Quality programme requirements’).

The long interval between Taylor’s description of Quality Management in 1911 until 1959, when the US Defense Department laid down its quality requirements for the first time, was perhaps due to an increase in global interest that developed only in the late 1950s. Since then, there has been a continuous application of these standards to contractors and manufacturers worldwide.

For civilian use in the United States, ANSI/ASQC, Standard C and Z1.15 were published in 1968. Since then, many countries and large organizations have been publishing their own quality control systems. For civilian reference, ‘A Guide to Quality Assurance’ was first published in 1972 (BS 4891). This was soon replaced by BS 5179, ‘Guide to Operation and Evaluation of Quality Assurance Systems’. This was upgraded by BS 5750 in six parts. To ensure consistency in all Standards and to make them universal a technical committee, TC 176, of the International Standards Organization (ISO), Switzerland, was entrusted with the task of drawing up such a set of standards. By 1994 they had introduced the following standards:

ISO 8402 – Quality Vocabulary.
ISO 9001 – Model for Quality Assurance in Design or
Development, Production, Installation and Servicing.
Applicable to those who design, produce, instal and service their products or carry out such activities.

ISO 9002 – Model for Quality Assurance in production, installation and servicing.
Applicable to those who make their products on the basis of some proven designs, or work as ancillaries for standard products.

ISO 9003 – Model for Quality Assurance in Final Inspection and Test. Applicable to those who are engaged in third-party inspection and testing.

ISO 9004 – Quality Management and Quality System (1,2,3&4) Elements – Guidelines.
Applicable to quality assurance for services, such as hotels and hospitals etc.

All these Standards have since been adopted by the member countries as their national Standards, fully or in slightly modified forms, to suit their own requirements and working conditions. These Standards define and clarify the quality norms and aim at in-house quality disciplines, to automatically and continually produce a product, provide a service or programme to the stipulated specifications, quality norms and customer needs. They guarantee a product or service with a minimum quality. The envisaged quality systems thus aim at a work culture that pervades all those involved in different key activities or processes, to achieve the desired goal through carefully evolved systems. The basic philosophy is ‘Do what you write and write what you do.’

Quality systems

These deal broadly with the quality concepts as applied to a product or services, such as design, programming or a process etc., practised by an organization, through better communication and understanding. They can be achieved through

• Quality assurance schemes, and
• Quality check systems

The above are implemented through Quality Management (QM).

Quality Management stresses participation by all involved in the work system, and their commitment to follow the systems meticulously and consistently.

There is a need for interaction and assessment of different activities or processes to overcome any shortcomings by improving or readjusting the system of working, operation or controls, to achieve a better work culture and an understanding and respect for all in the system. When followed, this will result in the following:

• Better work processes
• Better production control
• Timely remedial action to achieve the set goals of quality and productivity.
• Reviewing and implementing the changing needs of the product in the face of tougher competition or changed market conditions.

To draft quality systems and to adhere to such disciplines

This is a work culture, to be inculcated into the whole work-force and which must percolate from top management to the shop-floor. The systems must be effective, well communicated, understood thoroughly and adhered to strictly. The mode of system will largely depend upon the type of industry or services. Generally, the systems are based on a commonsense technique, to achieve the desired objectives, by dividing the total process related to designing, production, programming and other functions into many different key activities, identifying the likely areas or processes where the work process may deviate from the set parameters or where it can be further improved. All such key activities must be properly defined, documented, authorized and effectively enforced.

The human element, seen in errors, ignorance, lack of training, lethargy, illiteracy or indiscipline, or indifference, must be monitored carefully. This may require either an adequately qualified and experienced faculty or proper job training. Indifference, for reasons other than the above, would be a matter of human resource development (HRD), where a worker’s skills and habits may have to be adapted to fit into the system.

Ingredients of quality systems for a manufacturing unit

• Define the organizational structure
• Define the responsibilities
• Vendor selection and development, for the inputs that go into the production of the items
• Checks and controls over the inputs
• Product design
• Process, planning and development
• Stage inspection, checks and controls, tests and a feedback system for corrective measures. The system must help to identify the potential quality areas
• Records
• Documentation
• Packaging
• Storage
• Transportation
• Receipt at site and
• Installation and operation.

This is only a broad outline for formulating a system. Procedures not applicable may be deleted and those not covered and are considered necessary may be included in the above list.

Infrastructure facilities

To implement the above, the basic facilities that must be available are:

• Human resources and specialized skills
• Facility for training
• Design facilities and engineering back-up
• Manufacturing facilities
• Testing and quality check equipment
• Any other facility considered necessary to implement the quality systems in full.

**Emphasis**

Modern management systems stress the need for continuous monitoring of defined systems and procedures for enforcement and improvement of quality systems. These should minimize immediately and eliminate ultimately the recurrence of similar problems through preventive measures.

**Auditing (a monitoring tool)**

As emphasized above, full monitoring of the proper implementation of quality activities is essential. To achieve this, a periodic audit and review of the working of the system is an essential element in any Quality Management System. Shortcomings, if detected, must be corrected as soon as possible and prevented in the future. Documented reviews help in maintaining and improving management systems and techniques and ensure continuity and future references.

**Economics**

This is an extremely important aspect of the whole exercise. The basic purpose of all checks and controls is to reduce reworking, reprocessing, failures or rejections during the work process with a view to produce a product of the required quality and hence minimize cost for better financial returns. A high-cost input not commensurate with the type of the product may defeat the basic purpose of adopting such a system.

**Product performance and feedback**

This is essential to improve the product by upgrading the quality or modifying its design or other parameters that may make it more acceptable and competitive in the market. This is possible by creating a user-friendly approach to obtain reactions to the product’s performance.

**Customer quality checks**

For the customer to ascertain the capability of a producer to deliver goods or services to the required Standards it is essential for the producer to have all documents that establish his or her competence to deliver the goods or services, according to the prescribed Quality Standards. These documents may cover

- Adequacy of the Quality Systems supported through Quality Assurance Plans (QAPs), in design, process, installation and servicing
- Capability to achieve the required quality, supported by quality manuals
- Control over-procurement of raw material and components that compose inputs
- In-house checks of various activities
- In-house final inspection and testing.

All the above documents may then be compiled and sent to prospective customers for comments. Any suggestions may be incorporated into the original documents to further improve in-house working. These documents will define the quality objectives of the producing company.

**Guidelines to deviations**

Sometimes a compromise in the quality of the inputs (perhaps due to non-availability of a particular component to the required specification) may be necessary to avoid a production delay. Similar constraints in the design or process may also make it necessary to have a deviation in design, without undermining the quality requirements. The ISO emphasizes that, for such deviations, written authorization from a competent authority, and preferably also the written consent of the customer, is essential before implementing such a change. This will be for a specific period and for a specific number of items.

**Accreditation by ISO**

So far the ISO has provided the necessary guidelines for quality systems, as noted above, and which a producer can adopt in a way that may suit best a product and process line. The rest is left to the government of a country to appoint their own accrediting bodies for certification of producers. These agencies are then authorized to monitor, perform surveillance audits and issue certificates to organizations, who wish to obtain these certificates and conform to the predefined requirements of these Standards. However, if a product is for global sales, another certification by a government body of that country may also be necessary, resulting in a multiplicity of certifications which, besides being cumbersome, may also become time consuming. It is therefore relevant that the accrediting be necessarily, carried out at one point only by a central agency on behalf of ISO, and recognized by all member countries. Several of these bodies are now operating in various countries to recommend and certify producers.

**Total Quality Management (TQM)**

The above are broad guidelines along which producers can formulate a quality system to suit their needs. There are no hard and fast rules for disciplines and systems – these arise from experience and continuous practice. They must, however, be made more effective so that they inculcate respect and confidence in all, to adopt and follow them. No system, however good, can be imposed on anyone, unless they are willing to understand, accept and respect it. This may require an appropriate training programme which may also be made a part of the work system. The overall aim of the above exercise is to achieve ‘Total Customer Satisfaction’ through ‘Total Quality Management’ (TQM). Similar to a SCADA system (Section 24.11) as applied to the working and process activities of an organization in manufacturing or services. Total Quality Management is a comprehensive term for integrated activities that are put into practice, with care and development of human resources, to provide complete
satisfaction for a customer. It is a goal to be pursued with commitment and perseverance.

In this era of globalization, anyone who wishes to remain in the race and to excel must make TQM an ultimate objective and remember that ‘the pursuit to excellence is a never-ending journey’.


The river of time is ever flowing. TIME is a measure of change. Every passing moment in terms of products or services is related to surrounding environment and specific demands of end users of commodities at that period of time. Like TIME these DEMANDS too are ever changing. With rising acceptability of open market conditions (globalization), a need was felt to harmonize the earlier ISO Standards ISO-9000 (1994)-(9001, 2, 3, 4) into an integrated single Standard, adequate to address quality, environment, value for money and human resource requirements of an organization producing goods and services to customer’s fullest satisfaction. To accomplish the task of integration and modification of old Standards, technical committee of ISO (TC 176) was yet again assigned the task of preparing new Standards.

ISO-9000 (1994) had 20 elements addressing various activities in an organization requiring generation of different activities and maintenance of relevant documents and records. Table 11.0(1) gives the twenty essential elements of 1994 Standards.

Difficulties in interpreting ISO-9000 (1994)

Difficulties were experienced by the producers of goods and service agencies in interpreting some of these clauses.

<table>
<thead>
<tr>
<th>Clause</th>
<th>Element</th>
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<tbody>
<tr>
<td>4.1</td>
<td>Management Responsibility</td>
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<tr>
<td>4.2</td>
<td>Quality System Manual</td>
</tr>
<tr>
<td>4.3</td>
<td>Contract Review</td>
</tr>
<tr>
<td>4.4</td>
<td>Design Control</td>
</tr>
<tr>
<td>4.5</td>
<td>Document &amp; Data Control</td>
</tr>
<tr>
<td>4.6</td>
<td>Purchasing</td>
</tr>
<tr>
<td>4.7</td>
<td>Customer Supplied Products</td>
</tr>
<tr>
<td>4.8</td>
<td>Product Identification &amp; Traceability</td>
</tr>
<tr>
<td>4.9</td>
<td>Control of Production</td>
</tr>
<tr>
<td>4.10</td>
<td>Inspection and Testing</td>
</tr>
<tr>
<td>4.11</td>
<td>Inspection, Measuring &amp; Test Equipment</td>
</tr>
<tr>
<td>4.12</td>
<td>Inspection and Test Status</td>
</tr>
<tr>
<td>4.13</td>
<td>Control of Non-conforming Products</td>
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<tr>
<td>4.14</td>
<td>Corrective and Preventive Action</td>
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<tr>
<td>4.15</td>
<td>Handling, Storage, Packaging, Preservation &amp; Delivery</td>
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<td>4.16</td>
<td>Quality Records</td>
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<td>4.17</td>
<td>Internal Audits</td>
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<td>4.18</td>
<td>Training</td>
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<tr>
<td>4.19</td>
<td>After Sales-Service</td>
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<tr>
<td>4.20</td>
<td>Statistical Techniques</td>
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</table>

Prominent of them were Clauses 4.2, 4.4, 4.9, 4.14, and 4.20. Activities like only trading, testing, servicing, consultancy and other small activities created a lot of confusion in proper understanding of the application of these clauses. Technical Committee (TC 176) of ISO was also assigned the task to impart clarity and transparency to such anomalies.

The draft prepared by TC 176 was circulated to member countries and deliberated exhaustively. The result was a new document — ISO-9001 (2000). This was issued on 15 Dec. 2000 to all member countries. Transition time of three years was given to all organizations having ISO-9000 (1994) certification to switch over to ISO-9001 (2000) by Dec. 2003. All new organizations seeking ISO certification are now required to comply with ISO-9001 (2000)*.

The new Standard has suggested the following changes
- Facilitate integration into one management system
- Address continuous improvement
- Use a process model approach to quality management
- Improve compatibility with other management system Standards
- Address customer satisfaction more strongly
- Make the Standards more business orientated

This resulted in,
- Reduced number of clauses in the new Standard (Table 11.0(3))
- Explicit requirement for achieving customer satisfaction and continual improvement based on managing organizational processes
- Easier to use by business houses and service organizations
- Built on FIVE universal quality management principles as described in Table 11.0(3)
- Possibility of going beyond certification to achieving satisfaction, not just by customers but all concerned parties, shareholders and society as a whole

Thrust of new Standard

It lays greater emphasis on organizational performance by adopting to Process Approach rather than mere conformance to clauses of Standards. The revised Standards are noted in column 2 of Table 11.0(2) and focus on,
- Customer
- People
- Process Approach
- Factual Approach to Decision Making
- Continual Improvement and
- System Approach

Process approach

A strategy to continually improve the organizational

* Those desirous of acquiring ISO 9001 certification can approach accreditation agencies authorized for this purpose and operating in various countries. A brief list is provided in Table 11.10.
or service activity involving number of inputs and outputs and where control is essential at every stage to maintain high integrity of the process with optimum output and quality.

Continuous monitoring, corrective actions and process upgradation are mandatory activities to achieve an overall improvement in the process and the end results. A simple and logical Process Approach model is drawn in Figure 11.0(1). This can be suitably modified by an organization to better suit their process needs and specific control points.

These Standards are like an orifice to TQM and provide guidelines to quality seekers. One can adapt and expand them to fit into his system. The purpose is to achieve excellence through discipline, dedication and prudent management control in every activity and every field to result in a satisfactory organizational performance and to accomplish the set goals.

Factual approach to decision making

New Standard also lays emphasis on generation of data in each field of activity with basic aim at improving quality, health of organization and presentation. Data generated are studied and analysed and used as a guiding tool to control and minimize deviations if any and improve the process for efficient working and better results. More meticulous, prudent and accurate the data are, the better control and output results are. Thus for continuous progress and pursuit to excellence factual approach is a must. This is why Information Technology is a buzzword in today’s scenario of globalization.

FIVE main clauses

For a quick reference for the readers, Table 11.0(3)
provides the FIVE main clauses of ISO-9001 (2000). Introducing of these clauses (practices) in an organization is the first step towards TQM. This Standard is applicable to all organizations seeking ISO certification. An organization can also call for exemption with justification, to some of these clauses that are not relevant to them.

**Continual improvement**

Continual improvement is a very important feature of new Standards and is achieved by embracing P (Plan)-D(Do)-C(Check)-A(Act) process model more effectively by practising improved actions based on generation and analysis of data. To make monitoring of continuous growth/improvement requirement effective, new Standards require organizations to fix Measurable Growth Parameters and then monitor them for action and achievement of growth targets.

ISO-9001 (2000) implements PDCA process management cycle as under

Plan – Clause 5– Management Responsibility

Everything flows from management who defines the requirements for the system.

Do – Clause 7– Product Realization

Necessary processes are established, controlled and carried out.

Check – Clause 8– Measurement, Analysis and Improvement

The process results shall be measured, analyzed and opportunities for improvement identified.

Act – Clause 9– Measurement, Analysis and Improvement

Acting upon data identified in the check cycle, the suggestions for improvement can be implemented as per defined methodology.

**System approach**

Figure 11.0(2) illustrates a quality management system approach to improvement and growth.
Future trends in quality management

Environment and energy conservation are the needs of the hour and concerned countries of the world are working relentlessly to save environment and energy. A brief introduction to these aspects is provided at the Preface to the present edition of the book and Section 1.19. These countries have also promulgated statutory eco-norms for the awareness and practising of the same by industries and individuals. Other aspects of congenial working can be industrial safety, reducing noise pollution and saving on space, etc. It is advisable, that all industries at least those practising quality management systems may take note of these aspects and initiate to make them part of their quality systems. Presently if not mandatory, it is obligatory on part of all concerned to exercise such disciplines for the welfare of mankind and future generations. While modalities in this regard may be in the making by ISO, it is suggestive that organizations may take care of these disciplines right from now before they become a part of the future ISO requirements. Surely, those with foresight and initiative shall stand ahead of others.

SECTION 2

11.2 Testing of electrical machines

This section covers only those tests that are essential on a completed motor, irrespective of the manufacturing procedure and stage quality checks. If ISO 9001 guidelines are assimilated, practised and enforced by a manufacturer so that a customer’s trust is obtained, a final pre-despatch inspection by the customer may not be necessary. The customer, having gained confidence in the practices and Quality Assurance Systems of the manufacturer, may issue an authorization to the manufacturer to dispatch the material under their ‘own inspection certificate’, rather than an inspection by the customer. We discuss below the test requirements, procedure and the acceptance norms prescribed by various national and international Standards for such machines and adopted by various manufacturers.

To fulfil total quality requirements noted above the material inputs for the motor-stampings, steel, enamelled copper wire, insulations and varnishes, bearings, enclosure materials and hardware must be subjected to a series of acceptance tests according to norms and standard specifications. For example, enamelled copper wire used for windings must undergo tests at the initial inspection stage before use. Accordingly stage inspections must be carried out during processing of the various motor input components. Figure 11.1 identifies vital parts of a motor and the corresponding specification Standards, on which these components can be checked and tested. Instruments and gauges used for inspection must be periodically calibrated and checked for dimensional accuracy.

Purpose of testing

The purpose of testing an electrical motor is to ensure its compliance with the norms of design, material inputs and manufacturing accuracy. It determines the mechanical soundness and electrical fitness of the machine for its electrical and mechanical performance. Such tests determine the following:

1. Mechanical aspects: vibration and noise level.
2. Electrical aspects: guaranteed output and performance.
3 Temperature rise at the guaranteed output to ascertain the adequacy of the insulating material and life of the motor. If the temperature rise is more than permissible for the type of insulation used, it will deteriorate the insulating properties and cause thermal ageing. As a rule of thumb, a temperature rise of 10% more than the rated may reduce the life of the insulation by 40–50%. See Section 9.2 for more details.

4 Torque characteristics, i.e. starting torque, pull-out torque and pull-in torque, in the entire speed range to ensure that the motor will develop adequate torque at all speeds to meet the load requirement. See Section 2.5 for more details.

On an assembled motor the following visual checks are performed before it is run:

1 That all the covers and canopies are fitted in their correct locations.
2 Special-purpose motors such as increased safety motors, flame-proof or explosion-proof motors must be checked for gaps, clearances and creepage distances of all the mating parts forming flame paths. The construction of these motors must follow IEC 60079 as noted in the list of Standards (see also Section 7.11).
3 The terminal box for its correct position.
4 The terminal box for proper connections, number of terminals and their markings.
5 The correct direction of rotation of the cooling fans.
6 The heaters and thermistors when provided.
7 The clearance and creepage distances between the terminals and between each terminal and the ground.

On a wound rotor motor, the following additional checks are also necessary after removing the slip-ring covers, prior to testing:

1 The numbers, size and grade of the brushes and whether the brushes are bedded properly to the contours of the slip-rings.
2 Whether the brushes are free to move in the brush holder and are not slack.
3 The brush spring tension. Brush pressure, when measured, using finger spring balance, should be between 150 and 200 N/cm².
4 Whether the brushes are set concentrically on the slip-rings, and each individual brush holder is set approximately 2–2.5 mm from the slip-ring surface. Slip-rings must be concentric and free from damage and blow holes.

After the above checks the motor can be subjected to type and routine tests. For testing instruments, the following class and grades are recommended.

Figure 11.1 IS specifications for various parts as used in an electric motor
11.2.1 Electrical measurements

Selection of testing instruments

The indicating instruments used for electrical measurements must conform to IEC 60051 and have the following accuracies:

- For routine tests: class 1.0 or better, and
- For type tests: not inferior to class 0.5.

The current transformers and voltage transformers, when used, must conform to IEC 60044, as noted in the list of Standards. Instrument transformers with the following accuracies must be used:

- For routine tests: Class 1 accuracy
- For type tests: Class 0.5 accuracy

Quality of test power supply

- Voltage
  The voltage must approach a sinusoidal waveform and should be balanced. If at the time of conducting the tests the voltage is almost but not completely balanced, arithmetical average of the phase voltage must be used for calculating the machine’s performance.

Note
1 The voltage is considered to be virtually sinusoidal if none of the instantaneous values of the wave differ from the instantaneous value of the same phase of the fundamental wave by more than 5% of the amplitude of the latter (IEC 60034-1).
2 A system of three-phase voltage is considered to be virtually balanced if none of the negative sequence components exceeds 1% over long periods or 1.5% for short periods of a few minutes and zero sequence components exceed 1% of the positive sequence components (IEC 60034-1). See also Section 12.2.

- Current
  The line current in each phase of the motor should be measured. If the line current is not exactly equal in all phases, the arithmetical average of the phase current must be used for calculating the machine’s performance.

- Power
  Power input to a three-phase machine may be measured by two single-phase wattmeters, connected as in the two-wattmeter method (Section 11.4.3). Alternatively a single poly-phase wattmeter may be used. Power analyser is the best alternative.

- Frequency
  The frequency should be maintained as close to the rated frequency as possible. Any departure from the rated frequency will affect the losses and the efficiency as shown in Section 1.6.2.

11.2.2 Type tests

Type tests are conducted on the first machine of each type or design to determine the characteristics and demonstrate its compliance with the relevant Standards. These tests provide a standard reference for any subsequent similar machine. The following type tests can be conducted,

1. Resistance measurement of all windings and auxiliary devices (heaters and thermistors, etc.), when the machine is cold (at room temperature)
2. (i) Temperature rise test at full load
   (ii) Resistance measurement of all the windings and temperature measurement by thermometer when the machine temperature is stabilized.
3. Load test
4. Overspeed test
5. Speed–torque and speed–current curves usually for small motors due to limitation of dynamometer.
6. Vibration measurements and noise level tests to determine the machine’s mechanical performance
7. Verification of dielectric properties. Poor insulation causes leakage current leading to shock, fire and failure of the machine and hence the importance of this test
   (i) On the completed machine with wound coils or formed coils: power frequency voltage withstand or HV test
   (ii) Process tests during the manufacture of formed coils
      (a) Test for insulation resistance – discussed in Section 9.5.3
      (b) Test for dielectric loss factor or dissipation factor tan δ for rated voltages 5 kV and above
      (c) Test for impulse voltage withstand for rated voltages 3.3 kV and above.

Note
1 The impulse voltage test is meant specifically for formed coils only. It serves no purpose for a wound machine (VPI) (Section 9.3.2), which is already impregnated and cured as a whole mass.
2 The tests for insulation resistance and dielectric loss factor should, however, be carried out on a completed machine also with formed coils to establish reference data for field tests, as noted in Section 9.6. However, these tests on a completed machine with formed coils do not monitor the process quality of insulation.

8. No-load test
9. Locked rotor test
10. Measurement of starting torque, pull-out torque and pull-in torque for small motors as noted above
11. Open-circuit voltage ratio test for slip-ring motors
12. Verification of degree of protection.

11.2.3 Routine tests

Routine tests are conducted on subsequent similar machines. The purpose of a routine test is to ascertain that the machine is assembled correctly and will be able to withstand the appropriate high-voltage test, and will be in sound working condition, both electrically and mechanically. As a minimum requirement these tests will consist of:

1. Resistance measurement at room temperature
2. No-load test
3. Verification of dielectric properties
4. Insulation resistance test
5. Measurement of open-circuit rotor volts for slip-ring motors
6. Locked rotor test
11.2.4 Seismic disturbances

We provide a brief account of such disturbances in Section 14.6. This also deals with the recommended tests and their procedures to verify the suitability of critical structures, equipment and devices for locations that are prone to such disturbances. Large machines are usually verified by analysis.

11.2.5 EMC (immunity) and EMI (emission) tests [for details see Section 23.18 and 14.3.13]

Similar guidelines will apply as for switchgear and controlgear assemblies (Section 14.3.13). Accordingly, no test is applicable for machines not incorporating any electrical or electronic circuit that is susceptible to EM interferences. Large motors or critical motors, however, fitted with devices like PTC thermistors, temperature sensors, vibration probes, pulse transmitters, tacho-generator (TG) or other electronic circuits and synchronous motors, generators and d.c. motors incorporating electronic field excitation system (Section 16.3.4) may be influenced by EM interferences and all such circuits must be tested for EM compatibility (immunity). For details see IEC 60034-1 and the Standards mentioned in Section 14.3.13.

11.3 Procedure for testing

In the following we describe a brief procedure to conduct various tests and measurements and computation of the test results according to IEC 60034-1. (For more details of the testing procedure the reader should refer to the Standard.)

11.3.1 Resistance measurement

At the beginning of the test the motor must be at ambient temperature. In this condition the temperature and resistance of the windings should be recorded accurately. These values will be used later, with other test results, to evaluate the temperature rise and efficiency.

Many types of winding connections are used, depending upon the type of machine and the application for which it is designed. The basic star and delta connections are most common, but a combination of these two with parallel circuits is also used, on multi-speed and dual-voltage motors, as discussed in Section 6.1. The connection diagram of the motor, showing the connections of the windings and the terminal arrangement, should also be checked for correctness of the connections. Resistance across the line terminals of the windings should be measured, except for a star-connected motor, where phase resistance is measured.

Typical connections are shown in Figure 11.2, where

\[ R_1 = \frac{e}{2i} \Omega, \text{ in star-connected windings, and} \]

\[ R_1 = \frac{3}{2} \times \frac{e}{i} \Omega \text{ in delta-connected windings.} \]

The following two methods are commonly used for measurement of winding resistance.

The drop of potential method or voltmeter-ammeter method

In this method simultaneous readings of voltage at motor terminals and current are taken while using a d.c. source of supply and the resistance of the windings is calculated. Current must be restricted to 10% of the rated current of the windings. Errors introduced into the measurement, by the resistance of leads and contacts must be compensated.

The bridge method

Here, the unknown resistance is compared with a known resistance using a suitable bridge. Resistance above 1 \( \Omega \) can be measured by Wheatstone bridge. Resistance less than 1 \( \Omega \) can be measured by a Kelvin double bridge, where the lead resistance must also be compensated.

All precautions must be taken to obtain the temperatures of the windings when measuring cold resistance. These temperatures, when measuring the cold resistance, may be obtained by a thermometer placed in contact with the windings or by resistance temperature detectors, if they are provided in the windings. The temperature of the surrounding air will not be regarded as the temperature of the windings, unless the motor has been idle for a long period under similar atmospheric temperature condition. If the resistance of a copper conductor is known at one temperature, it may be calculated for any other temperature by using the following formula:

\[ R_1' = \frac{(235 + t_2)}{(235 + t_1)} \cdot R_1 \]

where

- \( R_1 \) = resistance measured at \( t_1 {}^\circ C \), and
- \( R_1' \) = resistance at \( t_2 {}^\circ C \)

If \( R_1, R_1' \) and \( t_1 \) are known, \( t_2 \) can be calculated.

In slip-ring motors the rotor winding resistance will be measured at the point of connection of the rotor winding to the slip-rings, so that the slip-ring resistance is eliminated from the measurement of the true rotor winding resistance.

11.3.2 Temperature rise test

This test is intended to determine the temperature rise in different parts of the motor windings while running at
rated conditions and the permissible temperature rise limits are specified in Table 11.1. While preparing for the temperature rise test the motor should be shielded from currents of air coming from adjacent pulleys, belts and other components to avoid inaccurate results. Sufficient floor space should be left between the machines to allow for free circulation of air. In normal conditions, a distance of 2 m is sufficient. The duration of the temperature rise test is dependent on the type and rating of the motor. For motors with continuous rating, the test should be continued until thermal equilibrium has reached. Whenever possible, the temperature should be measured both while running and after the shutdown.

While conducting the test the negative sequence voltage should be less than 0.5% of the positive sequence component. In terms of current, the negative sequence current should not exceed 2.5% of the positive sequence component of the system current. Measurement of any one of the components will be adequate.

For continuously rated machines, readings should be taken at intervals of one hour or less. For non-continuously rated machines, readings should be taken at intervals consistent with the time rating of the machine. The temperature rise test should continue until there is a variation of 1°C or less between the two consecutive measurements of temperature.

For motors with a short-time rating, the duration of the test should correspond to the specified short-time rating. At the end of the test the specified temperature rise limits should not exceed. At the beginning of the test, the temperature of the motor should be within 5°C of that of the cooling air.

In motors for periodic duty, the test should be continued until thermal equilibrium has been reached. Unless otherwise agreed, the duration of one cycle should be 10 minutes for the purpose of this test. Temperature measurements should be made at the end of a cycle to establish thermal equilibrium.

**Measurement of temperature**

When thermal equilibrium is reached, the motor must be stopped as quickly as possible. Measurements must be taken both while the motor was running and after shutdown (wherever possible). No corrections for observed temperatures are necessary if the stopping period does not exceed the values given in Table 11.2.

Where successive measurements show increasing temperatures after the shutdown, the highest value must be taken. When the rotor temperature is also required it must be measured by recording the highest temperature recorded in the thermometers placed on the rotor bars and core, in squirrel cage motors, and on collector rings in wound rotor motors. A thermometer should be inserted as soon as the rotating parts come to rest.

Where the temperature can be measured only after the motor has stopped (as in temperature measurement by the resistance method), a cooling curve is plotted, by determining the test points as rapidly as possible. Extrapolation of the cooling curve is carried out to determine the temperature at the instant of shutdown. This may be achieved by plotting a curve with temperature/resistance readings as ordinates and time as the abscissa using semi-logarithmic graph for the resistance and a logarithmic scale for the time. This curve can be plotted on semi-logarithmic graph paper similar to that shown in Figure 9.5(b) to obtain a straight-line plot of resistance versus time to help the correct extrapolation. The following are the recommended methods to determine the temperature rise:

1. Resistance method – this is the most preferred method for motors up to 5000 kW.
2. Embedded temperature detector (ETD) method – this method is used for stator windings of 5000 kW and above as in IEC 60034-1.

**Notes**

1. For motors 201–5000 kW – both the resistance or the ETD method may be used.
2. Thermometer method – this is recommended only when both resistance and ETD methods are not practicable.

### Table 11.1 Permissible temperature rise for naturally (indirectly) cooled motors

<table>
<thead>
<tr>
<th>Method of measurement</th>
<th>Insulation class</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Resistance</td>
<td>60</td>
</tr>
<tr>
<td>ETD</td>
<td>65</td>
</tr>
</tbody>
</table>

*On the basis of IEC 60034-1*

*a* – ≤ 5000 kW

*b* – ≥ 5000 kW

*Notes*

1. The temperature rise limits are based above an ambient temperature of 40°C. For temperatures other than 40°C see Section 1.6.2(C).
2. For exact details refer to IEC 60034-1.
3. For other types of cooling methods refer to IEC 60034-1.
4. Insulations class A and E are no longer practised but are retained for historical significance.
Table 11.2  Permissible stopping period of the motor after shutdown when it will require no temperature correction

<table>
<thead>
<tr>
<th>Power Range (kW)</th>
<th>Stopping Period (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–50</td>
<td>30</td>
</tr>
<tr>
<td>51–200</td>
<td>90</td>
</tr>
<tr>
<td>201–5000</td>
<td>120</td>
</tr>
<tr>
<td>Beyond 5000</td>
<td>By agreement</td>
</tr>
</tbody>
</table>

According to IEC 60034-1

Resistance method

This is the preferred method. The temperature of the winding is determined by observing the increase in resistance of the winding with respect to the cold resistance measured.

The resistance must be measured with extreme care and accuracy, since a small error in measuring the resistance will cause a much larger error in determining the temperature rise. When the temperature of the winding is to be determined by the resistance, the temperature of the winding before the test, measured either by thermometer or by ETD, may be considered as the cold temperature for the resistance measured. The machine must be left cold for at least 12 to 24 hours, depending upon the size of the machine, to obtain a stable reading.

For copper windings, the temperature rise \( t_2 - t_a \) may be obtained from the ratio of the resistance by

\[
\frac{R_2}{R_1} = \frac{235 + t_2}{235 + t_1}
\]

where

- \( t_a \) = temperature (°C) of cooling air or gas at the end of the test
- \( t_2 \) = temperature (°C) of the winding at the end of the test
- \( R_2 \) = resistance of the winding at the end of the test
- \( t_1 \) = temperature (°C) of the winding (cold) at the moment of the initial resistance measurement and
- \( R_1 \) = initial resistance of the winding (cold)

ETD method

Embedded temperature detectors are resistance temperature detectors (RTDs) or resistance thermometers or thermocouples, built within the machine during manufacture at points that are not accessible when the machine has been assembled. This method is generally employed for the likely hot spots of a machine such as the slot portion and the overhangs of the stator windings.

At least six detectors are built within the machine, suitably distributed around the circumference and placed between the layers along the length of the core where the highest temperature is likely to occur. Each detector is installed in intimate contact with the surface, whose temperature is to be measured and in such a way that the detector is effectively protected from contact with the cooling air. A detector embedded beneath the winding layer inside the slot is of little consequence for it will detect the temperature of the core and not of the winding. The location of the detectors must be as follows:

- For two coil sides per slot: When the winding has two coil sides per slot, each detector must be located between the insulated coil sides within the slot (see Figure 12.42).
- For more than two coil sides per slot: When the winding has more than two coil sides per slot, each detector must be located in a position between the insulated coil sides at which the highest temperature is likely to occur.
- Since overhangs are vulnerable parts of a stator winding, detectors can also be placed within them (Figure 12.39).

Note

The embedded temperature detector method is inappropriate for stator windings, which have only one coil side per slot, in such cases the resistance method must be used with the same limits of temperature rise. For checking the temperature of such a winding in service, an embedded detector at the bottom of the slot is of little use because it would give mainly the temperature of the iron core. A detector placed between the coil and the wedge will follow the temperature of the winding much more closely and is, therefore, better for check tests, although the temperature there may also be a little less than the actual one.

Thermometer method

This method is applicable where neither the embedded temperature detector nor the resistance method is possible. The thermometer method is also recognized in the following cases:

- When it is not practical to determine the temperature rise by the resistance method, as in the case of low resistance windings, especially when the resistance of joints and connections form a considerable percentage of the total resistance,
- Single-layer windings, revolving or stationary and
- When, for reasons of mass production, the thermometer method alone is used, although the resistance method would be possible.

In this method, the temperature is determined by thermometers applied to the accessible surfaces of the windings of the motor (see also Figure 10.10). The term ‘thermometer’ may include mercury or alcohol bulb thermometers as well as embedded thermocouples and resistance thermometers, provided the latter are applied to points accessible to the usual bulb thermometer also.

When bulb thermometers are employed where there is a likelihood of a magnetic field, alcohol thermometers should be preferred to mercury thermometers, as the latter are unreliable under such conditions.

Measurement of cooling air or gas temperature during test

The cooling air temperature should be measured by several thermometers placed at different points around and halfway up the motor, at a distance of 1–2 m and protected from heat radiation and draughts. The value to be adopted for the temperature of the cooling air or gas during a test should be the mean of the readings of the thermometers placed as mentioned above, taken at equal time intervals during the last quarter of the duration of the test.

In order to avoid error, due to time lag in the temperature measurement of large motors and variation
in the cooling air or gas temperature all reasonable precautions must be taken to reduce these variations and errors as much as possible.

In cooling by means of forced ventilation, or where the machine has water-cooled air or gas coolers, the temperature of the air or gas, where it enters the motor must be considered as the cooling air or gas temperature. For motors fitted with heat exchangers the temperature reading of incoming air or gas or water should also be taken.

**Cooling air temperature**

The motor may be tested at any convenient value of cooling medium temperature less than 40°C. But whatever the value of this cooling-medium temperature, the permissible rise of temperature during test should not exceed those shown in Table 11.1.

In motors intended to operate under conditions in which the maximum cooling air temperature may exceed 40°C, the temperature rise as given in the relevant specification must be reduced as follows:

- By 5°C if the temperature of the cooling air exceeds 40°C by 5°C or less
- By 10°C if the temperature of the cooling air exceeds 40°C by more than 5°C but not more than 10°C and
- By agreement if the temperature of the cooling air is more than 10°C above 40°C.

**Temperature rise of bearings**

The temperature rise of bearings may be measured as follows:

- For sliding contact bearings (sleeve or thrust bearings) the temperature readings must be taken from as near to the bearing surface as possible.
- For ball and roller type bearings the temperature readings must be taken at the stationary race.
- For oil lubricants it is customary to measure the temperature in the oil reservoir.
- In forced lubricating systems, incoming and outgoing temperature readings may be taken.

**Note**

1. The permissible temperature rise of the bearings will depend upon the type of lubricant used and the recommendations made by the lubricant and bearing manufacturers.
2. It may not be possible to measure the temperature rise of the bearings at the races in all cases. In such a case, it may be permissible to measure the temperature for ball and roller type bearings at the stationary race or at the bearing cover.

**Temperature correction**

1. For motors specified for operation at an altitude higher than 1000 m, but not in excess of 4000 m, the correction may be made as shown in Table 1.8.
2. A temperature rise test may be carried out at any convenient cooling air temperature. When the temperature of the cooling air during the test is lower than the stated site cooling air temperature by less than 30°C, no correction should be made on account of such a difference. When the temperature of the cooling air is lower by more than 30°C, the permissible temperature rise on test should be the permissible temperature rise under specified site conditions, reduced by a percentage numerically equal to one-third of the difference between the specified temperature of the cooling air at site and the temperature of cooling air on test, where both temperatures are expressed in degrees Celsius.

**Example 11.1**

If the specified temperature of the cooling air at site is 48°C and the temperature of the cooling air during test is 17°C (a difference of more than 30°C), the reduction in temperature rise to take account of this difference will be:

\[
\frac{48 - 17}{3} = 10.3
\]

The permissible temperature rise on test will therefore be 100 – 10.3% = 89.7% of the recommended temperature rise. These reductions apply to all the classes of insulation as indicated in Table 11.1 and the test is to be carried out at the manufacturer's works.

**11.4 Load test**

Tests on load are conducted to determine the performance of the machine, such as its efficiency, power factor, speed and temperature rise etc. For all tests, a machine with load should be properly aligned and securely fastened. Load characteristics are obtained by taking readings at high loads, followed by reading at lower loads. This is usually carried out at 125%, 100%, 75%, 50% and 25% of the full load values.

**Methods of loading**

1. **Brake and pulley method** (usually for very small motors). Considerable care needs be taken in the construction and use of the brake and pulley. When conducting this test conditions should be such that a scale pointer remains practically stationary at any given load. Proper cooling, preferably water cooling, should be provided for the pulley.
2. **Dynamometer method** (for medium-sized motors, say up to 500 h.p.). The output of an induction motor may be calculated by

\[
P_T = \frac{T_r \cdot N_r}{974} \text{ kW} \tag{1.8}
\]

3. **Calibrated machine**. When brake and pulley or dynamometer methods are not possible, the test motor may be loaded onto a calibrated generator. The efficiency curve of the generator must be available.

When it is not possible to conduct any of the above three methods, the test motor may be loaded onto an un-calibrated generator or any other loading device.

**11.4.1 To determine efficiency**

**By the input–output method**

As noted above, efficiency may be determined by adopting any of the following three methods:
• Brake and pulley
• Dynamometer and
• Calibrated machine.

By summation of losses

Calculation of efficiency is based on the readings obtained after the heat run test when the machine has achieved thermal stability. The losses will fall into following five groups:

1. Friction and windage loss (obtained from the no-load test (Figure 11.6))
2. Core loss (hysteresis and eddy current loss) (obtained from the no-load test (Figure 11.6))
3. Stator copper loss (primary loss)
4. Rotor copper loss (secondary loss)
5. Stray loss

The procedure to be followed is as follows:

• From the resistance measured across the stator line terminals at the conclusion of the no-load test, calculate the stator winding resistance $R_1$.
• Calculate the no-load stator copper loss: $i_1^2 \cdot R_1$ watts.
• Subtract the no-load stator copper loss from the stator input power $P_n$ at no-load, i.e. $(P_n - i_2^2 \cdot R_1)$. This is the net no-load loss made up of core, friction, windage and stray losses.
• Calculate the total stator winding resistance:
  
  $$R_{1\text{hot}} = 1.5 \times (1.5 \text{ for } 
  \Delta \text{-connected, and } 0.5 \text{ for } Y \text{-connected windings, Figure 11.2}) \times \text{cold values of the resistance, measured across the stator line terminals, corrected to the required temperature.}$$

  The required temperature values may be:
  
  For class A 75°C
  For class E 90°C
  For class B 95°C
  For class F 115°C
  For class H 130°C

• Calculate the stator copper loss on load: $I_2^2 \cdot R_{1\text{hot}}$.
• Add the net no-load loss and stator copper loss on load and subtract their sum from the stator input power measured on load. The remainder is the power input to the rotor.
• Calculate the rotor copper loss (input to the rotor $\times$ percentage slip on load).
• Subtract this rotor copper loss from the rotor input.
• Subtract the stray loss to give the motor output for nominal full load. The amount of stray loss is normally taken as 0.5% of the nominal power output of the machine. But in view of higher harmonics in the supply system because of large static power loads some manufacturers and consultants may consider this up to 1%. The stray losses at other values of loads are obtained from:

  $$(\text{required stator current})^2 \times \text{stray loss at full load}$$

  After deducting the stray loss, the resultant kW gives the machine output, i.e.

• Efficiency, $\eta = \frac{\text{kW output}}{\text{kW input}} \times 100\%$

  As a check, add together the net no-load loss, the stator copper loss on load, the rotor copper loss on load and stray loss to give the total losses (total fixed loss plus load loss) then

  $$\text{Efficiency, } \eta = \left(1 - \frac{\text{total kW losses}}{\text{kW input}} \right) \times 100\% - 0.5$$

  The two must tally.

IEEE-112 method B for efficiency calculation

As noted in Section 19.1, to comply with the EPACT (Energy Policy Act), energy saving is foremost, and hence the necessity of accurately determining the efficiency of a machine, to correctly compare the efficiencies of two similar machines of different manufacturers or even the same manufacturer. It is important to identify the better machine of the two. A small error in efficiency will mean a lot while assessing the energy saving in the long term and so also the payback period.

The input-output method noted above has been the most commonly used method presuming a certain percentage of stray losses. This assumption surely leaves scope for an error. The measurement of test quantities like speed, torque, voltage, current, wattage and temperature etc. may also introduce some error if precision instruments are not employed. IEEE method B suggests a more precise method of determining the efficiency of a machine. It stresses on employing precision measuring instruments at the first instance and then actually determining the stray load loss by separation of losses method, rather than assuming the same. For details consult the said Standard.

Note

The efficiency derived above is valid when the supply condition is sinusoidal. With the use of static drives this condition is disturbed because of harmonics that are now introduced on the output side of the inverter feeding the motor. The above efficiency calculations would now need a correction to account for additional stator and rotor copper losses ($FR$ losses) and iron losses caused by inverter harmonics. Either the test be now conducted with the drive connected or some margin be added in the estimated losses to account for this. For details see IEC 60034-2 or IEEE-112.

11.4.2 Slip measurement

For the range of load for which the efficiency is determined, the measurement of slip is very important. To determine slip by subtracting from the synchronous speed the value of speed, obtained through a tachometer is not recommended. The slip must be directly measured by one of the following methods:

1. Stroboscopic
2. Slip-coil
3. Magnetic needle
4. Any other suitable method.

Methods (2) and (3) are suitable for machines having slip of not more than 5%.
Stroboscopic method

On one end of the motor shaft a single black radial line is painted upon a white background. The slip is easily measured by counting the apparent backward rotations of the black line over a given period of time.

Slip-coil method

A suitable slip-coil, having approximately 700 turns of 1 mm diameter insulated wire, is passed axially over the motor and its two ends are connected to a centre-zero galvanometer. When the motor is running, the galvanometer pointer will oscillate. The number of oscillations should be counted in one direction only, that is to the left or to the right, for a period of, say, 20 seconds.

The following formula will determine the percentage slip:

\[ S = \frac{n \times 100}{t \cdot f} \%
\]

where

- \( S \) = slip (%)
- \( n \) = number of oscillations
- \( t \) = time in seconds taken for \( n \) oscillations, and
- \( f \) = supply frequency in Hz.

Magnetic needle method

In this method a magnetic needle suspended on a sharp point (so that it can rotate freely) is placed on the body of the motor in the horizontal plane. The needle will oscillate and the number of oscillations should be counted for a period of, say, 20 seconds. The percentage slip is then calculated by the formula given above.

11.4.3 Power Factor measurement

The Power Factor may be measured by one of the following three methods:

- Watt to volt-ampere ratio
- Two-wattmeter
- Power Factor meter

Watt to volt-ampere ratio method

The Power Factor is obtained by the ratio of the algebraic sum of wattmeter readings to volt-ampere readings. For a three-phase system:

\[ \text{Power Factor} = \frac{\text{Watts}}{\sqrt{3} \times \text{line volts} \times \text{line amperes}} \]

Two-wattmeter method

On a three-phase motor where the load is pulsating the Power Factor may be checked by the following formula, obtained from independent wattmeter readings:

\[ \text{Power Factor} = \frac{1}{1 + 3 \left( \frac{W_2 - W_1}{W_1 + W_2} \right)^2} \]

where

- \( W_1 \) = the higher of the two readings, and
- \( W_2 \) = the lower of the two readings.

If \( W_2 \) gives a negative reading it should be considered as a minus quantity. From the above formula, graphs can be plotted for Power Factor versus \( \frac{W_2}{W_1} \), \( W_2/W_1 \) being the ratio of lower wattmeter reading to the higher wattmeter reading.

If \( W_2 \) is negative, the ratio of \( \frac{W_2}{W_1} \) should be considered as a minus quantity. The falling curves should be designated ‘for \( \frac{W_2}{W_1} \)’ and the rising curves ‘for \( \frac{W_2}{W_1} \)’. Similarly, ordinates on the left-hand side should be designated for \( \frac{W_1}{W_2} \) and on the right-hand side for \( \frac{W_1}{W_2} \). See Figure 11.3.

Note

If two values of the Power Factor determined by the watt to volt-ampere ratio and two-wattmeter methods do not tally for a three-
phase motor, the test may be repeated to eliminate the error. However, where the load is fluctuating, a Power Factor determined by a two-wattmeter method will be higher than that determined by the watt to volt-ampere ratio method. In this case, the higher value should be taken as the correct reading. The difference is due to the inclusion of a pulsating component of current in volt-amperes, which is a function of load rather than of the motor itself. The Power Factor determined from the ratio of wattmeter reading is not affected by the presence of a pulsating current.

**Power Factor meter method**

In this method, a Power Factor meter is directly connected in the circuit and a direct reading is obtained at any loading.

**11.4.4 Overspeed test**

All motors are designed to withstand 1.2 times the maximum rated speed. The test is simple and may be carried out by running the motor for 2 minutes at the higher speed. After the test, the motor must have no deformation or any fault that may prevent it from operating normally.

**11.4.5 Test for speed–torque and speed–current curves**

The speed–torque characteristic is the relationship between the torque and the speed, in the range from zero to synchronous speed. This relationship, when expressed as a curve, will include breakdown torque (pull-out torque), pull-up torque and starting torque. The speed–current characteristic is the relationship of the current to the speed.

**Methods**

Speed–torque and speed–current tests may be carried out by the following methods:

- Dynamometer
- Pony brake
- Rope and pulley
- Calibrated machine.

Readings of voltage, current and speed should be taken. The torque value is obtained directly by the dynamometer, pony brake and rope and pulley methods and indirectly by the calibrated machine method. Speed–torque and speed–current tests must be conducted at a rated voltage or as near to this as practical. When it is necessary to establish values of current and torque at the rated voltage, based on tests made at reduced voltage, the current may increase by a ratio higher than the first power of the voltage and the torque by a ratio higher than the square of the voltage due to possible saturation of flux leakage paths. See also Figure 27.2(b) and note under serial number 9 Section 7.19 for more clarity. This relationship varies with the design and, as a first approximation, is sometimes taken as the current varying directly with voltage and torque with the square of the voltage.

It is therefore necessary to take precautions during the test to avoid an excessive temperature rise and consequent damage to the windings. For wound rotor motors, speed–torque and speed–current tests may be taken between synchronous speed and the speed at which the maximum torque occurs.

**Pull-up torque**

The motor should be mounted with a suitable loading arrangement and the rotor fully locked. The rated voltage at the rated frequency will then be applied to the motor terminals in the locked rotor condition. The loading on the motor will then be reduced slowly so that the motor can start and pick-up speed. The value of pull-up torque at which the rotor picks up speed and attains speed corresponding to pull-out torque condition must be noted.

**Pull-out torque**

The motor should be mounted with a suitable loading arrangement. The rated voltage, at the rated frequency, is then applied to the motor terminals at the no-load condition. The load on the motor may then be gradually increased, and the maximum load at which the motor stalls noted. The torque determined at this point is the pull-out torque.

**Note**

1. The motor should be immediately disconnected from the supply when it stalls.
2. The motor should not be kept in the locked rotor condition for more than a few seconds to avoid damage to the windings.

**11.4.6 Vibration measurement test**

The vibration limits have been classified into two groups:

1. For shaft heights 56 mm and above, IEC 60034-14 has prescribed three categories of vibration levels in terms of vibration velocity, one for normal use, \( N \), and the other two for precision applications, i.e. reduced level \( R \) and special-purpose \( S \). When required other than normal, these must be specified by the user to the manufacturer. Machines with a higher degree of balance should be used only when this is essential. Such machines may be far too expensive to produce, and sometimes not commensurate with the application.

2. For shaft heights more than 400 mm, IEC 60034-14 prescribes the vibration level, in terms of double amplitude vibration, which can also be derived from the velocity of vibration, using the following formula:

\[
a = 0.45 \times \frac{V_{r.m.s.}}{f}
\]

where

- \( a \) = double amplitude of vibration displacement, peak to peak (mm)
- \( V_{r.m.s.} \) = r.m.s. value of velocity of vibration (mm/s)
- \( f \) = frequency of vibration, which is approximately equal to the supply frequency in Hz.

Both these levels are indicated in Table 11.3. For more details and for conducting the vibration test, reference may be made to IEC 60034-14.

**11.4.7 Measurement of noise level**

When measuring the noise level, i.e. the limiting mean sound power level in dB for airborne noise emitted by a machine, reference may be made to the following IEC and ISO publications:

- **IEC 60034-9** – For recommended values of noise limits
Philosophy of quality systems and testing of electrical machines

A decibel (dB) is the unit of sound power level and is derived from the unit of sound measurement (‘bel’), so called after the American inventor Alexander Graham Bell and

\[ 1 \text{ dB} = \frac{1}{10} \text{ bel} \]


**ISO 3740**, Acoustics – Determination of sound power levels of noise sources – Guidelines for the use of basic standards and for the preparation of noise test codes.

### Table 11.3  Limits of vibration levels when measured in a state of free suspension

<table>
<thead>
<tr>
<th>Vibration grade(a)</th>
<th>Speed (N_s) (r.p.m.)</th>
<th>Maximum r.m.s. value of the vibration velocity (mm/s) for shaft height (H) (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(56 \leq H \leq 132)</td>
<td>(132 &lt; H \leq 225)</td>
</tr>
<tr>
<td>(N)</td>
<td>&gt; 600 \leq 3600</td>
<td>1.8</td>
</tr>
<tr>
<td>(R)</td>
<td>&gt; 600 \leq 1800</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>&gt; 1800 \leq 3600</td>
<td>1.12</td>
</tr>
<tr>
<td>(S)</td>
<td>&gt; 600 \leq 1800</td>
<td>0.45</td>
</tr>
<tr>
<td></td>
<td>&gt; 1800 \leq 3600</td>
<td>0.71</td>
</tr>
</tbody>
</table>

*Based on IEC 60034-14/1996*

\(a\)Vibration grade signifies the accuracy of rotor balancing, e.g. \(N\) = normal, \(R\) = reduced, \(S\) = special. This may be based on the type of installation and the accuracy of the function the motor may have to perform.

\(b\)For both 50 or 60 Hz systems.

**Note**

1. The level of vibration at site may be higher than that mentioned above, perhaps due to the foundation or the coupling of the load. This must be checked and adequate precautions taken to avoid excessive vibrations.
2. IEC 60034-14/1996 is now replaced by IEC 60034-14/2003. But we have retained the earlier one for general reference. For revised acceptance tests one may see the new standard that is now based on combination of displacement, velocity and acceleration rather than velocity alone.

in dB. A decibel (dB) is the unit of sound power level and is derived from the unit of sound measurement (‘bel’), so called after the American inventor Alexander Graham Bell and

\[ 1 \text{ dB} = \frac{1}{10} \text{ bel} \]

11.4.8 Verification of dielectric properties

#### Power frequency withstand or HV test

This test is conducted only when it has been determined that the insulation resistance, measured as noted in Section 9.5.3 is acceptable. The test should be performed immediately after the temperature-rise test on those occasions when the latter test is also to be carried out.

This test reveals any weakness of the insulation or insufficient clearance between coils or between winding and core. It consists of the application of a high voltage, as shown in Table 11.4, between the windings and the frame (or cores).

Windings that are not under test and all other metal parts must be connected to the frame during the test. The windings under test should be completely assembled. The

<table>
<thead>
<tr>
<th>Motor size and rating</th>
<th>Test voltage (r.m.s.)</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Stator windings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(i) LV motors &lt; 1 kW and rated voltage (V_i) &lt; 100 V</td>
<td>500 V + 2(V_i)</td>
<td>(a) For 220 V motors, the test voltage (= 1000 + 2 \times 220), i.e. minimum 1500 V</td>
</tr>
<tr>
<td>(ii) All sizes and ratings of motors</td>
<td>1000 V + 2(V_i) (minimum 1500 V)</td>
<td>(b) For 11 kV motors, the test voltage (= 1 + 2 \times 11 = 23) kV.</td>
</tr>
</tbody>
</table>

| 2 Rotor windings (for wound motors)        |                       |         |
| (i) Non-reversing motors                   | 1000 V + 2 RV         | RV = rated open circuit standstill voltage across the slip-rings |
| (ii) Motors suitable for reversing duty or braking during running by reversing the I/C supply | 1000 V + 4 RV         |         |

| 3 If high-voltage test needs be repeated at site during commissioning | At 80% of the above | |

| 4 Completely rewound windings             | Full test voltage as for S Nos 1 and 2 | |
| 5 Partially rewound windings             | 75% of the test voltage as for S Nos 1 and 2 | |
| 6 Overhauled machines                     | 1.5\(V_i\) minimum being 1000 V | |

*Based on IEC 60034-1*
test voltage should be of power frequency and as near to the sine waveform as possible. Component parts, such as space heaters, thermostats and resistance temperature detectors, which are connected to parts other than the power line, must be tested at twice their rated voltage, plus 1000 volts, with all other windings and components connected together and then connected to the frame (core). Insulation breakdown during the application of a high voltage should be considered as a dielectric failure. The test should commence at a voltage not more than one-half of the full test voltage. The voltage should be increased to the full value in not less than 10 seconds and this voltage will then be maintained for one minute. At the end of this period, the test voltage will be rapidly diminished to one-third of its value before switching off.

The test voltages for wound rotors, reversing and brake motors are also indicated in Table 11.4. Repetition of this test is not recommended to avoid excessive stresses on the insulation. However, when this becomes necessary such as at site before commissioning, the test voltage must be limited to only 80% of the actual test voltage. After the test, the insulation resistance must be checked again, to make sure that no damage has been caused to the windings.

**Dielectric loss factor or dissipation factor \( \tan \delta \)**

This is a test to monitor the quality and dielectric behaviour of the insulating system of high-voltage machines, 5 kV and above and ratings 1000 h.p. and above, during the course of manufacture of resin-rich formed coils. For details on \( \tan \delta \), see Section 9.6.1 and Figures 9.7 and 9.8. This is mainly an in-house stage inspection for such coils. It is conducted on each individual coil, during the course of manufacture, to check for adequate insulation impregnation and quality of insulation, before insertion into the stator slots. The same process would apply to the rotor slots of a wound rotor when the rotor open circuit voltage is a minimum of 5 kV, which is rare. This is commonly known as the dielectric loss factor or dissipation factor of a motor winding coil and is the basic measure of the condition of the insulation to ground. It also gives an idea of ageing or the general condition of the insulation. With the help of this data, the processing quality of the insulation of the coils can be easily monitored as well as the condition of the insulation between the conductor laminations, the inter-turn insulation and the insulation of the end windings (over-hangs) etc. This factor is also useful in determining the insulation condition of each slot of the stator or the rotor.

To carry out this test on a wound machine (post-impregnated) would be pointless as the quality of the insulation of such coils cannot be altered after they have been inserted into the slots. However, the test is carried out on a completed identical machine to establish reference data for field tests. Random sample testing is, however, possible with two identical coils placed in the slots. The test sample of slots can also be made. For more details see Section 9.6 and IEC 60894.

**Method of measurement and acceptance norms**

A Schering bridge* or an equivalent type of bridge is used to determine the values of loss factors \( \tan \delta \) and \( \Delta \tan \delta \), i.e. the increase in \( \tan \delta \) values with the voltage. A graph is then plotted between the behaviour of \( \tan \delta \) with the applied voltage as shown in Figure 9.8. This graph also provides basic reference data for field checks before the motor is energized.

The loss tangent should be measured on the samples at room temperature at voltages varying from 20% to 100% of the rated voltage at intervals of 20%. The initial value of \( \tan \delta_{0.6V_r} \) and the increment \( \Delta \tan \delta \), i.e. \( \frac{1}{2} (\tan \delta_{0.6V_r} - \tan \delta_{0.2V_r}) \) per measuring step should not exceed the values indicated in Table 11.5 for the rated voltages up to 11 kV.

It can be seen that up to 1.1 times the rated voltage \( (V_r) \), the \( \tan \delta \) value remains almost constant, and at 1.2\( V_r \) it increases slightly. At higher voltages it increases sharply, and may become too high to cause a discharge sufficient to char the insulation if this voltage is allowed to exist for a longer period.

**11.4.9 Impulse voltage withstand test of the insulation system for rated voltages 3.3 kV and above for machines wound with formed coils**

As discussed in Section 17.5 a machine may be subjected to voltage surges due to external causes (lightning) or internal causes (switching). By the power frequency HV test or the dissipation factor, as in Section 11.4.8, or insulation resistance tests as Section 9.5.3, the surge withstand level of the insulating system cannot be determined. Hence, the need for an additional impulse

---

*The basic principle of these methods is to charge a capacitor up to the specified test voltage and then discharge it through the coil under test.

<table>
<thead>
<tr>
<th>( \tan \delta_{0.2V_r} )</th>
<th>( \frac{1}{2} (\tan \delta_{0.6V_r} - \tan \delta_{0.2V_r}) )</th>
<th>( (\Delta \tan \delta ) per step of 0.2( V_r ))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>100% samples</strong></td>
<td><strong>95% samples</strong></td>
<td><strong>Remaining 5% samples</strong></td>
</tr>
<tr>
<td>( 30 \times 10^{-3} )</td>
<td>( 2.5 \times 10^{-3} )</td>
<td>( 3 \times 10^{-3} )</td>
</tr>
<tr>
<td>( 95 \times 10^{-3} )</td>
<td>( 5 \times 10^{-3} )</td>
<td>( 6 \times 10^{-3} )</td>
</tr>
</tbody>
</table>

**Note**

If more than 5% of the samples show test results in the range of columns 2 and 3, or between columns 4 and 5, the test can be regarded as satisfactory. Otherwise the test can be continued with an equal number of further samples, if necessary, even up to the total number of bars or coil sides.
voltage withstand capability test of a coil for HV systems. The increasing application of vacuum- and gas-filled (SF6) circuit breakers and contactors for switching of MV machines, has led to the need for a surge voltage withstand test on the multi-turn coils of a machine to account for the surges generated by a re-striking phenomenon, such as that caused by the closing or interrupting of contacts.

Until a few years ago, there was no widely accepted standard for a voltage endurance test of the rotating machines. Different agencies had adopted different practices on different assumptions, pending a final decision by the IEC working committee TC-2 of IEC 60034-15. The committee submitted its report in 1988 and the following test data, which are now universally adopted, are based on this report.

The impulse test by means of a directly injected steep fronted wave cannot be performed on a fully assembled machine as the bulk of the voltage, if the front of the wave is less than 1\(\mu\)s, will appear across the first few turns only. Also, in the event of a failure, the whole winding must be scrapped. The impulse test is therefore performed on completed individual resin-rich formed coils only after insertion into the slots.

The impulse test is basically an in-house coil insulation withstand test for surge voltages and forms a part of the test requirement for MV machines with resin-rich formed coils of 3.3 kV and above. Once the machine is assembled, such a test is unnecessary, as it may not be able to reveal deficiencies, if any, in the insulation of the coils deep inside the slots. Moreover, if a failure is noticed on the assembled machine, there is no option but to remove and scrap the coil.

LV motors

Since an impulse test is not conducted on a completed machine therefore no impulse test is prescribed for LV motors unlike for LV switchgear assemblies (Section 14.2). Moreover, a motor is protected naturally by the system impedances introduced through transformers, cables and switching devices that a lightning surge has to travel through before reaching the motor terminals damping its severity \(\frac{V}{T}\) – Figure 17.6 substantially.

To assign the impulse level

In Table 11.6 the values of column 2 relate to normal operating conditions. Abnormal conditions may prevail when the machine is exposed to overhead lines, the interrupting device has multiple re-strikes during a switching operation, or at locations expected to have surges higher than normal due to transferences, such as at a power generating station. For all these conditions, higher values of impulse levels, as in column 3 of Table 11.6, may be chosen or surge suppressors installed.

Test recommendations

1. The test coils should be finally processed and then embedded into the slots.
2. The number of sample coils must be two unless changed deliberately.
3. All coils that are subjected to this test must fulfill the test requirements. In the case of a failure, investigations must be carried out to establish the cause and the

<table>
<thead>
<tr>
<th>Type of impulse</th>
<th>Winding switching impulse withstand level, when subjected to switching impulses, with following wave fronts</th>
<th>Winding lightning impulse withstand level 1.2/50 (\mu)s impulse, phase to ground kV (peak)</th>
<th>Rated power frequency withstand voltage (r.m.s.) (as in Table 11.4 for stator windings) kV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nominal line voltage</strong> (V_r)</td>
<td><strong>Normal design level phase to ground kV (peak)</strong></td>
<td><strong>Special design level phase to ground kV (peak)</strong></td>
<td>3a</td>
</tr>
<tr>
<td>(kV)</td>
<td>Between 0.2 and 0.4 (\mu)s</td>
<td>0.2 (\mu)s (average value)</td>
<td></td>
</tr>
<tr>
<td>3.3</td>
<td>8.1</td>
<td>13.5</td>
<td>12</td>
</tr>
<tr>
<td>6.6</td>
<td>16.2</td>
<td>26.9</td>
<td>20</td>
</tr>
<tr>
<td>11.0</td>
<td>26.9</td>
<td>44.9</td>
<td>32</td>
</tr>
<tr>
<td>13.8</td>
<td>33.8</td>
<td>56.3</td>
<td>39</td>
</tr>
<tr>
<td>Design criteria</td>
<td>3 p.u. kV</td>
<td>5 p.u. kV</td>
<td>0.65 ((4V_r + 5)^a) kV</td>
</tr>
</tbody>
</table>

**Note**

\(V_r\) = line voltage in kV (r.m.s.)

p.u. = per unit voltage, which is the peak value of phase voltage in kV i.e. \(\sqrt{2} \cdot \frac{V_r}{\sqrt{3}}\)

\(^a\)IEC 60034-15 has prescribed an average impulse voltage, considering the average characteristics of the machine windings and the switching conditions. One may therefore decide between columns 3 and 3a, depending upon the exposure of the machine to the internal switching surges and surge protection devices if provided with the motor.

\(^b\)IEC 60034-15 recommends these values to be rounded off to the nearest whole number. The values noted above are not rounded off for more clarity.

\(^c\)See also Table 11.4.

\(^*\)For IEC 60038 new voltage systems see Introduction
same rectified before undertaking the insulating process on the next batch of coils.

**Test procedure**

1. For inter-turn insulation
   - The test should be performed by applying the voltage between the two terminals of the sample coils.
   - The inter-turn test voltage must be generated by damped oscillating discharge of capacitors or with the help of a high-voltage generator to pulse a fast-fronted damped oscillating voltage wave. In order to obtain an even distribution of the impulse between the coil turns, the front time of the first voltage peak must not be below 0.5 μs. The resultant waveform produced by the coil, is displayed on a storage oscilloscope, and can be compared with the waveform of a known good coil. Figures 11.4 and 11.5 show a clear difference in the waveforms between a good and a defective coil.
   - The voltage peaks between the terminals of the sample coils should be 50% of the value given in column 4 of Table 11.6, i.e. \( \frac{1}{2}(4V_r + 5) \) kV.

2. For main insulation (ground and inter-turn insulation withstand test)

   Any of the following methods can be adopted:

   - **Power frequency voltage test**
     - The HV test should be performed first by applying r.m.s. value \( (2V_r + 1) \) kV for one minute, as shown in Table 11.4 between coil terminals and ground. Then the applied voltage should be increased at 1 kV/s up to \( 2(2V_r + 1) \) kV, and then reduced instantly at least at 1 kV/s to zero. If there is no failure, the test will be considered as successful, fulfilling the requirement of column 4, of Table 11.6. This procedure would give a test voltage equivalent to \( 2.2 \sqrt{2} \cdot (2V_r + 1) \) kV which is even more than the values of column 4, i.e. \( > (4V_r + 5) \) kV.
     - A d.c. test is also permitted by IEC 60034-15. The d.c. voltage should be at least 1.7 times the peak of the power frequency routine test voltage, i.e. a minimum of \( 1.7 \times 2(2V_r + 1) \) kV.

   - **Impulse voltage test**
     - The full test voltage of column 4 of Table 11.6, i.e. a standard lightning impulse of \( \frac{1}{2}(2V_r + 1) \) kV, should be applied between the coil terminals and the ground. The number of impulses should be 5, unless agreed otherwise by the manufacturer and the user.

**11.4.10 Principal considerations in framing the specification for impulse voltage withstand level and underlying the test procedures**

1. When a steep fronted voltage surge occurs between one terminal of the machine and the ground the corresponding phase does not instantly (during the rise time \( t_1 \), Figure 17.3) adjust to the same potential at all the points on the curve. Hence, two types of voltages develop in the machine winding, i.e.
   - Voltage between copper and ground, which can be called the transverse voltage, and the voltage along the copper which can be called as longitudinal voltage.
   - While the transverse voltage stresses the main wall insulation, the longitudinal voltage stresses the inter-turn insulation. The bulk of the components of both kinds normally appear on the first or the entrance coil of the winding.

2. In practice, voltage surges can be of various shapes (Figure 17.2) and may even be so steep as to have a front time as low as 0.2 μs or less. For the purpose of the impulse test, however, only a standard lightning impulse, as defined by \( 1.2/50 \) (Section 17.6) can be considered.

3. The impulse level in column 4 of Table 11.6 has been so chosen that the machine winding will have a sufficiently high level of insulation to fit into the system of insulation co-ordination, as discussed in Section 17.11 and Table 11.6.

4. The test on a sample coil at 50% test voltage will indirectly represent the test on the whole machine, in that the sample coil is tested under almost the same conditions to which the whole machine would have
been subjected when applied with the full test voltage of column 4 of Table 11.6.

5 Quantum of impulse voltage. There is no agreed calculation to determine the severity of impulse that must be applied to these two sample entrance coils as this varies from one machine to another and other factors such as:
- Rise time $t_1$ (Figure 17.3) of the voltage impulse
- Length of the entrance coil, and
- Number of turns.

As discussed in Section 17.8 the bulk of the voltage of a fast-rising impulse wave applied to the whole winding will appear across the entrance turns. This may vary from 40% to 90%, depending on the steepness of the wave front. Report TC-2 of IEC 60034-15 has recommended a value of 50% as adequate to meet general requirements. However, this value may be finally decided by the manufacturer of the machine in consultation with the end user, based on the surge-generating source (interrupting device), its likely front time, the type of machine and its exposure to external surge-generating sources.

11.5 No-load test

The no-load test is a very informative method to determine the no-load current, core* and pulsation† losses, friction and windage losses, magnetizing current and the no-load power factor. The test also reveals mechanical imbalance, if any, performance of the bearings, vibration and noise level of the motor.

The motor is run on no-load at a rated frequency and voltage, until the watts input becomes constant (to ensure that the correct value of friction loss is obtained). Readings of line voltage, current, frequency and power input are taken.

The watts input is the sum of the friction and windage losses, core loss and no-load primary loss ($I_{n1}^2R_1$). The sum of friction, windage and core losses is obtained by subtracting the primary copper loss ($I_{n1}^2R_1$) at the temperature of the test from the input watts. If the values of current and power are recorded, from about 130% normal voltage downwards, and a graph of power against voltage plotted, the core loss can be separated, from friction and windage losses.

Interception with the zero voltage axis, which represents friction and windage losses, may be found by plotting a second graph with the square of the voltage as the abscissa and the watts as the ordinate (Figure 11.6).

11.5.1 Locked rotor test

This test is conducted by supplying the stator windings with the rotor in the locked condition. In slip-ring motors, the rotor windings are also short-circuited. The test is carried out to determine the soundness of the rotor in squirrel cage motors, and to measure the starting current, power factor, starting torque and impedance. It also enables us to draw a circle diagram, for single squirrel cage rotor motors and wound rotor motors. This test may be carried out at a reduced voltage that will produce the rated current of the motor. The locked rotor torque test is not to be performed on a wound rotor motor. The starting torque in a wound motor has no relevance, as it can be varied as desired. The locked rotor current test is carried out on both squirrel cage and wound rotor motors. It should be recognized that testing induction motors in the locked rotor condition involves unusual mechanical stresses and a high rate of heating. Therefore, it is necessary that:

- The direction of rotation be established prior to this test.
- The mechanical method of locking the rotors must be strong enough to prevent injury to nearby personnel or damage to equipment.
- As the windings are heated rapidly, the test voltage must be applied as quickly as possible. Care should be taken to ensure that the motor temperature does not exceed the permissible value for a given class of insulation.

The readings at any point should be taken within 6 seconds for motors of output 7.5 kW and below and 10 seconds for motors above 7.5 kW.

Measurement of starting torque, pull-out torque and pull-in torque

Any of the methods described in Section 11.4.5 may be adopted to measure the torques developed. The torque should be measured with the rotor in various positions, wherever possible. The minimum value should be taken as the starting torque. Readings of voltage, current, frequency and power input will also be taken. The starting torque and starting current may be extrapolated when the test is carried out at a reduced voltage. For extrapolation of the test results at rated voltage the test must be performed at least at three test voltages. At each test voltage, readings of voltage, current, torque, frequency

*Core loss is the magnetizing or hysteresis loss and represents the iron loss of the machine.
†Pulsation loss is the harmonic loss of the machine.
and power input must be taken. The values of starting current and starting torque may then be extrapolated from these curves. The effect of magnetic saturation is not considered in this test method.

**Alternate method**

When the locked rotor torque cannot be measured by the dynamometer or other methods it may be accurately determined as follows:

\[
\text{Torque} = \frac{974}{N_s} \times 0.9 \times (\text{input in kW} - \text{Stator } I^2 R \text{ loss})
\]

The factor 0.9 accounts for a 10% reduction in the torque as an arbitrary allowance for harmonic losses.

When the torque is determined by the above method, the voltage during the test should be so adjusted that the locked rotor current is approximately equal to the full load current. After the locked rotor test, the resistance of the stator windings should be measured and may also be considered for calculating the \( I^2 R \) losses.

**11.5.2 Open-circuit voltage ratio test for slip-ring motors**

In slip-ring motors normal voltage and frequency are applied to the stator with the connection of the rotor brush gear open-circuited. The phase voltages induced in the rotor are then measured across the slip-rings.

**11.5.3 Verification of degree of protection**

We have defined the various types of enclosures adopted by various manufacturers to suit different locations and environmental conditions in Tables 1.10 and 1.11. Here we briefly discuss methods for testing these enclosures to check their compliance with defined requirements.

These tests, however, do not cover special requirements or environmental conditions such as

- Explosive areas or
- Unusual service conditions that may cause corrosion, fungi, etc.

These requirements may require a special construction, a pressurizing arrangement or more sealings at the joints to prevent entry of dust or exit of an arc taking place inside the enclosure, or special treatment to the housing and larger clearances or creepage distances etc. For more details see Sections 7.14, 7.15, 7.16 and 7.17. Here we have limited our discussions to the testing of electrical equipment as in Tables 1.10 and 1.11. For other compliance tests, there may be an agreement between the manufacturer and the user or a third-party agency, as noted in Section 11.7, for certifying the use of equipment for hazardous areas.

**Note**

We have discussed the test procedures and tolerances in general terms. For more accurate test methods and tolerances see IEC 60529.

---

**Table 11.7 Protection against contact with live or moving parts**

<table>
<thead>
<tr>
<th>First characteristic number</th>
<th>Test requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No test is required</td>
</tr>
<tr>
<td>1</td>
<td>The test is carried out with a sphere of 50 mm diameter. The sphere should not touch live or moving parts inside the enclosure.</td>
</tr>
<tr>
<td>2</td>
<td>(a) Finger test In LV motors, a standard test finger as shown in Figure 11.7 is used, connected by an incandescent lamp to one pole of a supply of at least 40 V, the other pole of the supply being connected to the parts intended to be live in normal service. All parts must be connected electrically. The lamp should not glow when an attempt is made to touch the bare live parts or insufficiently insulated parts. Insufficiently insulated parts may be covered with a metal foil connected to those parts that are live in normal service. Conducting parts covered with varnish or enamel only or protected by oxidation or by a similar process may be considered as insufficiently insulated. In MV motors, the clearance is verified with the minimum clearance required to withstand the dielectric test as in Section 11.4.8.</td>
</tr>
<tr>
<td>3</td>
<td>(b) Sphere test The enclosure should not permit a ball of 12 mm diameter to enter the enclosure.</td>
</tr>
<tr>
<td>4</td>
<td>The test is carried out with a steel wire of 2.5 mm diameter. The wire should not go through the enclosure.</td>
</tr>
<tr>
<td>5</td>
<td>The test is carried out with a steel wire of 1 mm diameter. The wire should not go through the enclosure.</td>
</tr>
<tr>
<td>6</td>
<td>The test is similar as for number 5 but now no deposit of dust should be observed at the end of the test.</td>
</tr>
</tbody>
</table>
Table 11.8 Protection against ingress of water

<table>
<thead>
<tr>
<th>Second characteristic number</th>
<th>Test requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>No test is required</td>
</tr>
<tr>
<td>1</td>
<td>The test is carried out by the apparatus illustrated in Figure 11.9. Water is used and adjusted so that the discharge is 3 to 5 mm of water per minute. The enclosure under test is placed for 10 minutes in its normal operating position below the dripping apparatus, the base of which should be larger than the enclosure under test. After the test the amount of water which might have entered the interior of the enclosure should not interfere with satisfactory operation of the equipment. No water should accumulate near the cable gland plate or enter the cables.</td>
</tr>
<tr>
<td>2</td>
<td>The test equipment is the same as described for degree of protection 1. But the enclosure under test is tilted up to an angle of ( \pm 15^\circ ) in respect of its normal operating position successively, in two planes at right angles (to cover all four sides). The total duration of the test will be 10 minutes (2.5 minutes each side). The test results should be the same as for degree of protection 1.</td>
</tr>
<tr>
<td>3</td>
<td>The test is carried out by the apparatus illustrated in Figure 11.10(a). It consists of an oscillating tube, formed into a semi-circle, the radius of which is kept as small as possible, depending upon the dimensions of the enclosure under test, but not more than 1 m. For larger surfaces, a hand sprayer, as illustrated in Figure 11.10(b), may be used. During the test the moving shield is not removed from the spray nozzle. The water pressure is adjusted for a delivery of 10 litres/min. The test duration should be 1 minute/m² of the surface area under test, but for not less than 5 minutes. The tube is oscillated to describe an angle of 60° from the vertical in either direction. The duration of one oscillation will be about 2 seconds. The water supply should be at least 10 litres/min, at a pressure equal to a head of nearly 8 m of water (80 kN/m²). The enclosure under test is mounted in its normal position on a turntable, the axis of which will be vertical and height variable, located near the centre of the semi-circle formed by the oscillating tube. The table is rotated to spray all parts of the enclosure equally. The enclosure should be kept under a spray of water for 10 minutes. The test results should be the same as for degree of protection 1.</td>
</tr>
<tr>
<td>4</td>
<td>The test is similar to that described for degree of protection 3 except that the oscillating tube will now oscillate through an angle of almost 180° with respect to the vertical in both directions and at a speed of 90° per second. The support for the equipment under test may be grid-shaped, so that no water is accumulated at the base. The duration of the test will be 10 minutes. For larger surfaces the second method as noted in Figure 11.10(b) may be adopted but the moving shield must now be removed from the spray nozzle. The rest of the details remain the same as noted for number 3, when using a hand sprayer. The test results should be the same as for degree of protection 1.</td>
</tr>
<tr>
<td>5</td>
<td>The test is carried out by washing down the test enclosures in every direction by means of a standard hose nozzle of 6.3 mm inside diameter, as illustrated in Figure 11.11, held at 3 m from the enclosure with a water pressure equal to a head of nearly 3 m of water (= 30 kN/m²), enough to give a delivery rate of 12.5 litres/min. The duration of the test will be determined at 1 min/m² of the surface area under test, subject to a minimum of 3 minutes. The test results should be the same as for degree of protection 1.</td>
</tr>
<tr>
<td>6</td>
<td>The test procedure and test equipment is almost the same as for number 5 and generally as below: – Inside diameter of the test nozzle: 12.5 mm – Distance of the nozzle from the test enclosure: = 3 m – Water pressure: almost 10 m of water = (100 kN/m²) – The above water pressure will give a delivery rate of 100 litres/min. Test duration: at 1 min/m² of the surface area under test, subject to a minimum of 3 minutes. After the test, there will be no penetration of water inside the enclosure.</td>
</tr>
<tr>
<td>7</td>
<td>The test is carried out by completely immersing the test enclosure in water so that the head of water above the lowest portion of the enclosure is a minimum 1 m, while the highest portion is a minimum 150 mm. Duration of the test will be 30 minutes. After the test there must be no penetration of water inside the enclosure. This test may also be carried out in the following manner. The enclosure must be tested for one minute, with an inside air pressure equal to a head of about 1 m of water. No air should leak during the test. Air leakage may be detected by submerging the enclosure in water, with the just covering the enclosure.</td>
</tr>
<tr>
<td>8</td>
<td>The test procedure will depend upon the actual application.</td>
</tr>
</tbody>
</table>
Tests for the first number as in Table 1.10 and IEC 60034-5: protection against contact with live or moving parts
These tests may be carried out as shown in Table 11.7.

Tests for the second number as in Table 1.11: protection against ingress of water
These tests may be carried out as shown in Table 11.8.

11.6 Tolerances in test results
The test results so obtained will be subject to a tolerance as noted in Table 11.9, compared to data provided by the manufacturer based on their design data.

11.7 Certification of motors used in hazardous locations
Motors intended for such locations need special attention. Since such installations may be highly prone to explosion and fire hazards, third-party agencies are generally appointed by the government of a country to certify the use of particular equipment or device at such locations. These agencies, ensure that the equipment is designed and manufactured in conformity with the requirements
Table 11.9  Permissible tolerances in performance figures

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Item</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Efficiency</td>
<td>−15% of ((100 - \eta)) \quad \eta \text{ in } %</td>
</tr>
<tr>
<td></td>
<td>(a) By summation of losses:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Motors up to 50 kW</td>
<td>−10% of ((100 - \eta)) \quad \eta \text{ in } %</td>
</tr>
<tr>
<td></td>
<td>Motors above 50 kW</td>
<td>−15% of ((100 - \eta)) \quad \eta \text{ in } %</td>
</tr>
<tr>
<td></td>
<td>(b) By input–output test</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Total losses applicable to motors above 50 kW</td>
<td>+ 10% of total losses</td>
</tr>
<tr>
<td>3</td>
<td>Power Factor</td>
<td>−1/6 of ((1 - \cos \phi)). Subject to a minimum of 0.02 and maximum 0.07.</td>
</tr>
<tr>
<td>4</td>
<td>Slip at full load and at working temperature</td>
<td>± 20% of the guaranteed slip</td>
</tr>
<tr>
<td></td>
<td>(a) Machines having output 1 kW or more</td>
<td>± 30% of the guaranteed slip</td>
</tr>
<tr>
<td></td>
<td>(b) Machines having output less than 1 kW</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Breakaway starting current (for squirrel cage motors)</td>
<td>+ 20% of the guaranteed starting current (no lower limit)</td>
</tr>
<tr>
<td>6</td>
<td>Locked motor torque</td>
<td>−15% to + 25% of the guaranteed torque (+ 25% may be exceeded by agreement)</td>
</tr>
<tr>
<td>7</td>
<td>Pull-out torque</td>
<td>−10% of the guaranteed torque, except that after allowing for this tolerance, the torque will not be less than 1.6 or 1.5 times the rated torque</td>
</tr>
<tr>
<td>8</td>
<td>Pull-up (pull-in) torque</td>
<td>−15% of the guaranteed torque</td>
</tr>
<tr>
<td>9</td>
<td>Vibration</td>
<td>+10% of guaranteed classification</td>
</tr>
<tr>
<td>10</td>
<td>Noise level</td>
<td>+3 dB(A) over guaranteed value</td>
</tr>
<tr>
<td>11</td>
<td>Locked rotor current of squirrel cage motors with short-circuited rotor and with any specified starting apparatus</td>
<td>+20% of the guaranteed current (no lower limit)</td>
</tr>
<tr>
<td>12</td>
<td>Moment of inertia or stored energy constant, applicable to motors of frame sizes above 315</td>
<td>±10% of the guaranteed value</td>
</tr>
</tbody>
</table>

As in IEC 60034-1

Figure 11.9  Apparatus for the verification of protection against dripping water

Note  The support should be smaller than the equipment under test

Layer of sand and gravel to regulate flow of water, separated by metallic gauge and blotting paper.
For the second numeral | 3 | 4 |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Spraying angle $\alpha$</td>
<td>$\pm 60^\circ$</td>
<td>$\pm 180^\circ$</td>
</tr>
<tr>
<td>Surface covered $\beta$</td>
<td>$\pm 60^\circ$</td>
<td>$\pm 180^\circ$</td>
</tr>
</tbody>
</table>

As per IEC–60034–5 or 60529

**Figure 11.10(a)** Apparatus for splashing water

**Figure 11.10(b)** Hand-held sprayer
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of the relevant Standards. It is mandatory on the part of a manufacturer, supplying equipment for such locations, to first obtain certification for a product from such agencies before it can be used for such installations. These agencies undertake,

- Scrutiny of design and constructional details
- Thorough testing of the machine.

Based on their test certificates, approval certificates are issued by the relevant statutory authority of a country. A brief list of some such accrediting agencies worldwide is provided in Table 11.10 for general reference of the readers.

![Figure 11.11 Standard test nozzle for hose tests](image)

\[ D = 6.3 \text{ mm for the tests of second numeral 5} \]
\[ D = 12.3 \text{ mm for the tests of second numeral 6} \]

Table 11.10 Some accrediting agencies for certifying equipment for hazardous locations

<table>
<thead>
<tr>
<th>Agency</th>
<th>Agency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>Europe</td>
</tr>
<tr>
<td>Standards Association of Australia (SAA)</td>
<td>ÖVE (Austria)</td>
</tr>
<tr>
<td>SIMTARS – Department of Mines and Energy Test Safe</td>
<td>ISSEP (Institut Scientifique de Service Public) (Belgium)</td>
</tr>
<tr>
<td>Canadian Standards Association (CSA)</td>
<td>CEBEC (Belgium)</td>
</tr>
<tr>
<td>Wyle Laboratories</td>
<td>EZÜ (Czech Republic)</td>
</tr>
<tr>
<td>CSA International</td>
<td>DEMKO (Denmark)</td>
</tr>
<tr>
<td>UL Northbrook</td>
<td>SGS Fimko (Finland)</td>
</tr>
<tr>
<td>FM Global or Factory Mutual Research Corporation (FMRC) (More than 50 offices worldwide)</td>
<td>INERIS (National Institute for Industrial Environment and Risks) (France)</td>
</tr>
<tr>
<td>MET Laboratories, Inc.</td>
<td>LCIE (Laboratoire Central Des Industries Electriques) (France)</td>
</tr>
<tr>
<td>NRTL – Nationally Recognized Testing Laboratories</td>
<td>Underwriters Laboratories Inc. (UL) (Denmark, Germany, Italy, Netherlands, UK)</td>
</tr>
<tr>
<td>SGS U.S. Testing Company</td>
<td>PTB (Physikalisch-Technische Bundesanstalt) (Germany)</td>
</tr>
<tr>
<td>SIRA</td>
<td>TÜV Rheinland Product Safety (Germany)</td>
</tr>
<tr>
<td>Brazil</td>
<td>TÜV Product Service (Germany)</td>
</tr>
<tr>
<td>UL do Brasil Ltda.</td>
<td>VDE (Germany)</td>
</tr>
<tr>
<td>India</td>
<td>ELOT (Greece)</td>
</tr>
<tr>
<td>Central Mining Research Institute (CMRI)</td>
<td>MEEI (Hungary)</td>
</tr>
<tr>
<td>Japan</td>
<td>NSAI (Ireland)</td>
</tr>
<tr>
<td>RIHS – Safety Standard</td>
<td>IMQ (Italy)</td>
</tr>
<tr>
<td>Underwriters Laboratories Inc. (UL)</td>
<td>CESI (Centro Elettrotecnico Sperimentale Italiano) (Italy)</td>
</tr>
<tr>
<td>Korea</td>
<td>SNCH (Luxembourg)</td>
</tr>
<tr>
<td>Underwriters Laboratories Inc. (UL)</td>
<td>KEMA (Netherlands)</td>
</tr>
<tr>
<td>Russia</td>
<td>NEMKO Compliance West, Inc. (Norway)</td>
</tr>
<tr>
<td>TCCExEE</td>
<td>CERTIF (Portugal)</td>
</tr>
<tr>
<td>ITS – InterTek Testing Service</td>
<td>SIQ (Slovenia)</td>
</tr>
<tr>
<td>Moody International Russian Certification Service</td>
<td>LOM (Laboratorio Oficial Madariaga) (Spain)</td>
</tr>
<tr>
<td>Taiwan</td>
<td>AENOR (Spain)</td>
</tr>
<tr>
<td>Underwriters Laboratories Inc. (UL)</td>
<td>Electrosuisse (Switzerland)</td>
</tr>
<tr>
<td>For other countries</td>
<td>INTERTEK SEMKO (Sweden)</td>
</tr>
<tr>
<td>IEC – International Electrotechnical Commission</td>
<td>ASTA (UK)</td>
</tr>
<tr>
<td></td>
<td>BEAB (UK)</td>
</tr>
<tr>
<td></td>
<td>British Approvals Service for Electrical Equipment in Flammable Atmospheres (BASEEEF(2001)Ltd) (UK)</td>
</tr>
<tr>
<td></td>
<td>BSI (UK)</td>
</tr>
<tr>
<td></td>
<td>EECS – Electrical Equipment Certification Service (UK)</td>
</tr>
<tr>
<td></td>
<td>SCS-Sira Certification Service (UK)</td>
</tr>
</tbody>
</table>
### Relevant Standards

<table>
<thead>
<tr>
<th>IEC</th>
<th>Title</th>
<th>IS</th>
<th>BS</th>
<th>ISO</th>
</tr>
</thead>
<tbody>
<tr>
<td>60034-14/2003</td>
<td>Rotating electrical machines. Mechanical vibration of certain machines with shaft height 56 mm and higher.</td>
<td>12075/2002</td>
<td>BS 4999-142/1987</td>
<td>–</td>
</tr>
<tr>
<td>60034-17/2003</td>
<td>Guide for application of cage induction motors when fed from converters.</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>60038/1994</td>
<td>IEC Standard voltages.</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>60051-1 to 9</td>
<td>Direct acting indicating analogue electrical measuring instruments and their accessories.</td>
<td>1248-1 to 9</td>
<td>BS 89-1 to 9</td>
<td>–</td>
</tr>
<tr>
<td>60060-1/1989</td>
<td>High voltage test techniques for voltages higher than 1 kV. General definitions and test requirements.</td>
<td>2071-1/1999</td>
<td>BS 923-1/1990</td>
<td>–</td>
</tr>
<tr>
<td>60068-2-47/1999</td>
<td>Environmental testing. Tests. Mounting of components, equipment and other articles for dynamic tests including shock (Ea), bumb (Eb), vibration (Fc and Fd) and steady-state acceleration (Ga) and guidance.</td>
<td>9001-13/2003, 9001-15/2001, 9001-17/2001</td>
<td>BS EN 60068-2-47/2000</td>
<td>–</td>
</tr>
<tr>
<td>60072-1/1991</td>
<td>Dimensions and output series for rotating electrical machines. Frame number 56 to 400 and Flange number 55 to 1080.</td>
<td>1231/1997</td>
<td>BS 4999-141/2004</td>
<td>–</td>
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<tr>
<td>IEC</td>
<td>Title</td>
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<tr>
<td>60079-12/1978</td>
<td>General recommendations on the selection of the appropriate group of electrical apparatus based on safe gaps and minimum igniting currents.</td>
<td>–</td>
<td>–</td>
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<tr>
<td>60079-14/2002</td>
<td>Electrical installations in hazardous areas (other than mines).</td>
<td>5572/1999</td>
<td>BS EN 60079-14/2003</td>
<td>–</td>
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<tr>
<td>60079-17/2002</td>
<td>Inspection and maintenance of electrical installations in hazardous areas (other than mines).</td>
<td>–</td>
<td>BS EN 60079-17/2003</td>
<td>–</td>
</tr>
<tr>
<td>60079-19/1993</td>
<td>Repair and overhaul for apparatus used in explosive atmospheres (other than mines or explosives).</td>
<td>–</td>
<td>BS IEC 60079-19/1993</td>
<td>–</td>
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<tr>
<td>60079-20/1996</td>
<td>Data for flammable gases and vapours for electrical apparatus.</td>
<td>–</td>
<td>–</td>
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<tr>
<td>60894/1987</td>
<td>Specification for the insulation of bars and coils of high voltage machines, including test methods.</td>
<td>–</td>
<td>BS 4999-144/1987</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>Guide for testing insulation resistance of rotating machines, rated for 1 MW and above.</td>
<td>7816/2002</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>Temperature rise measurement of rotating electrical machines</td>
<td>12802/1999</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>IEC</td>
<td>Title</td>
<td>IS</td>
<td>BS</td>
<td>ISO</td>
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<tr>
<td>–</td>
<td>Guide for testing three phase induction motors</td>
<td>4029/2002</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>Methods of determination of efficiency of rotating electrical machines.</td>
<td>4889/2002</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>Rotating machines. Specifications for tests.</td>
<td>–</td>
<td>BS 4999-143/1987</td>
<td>–</td>
</tr>
<tr>
<td>–</td>
<td>Test code for the measurement of airborne noise emitted by rotating electrical machines.</td>
<td>–</td>
<td>–</td>
<td>1680-1/1986</td>
</tr>
<tr>
<td>–</td>
<td>Determination of Sound power levels of noise sources.</td>
<td>–</td>
<td>BS 4196-5/1981</td>
<td>3740/2000</td>
</tr>
</tbody>
</table>

**Relevant US Standards ANSI/NEMA and IEEE**

- IEEE-792/1995 Recommended practice for the evaluation of the impulse voltage capability of insulation systems for a.c. electrical machinery employing form wound stator coils.
- NEMA/MG-1/2003 Motors and generators rating, construction, testing and performance.

**Notes**

1. In the table of relevant Standards while the latest editions of the Standards are provided, it is possible that revised editions have become available or some of them are even withdrawn. With the advances in technology and/or its application, the upgrading of Standards is a continuous process by different Standards organizations. It is therefore advisable that for more authentic references, one may consult the relevant organizations for the latest version of a Standard.
2. Some of the BS or IS Standards mentioned against IEC may not be identical.
3. The year noted against each Standard may also refer to the year it was last reaffirmed and not necessarily the year of publication.
Further Reading

2. DOC-ETDC 15(3059), Recommendation on insulation resistance test for 3.3 kV motors, 1000 kW and above, June (1987).
5. IEEE, Results of an investigation on the over-voltages due to a vacuum circuit breaker when switching an H.V. motor, IEEE 85 SM 370-2(1985).