IEEE Standard Requirements for Load Tap Changers

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Abstract: Electrical and mechanical performance and test requirements for load tap changers installed in power transformers and voltage regulating transformers of all voltage and kVA ratings are covered.
Keywords: load tap changer, phase shifting transformer, regulating transformer

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Introduction

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In the interest of furthering international standardization for load tap changers, portions of this standard have been reproduced by permission of the International Electrotechnical Commission (IEC), which retains the copyright.

This document is a new standard that has been developed by the Load Tap Changer Performance Requirements Working Group of the Transformers Committee. Its main intent is to provide standard performance and test requirements for both resistance and reactance type load tap changers. In many respects this standard parallels the IEC-214 (1989), Standard for On-Load Tap Changers, which covers resistance-type load tap changers in great detail, but reactance type load tap changers in lesser detail. This IEEE standard complements the IEC standard insofar as it provides additional performance and test requirements for reactance-type load tap changers, while essentially adopting, although sometimes with modification, the IEC requirements for resistance type load tap changers.

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IEEE Standard Requirements for Load Tap Changers

1. Overview

1.1 Scope

This standard covers electrical and mechanical performance and test requirements for load tap changers installed in power transformers and voltage regulating transformers of all voltage and kVA ratings. It relates mainly to load tap changers immersed in transformer mineral oil, but may also be used for other insulating fluids insofar as conditions are applicable.

1.2 Purpose

The purpose of this standard is to provide standard performance and test requirements for load tap changers.

2. References

This standard shall be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply.

ANSI C57.12.10-1987, American National Standard for Transformers, 230 kV and Below, 833/958 through 8333/10 417 kVA, Single-Phase, and 750/862 through 60 000/80 000/100 000 kVA, Three-Phase without Load Tap Changing; and 3750/4687 through 60 000/80 000/100 000 kVA with Load Tap Changing—Safety Requirements.[1]

IEEE Std 4-1995, IEEE Standard Techniques for High Voltage Testing.[2]

IEEE Std 100-1992, The New Standard Dictionary of Electrical and Electronics Terms (ANSI).[3]

[1]ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA.
[2]As this standard goes to press, IEEE Std 4-1995 is approved but not yet published. The draft standard is, however, available from the IEEE. Anticipated publication date is fall 1995. Contact the IEEE Standards Department at 1 (908) 562-3800 for status information.
[3]IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA.

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IEEE Std C57.12.00-1993, IEEE Standard General Requirements for Liquid-Immersed Distribution, Power and Regulating Transformers (ANSI).

IEEE Std C57.12.80-1978, Terminology for Power and Distribution Transformers (ANSI).

IEEE Std C57.12.90-1993, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers, and Guide for Short-Circuit Testing of Distribution and Power Transformers (ANSI).

IEEE Std C57.91-1995, IEEE Guide for Loading Mineral-Oil-Immersed Transformers.[4]

IEEE Std C57.113-1991, IEEE Guide for Partial Discharge Measurement in Liquid-Filled Power Transformers and Shunt Reactors (ANSI).

3. Definitions

3.1 arcing switch: A switching device used in conjunction with a tap selector to carry, make, and break current in circuits that have already been selected.

3.2 arcing tap switch: A switching device capable of carrying current and also breaking and making current while selecting a tap position. It, thereby, combines the duties of an arcing switch and a tap selector.

3.3 bypass contacts: For reactance-type load tap changers (LTCs), a set of through current-carrying contacts that commutates the current to the transfer contacts without any arc.

3.4 change-over selector: A device designed to carry, but not to make or break current, used in conjunction with a tap selector or arcing tap switch to enable its contacts, and the connected taps, to be used more than once when moving from one extreme position to the other.

3.5 circulating current: The current that flows through the transition impedance as a result of two taps being bridged during a tap change operation for resistance-type LTCs or being in the bridging position for reactance-type LTCs.

3.6 coarse change-over selector: A change-over selector that connects the tap winding to a coarse winding, a main winding, or to portions of the main winding.

3.7 coarse/fine operation: A winding arrangement in which a coarse change-over selector connects the tap winding to the coarse or main winding, and allows the use of the taps twice when travelling through the tapping range.

3.8 coarse winding: A winding that extends the regulating range beyond the range of the finely tapped winding.

3.9 cycle of operation: The movement of the LTC from one end of its range to the other and back to its original position.

3.10 design test: A test made on an LTC or the components of an LTC, or a range of LTCs or components all based on the same design, to prove compliance with this standard.

NOTE — A range of LTCs is a number of LTCs based on the same design and having the same characteristics, with the exception of the insulation levels to ground and possibly between phases, the number of steps and the value of the transition impedance.

3.11 drive mechanism: The means by which the LTC is actuated.

3.12 insulation level: The withstand values of the impulse and power frequency test voltages to ground, and where appropriate, between the phases, and between those parts where insulation is required.

3.13 linear operation: A winding arrangement in which the tap winding is directly connected to the main winding and where the taps can be used only once when travelling through the tapping range.

[4]As this standard goes to press, 1EEE Std C57.91-1995 is approved but not yet published. The draft standard is, however, available from the IEEE. Anticipated publication date is winter 1996. Contact the 1EEE Standards Department at 1 (908) 562-3800 for status information.

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3.14 load tap changer (LTC): A selector switch device, which may include current interrupting contactors, used to change transformer taps with the transformer energized and carrying full load.

3.15 main contacts: For resistance-type LTCs, a set of through current-carrying contacts that have no transition impedance between the transformer winding and the contacts and commutates the current to the main switching contacts without any arc.

3.16 main switching contacts: For resistance-type LTCs, a set of contacts that has no transition impedance between the transformer winding and the contacts and makes and breaks current.

3.17 maximum rated step voltage: The highest value of rated step voltage for which the LTC is designed.

3.18 maximum rated through current: The rated through current for which both the temperature rise of the contacts and the service duty test apply.

3.19 number of inherent tap positions: The highest number of tap positions for half a cycle of operation for which an LTC is designed.

3.20 number of service tap positions: The number of tap positions for half a cycle of operation for which an LTC is used in a transformer.

NOTE — The above two terms, 3.19 and 3.20, are generally given as the ± values of the relevant numbers, e.g., ± 16 positions. They are, in principle, valid also for the motor-drive mechanism. When the term *number of tap positions* is used in connection with a transformer, this always refers to the number of service tap positions of the LTC.

3.21 plus/minus operation: A winding arrangement in which one or the other end of the tap winding is connected by a reversing change-over selector to the main winding, and allows use of the taps in a buck or boost mode when travelling through the tapping range.

3.22 preventive autotransformer: An autotransformer (or center-tapped reactor) used in load tap changing and regulating transformers, or step-voltage regulators to limit the circulating current when operating on a position in which two adjacent taps are bridged, or during the change of taps between adjacent position.

3.23 rated frequency: The frequency of the alternating current for which the LTC is designed.

3.24 rated step voltage: For each value of rated through current, the highest permissible voltage between successive tap positions.

NOTE — Step voltage of resistance-type LTCs means tap to tap voltage (no bridging position).

3.25 rated through current: The current flowing through the LTC towards the external circuit, which the apparatus is capable of transferring from one tap to another at the relevant rated step voltage, and which can be carried continuously while meeting the requirements of this standard.

NOTE — Concerning the relationship between rated through current and the relevant step voltage, see 5.2.

3.26 recovery voltage: The power frequency voltage that appears across each set of main switching, transition, or transfer contacts of the arcing switch or arcing tap switch after these contacts have broken the switched current.

3.27 relevant rated step voltage: The value of rated step voltage that corresponds to a specific value of rated through current.

3.28 reversing change-over selector: A change-over selector that connects one or the other end of the tap winding to the main winding.

3.29 routine test: A test made on each completed LTC to establish that the LTC is without manufacturing defects, with the design having been verified by a design test.

3.30 switched current: The prospective current to be broken during a switching operation by each set of main switching or transition contacts (resistance-type LTC) or transfer contacts (reactance-type LTC) incorporated in the arcing switch or arcing tap switch.

3.31 tap change operation: A complete sequence of events from the initiation to the completion of the transition of the through current from one tap position to an adjacent one.

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3.32 tap selector: A device designed to carry, but not to make or break current, used in conjunction with an arcing switch to select tap connections.

3.33 transfer contacts: For reactance-type LTCs, a set of contacts that makes and breaks current.

NOTE — In cases where no bypass contacts are provided, the transfer contact is a continuous current carrying contact.

3.34 transition contacts: For resistance-type LTCs, a set of contacts that is connected in series with a transition impedance and makes and breaks current.

3.35 transition impedance: A resistor or reactor consisting of one or more units that bridge adjacent taps for the purpose of transferring load from one tap to the other without interruption or appreciable change in the load current, at the same time limiting the circulating current for the period that both taps are used. Normally, reactance-type LTCs use the bridging position as a service position and, therefore, the reactor is designed for continuous loading.

4. Service conditions

Unless specified otherwise, LTCs shall be suitable for operation when immersed in insulating fluid over a range of temperatures from –25 °C to 100 °C.

5. Rating

5.1 Rated characteristics

The rated characteristics of an LTC are as follows:

a) Rated through current
b) Maximum rated through current
c) Rated step voltage
d) Maximum rated step voltage
e) Rated frequency
f) Rated insulation level

5.2 Interrelation between rated through current and rated step voltage

Within the maximum rated through current of the LTC there may be different assigned combinations of values of rated through current and corresponding rated step voltage. When a value of rated step voltage is referred to as a specific value of rated through current, it is called the *relevant rated step voltage.*

6. Design tests

The following design tests shall be performed on an LTC of each stated rating:

a) Temperature rise of contacts
b) Switching
c) Short-circuit current
d) Transition impedance
e) Mechanical
f) Dielectric

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6.1 Temperature rise of contacts

6.1.1 Maximum rated through current

While carrying 1.2 times maximum rated through current continuously, tests shall be performed to verify that the steady-state temperature rise of the contacts does not exceed 20 °C above the temperature of the insulating fluid surrounding the contacts. The temperature rise limit applies to both plain and plated contacts. A temperature rise test is required on only one phase of a three-phase LTC.

6.1.2 Overload capability

LTCs that comply with the above definition of maximum rated through current, and when installed and properly applied in a transformer or regulating transformer, can be loaded in accordance with the applicable ANSI or IEEE loading guide.[5]

6.1.3 Test requirements

Temperature rise tests shall be performed at ambient temperature. The temperature of the surrounding insulating fluid shall be measured at not less that 25 mm below the contacts. Temperatures shall be measured by thermocouples or other suitable means positioned on the surface of the contacts as near to the point of contact as is practicable.

The temperature is considered to be at steady state when the difference of the temperature between the material being measured and the surrounding medium does not change more than 1 °C over a period of 1 h.

For reactance-type LTCs, the highest temperature rises will be experienced in the bridging position. The current in the bridging position is determined by the through current, as well as by the circulating current and the power factor of the through current. The design test shall be performed in the bridging position and with currents calculated on the following bases:

a) Through current equal to 1.2 times the maximum rated through current
b) Circulating current equal to 50% of the maximum rated through current (or otherwise specified by the manufacturer and stated in the design test report)
c) Power factor equal to 80%

6.2 Switching tests

Switching tests, which include service duty tests and breaking capacity tests, shall simulate the most demanding conditions for which the LTC is rated. Refer to annexes A and B for the most demanding conditions for resistance and reactance-type LTCs, respectively, for the majority of contact arrangements.

The switching tests may be limited to the arcing switch or arcing tap switch after proving that the contact operating conditions are not affected by such limitation.

If the arcing switch or arcing tap switch has several sets of contacts that operate in a definite sequence, it is not permitted to test each set of contacts separately from the others unless it can be proved that the operating conditions of any one set of contacts are not affected by the operation of the other sets of contacts.

Where resistors are used as transition impedances, they may be placed outside the apparatus if necessitated by the construction of the LTC or the test circuit, and they may have a higher thermal capacity than those which are employed in service, unless otherwise specified.

[5]Information on references can be found in clause 2

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The value and type of the transition impedance shall be stated.

Contacts and insulating fluid shall not be renewed during each of the tests.

In the case of three-phase switches, it is normally sufficient to test the contacts of only one phase.

If a particular LTC has more than one combination of rated through current and rated step voltage, at least two breaking capacity tests shall be performed—one at maximum rated through-current and its relevant rated step voltage, and one at the maximum rated step voltage and its relevant rated through-current.

The arrangement for testing shall be such that, except where otherwise specified, neither the switched current, nor the recovery voltage nor the product of these shall, in any case, vary more than −5% to +10% of the calculated values appropriate to the switching cycle (see table A.1 in annex A for resistance switching or table B.1 in annex B for reactance switching) at the appropriate through current and relevant rated step voltage.

6.2.1 Service duty test

This test shall be performed in accordance with one of the subclauses below.

After the tests, inspection of contact wear shall take place. The results of this inspection shall leave no doubts as to the suitability of the LTC for service.

NOTE — The results of these tests may be used by the manufacturer to demonstrate that the contacts used for making and breaking current are capable of performing, without replacement of the contacts, the number of tap change operations guaranteed by the manufacturer at the rated through current and at the relevant rated step voltage.

6.2.1.1 Service duty test at rated step voltage

The contacts on arcing switches and arcing tap switches shall be subjected to a number of operations corresponding to 50 000 tap change operations when carrying a current corresponding to not less than the maximum rated through current and the relevant rated step voltage.

In order to approximate service conditions, arcing tap switches shall have the test performed over not more than eight tap change positions (excluding dead positions), these being centrally disposed about the change-over selector if such is incorporated into the LTC design.

Comparison of oscillograms taken at regular intervals during the test shall show that there is no significant alteration in the characteristics of the LTC in such a way as to endanger the operation of the apparatus. Twenty oscillograms shall be taken at the start of the test, and 20 after each succeeding 12 500 operations, making a total of 100 oscillograms.

NOTE — Generally, it is sufficient to compare the series of oscillograms taken at the beginning and at the end of the test.

6.2.1.2 Service duty test at reduced step voltage

A test at reduced step voltage may be performed as follows:

a) One hundred operations at the maximum rated through current and the relevant rated step voltage shall be performed with new contacts in clean insulating fluid. Each operation shall be recorded by oscillograph.
b) When the oscillograms taken in item a) indicate that the arcing time does not exceed 1.2/(2f) s (f = rated frequency in Hz), then the number of operations of the service duty test as described in item d), below, shall be 50 000.
c) When the oscillograms taken in item a) indicate that arcing times in excess of 1.2/(2f) s are occurring, then the number of operations of the service duty test in item d) shall be increased by the following amount:
$2S/100 \times 50\ 000$

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where

S is the total number of half-cycles of arcing current in the 100 operations from a), above, which exceed 1.2/(2f) s.

d) A service duty test of 50 000 operations, increased by the number of operations resulting from item c), if applicable, shall be performed with a current not less than the maximum rated through current and at reduced step voltage. This voltage shall be such that the switched current is not less than that occurring during operations at the relevant rated step voltage; furthermore, current chopping shall not occur. In order to obtain the specified test conditions, the value of the transition impedance shall be suitably modified.

e) Without change of contacts or of insulating fluid, 100 operations shall be performed at the maximum rated through current and the relevant rated step voltage, with each operation being recorded by oscillograph. Comparison of these oscillograms with those taken in the series of operations under item a) shall show no alteration in the characteristics of the LTC, such as might endanger the operation of the apparatus.

The test sequence specified above is designed to give substantially the same contact erosion as would occur with maximum rated through current and relevant rated step voltage.

6.2.2 Breaking capacity test

Forty operations shall be performed at a current corresponding to twice the maximum rated through current and at the relevant rated step voltage. The forty operations shall be performed over not more than eight tap change positions (excluding dead positions), these being centrally disposed about the change-over selector if such is incorporated in the LTC design.

Oscillograms shall be taken for each operation, and the results shall indicate that in no case is the arcing time such as to endanger the operation of the apparatus. For example, dragging of the arc across the contacts could result in short circuiting the regulating winding of a transformer.

The breaking capacity test for resistance-type LTCs shall be performed, if possible, with a transition resistor of the same thermal and ohmic design as that to be employed in service. If this is not possible, the resistor as used in service shall be tested separately in accordance with 6.4.1, but with twice the maximum rated through current for one operation only.

6.2.3 Simulated test circuits

The tests described in 6.2.1 and 6.2.2 may be performed with simulated circuits provided it is proven that the test conditions are substantially equivalent. Two simulated test circuits that are relevant for resistor type LTCs only are described in annex D.

6.3 Short-circuit current test

All contacts of different design that carry current continuously shall be subjected to short-circuit currents, each of at least 2 s duration. In the case of three-phase LTCs, it is sufficient to test the contacts of one phase only unless otherwise specified.

Three applications shall be made with an initial peak current of 2.5 (± 5%) times the rms value of the short-circuit test current. The load impedance shall exhibit an X/R ratio of 12 or more in order to accomplish the desired degree of asymmetry. The contacts shall not be moved between these applications.

When there are no facilities for point-on-wave switching, a resistive load may be used. The rms value of the short-circuit test current may be increased so that the peak current is obtained for the three applications and the test duration reduced. When using this method, the product of the square of the increased rms current and the shorter test duration shall be not less-than the product of the square of the rated short-circuit rms current and the 2 s duration.

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The values of the short-circuit test current to be applied shall be as shown in figure 1.

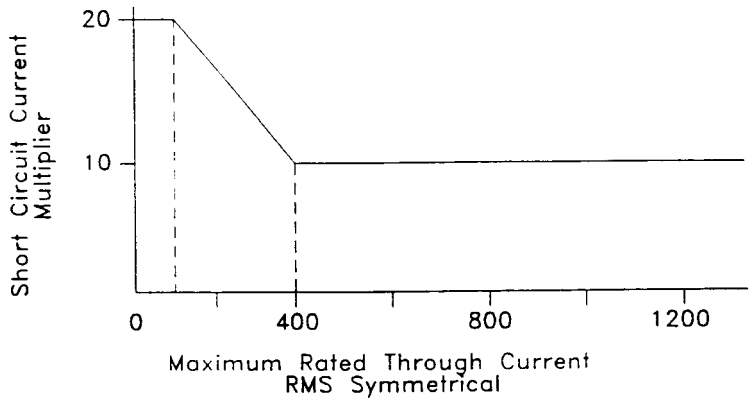

Figure 1—Short-circuit multiple of the maximum rated through current

The open circuit voltage for the test shall be at least 50 V. At the conclusion of the test, the contacts shall not have been damaged so as to prevent continuing correct operation at rated current. Other current-carrying parts shall not show signs of permanent mechanical distortion.

For reactance-type LTCs the short-circuit current is divided into two equal parts at the tap selector or arcing tap switch contacts and the transfer or bypass contacts. Therefore, the test current carried by each contact will be only 50% of the full test current.

6.4 Transition impedance test

6.4.1 Transition resistors

To meet the overload requirements of 6.1.2, the test shall be performed with 1.5 times the maximum rated through current and at the relevant rated step voltage. The resistor shall be mounted in the LTC as in service.

The resistor shall be loaded by operating the LTC. The number of operations shall be equivalent to one-half of an operation cycle (see 3.12). The operations shall be uninterrupted with the driving mechanism operating at its normal speed.

The temperature of the resistor at the final operation shall be determined and recorded. The temperature rise above the surrounding medium at 1.5 times maximum rated through current shall not exceed 350 °C. The temperature of resistors and of parts adjacent to them shall be limited to a value such that the characteristics of the assembly are not affected.

If it is not practicable to determine the temperature of the transition resistor according to the above, the method given in annex C may be employed.

NOTE — In cases when the rated through current or the relevant rated step voltage is different from the maximum rated through current and the relevant rated step voltage, it is permissible to calculate the thermal rating of the resistor from the results of the design test.

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6.4.2 Transition reactors

Transition reactors are normally tested in accordance with the specification for the transformer with which the tap changer is intended for use.

NOTE — Precautions should be taken in the design of the transition reactors to avoid high inrush currents during switching.

6.5 Mechanical tests

6.5.1 Mechanical endurance test

The LTC shall be assembled and filled with insulating fluid or immersed in a test tank filled with clean insulating fluid, and operated as for normal service conditions. The contacts shall not be energized and the full range of taps shall be utilized until 500 000 tap-change operations have been performed. At least 15 625 operations shall be carried out on the change-over selector, if applicable.

For LTCs located in a separate compartment, this test may be performed at ambient temperature. For LTCs located in the main tank of the transformer, half the number of operations shall be performed at a temperature of not less than 75 °C and half at a lower temperature (ambient or higher), for example during the heating or cooling period, with daily temperature cycles being permitted.

Ten timing oscillograms for the arcing switch and tap selector or the arcing tap switch and, if applicable, for the change-over selector, shall be taken at the start and finish of the mechanical endurance test. Comparison of these recordings shall show no significant difference in the timing of the movement of the contacts.

For either type of LTC (located in a separate compartment or in the main tank), 100 operations shall be performed with the arcing switch only or with an arcing tap switch at −25 °C insulating fluid temperature. The operation of the arcing switch or arcing tap switch shall be recorded by oscillograph. Comparison of these oscillograms with those obtained in accordance with the previous paragraph shall show suitability for service.

During mechanical endurance tests there shall be no failure or undue wear of the mechanical parts that would cause erratic LTC operation or would lead to mechanical failure if operation continued. Scheduled servicing, such as lubrication and minor adjustments according the manufacturer's written instructions, is permitted during the test.

6.5.2 Sequence test

With the LTC assembled as in service, and with clean insulating fluid, it shall be operated over one complete cycle of operation. With the contacts energized at the voltage of the recording equipment, the exact time sequence of operation of the tap selector, change-over selector, and arcing switch or arcing tap switch, as applicable, shall be recorded.

6.6 Dielectric tests

6.6.1 General

The dielectric requirements of an LTC depend on the transformer or regulator winding to which it is to be connected.

The transformer or regulator manufacturer shall be responsible not only for selecting an LTC of the appropriate insulation level, but also for the insulation level of the connecting leads between the LTC and the windings of the transformer or regulator.

The LTC compartment shall be filled with clean insulating fluid or immersed in a test tank filled with clean insulating fluid before the tests detailed in 6.6.3 are performed.

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6.6.2 LTC categories

To permit selection of appropriate voltage tests, LTCs shall be categorized according to table 1.

Table 1—LTC categories

Category	Application
1	For use at the neutral point of windings
2	For use at other than the neutral point of windings

6.6.3 Nature of tests

The insulation level of the LTC shall be demonstrated by dielectric tests performed on the following insulation spaces:

a) Test 1: live parts to ground
b) Test 2: between phases, if applicable
c) Test 3: between the first and last contacts of the tap selector or arcing tap switch and, where applicable, of the change-over selector
d) Test 4: between any two adjacent contacts of the tap selector or arcing tap switch or any other contacts relevant to the LTC contact configuration
e) Test 5: between arcing switch contacts in their final open position

6.6.4 Test voltages

6.6.4.1 Category 1

For test 1, the test voltages shall comply with appropriate values from table 2. For tests 2, 3, 4, and 5, appropriate withstand values of lightning impulse voltage and, if applicable, of power frequency voltage with a duration of 60 s shall be determined and reported by the manufacturer of the LTC.

6.6.4.2 Category 2

For tests 1 and 2, test voltages shall comply with the appropriate values from table 2. For tests 3, 4, and 5, appropriate withstand values of lightning impulse voltage and, if applicable, of power frequency voltage with a duration of 60 s shall be determined and reported by the manufacturer of the LTC. Test voltage levels for the partial discharge test, when required and as described in 6.6.9, shall comply with the appropriate values from table 3.

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Table 2—Insulation levels for LTCs

Nominal voltage level of LTC (kV)	Applied voltage test level (kV rms)	Basic lightning impulse level (kV crest)	Switching impulse level (kV crest)
15 and below	34	110	—
25	50	150	—
34.5	70	200	—
46	95	250	—
69	140	350	—
115	230	550	—
138	275	650	—
161	325	750	—
230	395	900	—
287	460	1050	—
345	520	1175	975

6.6.5 Application of test voltages

For the dielectric tests, the LTC shall be assembled, arranged, and processed in a manner similar to that in service. It is not, however, necessary to include leads for connecting the LTC to the windings of a transformer. The test may be performed on separate components provided it can be shown that the same dielectric conditions apply.

For tests 1 and 2 for category 2 LTCs, the live parts of each phase shall be short-circuited and connected either to the voltage source or to ground, as appropriate.

Dielectric tests shall be performed in the following sequence:

a) Lightning impulse
b) Switching impulse, when required
c) Applied voltage
d) Partial discharge, when required

6.6.6 Applied voltage test

The test shall be performed with a single-phase alternating voltage. The duration of each test application shall be 60 s.

6.6.7 Basic lightning impulse insulation test

The wave for the test shall be the standard 1.2×50 μs impulse as defined in IEEE Std 4-1995. Each test shall consist of three voltage applications of positive polarity and three of negative polarity at the required value selected from table 2.

6.6.8 Switching impulse test

This test is applicable to category 2 LTCs having a nominal voltage level of 345 kV. The test shall be made between active and grounded parts of the LTC. The test configuration shall be stated by the manufacturer. The impulse wave shape shall be a standard 250×2500 μs impulse as defined in IEEE Std 4-1995. Each test shall consist of three voltage applications of negative polarity at the required value shown in table 2.

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6.6.9 Measurement of partial discharges

For category 2 LTCs having a nominal voltage level of 115 kV and above, a partial discharge test shall be made between active parts and grounded parts of the LTC. This test is not required for category 1 LTCs.

The test configuration shall be determined and reported by the LTC manufacturer. The test shall be performed with a single-phase alternating voltage.

The time sequence for the application of test voltage shall be as shown in figure 2. The voltage shall be switched on and then increased to the extended period test level for a duration of 5 min. The voltage shall then be raised to the enhancement voltage level for 5 s after which it shall be reduced to the extended period test level for a period of one-half hour. The duration of the test shall be independent of the test frequency.

During the entire test sequence, partial discharges shall be monitored. The partial discharge level during the half hour portion of the test shall not be above the allowable ambient level, which shall not exceed 10 μV or 50 pc. The test voltages shall be as shown in table 3.

The partial discharges shall be observed and evaluated as follows:

a) Before and after the application of test voltage, the background noise level shall be recorded.
b) During the raising of voltage up to the extended period test level and back down again, inception and extinction voltages shall be noted.
c) A reading shall be taken and noted during the first period at the extended period test level.
d) Partial discharge values at the enhancement level shall be recorded.
e) During the half hour duration of the extended period test level, the partial discharge level shall be continuously observed and readings recorded at 5 min intervals.

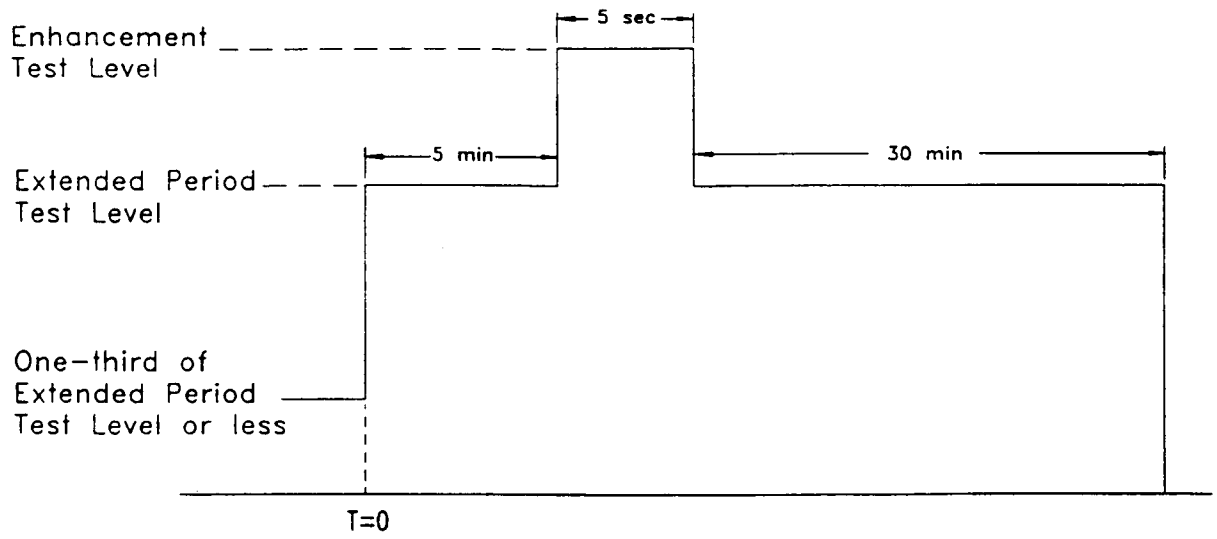

Figure 2—LTC partial discharge test

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Table 3—Voltage levels for partial discharge test

Nominal voltage level of LTC (kV)	Extended period test level, phase-to-ground (kV rms)	Enhancement test level, phase-to-ground (kV rms)
115	105	120
138	125	145
161	145	170
230	210	240
287	260	300
345	315	360

The test is successful if no collapse of the test voltage occurs, and the continuous level of partial discharge during the half hour duration of the extended period test level remains below the specified limit and does not show a steadily rising trend.

If the partial discharge reading rises above the specified limit for a period not to exceed 5 min and then returns below this level again, the test may continue without interruption until acceptable readings have been observed for one half hour. Occasional momentary variations should be disregarded.

7. Routine tests

The following routine tests shall be performed on each completed LTC intended for application in all power transformers and in voltage regulating transformers with a rated throughput above 1000 kVA single phase or 3000 kVA three phase.

7.1 Mechanical test

With the LTC fully assembled, but without the contacts energized, ten complete cycles of operation shall be performed without failure.

7.2 Sequence test

During the routine mechanical test of 7.1, the sequence of operations of the LTC shall be recorded with the operation of the arcing switch or arcing tap switch being recorded by oscillograph for one-half of a complete cycle of operation. The results of the recording shall be substantially in agreement with those of the sequence design test of 6.5.2.

7.3 Auxiliary circuits insulation test

The LTC control wiring shall withstand without failure a power frequency test of 1.5 kV applied for 1 min between all live terminals and the frame.

8. Nameplate

The LTC nameplate shall be in accordance with ANSI C57.12.10-1987 and shall include the items listed below:

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a) Number and year of this standard
b) Manufacturer's name
c) Serial number
d) Manufacturer's type designation
e) Year of manufacture
f) Maximum rated through current
g) Basic lightning impulse insulation level to ground

The nameplate shall be permanently attached to the LTC compartment.

9. Test report

9.1 Design test report

The report shall include the following:

a) Full details of the test arrangement (e.g., assembly, arrangement, and processing) with explanatory sketches as necessary.
b) Full details of all tests applied in accordance with clause 6

9.2 Routine test report

A routine test report shall be provided for each LTC produced. The report shall provide full details of all tests applied in accordance with clause 7

10. Motor-drive mechanism

10.1 Temperature of motor-drive mechanism environment

Unless specified otherwise, motor-drive mechanisms shall be suitable for operation in any ambient air temperature from −25 °C to 40 °C.

10.2 Permissible variation of auxiliary supply

The drive motor and the electrical control of the motor-drive mechanism shall be designed to operate satisfactorily within the limits of 85% to 110% of rated voltage and 90% to 105% of rated frequency.

10.3 Design tests for motor-drive mechanisms

10.3.1 Mechanical load test

If the LTC is operated by a separate motor-drive mechanism, the output shaft shall be loaded by the largest LTC for which it is designed or by an equivalent simulated load. At such a load, 500 000 operations shall be performed at room temperature across the entire tap range. Additional cooling of the motor-drive is permissible during this test.

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During this test, 10 000 operations shall be performed with the motor supply voltage at 85% of rated drive motor voltage. Also, 10 000 operations shall be performed at 110% of rated drive motor voltage. In addition, 100 operations shall be performed at a temperature of −25 °C.

The correct functioning of the tap position indicator, limit switches, restarting device, and operation counter shall be verified during this test. At the completion of this test, the LTC shall be operated manually, if applicable, through one cycle of operation (see 2.12). The test shall be considered to be successful if there is no mechanical failure or any undue wear of the mechanical parts. Normal servicing according to the manufacturer's instruction book is permitted during the test. During this test, the heating system of the motor-drive mechanism shall be switched off.

10.3.2 Overrun test

It shall be demonstrated that, in the event of a failure of the electrical limit switches, the mechanical end stops will prevent operation beyond the end positions when a motorized tap-change is performed and that the motor-drive mechanism will not suffer either electrical or mechanical damage.

10.4 Routine tests for motor-drive mechanism

The following routine tests shall be performed on each motor-drive mechanism intended for application in all power transformers and in voltage regulating transformers with a rated throughput above 1000 kVA single phase or 3000 kVA three phase.

10.4.1 Mechanical tests

The motor-drive mechanism in the service condition or with an equivalent simulated load shall be operated electrically for ten cycles of operation without failure. During this test, correct functioning of mechanical components shall be verified.

After the above test, two further cycles of operation shall be performed—one at the minimum and one at the maximum level of voltage stated in 10.3.1.

10.4.2 Auxiliary circuits insulation test

Auxiliary circuits, except for the motor and such elements that are to be tested with lower test voltages according to applicable standards, shall withstand a power frequency voltage of 1.5 kV applied for 1 min between all active terminals and the grounded frame.

10.5 Nameplate for motor-drive mechanism

Each motor-drive mechanism shall be provided with a nameplate showing the following items listed below. When the motor-drive mechanism is an integral part of the LTC, a combined nameplate for the LTC and the motor-drive mechanism may be provided.

a) Number and year of this standard
b) Manufacturer's name
c) Serial number and type designation
d) Year of manufacture
e) Rated voltage, frequency, and horsepower of the motor
f) Rated voltage and frequency of the control equipment
g) Number of service operating positions

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10.6 Test report for motor-drive mechanism

10.6.1 Design test report

The design test report shall include full details of all tests applied in accordance with 10.3.

10.6.2 Routine test report

A routine test report shall be provided for each motor-drive mechanism produced. The report shall provide full details of all tests applied in accordance with 10.4.

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Annex A Switching duty relating to load tap changers with resistor transition

(Informative)

A.1 Additional definitions

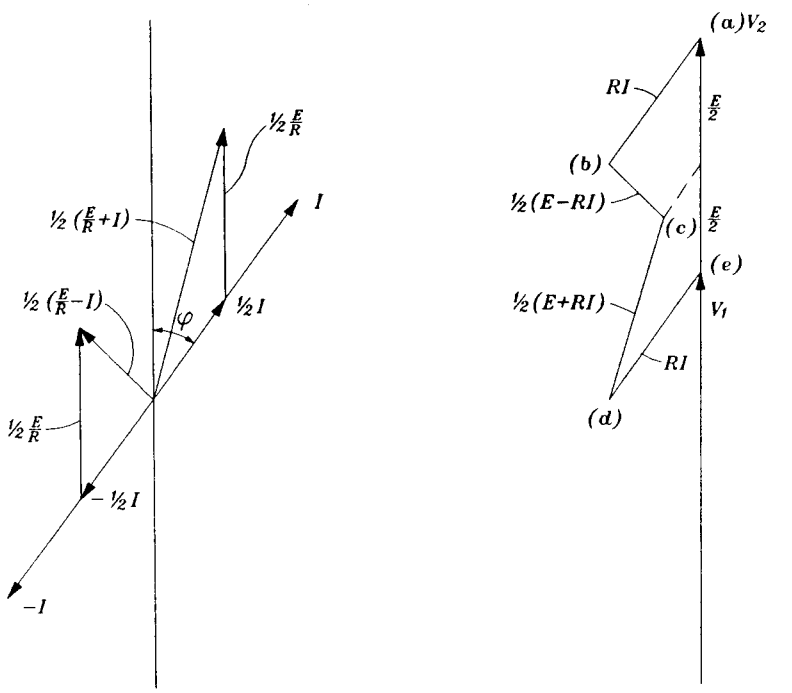
A.1.1 flag cycle: A method of performing a tap change operation in which the through current is diverted from the main contacts before the circulating current starts to flow.

A.1.2 symmetrical pennant cycle: A method of performing a tap change operation in which the circulating current starts to flow before the through current is diverted from the main contacts.

NOTES:

1 — The above two cycles require that the through current connection is at the midpoint of the transition impedance when this is carrying the circulating current.

2 — The derivation of the designations “flag cycle” and “pennant cycle” arises from the appearance of the phasor diagrams showing the change in output voltage of the transformer in moving from one tap to the adjacent one. In the “flag cycle” the change of voltage comprises four steps, while in the “pennant cycle” only two steps occur. See figures A.1 and A.2.



a) Current phasors showing switched currents

b) Voltage phasors during tap transition

NOTES

1—System voltage progression during transition steps shown in brackets (a) through (e)

2— φ = load power factor angle

3—Shown for $\left|\frac{E}{R}\right| \cong 1.35|I|$

Figure A.1—Flag cycle

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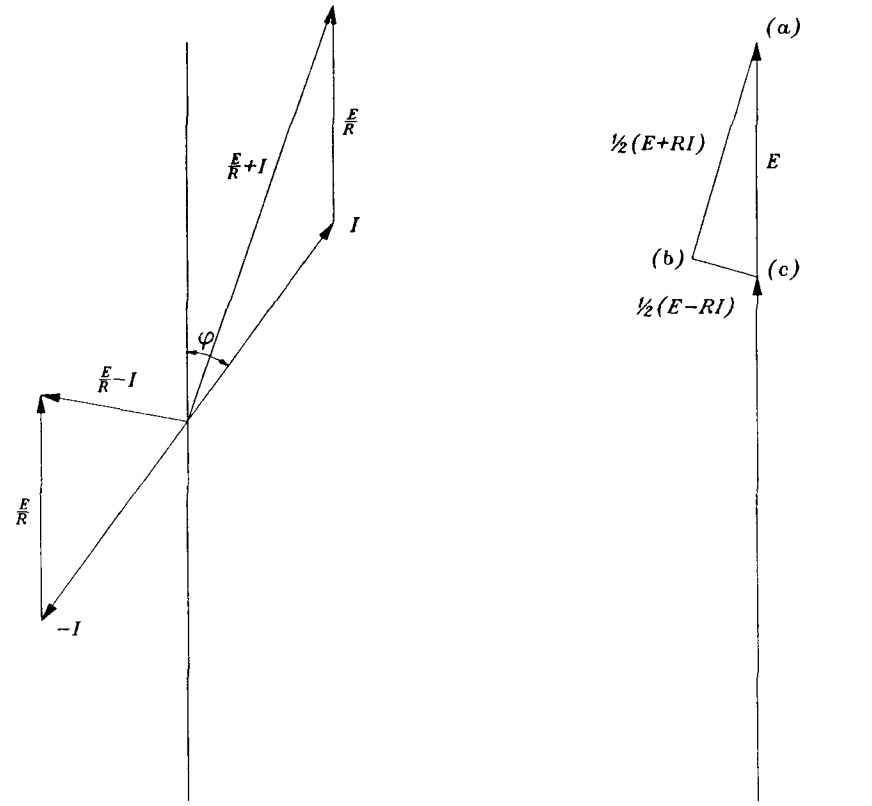

a) Current phasors showing switched currents

b) Voltage phasors during tap transition

NOTES

1—System voltage progression during transition steps shown in brackets (a) through (c)
2— φ = load power factor angle
3—Shown for $\left|\frac{E}{R}\right| \cong 1.0|I|$

Figure A.2—Symmetrical pennant cycle

A.2 Duty on main and transition contacts

Table A.1 shows typical contact arrangements used for flag and pennant cycles on arcing switches and arcing tap switches. Only one pair of contacts is shown for each function, although in practice, this may represent a set of contacts.

Table A.1 also shows the number of circuit transfer operations performed, together with the duty performed, by each pair of contacts for each combination of switched current and recovery voltage during a number of cycles of operation 0corresponding to “N” tap change operations.

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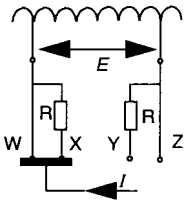
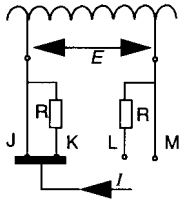
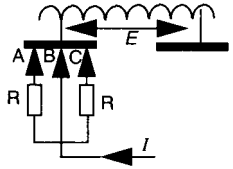
Table A.1—Duty on main and transition contacts for resistance-type LTCs

Type of switch	Operating cycle	Diagram of connections	Contact operating order	Main contact duty: Con-tact	Main contact duty: Switched current	Main contact duty: Recovery voltage	Main contact duty: Number of operations	Transition contact duty: Contact	Transition contact duty: Switched current	Transition contact duty: Recovery voltage	Transition contact duty: Number of oper-ations
Arcing switch	Flag cycle		W breaks Y makes X breaks Z makes	W	*I*	*RI*	*N*/2	X	1/2 (*E*/*F*+*I*)	*E*+*RI*	*N*/4
									1/2 (*E*/*R*–*I*)	*E*–*RI*	*N*/4
				Z	*I*	*RI*	*N*/2	Y	1/2 (*E*/*F*+*I*)	*E*+*RI*	*N*/4
									1/2 (*E*/*R*–*I*)	*E*–*RI*	*N*/4
	Symmetrical pennant cycle		L makes J brakes W makes K breaks	J	*E*/*R*+*I*	1/2 (*E*+*RI*)	*N*/4	K	*E*/*R*	*E*	*N*/2
					E/*R*–*I*	1/2 (*E*–*RI*)	*N*/4				
				M	*E*/*R*+*I*	1/2 (*E*–*RI*)	*N*/4	L	*E*/*R*	*E*	*N*/2
					E/*R*–*I*	1/2 (*E*–*RI*)	*N*/4				
Arcing tap switch	Flag cycle		C breaks B breaks C makes A breaks B makes A makes	B	*I*	*RI*	*N*	A	1/2 (*E*/*R*+*I*)	*E*+*RI*	*N*/2
								C	1/2 (*E*/*R*–*I*)	*E*–*RI*	*N*/2

NOTES:
1 — Other circuits involving multiple resistors are not included, as they are extensions of the above basic circuits.
2 — For the purpose of clarity, the diagram of connections and contact operating order are given for one direction of movement of the switch. The expressions for contact duty and number of operations, howeve, take into account the movement of the switch in both directions.

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In the expressions for current and voltage in table A.1 the plus (+) and minus (−) signs indicate phasor addition and subtraction, not algebraic expressions. The duty on the contacts is consequently affected by the power factor of the load on the transformer, which controls the phase angle between the through current *I*, and the step voltage *E*. The effect of the load power factor on the duty of the various contacts is shown in table A.2.

Table A.2—Effect of load power factor on circuit breaking duty for resistance type load tap changers

Type of Switch	Operating cycle	Main contacts		Transition contacts	
		Contact	Effect of load power factor	Contact	Effect of load power factor
Arcing switch	Flag cycle	W and Z	None	X and Y	Maximum duty at power factor = 1.0
	Symmetrical pennant cycle	J and M	Maximum duty at power factor = 1.0	K and L	None
Arcing tap switch	Flag cycle	B	None	A and C	Maximum duty at power factor = 1.0

If the transition resistance is divided into two units, these are assumed to be of equal value, each equal to *R*.

The arrangements shown are by no means exhaustive; other possible arrangements exist and are used such as the multiple resistor cycle, which may be an extension of either the flag cycle or pennant cycle principle.

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Annex B Switching duty relating to lcad tap changers with reactor transition (Informative)

B.1 Additional test parameters

B.1.1 Service duty test (see 6.2.1)

a) Current: Rated through current
b) Voltage: Relevant step voltage
c) Preventive auto: Circulating current in bridging position equal to 50% of the rated through current or as otherwise specified by the manufacturer and stated in the design test report.
d) Power factor: 80%
e) Number of operations: 50 000

B.1.2 Breaking capacity test (see 6.2.2)

a) Current: Twice the maximum rated through current.
b) Voltage: Relevant step voltage
c) Preventive auto: Circulating current in bridging position equal to 50% of the rated through current or as otherwise specified by the manufacturer and stated in the design test report.
d) Power factor: 0%
e) Number of operations: 40

B.2 Duty on switching contacts

Tables B.1, B.2, and B.3, respectively, show the duty on switching contacts for LTCs with the following three types of switching: Arcing tap switch

f) Arcing switch and tap selector
g) Vacuum interrupter

Likewise, figures B.1 and B.2, B.3 and B.4, and B.5 and B.6, show the operating sequence and phasor diagrams for the three types of reactance-type LTCs.

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Table B.1—
Duty on switching contacts for reactance-type LTCs with arcing tap switch
Switching direction from position 1 to position 5*

Position†	Contact operation	Contact	Switched current	Recovery voltage
1 on tap 1	N/A	G	—	—
		H	—	—
2 Transition to bridging (arcing switch opens)	H breaks	G	—	—
		H	1/2 I‡	1/2 IZ
3 Bridging taps 1 and 2	H makes	G	—	—
		H	—	—
4 Transition to on-tap 2	G breaks	G	1/2I + E_T/Z**	E_T + 1/2 IZ
		H	—	—
5 On tap 2	G breaks	G	—	—
		H	—	—

NOTES:
1 — See figure B.1 for contact position diagrams and figure B.2 for phasor diagrams.
2 — All additions shown in the table are phasor additions.

*When transition to on-tap is in the reverse direction (position 5 to position 1) the switched current at G contact is 1/2 I and the corresponding recovery voltage is 1/2 IZ (position 4). The switched current at H contact is E_T/Z − 1/2I and the corresponding recovery voltage is E_T − 1/2 IZ (position 2).
†Positions 1, 3, and 5 are operating positions.
‡I = load current
**$E_T/Z = I_C$ (circulating current), Z = impedance of preventive autotransformer, and E_T = tap voltage

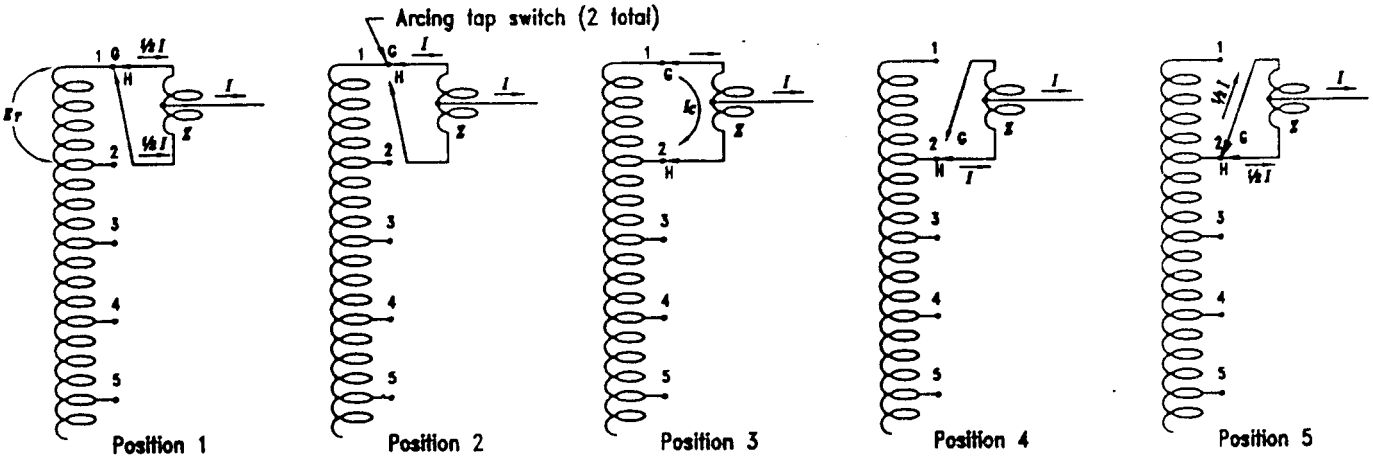

Figure B.1—Operating sequence of arcing tap switch

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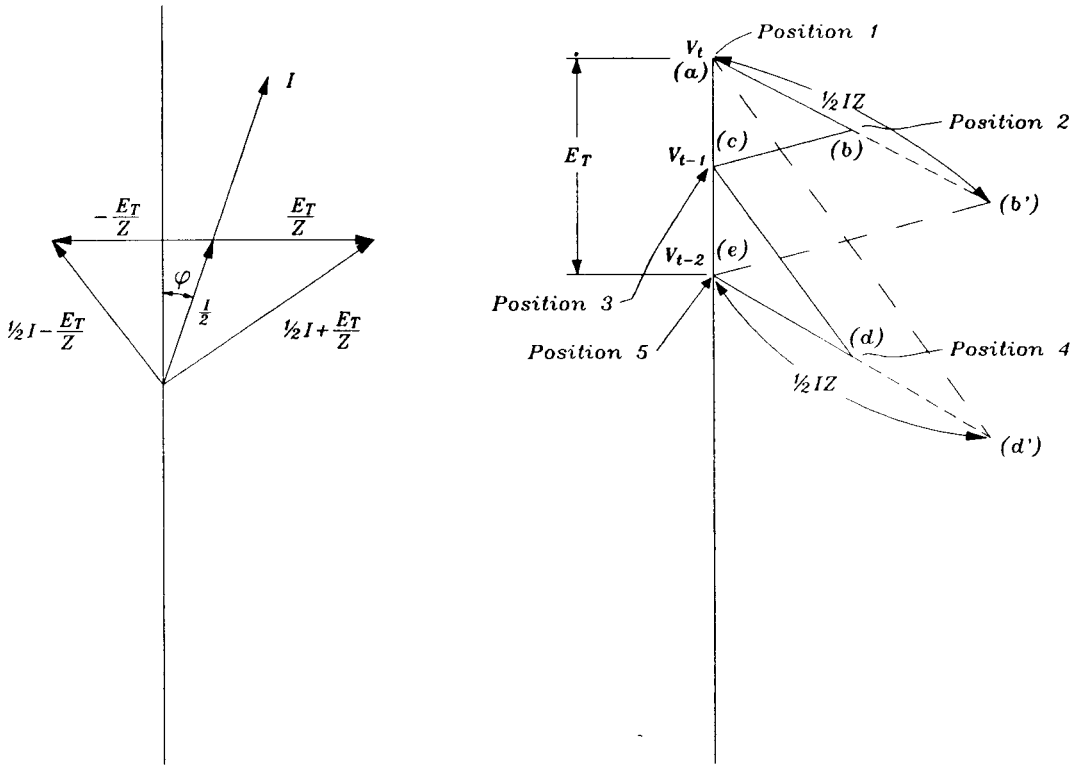

a) Current b) Voltage

NOTES

1—System voltage progression during transition steps for two tap position change operations shown in brackets (a) through (e) in figure b). Positions (a), (c), and (e) represent quiescent operation. Positions (b) and (d) represent momentary operation due to reactance drop.

2—Phasors (a–b´) and (e–d´) represent reactor voltage due to transformer action.

3—Shown for $\left|\frac{E_T}{Z}\right| \cong 0.5|I|$

Figure B.2—Current and voltage phasors for reactance-type LTCs with arcing tap switch

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Table B.2—
Duty on switching contacts for reactance-type LTCs with arcing tap switch and tap selector
Switching direction from position 1 to position 7*

Position	Contact operation	Contact	Switched current	Recovery voltage
1† On tap 1	N/A	G	—	—
		H	—	—
2 Transition to bridging (arcing switch opens)	H breaks	G	—	—
		H	1/2 I‡	1/2 IZ
3 Transition to bridging (selector moves to bridging)	Selector moves to bridge taps 1 and 2	G	—	—
		H	—	—
4 Bridging taps 1 and 2	H makes	G	—	—
		H	—	—
5 Transition to on-tap 2 (arcing switch opens)	G breaks	G	$1/2I + E_T/Z$**	$E_T + 1/2IZ$
		H	—	—
6 Transition to on-tap 2	Selector moves to tap 2	G	—	—
		H	—	—
7 On tap 2	G breaks	G	—	—
		H	—	—

NOTES:
1 — See figure B.3 for contact position diagrams and figure B.4 for phasor diagrams.
2 — All additions shown in the table are phasor additions.

*When transition to on-tap is in the reverse direction (position 7 to position 1) the switched current at G contact is 1/2 I and the corresponding recovery voltage is 1/2 IZ (position 6). The switched current at H contact is $E_T/Z - 1/2I$ and the corresponding recovery voltage is $E_T - 1/2\ IZ$ (position 3).
†Positions 1, 4, and 7 are operating positions.
‡I = load current
**$E_T/Z = I_c$ (circulating current), Z = impedance of preventive autotransformer, and E_T = tap voltage

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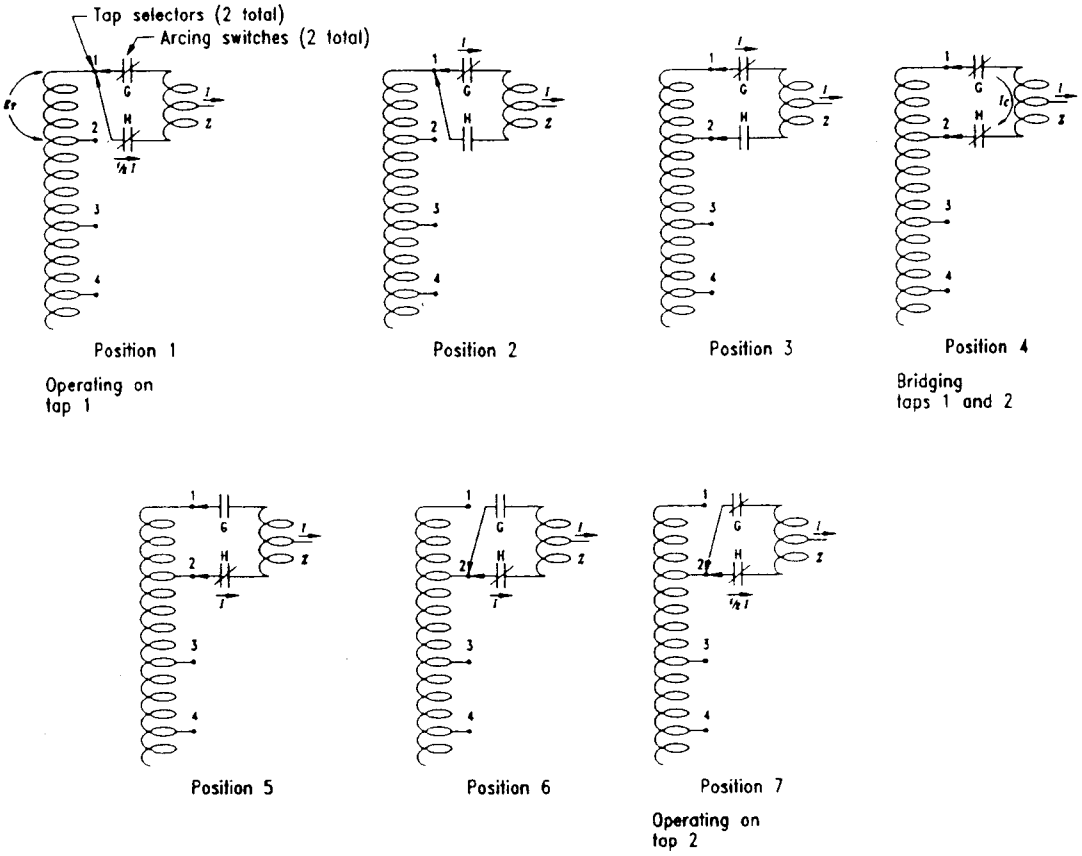

Figure B.3—Operating sequence of LTC with arcing switch and tap selector

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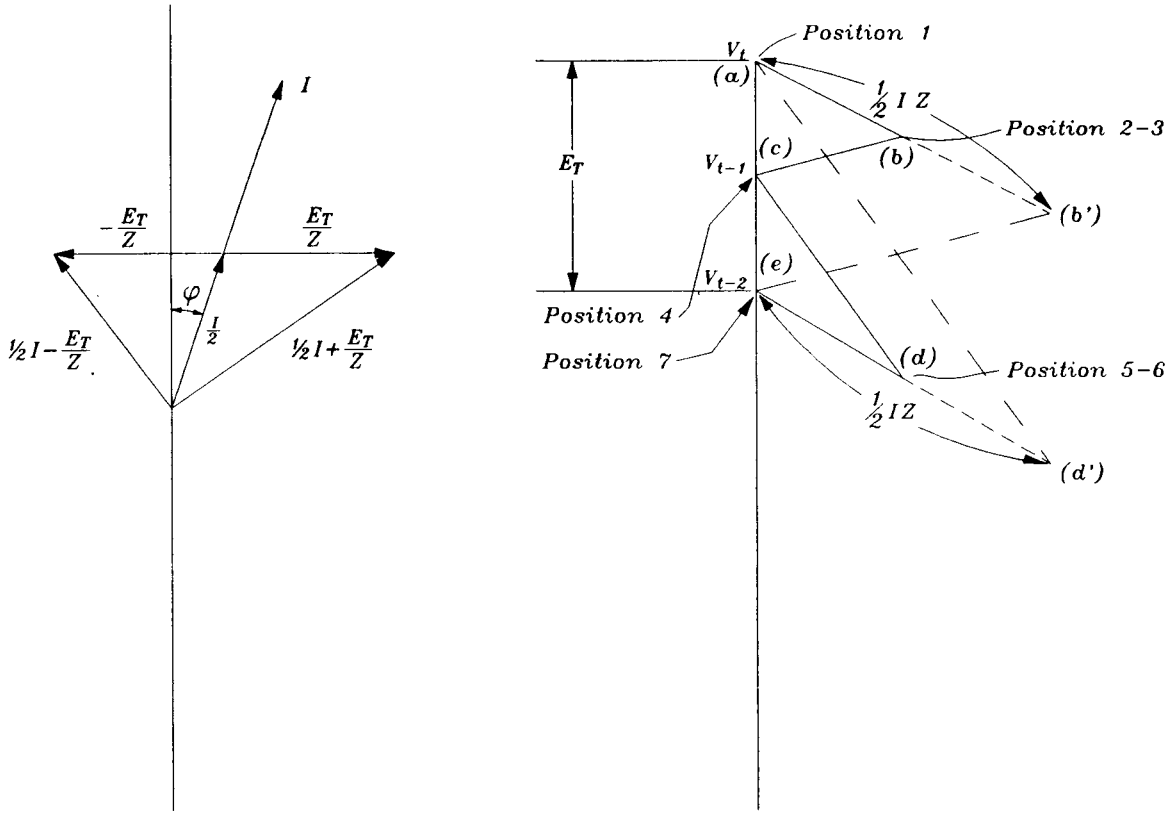

a) Current b) Voltage

NOTES

1—System voltage progression during transition steps for two tap position change operations shown in brackets (a) through (e) in figure b). Positions (a), (c), and (e) represent quiescent operation. Positions (b) and (d) represent momentary operation due to reactance drop.

2—Phasors (a–b′) and (e–d′) represent reactor voltage due to transformer action.

3—Shown for $\left|\frac{E_T}{Z}\right| \cong 0.5|I|$

Figure B.4—Current and voltage phasors for reactance-type LTCs with arcing switch and tap selector

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Table B.3—
Duty on switching contacts for reactance-type LTCs with vacuum interrupter Switching direction from position 1 to position 11*

Position†	Contact operation	Contact	Switched current	Recovery voltage
1 On tap 1	G	closed	—	—
	V	closed	—	—
	H	closed	—	—
2 Transition to bridging (by-pass switch opens)	G	closed	—	—
	V	closed	—	—
	H	open	—	—
3 Transition to bridging (vacuum switch opens)	G	closed	—	—
	V	breaks	1/2 I‡	1/2 IZ
	H	closed	—	—
4 Transition to bridging (selector moves to tap 2)	G	closed	—	—
	V	open	—	—
	H	open	—	—
5 Transition to bridging (vacuum switch closes)	G	closed	—	—
	V	makes	—	—
	H	open	—	—
6 Bridging taps 1 and 2 (by-pass switch closes)	G	closed	—	—
	V	closed	—	—
	H	closed	—	—
7 Transition to on-tap 2 (by-pass switch opens)	G	open	—	—
	V	closed	—	—
	H	closed	—	—
8 Transition to on-tap 2 (by-pass switch opens)	G	open	—	—
	V	breaks	$1/2I–E_TZ$**	E_T+1/2IZ
	H	closed	—	—
9 Transition to on-tap 2 (selector moves on tap 2)	G	open	—	—
	V	open	—	—
	H	open	—	—
10 Transition to on-tap 2 (vacuum switch closes)	G	open	—	—
	V	makes	—	—
	H	closed	—	—
11 On tap	G	closed	—	—
	V	closed	—	—
	H	closed	—	—

NOTES:
1 — See figure B.5 for contact position diagrams and figure B.4 for phasor diagrams.
2 — All additions shown in the table are phasor additions.

*When transition to on-tap is in the reverse direction (position 11 to position 1) the switched current at V contact is 1/2 I and the corresponding recovery voltage is 1/2 IZ (position 9). The switched current at V contact is E_T/Z – 1/2I and the corresponding recovery voltage is E_T – 1/2 IZ (position 4).
†Positions 1, 6, and 11 are operating positions.
‡I = load current
**$E_T/Z = I_c$ (circulating current), Z = impedance of preventive autotransformer, and E_T = tap voltage

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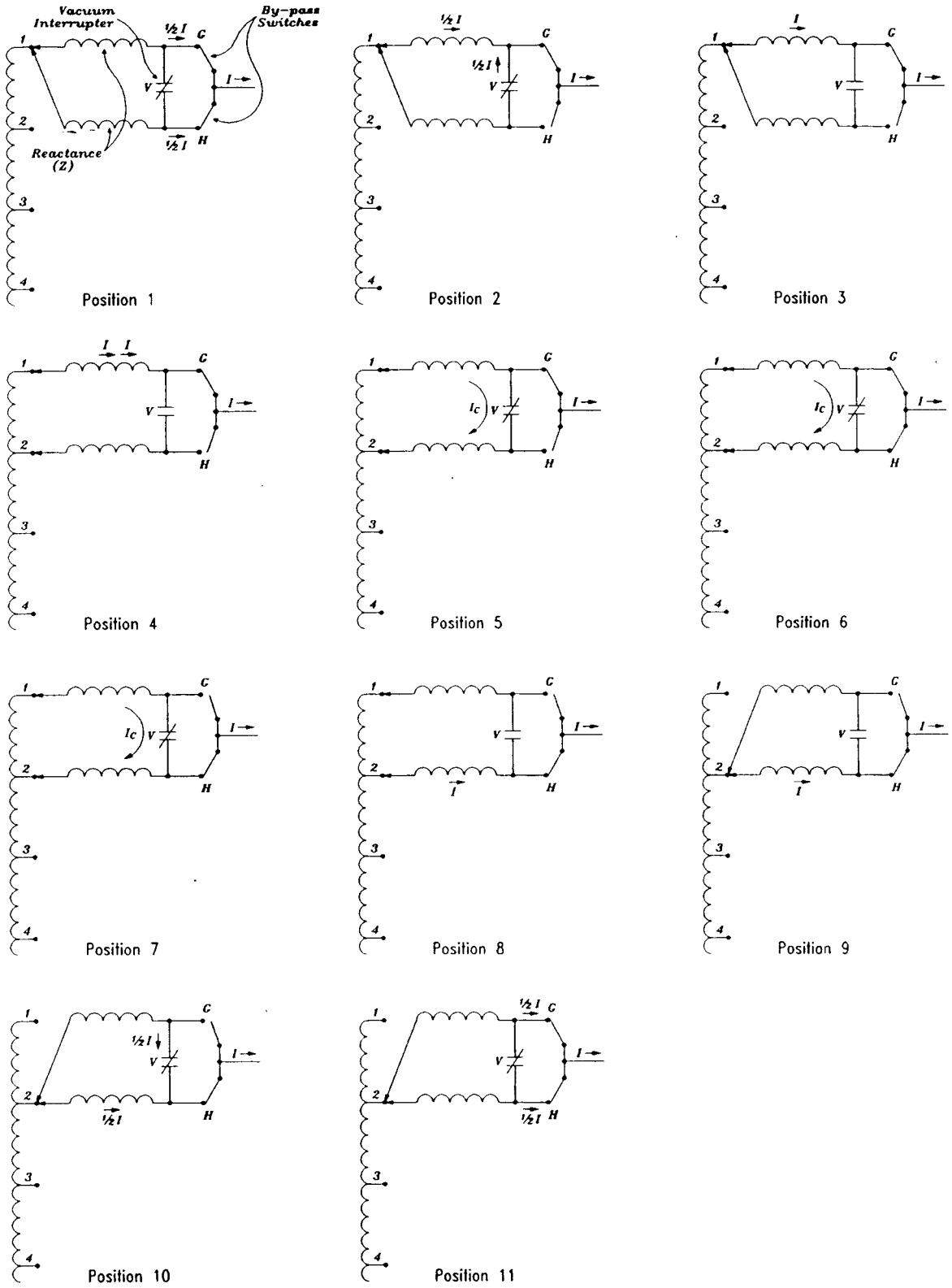

Figure B.5—Operating sequence of LTC with vacuum interrupter and tap selector

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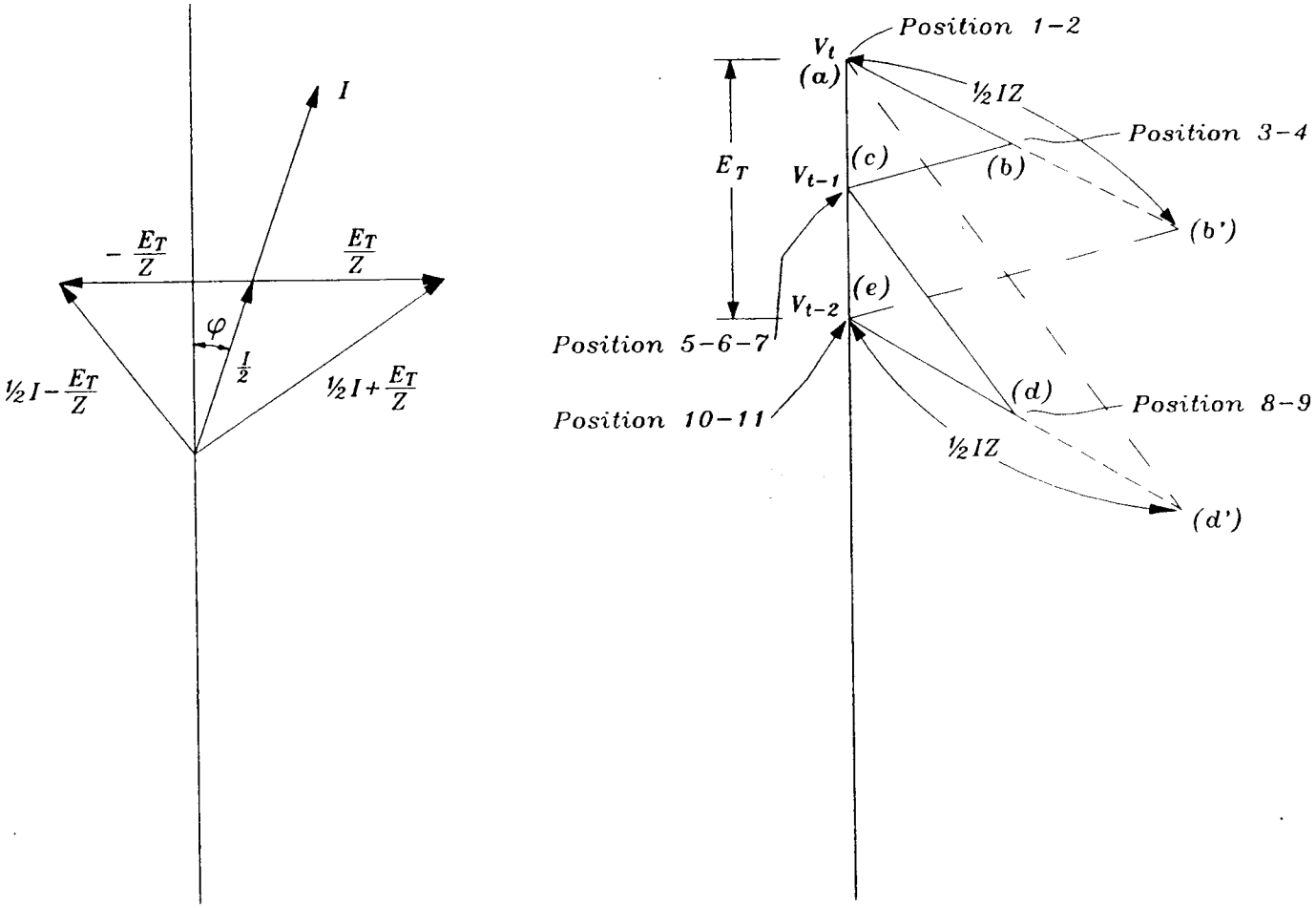

a) Current b) Voltage

NOTES

1—System voltage progression during transition steps for two tap position change operations shown in brackets (a) through (e) in figure b). Positions (a), (c), and (e) represent quiescent operation. Positions (b) and (d) represent momentary operation due to reactance drop.

2—Phasors (a–b´) and (e–d´) represent reactor voltage due to transformer action.

3—Shown for $\left|\frac{E_T}{Z}\right| \cong 0.5|I|$

Figure B.6—Current and voltage phasors for reactance-type LTCs with vacuum interrupter

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Annex C Method of determining the equivalent temperature of the transition resistor using power pulse currents

(Informative)

a) Set up the resistor in an LTC or in a thermally equivalent situation, with suitable arrangements being made to measure the temperature of the resistance material. The thermocouples or thermometers for measuring the temperature of the cooling medium should be positioned 25 mm or more below the lowest point of the resistance material.
b) Measure and record the temperatures of the resistance material and of the cooling medium at the start of the test.
c) The test shall be performed with current I_p, the rms value of which is obtained from the following equation:

$$I_p = 1/\sqrt{k}\left[\sqrt{\sum_{i=1}^{n}(I_i^2 \times t_i)/\sum_{i=1}^{n} t_i}\right]$$

where

I_i is the value of current
t_i is the time during which the I_i is flowing, both quantities being taken as the mean value from the 100 oscillograms recorded at the service duty test according to 6.2.1
k is the coefficient chosen to suit the testing requirements of the resistor, the value selected to be between 5 and 10, bearing in mind that the heating phenomena shall remain adiabatic

The resistor shall be subjected to the above current for a number of times corresponding to one half of one cycle of operation.

The duration of the current application shall be determined from the following equation:

$$t_p = k\sum_{i=1}^{n} t_i$$

The rest period during which current does not flow through the resistor shall be equal to the minimum time interval that can occur between two consecutive operation of the LTC.

To determine the peak temperature, extrapolation of recorded values may be necessary.

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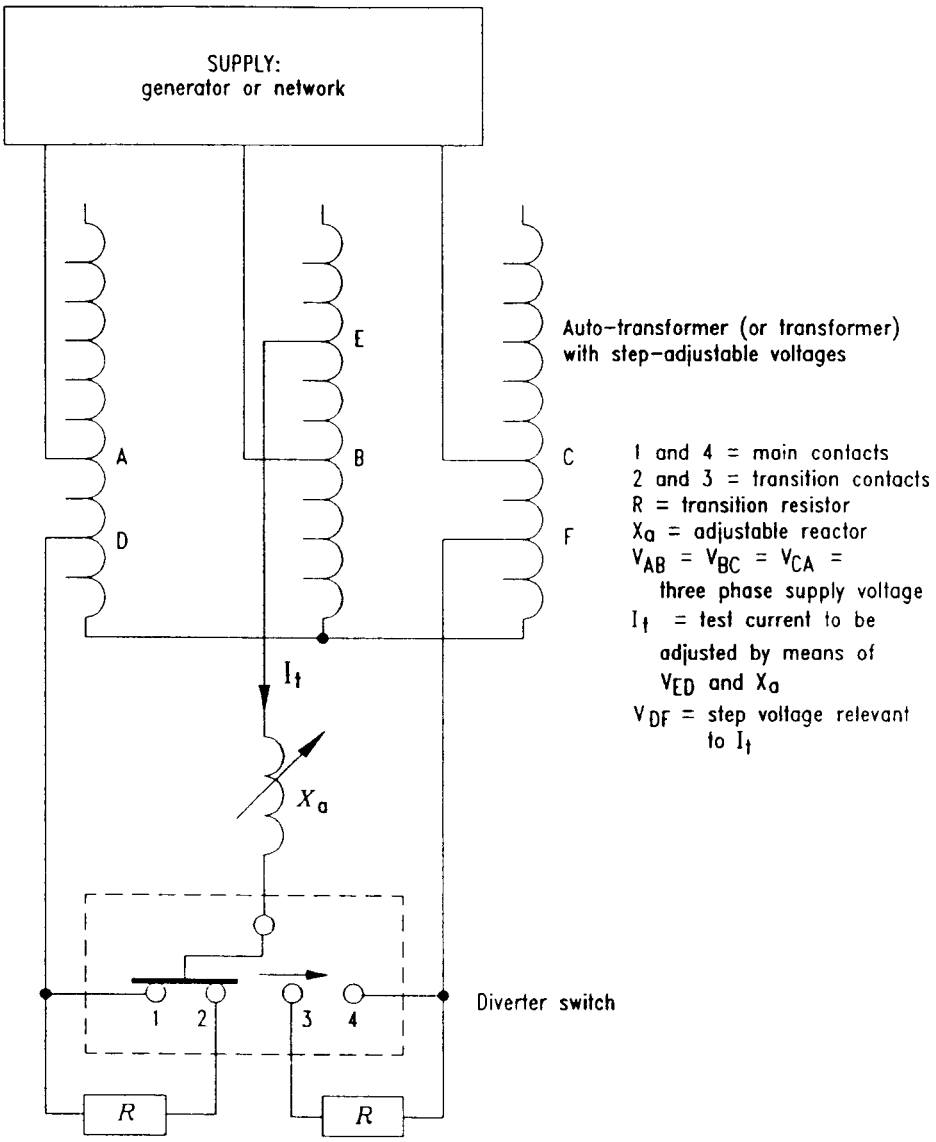
Annex D Simulated circuits for service duty and breaking capacity tests for resistance-type LTCs

(Informative)

Two proven simulated test circuits are shown in figure D.1 (transformer method) and in figure D.2 (resistance method). Refer to 6.2.3. These test circuits are given for information only and the use of different circuits is permissible.



NOTE—In order to meet the requirements of 6.2.1 and 6.2.2 and to take into account the reactances of the circuit and supply, the current and voltage values occurring on the four contacts shall be controlled, and when necessary, suitably adjusted, e.g., by means of variations of the V_{ED}, X_a, and R values and/or of the mutual phase of the voltage phasors.

Figure D.1—Simulated test circuit—Transformer method

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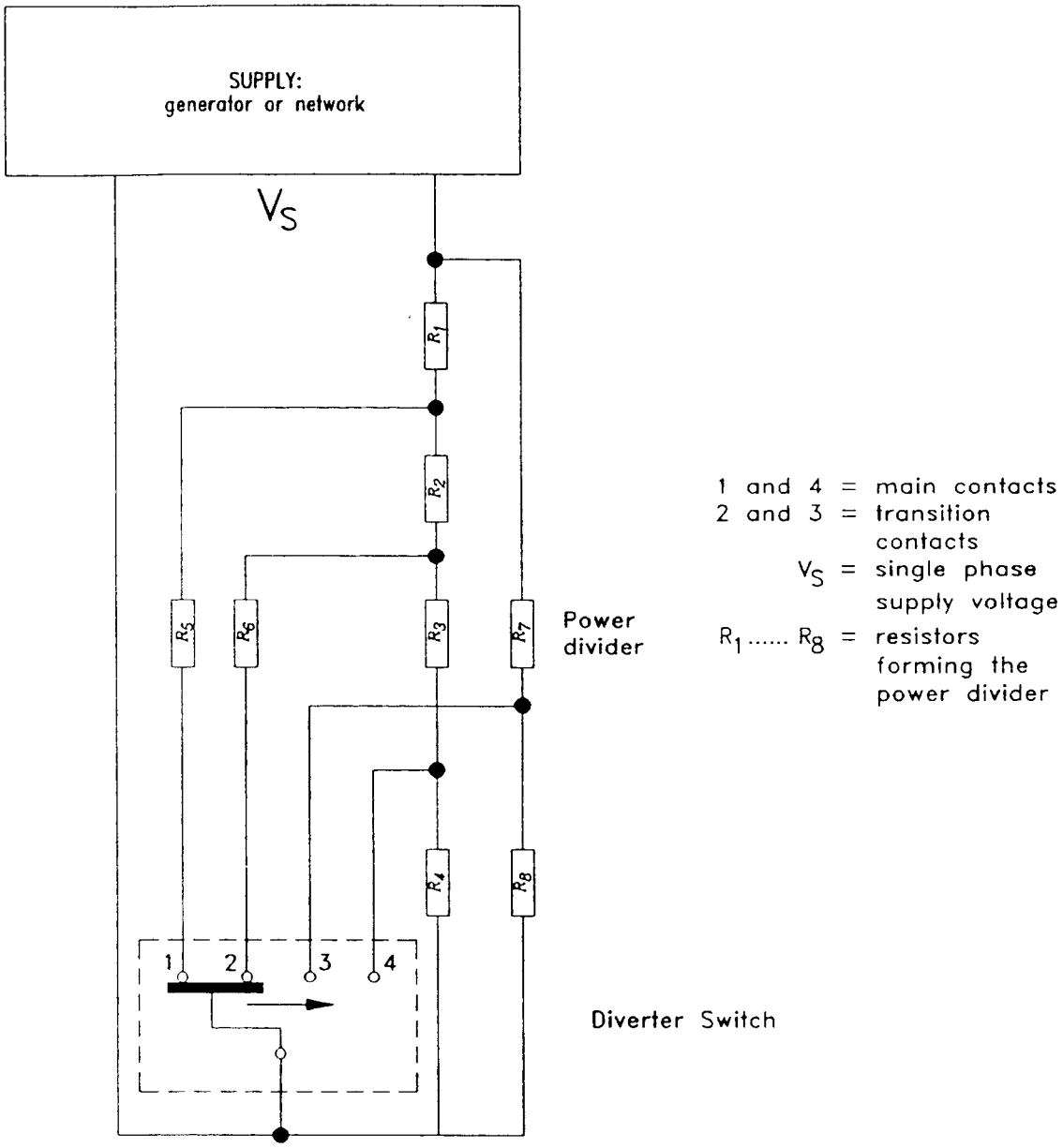

NOTE—The calculated current and voltage values occurring in the whole tap change operation on the four contacts shall be used to calculate the power divider.

Figure D.2—Simulated test circuit—Resistance method

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In the case under consideration (flag cycle on a four contact arcing switch), the equations for the most demanding conditions are the following:

$$R_1 = \frac{V_S(V_S - V_1)}{I_4(V_S - V_4) + V_2 I_2}$$

$$R_2 = \frac{V_S(V_1 - V_2)}{I_4(V_S - V_4) + V_2 I_2} + \frac{V_S}{I_4(V_S - V_4)} \times \frac{V_2 I_2 (V_S - V_2)}{I_4(V_S - V_4) + V_2 I_2}$$

$$R_3 = \frac{V_S}{I_4} \times \frac{V_2 - V_4}{V_S - V_4}$$

$$R_4 = \frac{V_S}{I_4} \times \frac{V_4}{V_S - V_4}$$

$$R_5 = \frac{V_1}{I_1} - \frac{V_1(V_S - V_1)}{I_4(V_S - V_4) + V_2 I_2}$$

$$R_6 = \frac{V_2}{I_2} - \frac{V_2(V_S - V_2)}{I_4(V_S - V_4)}$$

$$R_7 = \frac{V_S}{I_3}$$

$$R_8 = \frac{V_3}{I_3} \times \frac{V_S}{V_S - V_3}$$

where

I_1 and I_2 are the switched current rms values of contacts 1 and 2
V_1 and $V_2$are the recovery voltage rms values of contacts 1 and 2
V_3 and $V_4$are the applied voltage rms values of contacts 3 and 4
I_3 and I_4 are the making current rms values of contacts 3 and 4

In order to meet the requirements of 6.2.1 and 6.2.2 and to take into account the impedance of the supply, the current and voltage values occurring on the four contacts shall be controlled and, when necessary, adjusted by means of small variations or the R_1 ohmic value.

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Annex E Tutorial information on LTC application

(Informative)

E.1 Application of LTC to transformers

E.1.1 Basic arrangements of tapped windings

A change of the ratio is accomplished by adding or subtracting turns to either the primary or secondary winding. Three basic arrangements are shown in figure E.1. Depending on system and design parameters of the transformer arrangement a), b), or c) can be applied.

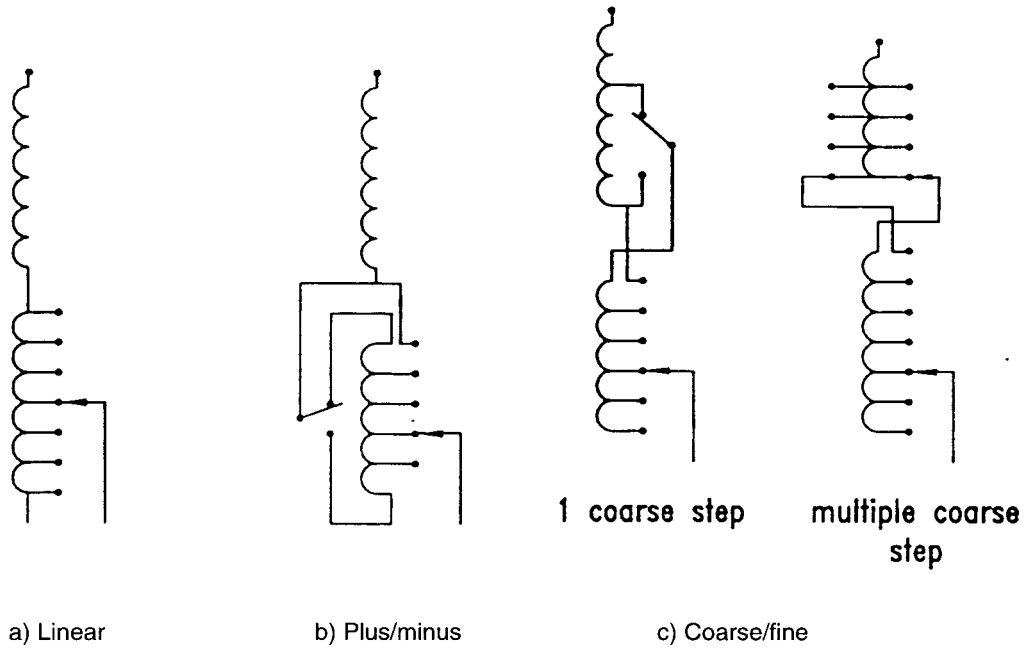

Figure E.1—Basic arrangements of tapped windings

On power transformers the linear arrangement shown in figure E.1a) is generally applied for a moderate regulating range up to a maximum of 20%.

If a reversing change-over selector is applied as shown in figure E.1b), the tapped winding voltage can be added or subtracted from the main winding voltage in which case the regulating range can be increased or the number of taps on the tapped winding can be reduced. However, in the position with the minimum number of effective turns the total winding is in the circuit which causes maximum load losses in the transformer.

Figure E.1c) shows the coarse/fine arrangement. The advantage of this arrangement is that load losses are lower at the tap position with the minimum number of turns. From the dielectric point of view, however, this arrangement requires a more complicated winding layout. The multiple coarse step arrangement lends itself to large regulating ranges as used on rectifier and furnace transformers.

Depending on system and operating requirements, the basic winding arrangements shown in figure E.1 are applied to two winding transformers as well as to voltage and/or phase angle regulating transformers.

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On two winding wye-connected power transformers, a very common winding arrangement has the regulation applied at the neutral end as shown in figure E.2.

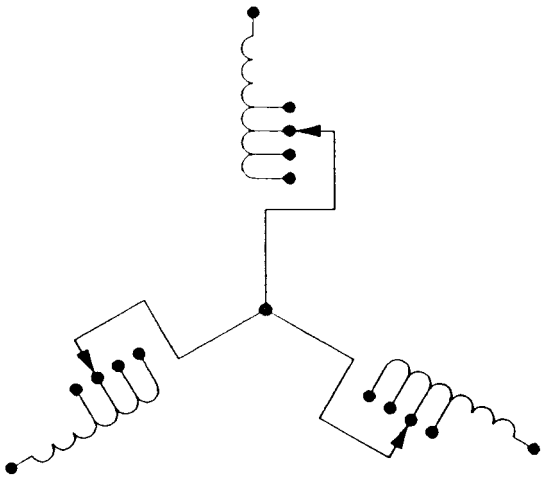

Figure E.2—LTC in wye-connected winding

For turns ratio control in delta-connected windings, arrangements as shown in figure E.3 are applied. The choice between figures E.3a), b), or c) depends on the highest system voltage and on such parameters as transformer impedance, insulation level, and the particular LTC used.

The winding arrangement in figure E.3a) requires a three-phase LTC with insulation between phases dictated by the highest system voltage applied. The winding arrangement shown in figure E.3c) reduces the dielectric stresses of the phase-to-phase insulation of the LTC to half of the highest system voltage. The winding arrangement of figure E.3b) is advantageous because it allows the use of one two-pole and one single-pole LTC. The winding arrangements shown in figures E.3a) and c) can be used if three single pole line-end LTCs are applied.

For autotransformers the winding arrangements of figure E.4 are used. Autotransformers are always wye-connected, however, different arrangements are used to affect turns ratio control. Depending on the regulating range, system conditions, and weight and size restrictions, the most appropriate arrangement is chosen.

The advantage of the arrangement shown in figure E.4a) is that the tapped winding is at the neutral end and can be designed for graded insulation, thereby permitting a three-phase neutral end LTC to be used.

For autotransformers on systems where, predominantly, the low voltage is regulated, the arrangements shown in figures E.4a), b), d), and e) are used. Using arrangement in figure E.4d), the regulating range can be doubled.

If a higher variation in the high voltage than in the low voltage is expected for autotransformers, the arrangement of figure E.4c) can be used. The advantage is the lower through current of the LTC and, therefore, the possibility of using an LTC with a lower current rating.

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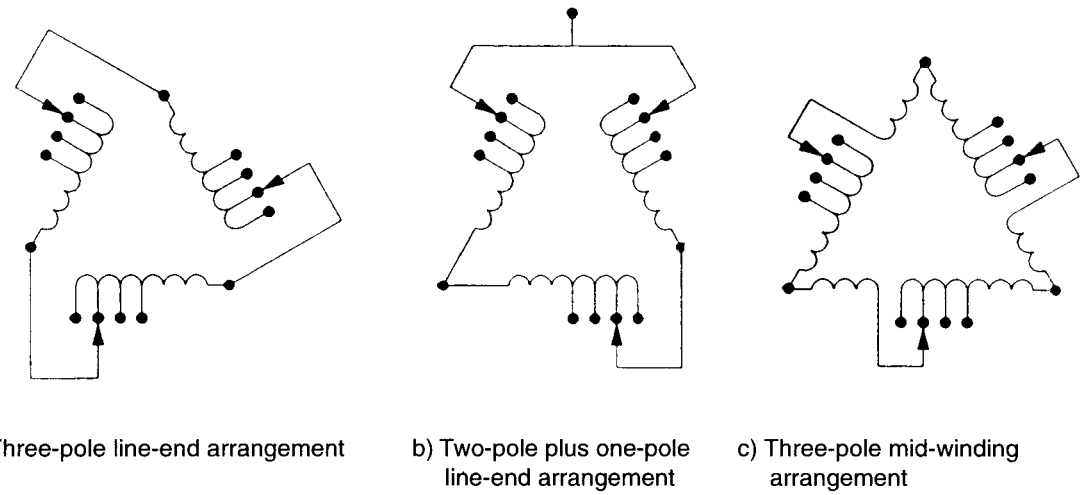

Figure E.3—LTCs in delta-connected windings

The winding arrangement shown in figure E.4e) has been used on autotransformers where the low voltage exceeds the voltage class of available LTCs. The same arrangement is often used on two winding or furnace autotransformers in order to adapt the characteristics of the intermediate circuit to standard LTC ratings.

E.2 Design concepts and functional description of LTCs

In order to change taps under load, two basic methods have been developed and are in use today—the reactance switching method and the resistance switching method. Both methods have been incorporated into reliable LTCs and are described below.

In order to change the turns ratio of a transformer under load, two design concepts are used. The first consists of an arcing switch, and a tap selector, and the second consists of an arcing tap switch, which combines the function of the arcing switch and of the tap selector into one device. Both concepts can be used with or without a change-over selector.

E.2.1 Resistance-type LTCs

The resistance method is illustrated by the following examples. Figure E.5 shows a LTC with an arcing switch and a tap selector, and figure E.6 with an arcing tap switch.

Using the arcing switch and tap selector concept, the tap change operation is accomplished in two steps. The tap adjacent to the one in service is pre-selected by the tap selector without the flow of current. The arcing switch then transfers the current from the tap in service to the pre-selected one. The complete sequence is actuated by the motor-drive mechanism, which is comprised of a drive motor, reduction gear, control, and safety devices. The motor-drive mechanism actuates the tap selector by geneva gears and simultaneously winds up a stored-energy spring mechanism that actuates the arcing switch on completion of the wind-up process. This is accomplished in a rapid fashion resulting in a transfer time of approximately 40 ms to 60 ms depending on type and design. The arcing switch operating cycle is carried out as soon as the spring is released, and is independent of the motor-drive mechanism. The transition resistors are inserted into the circuit for a loading time of about 20 ms to 30 ms depending, again, on type and design. The total time for one tap change between initiation of the motor drive mechanism to the completion of the tap change operation amounts to 2 s to 10 s, depending on manufacturer.

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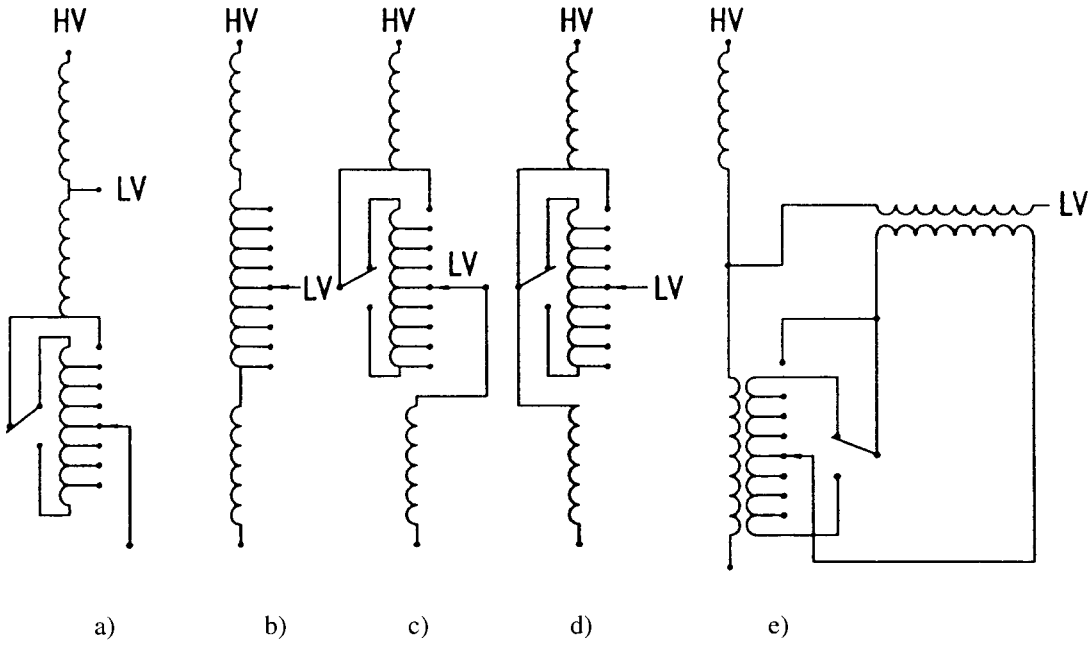

Figure E.4—LTCs in autotransformers

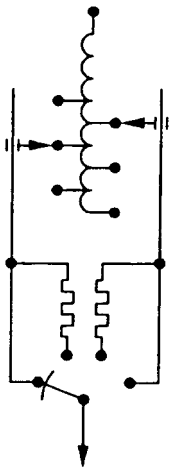

Figure E.5—Arcing switch—Tap selector concept—Resistance-type LTC

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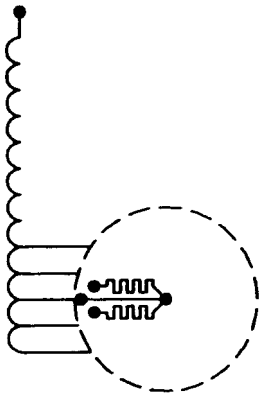

Figure E.6—Arcing tap switch concept—Resistance-type LTC

Figure E.7 shows the operating sequence described above. For this example, the so-called “flag-cycle” is used for the arcing switch.

The tap selector sequence of operation shown in figure E.7 a), b), and c) is a relatively slow process actuated by the motor-drive mechanism in approximately 2 s to 6 s. The arcing switch operation shown in figure E.7d) through g) is carried out in a rapid action actuated by the stored-energy spring within 40 ms to 60 ms.

The arcing tap switch carries out the tap change from the tap in service to the adjacent tap in one step and is illustrated in figure E.8. As before, the motor-drive mechanism winds up a stored-energy spring which, after its release, actuates the moveable contact system of the arcing tap switch in rapid action from one tap to the next one. Depending on the type and design, the actual transfer time is in the order of 40 ms to 180 ms.

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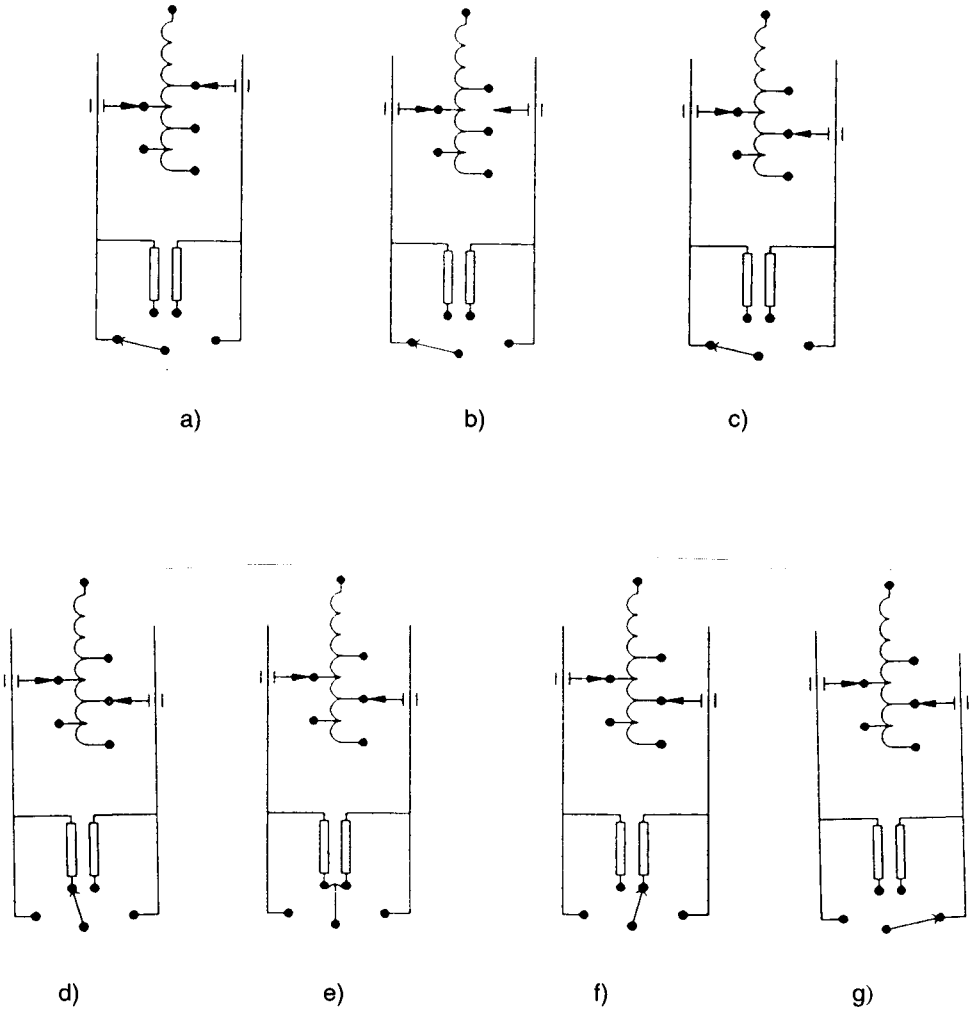

Figure E.7—Operating sequence of arcing switch and tap selector—Resistance-type LTC

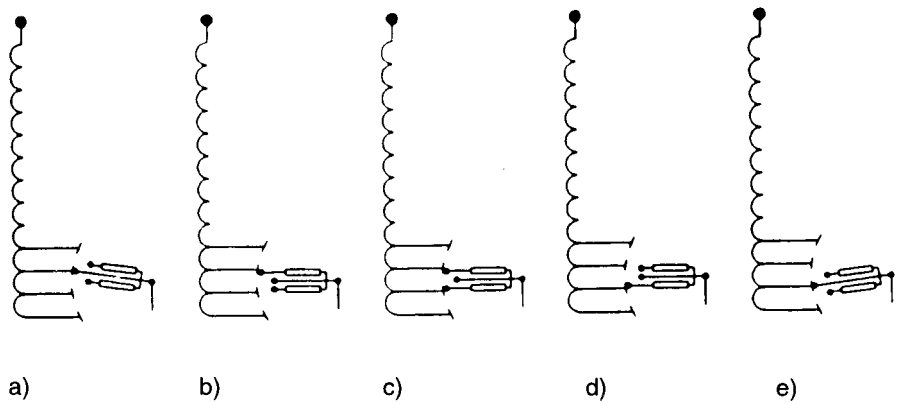

Figure E.8—Operating sequence of arcing tap switch—Resistance-type LTC

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E.2.2 Reactance-type LTCs

Compared to the resistance-type LTC, the reactance-type LTC requires only half the number of taps of the regulating winding for the equivalent number of service positions because the bridging position is also a service position.

For reactance-type LTCs, the following three types of switching are used:

a) Arcing tap switch
b) Arcing switch with tap selector
c) Vacuum interrupter

The operating sequences for these three types are shown in annex B (see figures B.1, B.3, and B.5).

Annex F Bibliography

(Informative)

[B1] IEC 214 (1989), On-load tap-changers.

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