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TECHNICAL REPORT

colour inside

Explanation of the mathematical addition of working voltages, insulation between circuits and use of PELV in TC 34 standards

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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EXPLANATION OF THE MATHEMATICAL ADDITION OF WORKING VOLTAGES, INSULATION BETWEEN CIRCUITS AND USE OF PELV IN TC 34 STANDARDS

FOREWORD

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IEC TR 63139, which is a Technical Report, has been prepared by IEC technical committee 34: Lamps and related equipment.

The text of this Technical Report is based on the following documents:

DTR	Report on voting
34/415/DTR	34/493A/RVDTR

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

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

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

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- amended.

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INTRODUCTION

This document provides background information to the following subjects being introduced into IEC TC 34 standards to cover new technologies associated with the use of LED light sources and controllable products.

This document consists of the following subdivisions:

Clause 4 – Mathematical addition of working voltages;

Clause 5 – Insulation between circuits;

Clause 6 – Use of protective extra low voltage (PELV);

Clause 7 – Insulation between LV supply and control line conductors.

EXPLANATION OF THE MATHEMATICAL ADDITION OF WORKING VOLTAGES, INSULATION BETWEEN CIRCUITS AND USE OF PELV IN TC 34 STANDARDS

1 Scope

This document is related to the insulation coordination in TC 34 standards and provides explanations on mathematical addition of working voltages, insulation between circuits, use of protective extra low voltage (PELV) and insulation between LV supply and control line conductors in order to cover new technologies associated with the use of LED light sources and controllable products.

It describes in which way the addition of supply voltages and working voltages can be arranged for an assessment of the electrical insulation requirements (e.g. creepage distances and clearances) in a system if a first failure occurs.

Furthermore the actual failure scenarios given in IEC 60598-1:2014 and IEC 60598-1:2014/AMD1:2017, Annex X and IEC 61347-1:2015, Clause 15 are explained in greater detail and the rationale behind the protective requirement for each situation is given (e.g. possible LV primary to ELV secondary does not lead to an overburden of the insulation in the second circuit).

This document also describes the possibility to increase immunity and reliability of electronic circuits, used in combination with LEDs, with the use of PELV and the associated safety consequences for this system.

The insulation between LV supply and control line conductors is also important and this document explains why this is an essential safety consideration for a complete installation system.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

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4 Mathematical addition of working voltages

Insulation requirements between live parts and accessible conductive parts as function of the controlgear input/output insulation classification and the insulation class of the luminaire are given in IEC 60598-1:2014, Table X.1 and IEC 61347-1:2015, Table 6.

Insulation requirements in TC 34 standards are based on a hazard assessment with the assumption that a certain failure will occur.

The required insulation is normally based on the working voltage U_{OUT}, but in some specific failure cases when the basic insulation between supply and output of a controlgear fails, the supply voltage should be added to U_{OUT}. For controlgear with double or reinforced insulation between primary (U_{SUPPLY}) and secondary (U_{OUT}) this type of failure is not expected.

In case of failure of the basic insulation within the controlgear the following assumptions are made:

- there is an increased output voltage,
- the luminaire remains working, and the increased voltage is present for a time long enough to create a conduction track across the insulation (known as tracking).

For 50/60 Hz transformers inside the controlgear, this failure condition results in the addition of the voltages that can be calculated by the simple summation of the two values. In electronic controlgear this situation may result in a more complex summation due to the complexity of the oscillating circuit that may influence the result.

The best method to check the output voltage in case of insulation failure is to measure the output voltage directly on a sample of controlgear with the fault simulated. The failure of the insulation and the output voltage should be measured against earth (or zero potential). This method has been found not to be practical due to the following reasons:

- differing supply conditions (voltage/frequency);
- difficulty in simulating exactly the failure condition;
- difficulty in making accurate and reproducible measurements.

For the above mentioned reasons the mathematical calculation of the sum of the voltages has been found to be more appropriate, reproducible and easy to calculate, even if the result may in some cases be lower than the real measurement. Designing and testing the insulation properties of the output circuit with an increased voltage value is considered as a necessary safety provision to cover this first failure condition which can occur inside basic insulated controlgear.

The approximation given by the mathematical calculation is considered to provide sufficient severity, compared to the possible practical failure voltage, to ensure the safety of the product through its lifetime. With the selected formula most of the expected failure cases are covered. Higher voltages occurring in very rare cases will not have any serious impact.

The formulas to be used for combining the input and output voltages of the controlgear, with basic insulation between supply and output, are given in Table 1.

Table 1 – Addition of voltages

U_{supply}	U_{OUT}	Phase relationship	Voltage calculation for insulation design
AC	AC	Same frequency and no phase shift	$U = U_{AC1} + U_{AC2}$
AC	AC	Same frequency and with phase shift	$U = \sqrt{U_{AC1}^2 + U_{AC2}^2 + 2\, U_{AC1}\, U_{AC2} \cos\varphi}$
AC	AC	Different frequency	$U = \sqrt{U_{AC1}^2 + U_{AC2}^2}$
AC	DC	No phase shift	$U = \sqrt{U_{AC}^2 + U_{DC}^2}$
DC	AC	No phase shift	$U = \sqrt{U_{AC}^2 + U_{DC}^2}$
DC	DC	No phase shift	$U = U_{DC1} + U_{DC2}$
NOTE 1 Voltages in the table are RMS values.			
NOTE 2 The AC and DC calculation is typical for LED applications.			

Figure 1 shows the simulation of the possible fault between input and output terminals (red line) with the mathematical calculation providing the expected output voltage that may occur.

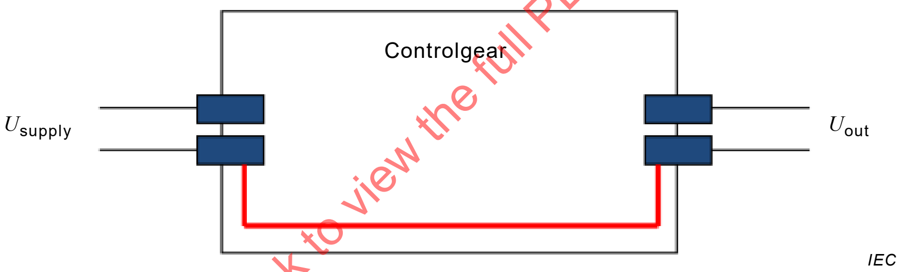


Figure 1 – Input/output failure simulation

For background information, the formula $U = \sqrt{U_{AC}^2 + U_{DC}^2}$ (line 4 of Table 1) for the specific case of a combination of an AC and DC voltage is derived from the following Formulas (1) to (5). It may be regarded as a showcase for any of the formulas from Table 1.

U is the RMS value (U_{RMS}) of the voltage $u(t)$

$$U = U_{RMS} = \sqrt{\overline{u^2(t)}} \tag{1}$$

In the particular case given, $u(t)$ consists of an AC (sinusoidal) part with peak voltage U_1 and frequency ω and a DC part U_{DC}. It can be derived that

$$U^2 = \overline{u^2(t)} = \frac{\int_0^T u^2(t)\,dt}{T} = \frac{\int_0^T (U_1 \sin(\omega t) + U_{DC})^2\,dt}{T} =$$

$$\frac{U_1^2}{T}\int_0^T \sin^2(\omega t)\,dt + \frac{2U_1U_{DC}}{T}\int_0^T \sin(\omega t)\,dt + \frac{1}{T}\int_0^T U_{DC}^2\,dt \tag{2}$$

Evaluating this integral yields

$$U^2 = \frac{1}{2}\frac{U_1^2}{T}\left(t - \frac{1}{\omega}\sin(\omega t)\cos(\omega t)\right)\Big|_{t=0}^{t=T} - \frac{2\,U_1 U_{\mathrm{DC}}}{T\omega}\cos(\omega t)\Big|_{t=0}^{t=T} + \frac{1}{T}U_{\mathrm{DC}}^2 T \qquad (3)$$

$$U^2 = \frac{U_1^2}{2} + U_{\mathrm{DC}}^2 \qquad (4)$$

And thus,

$$U = \sqrt{\frac{U_1^2}{2} + U_{\mathrm{DC}}^2} = \sqrt{U_{\mathrm{AC}}^2 + U_{\mathrm{DC}}^2} \qquad (5)$$

5 Insulation between circuits

5.1 General

New requirements have been added to those in IEC 60598-1 and IEC 61347-1 concerning the requirements for insulation between different types of circuit and to conductive accessible parts. For insulation requirements between active parts and accessible conductive parts and examples of controlgear with different insulation systems see Table 2 and Figure 2.

In case of a failure in the basic insulation, with the assumptions made in Clause 4, between the supply voltage and the output circuit, the insulation in the second circuit will have an increase chance of failing; this can be regarded as a follow up failure, which is by definition still a single fault. This means that the insulation in the secondary circuit should be able to cope with this higher voltage.

The following explanations provide information regarding the technical rationale associated with these requirements.

The numbers in brackets (1) to (18) detailed in Table 2 refer to the content of IEC 60598-1:2014, Table X.1 and IEC 61347-1:2015, Table 6. A comparison with possible failure conditions is shown in Figures 3 to 7. Each combination has been evaluated and the consequences are listed in 5.3 with the requirements for the insulation which is needed for each numbered case.

5.2 Insulation requirements between active parts and accessible conductive parts

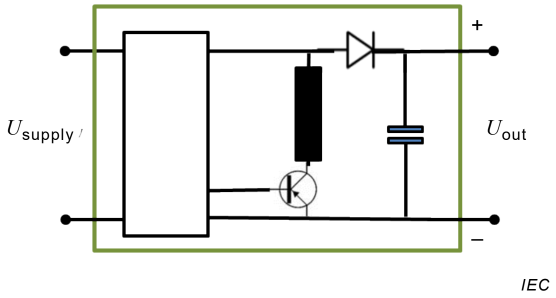
Explanations to the application of the insulation requirements are given in Table 2 and Figure 2.

Table 2 – Insulation requirements between active parts and accessible conductive parts

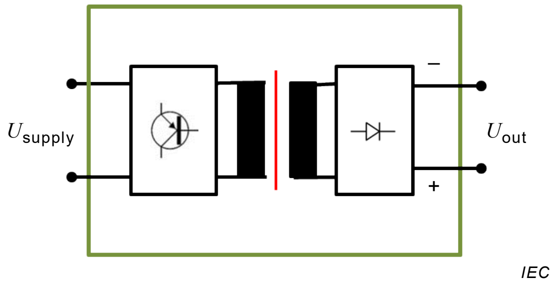
Controlgear		Required insulation between active parts and accessible conductive parts		
Insulation between LV supply and secondary circuits	Output voltage	**Class I** Insulation of accessible earthed conductive parts	**Class II** Insulation of one accessible conductive part or more than one with equipotential bonding	**Class II** Insulation of more than one accessible conductive part without equipotential bonding
none	$U_{out} > LV_{supply}$	**(1)** Basic insulation complying with U_{out}	**(7)** Double or reinforced insulation complying with U_{out}	**(13)** Double or reinforced insulation complying with U_{out}
	$U_{out} \leq LV_{supply}$	**(2)** Basic insulation complying with LV_{supply}	**(8)** Double or reinforced insulation complying with LV_{supply}	**(14)** Double or reinforced insulation complying with LV_{supply}
basic	Voltages above ELV	**(3)** Basic insulation complying with U_{out}	**(9)** Supplementary insulation complying with U_{out} + LV_{supply}	**(15)** Insulation has to fulfil the higher requirement of a) or b): a) Supplementary insulation complying with U_{out} + LV_{supply} b) Double or reinforced insulation complying with U_{out}
	ELV (FELV)	**(4)** Basic insulation complying with U_{out}	**(10)** Supplementary insulation complying with U_{out} + LV_{supply}	**(16)** Supplementary insulation complying with U_{out} + LV_{supply}
double or reinforced	Voltages above ELV	**(5)** Basic insulation complying with U_{out}	**(11)** Basic insulation complying with U_{out}	**(17)** Double or reinforced insulation complying with U_{out}
	ELV (SELV)	**(6)** Basic insulation complying with U_{out} See also requirements in IEC 60598-1:2014 and IEC 60598-1:2014/ AMD1:2017, Sections 8, 10 and 11	**(12)** Basic insulation complying with U_{out} See also requirements in IEC 60598-1:2014 and IEC 60598-1:2014/ AMD1:2017, Sections 8, 10 and 11	**(18)** Basic insulation complying with U_{out} See also requirements in IEC 60598-1:2014 and IEC 60598-1:2014/ AMD1:2017, Sections 8, 10 and 11

NOTE 1 The content of this table is identical to that of IEC 60598-1:2014, Table X.1. The corresponding Table 6 in IEC 61347-1:2015 is technically equivalent.

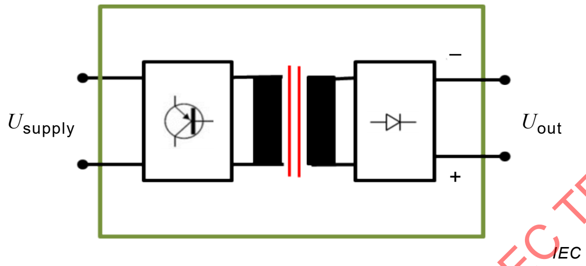
NOTE 2 The numbers in brackets are used as references in Table 3.



a) Controlgear without insulation between U_{supply} and U_{out}



b) Controlgear with basic insulation



c) Controlgear with doubled or reinforced insulation

NOTE One red line between the primary and secondary winding of the transformer stands for "basic insulation" and two red lines for "doubled or reinforced insulation".

Figure 2 – Examples of controlgear with different insulation systems

5.3 Possible failure conditions

Figures 3 to 7 shown detailed various failure conditions encountered in circuits for LED products.

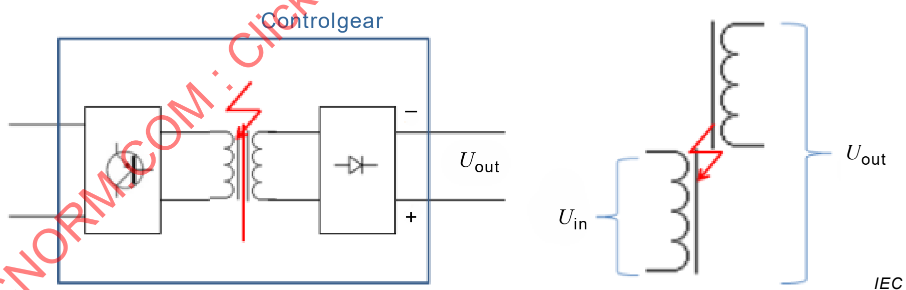


Figure 3 – Condition A: failure between input and output circuits

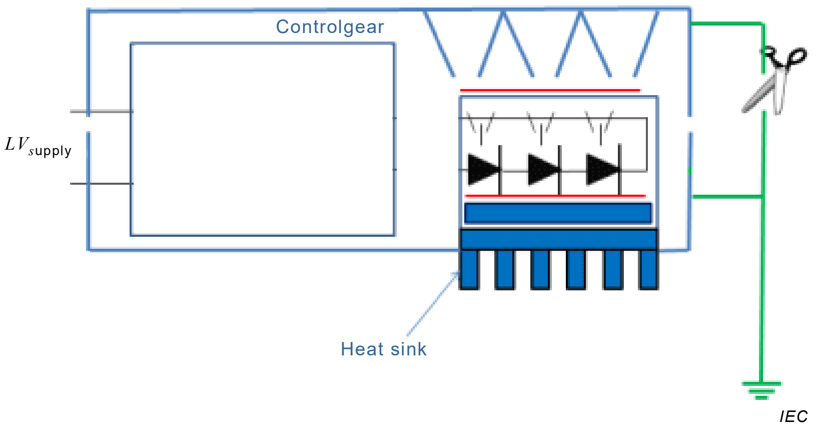


Figure 4 – Condition B: earth failure/equipotential bonding failure (interruption of the connection continuity)

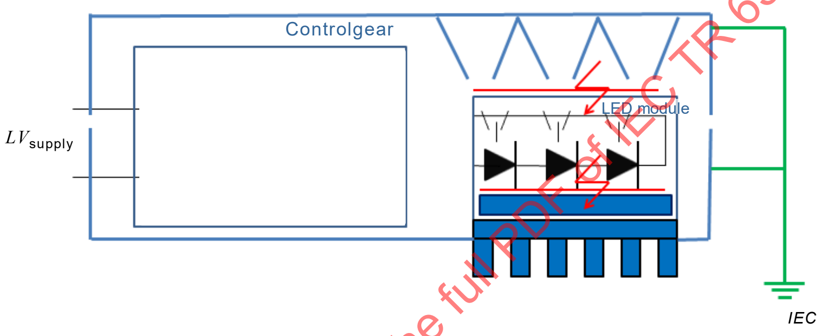


Figure 5 – Condition C: insulation failure between output circuits and accessible earthed metal part

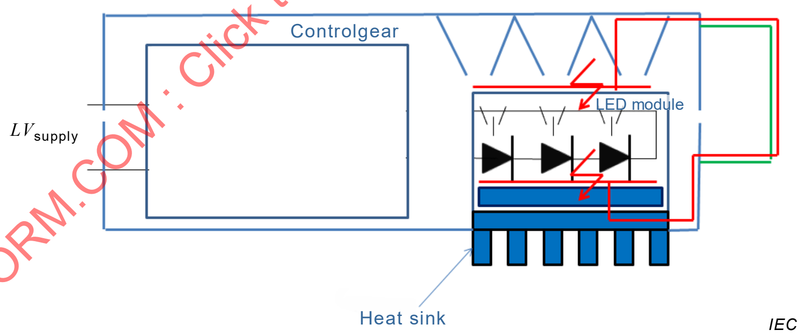


Figure 6 – Condition D: insulation failure between output circuit to conductive parts which are connected together (equipotential bonding)

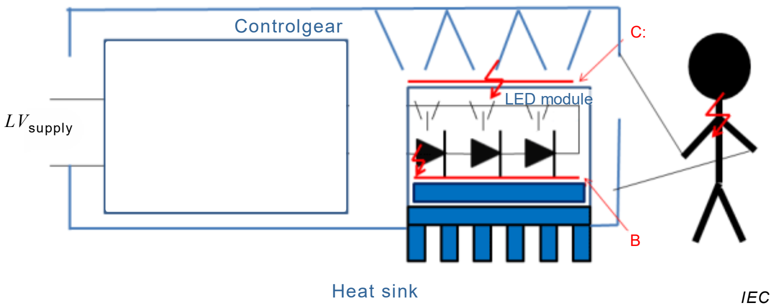


Figure 7 – Condition E: insulation failure between output circuit and different conductive parts not connected together (no equipotential bonding)

6 Circuits analysis

Table 3 provides an overview of the possible hazard related to the failure conditions described in 5.3. Each combination has been evaluated and the consequences are listed with the requirements for the insulation which is needed for each numbered case in Table 2.

Table 3 – Circuit analysis overview

Table 2 references	Failure conditions (see 5.3)	Consequential circuit analysis
(1) and (2)	A	NA
	B	The second line of defence is the basic insulation.
	C	The second line of defence is the earth connection.
	D	NA
	E	NA
(3) and (4)	A	The second line of defence is the earth connection. (Consequential failures due to high voltage also protected by earth connection).
	B	The second line of defence is the basic insulation. (Otherwise different conductive parts which become unbounded may have different potentials).
	C	The second line of defence is the earth connection.
	D	NA
	E	NA
(5)	A	NA (There is double or reinforced insulation).
	B	The second line of defence is the basic insulation. (Otherwise different conductive parts which become unbounded may have different potentials).
	C	The second line of defence is the earth connection.
	D	NA
	E	NA

Table 2 references	Failure conditions (see 5.3)	Consequential circuit analysis
(6)	A	NA (There is double or reinforced insulation).
	B	Basic insulation required for SELV voltages above the limits defined by IEC 60598-1:2014, Section 8.
	C	Basic insulation required for SELV voltages above the limits defined by IEC 60598-1:2014, Section 8.
	D	NA
	E	NA
(7) and (8)	A	NA
	B	Double or reinforced insulation provides safety.
	C	NA
	D	Double or reinforced insulation provides safety.
	E	NA
(9) and (10)	A	The second line of defence is supplementary insulation.
	B	The second line of defence is supplementary insulation.
	C	NA
	D	The second line of defence is the basic insulation in the controlgear.
	E	NA
(11)	A	NA (There is double or reinforced insulation).
	B	The second line of defence is basic insulation.
	C	NA
	D	The second line of defence is equipotential bonding.
	E	NA
(12)	A	NA (There is double or reinforced insulation).
	B	Basic insulation. Required for SELV voltages above the limits defined by IEC 60598-1:2014, Section 8.
	C	NA
	D	Basic insulation required for SELV voltages above the limits defined by IEC 60598-1:2014, Section 8.
	E	NA
(13) and (14)	A	NA
	B	NA
	C	NA
	D	NA
	E	Double or reinforced insulation provides safety.
(15)	A	The second line of defence is supplementary insulation.
	B	NA
	C	NA
	D	NA
	E	Double or reinforced insulation provides safety. (After the first failure of insulation no change of operation may be noticed. In case of further failure, the two conductive parts could show different potential).

Table 2 references	Failure conditions (see 5.3)	Consequential circuit analysis
(16)	A	The second line of defence is supplementary insulation.
	B	NA
	C	NA
	D	NA
	E	The second line of defence is the basic insulation in the controlgear. (ELV voltage cannot create dangerous voltages between different conductive parts).
(17)	A	NA (There is double or reinforced insulation.)
	B	NA
	C	NA
	D	NA
	E	Double or reinforced insulation provides safety. (After the first failure of insulation no change of operation may be noticed. In case of further failure, the two conductive parts could show different potential).
(18)	A	NA (There is double or reinforced insulation).
	B	NA
	C	NA
	D	NA
	E	Basic insulation required for SELV voltages above the limits defined by IEC 60598-1:2014, Section 8.
NOTE 1 The failure of functional insulation is not considered as single “fault condition” so functional insulation cannot be considered as first or second line of defence. NOTE 2 NA = Not applicable as the fault condition is not expected.		

7 Use of PELV

7.1 General

With the use of electronic circuits in combination with LEDs, the immunity and reliability aspects become more important.

LEDs are very sensitive to voltages that can damage the PN junction. Mains voltage transients and electrostatic discharge may produce voltages far above 1 kV.

One solution to limit the risk of damaging voltages is to establish a grid where all parts are connected together (circuit and body of the luminaire). In this way the LEDs are more protected and are not subjected to extra voltages. The connection of ELV parts to earth provides such a situation.

In the wiring rules standard, IEC 60364-4-41, and in other standards (e.g. transformer standard IEC 61558-1), connecting an ELV circuit to earth is allowed. This is called protective extra low voltage (PELV).

7.2 Characteristics of PELV (protective extra low voltage) circuits

In IEC 61140:2016, 3.26.2, a PELV system is defined as "an electrical system in which the voltage cannot exceed the value of ELV

- under normal conditions, and
- under single-fault conditions, except earth faults in other electric circuits."

Taking into consideration the requirements of IEC 61140 and IEC 60364-4-41, the following requirements are given:

- limitation of voltage in the PELV system to the upper limit of voltage Band I, 50 V AC or 120 V DC (see IEC 60449), and
- protective separation (for example double or reinforced insulation) of the PELV system from all circuits other than SELV and PELV circuits, and basic insulation between the SELV or PELV system and other SELV or PELV systems.

In PELV circuits one pole is connected to earth for functional reasons. This requirement is the difference between SELV and PELV. SELV circuits should not be connected to earth while PELV allows this connection. Additional requirements have to be taken into consideration for the safety of the products using PELV which are explained below.

To avoid any dangerous situation, the connection between the PELV circuit and the protective earth (wire or PCB track) should fulfil the requirements for functional earth.

Controlgear providing SELV can be used for PELV systems with appropriate management of voltage and accessibility limits (see below) by the luminaire manufacturer.

7.3 Requirements for PELV circuits in addition to SELV

7.3.1 Voltage limitations

As indicated above, PELV circuits have one pole connected to earth. This influences the allowed accessibility of the circuits. For SELV circuits, under certain voltage limitation, it is allowed to touch both poles of the SELV circuit; for PELV circuits the accessibility of the pole not connected to earth may create additional risks. In normal use the earth potential may be raised by the failure of other appliances connected to the same supply network. Earthed circuits can reach voltage levels up to 50 V before any circuit protection operates and this should be taken into consideration. This means that, in practice, the pole connected to earth may always be accessible while the other pole may have a potential which can create a danger due to the sum of the voltages.

IEC product and installation standards specify different voltage limits for accessibility due to the use of the voltage, its application, and risk. If an insulation failure occurs between live conductors and earth, the voltage of the earthed parts of the building installation may have an increased potential.

Figure 8 and Figure 9 illustrate the two possible situations.

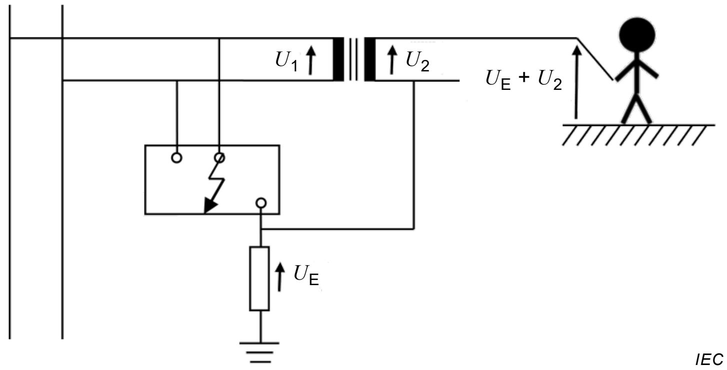


Figure 8 – PELV circuit in the most adverse condition (touch voltage is the sum of U_E and U_2)

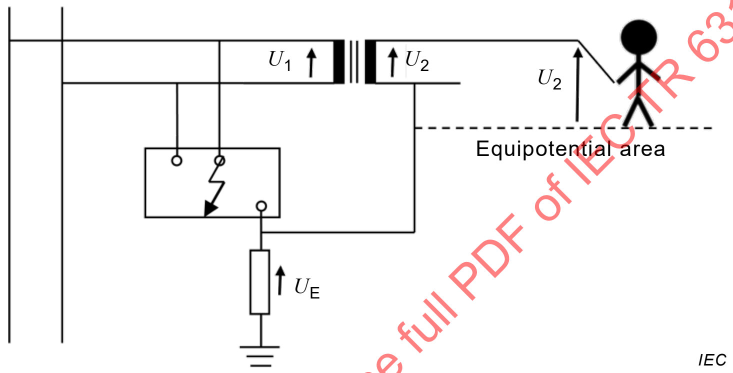


Figure 9 – PELV circuit with a person located in an equipotential location (touch voltage is U_2 only)

For luminaires and controlgear, the location where the product will be installed is normally not known, so the voltage limits for the second pole accessibility have been selected from IEC 60364-4-41, taking into account the most unfavourable conditions (see IEC 60364-4-41:2005, 414.4.5): 12 V AC or 30 V ripple free DC under both wet and dry conditions.

7.3.2 Touch current and protective conductor current

In the horizontal standards IEC 61140 and IEC 60364-4-41, the ELV connection to earth is only allowed for functional purposes. This is because the PELV circuit cannot guarantee the current carrying capability to handle the high fault currents that could arise when an insulation failure in this circuit or other circuits occurs. This explains why double or reinforced insulation from supply is also required.

The connection to the earth circuit for functional reasons may be made in two different ways:

- connection to the protective earth circuit: this can be made in Class I equipment;
- connection to the functional earth: this can be made in fixed Class II equipment;