A NEW SUMMARY ON THE IEC PROTECTION AGAINST ELECTRIC SHOCK

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Abstract **— The IEC publication 60364-4-41 "Electrical installations of buildings" fifth edition offers a layout rationalized of protective measures; protection under normal conditions is provided by basic protective provisions and protection under single fault conditions is provided by fault protective provisions. The author proposes a revision of a previous paper on "A summary of the IEC protection against electric shock" and refers also of the IEC protection measures for common grounding systems of HV/LV parts in TN system installations.**

For the electrical risk assessment, the paper suggests the analysis of the risk exposure in analogy with dynamical collisions problems. For generality and simplicity the standard IEC proposes a conventional approach for the safety design; it is responsibility of the designer to verify that in each installation the conventional safety conditions must be applied but also to perfect them to the specific actual situations.

Index Terms**— protection against electric shock, electrical risk, system grounding, safety, common and global grounding**

SYMBOLS

The symbols in the figures and in the text are:

CP circuit protection
d, i direct, indirect contact
I_a automatic operating current of the disconnecting protective device within the admissible t_a time stated in table I
$I_{\Delta n}$ rated residual operating current of the protective device
t_d disconnecting time of the protective device
I_T ground-fault current
L1 line conductor
N neutral conductor
PE ground-fault conductor
R_A resistance of ground electrode for the equipment system grounding
R_N resistance of ground electrode for the neutral point of supply
R_T resistance of ground electrode for the system grounding
U nominal voltage, a.c. r.m.s.
U_L conventional prospective touch voltage limit which is permitted to be maintained indefinitely in specified conditions of external influences ($\geq$ 5 s) (in normal conditions, 50 V a.c. r.m.s. or 120 V ripple-free d.c.)
$U_{Lt}(t)$ permissible prospective touch voltage limit for an admitted duration $t=t_a$[s] (subscripts LV, HV for low and high voltage)
U_o nominal a.c. or d.c. line to ground voltage r.m.s.
$U_t(t)$ prospective touch voltage; a.c. r.m.s.
Z_{L1} impedance of line conductor, source impedance included
Z_N impedance of neutral conductor
Z_{PE} impedance of ground-fault conductor
Z_S impedance of the complete ground-fault circuit (fault loop impedance)
Z_t impedance of prospective touch voltage :Z'_t of distribution circuits, Z''_t of final circuits.
Z_r residual impedance equal to $Z_S - Z_{L1} - Z_t$
u.s.f. unity step function $u(t-t_0)$ of the parameter t (time) equal to 1 if t is higher than the reference value t_0, otherwise zero
w.s.f. window step function of time t that is equal to 1 in the time interval $t_{final}-t_{start} = \tau$, otherwise zero, obtained as $u(t-t_s) - u(t-t_f)$
e(t) w.s.f.=1 when an electrical equipment is in failure on the conductive enclosure that bridges the isolation distance
p(t) w.s.f.=1 when the protection is activated to disconnect the fault in t_d
r(t) w.s.f.=1 when a collision risk exposure is active on the conductive part
k(t) w.s.f.=1 when someone touches the conductive part
π(t) w.s.f.=1 when a collision, hot contact, is active
w(t) collision weight u.s.f.=1(fatal) if the collision has a not admissible duration

INTRODUCTION : THE FIFTH EDITION OF THE IEC STANDARD

The IEC publication 60364-4-41 "Electrical installations of buildings" fifth edition [1] states that the fundamental rule of protection against electric shock is that hazardous-live-parts must not be accessible and accessible conductive parts must not be hazardous live, neither under normal conditions nor under single fault conditions.

Protection under normal conditions is provided by basic protective provisions (protection against the direct contact in the fourth edition) and protection under single fault conditions is provided by fault protective provisions (protection against the indirect contact). Alternatively, protection against electric shock is provided by an enhanced protective provision, which provides protection under normal conditions and under single fault conditions.

Additional protection is specified as part of a protective measure under certain conditions of external influences and in certain special locations .

The following protective measures generally are permitted: - automatic disconnection of supply, - double or reinforced insulation (Class II equipment), - electrical separation for the supply of one item of current-using equipment, - extra-low-voltage (Safety and Protective Extra-Low Voltage SELV and PELV). The special protective measures as the use of obstacles and placing out of reach, non-conducting location, ground-free local equipotential bonding, shall only be used in installations accessible to skilled or instructed persons or installation under the supervision of skilled or instructed persons. In each part of an installation one or more protective measures shall be applied, taking account of the conditions of external influence.

The protective measures applied in the installation shall be considered in the selection and erection of equipment.

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The paper discusses principally about the fault protective measure of the automatic disconnection of supply and examines the a.c. cases only.

PROTECTION BY AUTOMATIC SUPPLY DISCONNECTION

Types of system grounding and property of the HV/LV transformer. Common and global grounding.
Automatic disconnection of supply is a protective measure in which:

– basic protection is provided by basic insulation of live parts or by barriers or enclosures,

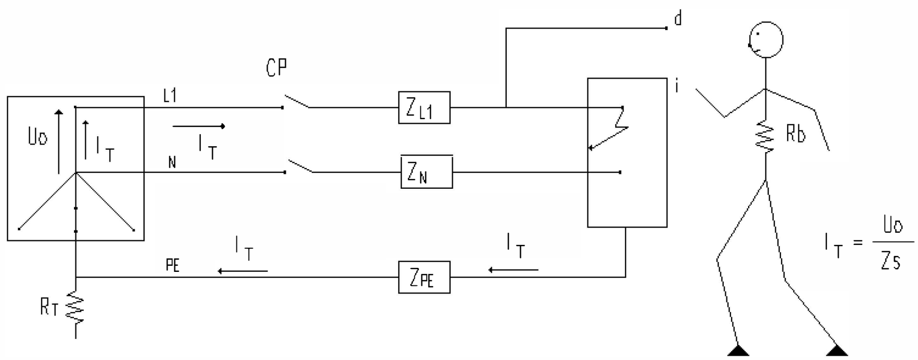

Figure 1 TN-system: fault-current path during a ground-fault

– fault protection is provided by protective grounding, equipotential bonding and automatic disconnection in case of a ground fault. Where this protective measure is applied, Class II equipment may also be used.

Exposed-conductive-parts shall be connected to a protective conductor under the specific conditions for each type of system grounding.

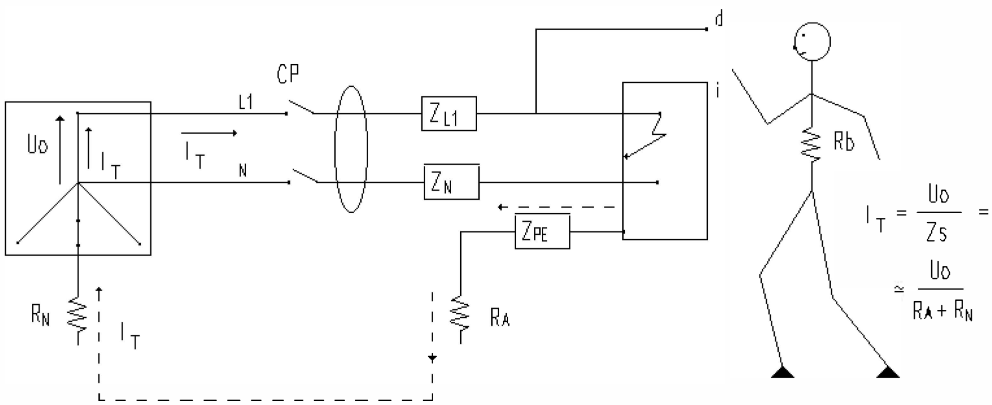

Figure 2 TT-system: fault-current path during a ground-fault

The types of system grounding are classified as: TN-system, TT-system and IT-system. The first letter T (Terre =Ground) or I (Isolated) is for system respectively solidly grounded or ungrounded, the second letter N or T is for the connection of the exposed conductive parts respectively to the same grounded point of the supplying power system (TN-system Figure 1) or to an independent ground electrode (TT-system Figure 2).

TN-S system is the most general case of a TN-system and presents the neutral N and the protective ground fault conductor PE as being separated. Besides, the TN-C system provides in the same conductor (PEN) both the protective ground fault conductor PE and the function of the neutral N. For this system, it is not possible to use residual protective devices. Finally, the TN-C-S system is the combination of the TN-C system followed by the TN-S system.

TN-system and TT-system are erected to promote the circulation of ground-fault current and to favor automatic disconnection of supply.

On the contrary, IT-system is erected to limit and to control the circulation of the leakage current; finally the protection by electrical separation is erected to prevent the same circulation (protection by electrical separation of an individual circuit supplied through a separation source, i.e. an isolating transformer).

The impedance Z_S of the complete ground-fault circuit should be low enough to ensure sufficient flow of ground-fault current, for fast operation of the proper circuit protective devices.

To contribute to a ground-fault current path of low impedance, the grounding conductor PE must be run adjacent to the power cables with which it is associated, i.e. inside the same conduit or the same raceway.

The ground-fault currents have in general higher values in TN system than in TT-system, considering that the electrode resistance R_T is out of the ground-fault circuit (Z_S=Z_{PE}+Z_{L1}).

In TT-system, ground-fault current is normally determined by the electrodes resistances (R_A, R_N), considering that by comparison with these resistances the other impedances of

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ground-fault circuit (as Z_{L1} , Z_{PE}) are in general negligible ($Z_S \cong R_A+R_N$). The ground electrode system R_N of the public distribution is generally included in a proper interconnected ground system by means of MV cable sheaths, buried ground conductors, counterpoises, etc. In this case, actually more frequent, R_N assumes a very low value than R_A.

So, in TN-system, the use of the overcurrent protective devices can be sufficient, whereas in TT-system the use of residual-current protective devices can be necessary. A safety progress will be the conversion of the multiple systems of grounded electrodes R_A of TT-systems at least in TN-S systems by the connection with the utilities ground electrodes R_N.

In each building the grounding conductor, the main grounding terminal and the following conductive parts shall be connected to the protective equipotential bonding (metallic pipes, e.g. gas, water services; structural extraneous-conductive-parts, e.g. metallic central heating and air-conditioning systems; metallic reinforcements of constructional reinforced concrete, if reasonably practicable).

Let's consider that for TN systems is very important to have supplementary equipotential bonding that reduce locally the $Z_t = Z_{PE}$ and so the touch potential. Differently, for the TT-system it can be sufficient to have a good main equipotential bonding system for reducing the touch potential, because a reduction of Z_{PE} has a negligible influence on $Z_t = R_A + Z_{PE}$.

The use of TN-system or TT-system is conditioned by the property of the high/low voltage transformer.

In a power system supplied by an utility transformer, TT-system can be erected only. Where the grounding is provided from a public or other supply system, compliance with the necessary conditions external to the installation is the responsibility of the supply network operator.

In a power system supplied by a proper transformer, the TN system is recommended for LV equipment, common also with HV equipment. Due to the close proximity of equipment it is not possible to separate the grounding systems.

Cautious considerations should be given in applying to HV/LV common grounding system the same values of permissible touch voltages admitted in power substations that are characterized by: - a better dimensioning, - a smallest probability of hot contacts or "collisions" that present higher additional resistances (like shoes) - specific trained personnel. At this aim it is cautiously required that the GPR ground potential rise U_G assumes values lower than the permissible touch voltage U_{LtHV} during a fault duration.

Global grounding system is an "equivalent grounding system created by the interconnection of local grounding systems that ensures, by the proximity of the grounding systems, that there are no dangerous touch voltages"[6]. Such systems permit the division of the ground fault current in a way that results in a reduction of the ground potential rise at the local grounding system. So that it could be said to form a quasi-equipotential surface. The existence of a global grounding system may be determined by sample measurements or calculation for typical systems. Typical examples of global grounding systems are in city centers, urban and industrial areas with distributed low- and high-voltage grounding that could be organized and managed as a public "grounding service" as water or gas.

General safety requirements : unified model

The figure 3 shows a general scheme in a model unified for all the grounding systems (TN-,TT-,IT-systems). The component elements to consider are: a) the faulting electrical equipment and the supplying part of the power system; b) the operator; c) the protective device.

Consequently, the design parameters that characterize this protection measure at any point of the installation are:

a) the ground fault current $I_T = U_o/Z_s$ and the touch voltage $U_t = Z_t \cdot I_T = (Z_t/Z_s) \cdot U_o$. Since U_o is generally fixed, I_T depends on the fault loop impedance Z_s and U_t depends on the ratio Z_t/Z_s , where Z_t is the impedance of prospective touch voltage.
b) the conventional touch voltage limits $U_{Lt}(t)$ (table I columns 2 and 10) that define the correspondent maximum times t_a (table I column 1 and 9) in which U_{Lt} can persist (Figure 4);
c) the time current characteristic curve I-t of the protective device.

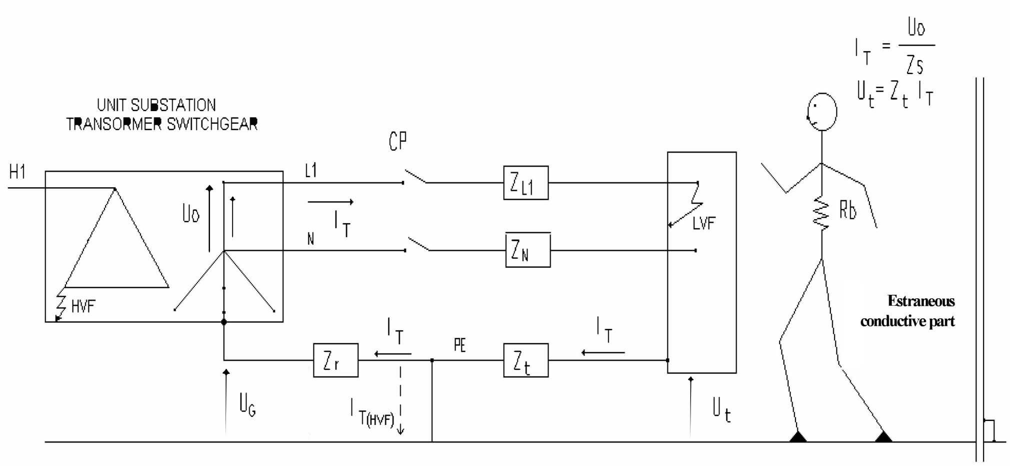

Figure 3 General scheme for protection by automatic supply disconnection: fault-current path during a LV and HV fault

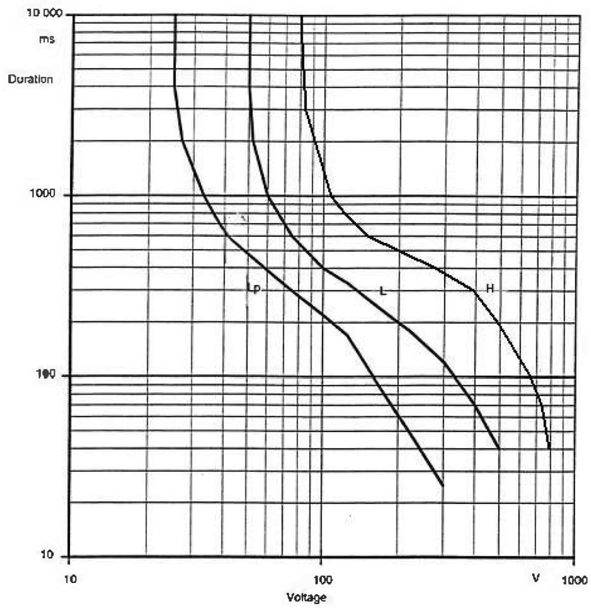

Figure 4 Maximum prospective touch voltage U_{Lt} duration curves: - H for HV installations (according to IEC 61936-1 [6]), - L and L_p for LV installations normal and special conditions respectively (according to IEC 61200-413 [7])

Following a ground fault I_T in a part of the installation supplied by U_o , the touch voltage $U_t = (Z_t/Z_S)\ U_o$ cannot be maintained at any point of the installation in excess of the maximum time t_a that guarantees permissible the touch voltage U_t ($U_{Lt}(t_a) = U_t$).

The figure 4 shows the maximum prospective touch voltage U_{Lt} duration curves: - H curve for HV installations (according to IEC 61936-1 [6]); - L and Lp for LV installations normal and special conditions respectively (according to IEC 61200-413 [7]. In normal conditions the conventional voltage limit U_L for LV installations [5] is assumed equal to 50 V a.c. r.m.s. or 120 V ripple-free d.c. (for HV installations [6] is assumed 80 V). Lower values may be required in special conditions.

It is necessary to adopt a protective device with an operating current I_a ensuring the automatic disconnection in a tripping time t_d equal or lower than the value t_a stated by curves of figure4.

This requirement is met if the following conditions are fulfilled:

$$I_T = U_o / Z_S \quad (1)$$

$$U_t = Z_t \cdot I_T = (Z_t/Z_S)\ U_o \quad (2)$$

$$U_t \leq U_{Lt}(t_a) \quad (3)$$

$$I_a\ (t_a) \leq I_T \quad (4)$$

It is clear that the protective measure necessitates coordination of :

- the type of system grounding (TN-system, TT-system

TABLE I

PARAMETERS AND VALUES FOR SAFETY CONDITIONS

LV								HV		
		TN System			TT System			Common ground		
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
t_a [s]	U_{Lt} [V]	Class U_{OMAX}	R1 (≤32A) t_d variable	R2 (>32A) t_d = 5s	Class U_{OMAX}	R1 (≤32A) t_d variable	R2 (>32A) t_d = 1s	t_a [s]	U_{Lt} [V]	R3 t_d assigned
			$Z_t/Z_s \leq U_{Lt}/U_O$			$Z_t/Z_s \leq U_{Lt}/U_O$				$U_{Lt\ HV}$ / $U_{Lt\ LV}$
			Ref.Val. ≈ 0,5	Ref.Val. <<0,5		Ref.Val ≈ 1	Ref.Val <<1			Ref.Val =2
			(2)/(3)	*50/(3)*		*(2)/(6)*	*60/(6)*			*(10)/(2)*
5.00	50	50			50			5.00	80	1,60
1	60							1	107	1,78
0.80	67	120	0,56	0,42				0.80	120	1,79
0.40	100	230	0,43	0,22				0.40	289	2,89
0.30	120				120	1,00	0,50	0.30	398	3,32
0.20	200	400	0,50	0,13	230	0,87	0,26	0.20	500	2,50
0,1	310	>400	$310/U_O$	$50/U_O$				0,1	660	2,13
0.07	400				400	1,00	0,15	0.07	729	1,82
0.04	500				>400	$500/U_O$	$60/U_O$	0.04	800	1,60
IEC 61200-413		*Safe Conventional Protection SCP $t_d \leq t_a$*						IEC61936-1		

Columns

1&2 Limit values of admissible durations t_a and related permissible touch voltages U_{Lt} according to IEC61200-413 (LV)

9&10. Limit values of admissible durations t_a and related permissible touch voltages U_{Lt} according to IEC 61936-1 (HV)

3&6 Class of nominal voltage to ground (the correlation between U_{0MAX} values (3) &(6) and t_a values (1) is according IEC 60364-4-41).

4&7 Maximum prospective ratio Z_t/Z_s that link U_{0MAX} values (3)&(6) to the variable t_a (1) for a SCP

5&8 Maximum prospective ratio Z_t/Z_s that link U_{0MAX} values (5)&(8) to $t_d = t_a$ = 5s & 1s for a SCP (Note $Z_t = Z'_t$ for distribution circuits)

11 An assigned t_d (9) defines a U_{LtHV} (10): the values (11) can range from 2 to 5 for a conventional compatibility between the HV and LV ground systems. Assuming 2 as recommended value a quality threshold should be to satisfy $U_G/\ U_{LtHV} \leq 2/\ (U_{LtHV}/\ U_{LtLV})$

and IT-system),

- the characteristics of protective devices.

It must be considered that: - overcurrent protective devices with an inverse time characteristic are characterized by a long disconnecting time which in any case must fulfill $t_d \leq t_a$;
- overcurrent protective devices with an instantaneous tripping characteristic or residual-current protective devices are characterized by a short disconnecting time t_d, which can guarantee high values of $U_{Lt}(t_a)$ until U_o .

In a.c. systems, residual current protective devices (RCDs) with rated residual operating current not exceeding 30 mA provide an additional protection for: –socket-outlets with a rated current not exceeding 20A that are for use by ordinary persons and are intended for general use; - mobile equipment with a current rating not exceeding 32A for use outdoors.

Against direct contact with the supply voltage to ground, the use of such RCDs up to 30 mA is recognized, by IEC standard, only an additional protection, because the actual current flowing through the body to ground, cannot be limited by the RCD.

In general, at each point of installation where the conditions (3) and (4) cannot be fulfilled or is very difficult to be pursued:

- it is possible to evaluate if the risk is acceptable,
- it is possible to provide local bonding, defined as supplementary equipotential bonding, that is equivalent to reduce the local value of Z_t (Figure 5).

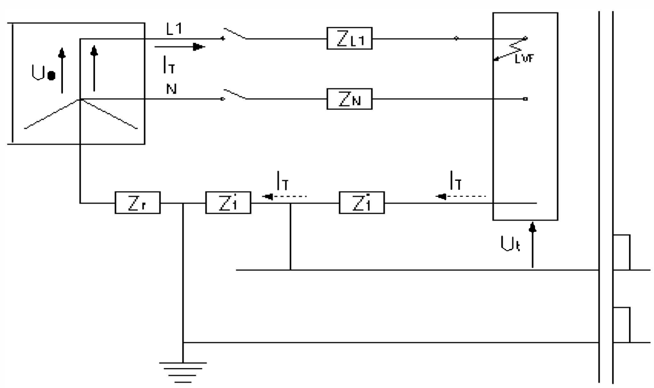

Figure 5 General scheme: fault current path during a ground fault. Local equipotential bonding

Conventional approach: specific safety requirements for each system grounding.

A simplified approach allows to reduce the four requirements (1), (2), (3) and (4) to a sole safety requirement focused for each system grounding and so to introduce the IEC method.

The aim of the simplification is to make reference to parameters easier to known also in the preliminary design that is a priority of standardized guidelines.

These parameters are selected according to the type of system grounding:- the nominal voltage to ground U_0 and the fault loop impedance Z_S suitable for TN-systems and in fifth edition of [1] also for TT-systems - the conventional voltage limit U_L (in substitution of U_{Lt}) and $Z_t = R_A$ for TT-systems, - the GPR ground potential rise U_G and $Z_S = R_T$ for HV common system grounding.

It is possible to define the following sole safety condition referred to the parameters U_0, U_L , U_G, Z_s and Z_t

$$I_a\,(t_a) \leq U_o\,/\,Z_S = U_L/\,Z_t = U_G(t_a\,)/\,Z_S \qquad (5)$$

that is the most general condition, which summarizes the above mentioned four conditions.

This simplified approach requires to assume the ratio $Z_t/Z_S=U_t/U_o$ stated on conventional limit values, depending on U_o and on the type of system grounding.

For U_0 the IEC 60364-4-41 introduces 5 classes, U_{0MAX} = 50, 120, 230, 400, >400 V, that assume like reference the maximum value of the same class. In particular the classes are: 50 V for U_0 values equal or lower than 50V; 120 V for U_0 values between 51÷120V; 230V for U_0 values between 121÷230V; 400V for U_0 values between 231÷400V; >400V for U_0 values higher than 400V.

It is well known that the time is an essential parameter in the risk reduction [8]: the IEC approach relates each class of U_{0MAX} to a prospective touch voltage U_t that fixes the admissible maximum time t_a. To guarantee the safe goal of a disconnecting time t_d equal or lower than t_a it is clear that the protective measure necessitates an adequate coordination of the characteristics of protective device.

For the ratio Z_t/Z_S, let's consider that in TN-system in general the impedance of prospective touch voltage Z_t equal to Z_{PE} is lower than Z_{L1} and so it is realistic that the ratio $Z_t/Z_s = Z_{PE}/(Z_{PE}+ Z_{L1})$ is lower than 0.5 (Z_t/Z_s<0.5). In example for the class U_{0MAX} 230 V results $U_t= Z_t/Z_sU_0$<115 V.

In TT-system, the IEC publication assumes the impedance Z_t=R_A including in R_A the value of Z_{PE} and in the last edition [1] cautiously presupposes $Z_S \cong R_A+R_N \cong R_A$, so the ratio Z_t/Z_s could be assumed equal to 1 ($Z_t/Z_s \cong 1$). In example for the class U_{0MAX} 230 V results $U_t= Z_t/Z_sU_0 \cong 230$V.

In synthesis, for TN system Z_t/Z_S is considered generally lower than 0.5 and for TT system Z_t/Z_S is considered generally lower than 1.

In LV system of assigned U_o class, the prospective touch voltage $U_t=(Z_t/Z_S)\ U_{oMAX}$ remains fixed and consequently for satisfying $U_t=U_{Lt}$ it remains fixed the maximum admissible t_a time (i.e. table I TN-system: for U_{oMAX}=230V column 3, Z_t/Z_S = 0.43 column 4, U_{Lt} = 100 V column 2, t_a=0.4 s column 1; TT-system: for U_{oMAX}=230V column 6, Z_t/Z_S = 0.87 column 7, U_{Lt} = 200 V column 2, t_a=0.2 s column 1).

Let's consider that for the common HV/LV grounding system it is preliminarily known the HV ground fault current I_T and the fault disconnecting t_d that are communicated by the supply network operator. In order that the HV system grounding assumes in the t_d duration a touch voltage and cautiously a GPR ground potential rise lower or equal to the permissible $U_{LtHV}(t_a=t_d)$ (H curve of figure 4). To satisfy this condition, it is clear that the system impedances Z_S that is the ground resistance R_T necessitates an adequate dimensioning.

Evaluation Of The Electrical Risk

Risk analysis by time windows intersections

Considering that the conventional IEC approach highlights the time as basic safe parameter, for analyzing and assessing the electric hazard the author suggests an approach in analogy with the study of the collisions of masses [4] and the "intersections" theory [9] [10]. The analysis proposes to assume the components of the *electric hazard* as waves evolving in the *time* and examines their intersections. The contact of an operator with a live conducting part generally originates a conflicting intersection that is a "collision" between the source and the ground, because the source is grounded by the operator.

Two events and a protective measure have to be considered: a) the *electric fault event e(t)*, interesting electrical equipment or wiring; b) the *contact event k(t)* of an operator with an exposed conductive part, c) the active *protective measure p(t)* combines a grounding system of the exposed conductive parts and a protective device that disconnects or detects the fault.

In the time dimension, each system event is characterized by a time-stream , that is the time-exposure of e(t), k(t) and p(t).

To represent graphically (Figure 6) the waves of the components e(t), p(t) k (t), it is useful to introduce the window step function w.s.f.(τ) obtained as difference between two unit step functions

$$w.s.f.(\tau) = u(t-t_s) - u(t-t_f) \quad (6)$$

It is adopted the Greek symbol τ to show a finite time interval between a starting time t_s and final time t_f : the w.s.f.(τ) is equal to 1 in the time interval τ, otherwise zero,

The waves of the components as windows of area τ make easier the analysis of their intersections.

The fault event e(t) evolves from a random starting time to a natural extinction. The e(t) event and the active protection p(t) constitute respectively the action of a hazard and the reaction to stop it. The combination characterizes a "risk *exposure"* r(t) of a time interval $t_d=\tau_d$ that is a window of area τ_d, intersection between the two duration intervals of e(t) and p(t), also if in general p(t) is an included subset of e(t).

The simultaneous "hot" contact of the operator $\tau_c \le \tau_d$ during the risk exposure has to be considered a *collision* that is an intersection between the windows contact k(t) and the risk exposure r(t).

The collision π(t) (π symbol of window) can be expressed as

$$\pi(t) = e(t) \cap p(t) \cap k(t) = r(t) \cap k(t) \quad (7)$$

The active system *p(t)* has to reduce the exposure window preventing their collision.

For evaluating *safe or fatal* their collision the analogy suggests to control the collision "weight" w(t) of the prospective touch voltage in the ground fault event.

The IEC protection measure operates organizing that the I_T ground fault current in each part of the installation supplied by U_o overcomes the tripping current I_a of the protective device, so that a collision τ_c cannot be maintained at any point of the installation in excess of the maximum time t_a that guarantees permissible the touch voltage $U_t \le U_{Lt}(t_a)$.

The collision π(t) can be weighted by the unit step function

$$w(t) = u\,(k(t) \cap t_d - t_a) = u\,(\tau_c - t_a) \quad (8)$$

that remains zero as much as t_d is low and/or a "hot" contact does not happen. Let's note that the actual time duration τ_c of the collision that is the intersection time window $\tau_c = k(t) \cap t_d$ can be cautiously increased to the total time duration t_d that is a not random parameter.

The condition $\tau_c=t_d$ is the worst case of an ever simultaneous contact that is a collision during all the interval t_d. An example is the shock hazard by portable equipment that needs to be

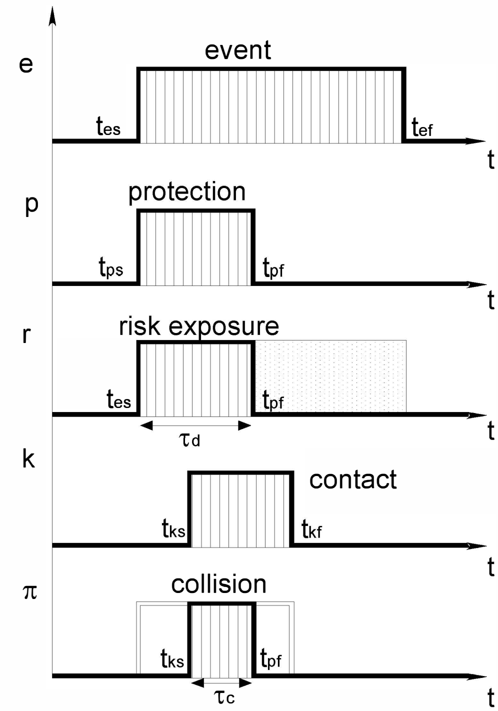

Figure 6 Time exposure wave of e(t), p(t), r(t), k(t), π(t)

hand-held during use (always k=1) within the electric operation.

In the general cases, considering that k(t) is random, the actual time duration τ_c is random. So that, it is conservative to adopt the known disconnecting time τ_d of the protective device.

In conclusion, the protection practice in IEC standards is based on controlling the eventual "collision":

- for LV system grounding [1], by an adequate design of the fault loop impedance Z_S and a coordination of the characteristics of the protective device (t_d) to limit the colliding time inside the admissible value t_a (*safe conventional protection SCP*) or avoiding the persistence of the collision exposure time (*probable conventional protection PCP*) ;
- - for common HV/LV system grounding [6], by a design of the ground resistance R_T adequate to maintain eventual colliding times in the admissible value (*safe conventional protection*), considering that the HV ground fault current I_T and the fault duration t_d are independently fixed.

In the case of a fault occurring in portable equipment, which needs to be hand-held during use, contact is certainly simultaneous. For parts of installations (as branch-circuits) intended to supply portable, mobile and other equipment having hand-held exposed conductive parts, the touch voltages and the times of the table I must be respected (conditions (3) and (4)). It is cautious to limit the colliding time for guaranteeing that the touch voltages remain always admissible guaranteeing a safe conventional protection during the fault disconnection t_d .

In the case of the fixed-in-place equipment the exposed conductive parts have a lower probability of simultaneous contact and it is cautious to avoid the persistence of the collision exposure time offering a probable conventional protection (safe after the fault disconnection t_d).

Three rules in IEC approach

The safety design is based on ensuring appropriate protection measures to limit the touch voltage. For purposes of generality and simplicity of application, the standard IEC proposes a conventional approach of reference assuming admissible time values for each class of U_0 and type of system grounding. It is responsibility of the designer to project and verify that the conventional safety conditions are applied, but also to perfect them to the special situations of the installation.

In practice, the IEC approach adopts the three following rules for the disconnecting time t_d:

- *the rule 1 assumes for each class of* U_{oMAX} *a variable* t_d *time conventionally correlated with a realistic prospective ratio* Z_t/Z_S *and applies to final circuits not exceeding 32A.*

The maximum disconnection times are dependent of the classes of U_0 voltage and the type of TN system or TT system. Realistic prospective limit values of the ratio Z_t/Z_S (table I columns 4 and 7) have been assumed to determine and conventionally to guarantee: the ratio U_{Lt}/U_{oMAX}, the related U_{Lt} (column 2) and so the time (column 1) (*safe conventional protection)*. In an actual final circuit not exceeding 32A if the ratio Z_t/Z_S is higher than the value shown in column 4, the protection remains only conventional. Differently in installations of nominal voltage U_0 lower than the value U_{0MAX} of its class, the maximum ratio Z_t/Z_S permissible to guarantee the safety condition assumes the actual value U_{Lt}/U_o higher than U_{Lt}/U_{oMAX}..

A protective device shall automatically interrupt the supply to final circuits not exceeding 32A in the event of a ground fault of negligible impedance in the circuit or equipment within the disconnection time required in table I columns 1. “Where in TT systems the disconnection is achieved by an overcurrent protective device and the protective equipotential bonding is connected with all extraneous-conductive-parts within the installation, the maximum disconnection times applicable to TN systems may be used” (note in table 41.1 [1]). It is possible to consider as reference Z_t=Z_{PE} and to assume Z_t/Z_S < 0.5.

- *the rule 2 assumes a fixed time* t_d *not exceeding 5 s (related to* U_L *=50V) or 1 s (related to* U_{Lt}*= 60V) and applies to distribution circuits and circuits exceeding 32A.* The disconnection times are dependent of the type of TN system or TT system. The rule offers a *probable conventional protection* avoiding the persistence of the collision exposure time (safe after the fault disconnection t_d).

The designer could inspect that a *safe conventional protection* is guaranteed if the ratio Z_t/Z_S of the circuit in installation of the type of TN system or TT system is equal or lower than $50/U_o$ or $60/U_o$ respectively. Columns 5&8 of table I show the specific values of ratios Z_t/Z_S related to the U_{0MAX} class values

- *the rule 3 imposes that the GPR* U_G *has to be equal or lower than the permissible* U_{LtHV} *correspondent to the disconnecting time* t_d *of the utility protection. It applies to common HV/LV grounding systems.*

The requirement $U_G \leq U_{LtHV}$ of a GPR value U_G equal or lower than the permissible touch voltages U_{LtHV} of the H curve of figure 4, offers a safe compatibility of HV ground system with the LV voltage ground system, where the lower values of L curve have to be satisfied. In fact, it has to be considered that the GPR U_G in a HV system grounding of adequate design assumes values higher than the actual touch voltages U_{tHV} inside and in the vicinity of the grounding system. A typical value of this gap of U_G on U_{tHV} is 2 and may be up to 5: the ratio U_{LtHV}/U_{LtLV} (table I column 11) complies with this range, guaranteeing an equivalent safe conventional protection.

The requirement $U_G/U_{LtHV} \leq 1$ appears a simplified condition to apply and to balance the difference between the permissible limit values of the touch voltage in HV and LV installations. Assuming 2 as cautious recommended value of the gap U_G/U_{tHV}, a quality threshold in designing a common HV/LV ground system should be to satisfy the condition

$$U_G/U_{LtHV} \leq 2/(U_{LtHV}/U_{LtLV}) \qquad (9)$$

IEC SAFETY REQUIREMENTS FOR TN-SYSTEMS, TT-SYSTEMS AND COMMON HV/LV SYSTEM GROUNDING

TN-systems ($Z_S=Z_{PE}+Z_{L1}$, $Z_t = Z_{PE}$).

The characteristics of the protective devices and the circuit impedances shall fulfil the following requirement:

$$Z_s I_a \leq U_o \qquad (10)$$

where : - Z_s is the impedance in ohms (Ω) of the fault loop comprising: the source, the line conductor up to the point of the fault, and the protective conductor between the point of the fault and the source;

- I_a is the current in amperes (A) causing the automatic operation of the disconnecting device within the time specified in table I and related to the U_{0MAX} for final circuits not exceeding 32A (rule 1) and not exceeding 5 s for distribution circuits and for final circuits exceeding 32A (rule 2). When a residual current protective device (RCD) is used, the disconnection times in accordance with the same over specified times of table I relate to prospective residual fault currents higher than the rated residual operating current, typically 5 $I_{\Delta n}$.

The professional designer must verify that the conventional safety requirement (10) is applied, but can also validate it to the actual ratio of Z_t/Z_S of the installation related to the effective U_0 value.

TT-systems ($Z_S=Z_{L1}+R_A+Z_{PE}+R_N \cong R_A+R_N$ $\;Z_t=R_A+Z_{PE} \cong R_A$)

Where a residual current protective device (RCD) is used for fault protection, the following conditions shall be fulfilled:

i) the disconnection time specified in table I related to the U_{0MAX} for final circuits not exceeding 32A (rule 1) and not exceeding 1s for distribution circuits and for final circuits exceeding 32A (rule 2) related to residual fault currents higher than $I_{\Delta n}$, typically 5 $I_{\Delta n}$., that is

$$R_A \, 5 \, I_{\Delta n} \leq U_0 \qquad (11)$$

ii) $R_A I_{\Delta n} \leq 50$ V (12)

where : - R_A is the sum of the resistance in Ω of the ground electrode and the protective conductor for the exposed conductive-parts,

- $I_{\Delta n}$ is the rated residual operating current of the RCD.

Where an over-current protective device is used the following condition shall be fulfilled:

$$Z_s \times I_a \leq U_0 \quad (13)$$

where: - Z_s is the impedance in Ω of the fault loop comprising: the source, the line conductor up to the point of the fault, the protective conductor of the exposed-conductive-parts, the grounding conductor, the ground electrode of the installation R_A and the ground electrode of the source R_N;

- I_a is the current causing the automatic operation of the disconnecting device within the times specified in table I for final circuits not exceeding 32A and not exceeding 1 s for distribution circuits and for final circuits exceeding 32A.

Common HV/LV system grounding

Special consideration should be given to HV grounding system common to the LV system if this common system is not part of a global grounding system. The requirement

$$U_G \leq U_{LtHV} \quad (14)$$

could be perfected on the basis of the rule 3 adopting a special care to the equipotential bonding inside the system grounding. The design of the grounding system and a preliminary determination of the ground resistance R_T and the ground potential rise U_G can be accomplished as follows:

a) collect design data of ground fault current I_T, fault duration t_d that are communicated by the supply network operator;
b) determine the current discharged into soil from grounding system, based on ground fault current and on appropriate reduction factors;
c) determine the overall impedance to ground, based on the layout, soil characteristics, and parallel grounding systems, generally the ground resistance R_T;
d) determine ground potential rise GPR U_G;
e) if the ground potential rise is below the permissible touch voltage U_{LtHV} and the requirements of table 1 are met the design is complete (quality threshold is the (9));
f) if not, determine if touch voltages inside and in the vicinity of the grounding system are below the tolerable limits.

CONCLUSIONS

The protection practice against the electric shock points to solve the "collision" by an active measure: the fault opens a time window of risk, the protection has to close it. The protection has to limit the fault exposure persistence in a conventional time (probable protection) as general objective. A safe protection is conventionally guaranteed if the colliding time is lower than the admissible value or at the least assumes a value as lowest as possible (additional protection).

In conclusion, a practical recommendable criterion to avoid or mitigate the injury or damage occurring with an electrical equipment is in the case of portable (mobile) electrical equipment to prevent the appearance of the electrical potential using also double insulation and Class II equipment. Whereas in the case of fixed electrical equipment it can be sufficient to limit the persistence of the electrical potential by grounding and automatic disconnection of the supply.

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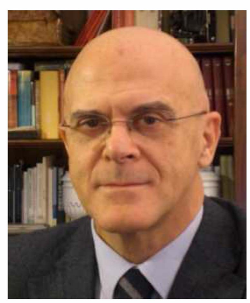

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