NISTIR 6013

Electromagnetic Immunity of Single-Phase Personnel Protection Devices for Electric Vehicle Battery Chargers

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May 1997

U.S. DEPARTMENT OF COMMERCE
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Electromagnetic Immunity of Single-Phase Personnel Protection Devices

FOREWORD

This document has been developed as a contribution to a forthcoming standard to be published by the Underwriters Laboratories concerning the safety of Personnel Protection Devices. The initial approach was to develop recommendations in part on the basis of emission data to be provided by manufacturers of electric vehicle battery chargers, and in part on available information on the electromagnetic environment of the ac low-voltage systems from which the chargers are to be powered. As it turned out, the data obtained from the charger manufacturers (through the electric vehicle manufacturers) were quite limited. Consequently, the primary source of information became the published and in-preparation publications of the International Electrotechnical Commission (IEC) on electromagnetic compatibility.

With due respect for copyright conventions, the information presented in the IEC publications on immunity tests and electromagnetic environment has been referred to in proposing immunity levels of the Personnel Protection Devices (PPDs). Appendix A gives a list of the publications consulted in defining the proposed levels. In addition to the normal operation of the PPD, consideration has also been given to the case of a partial failure of the battery charger which might result in a current waveform that could interfere with proper operation of the PPD and thus interfere with its safety function.

The electromagnetic environment in which the PPD is required to maintain its function is a combination of the environment established by the power system, upstream of the PPD, and of the environment established by the battery charger system, downstream of the PPD. Because the information on all possible battery charger designs is not available, some assumptions have been made in this respect, which need to be validated by charger manufacturers. Compared to the direct galvanic (conductive) coupling of the PPD to these two environments, radiated disturbances that could be coupled into the PPD circuits are considered a negligible damage risk, but spurious tripping might be an issue. Rather than to specify the application of radiated EMC tests which require specialized equipment and procedures, the successful field experience of ground fault interrupters evaluated by conducted high-frequency tests has been adopted as a reference for this document.

The postulated requirements are based on the concept that three levels of electromagnetic disturbances[1] should be considered, with corresponding acceptable consequences:

- Disturbances with no effect on the operation of the PPD;
- Disturbances that might cause erroneous tripping of the PPD, not a direct safety hazard but an annoyance that might induce some users into by-passing the device in an unauthorized manner;
- Disturbances that might cause the PPD to fail in an open mode, maintaining safety but losing power.

Any failure mode that might allow continuous delivery of power to the battery charger but with loss of the personnel protection function is not acceptable.

The draft of this document was developed for the Electric Power Research Institute, and reviewed by members of the Personnel Protection Devices Committee. The contributions from these committee members are gratefully acknowledged.

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SUMMARY

This document is based on a synthesis of several sources including primarily Basic Standards and Product Standards of the IEC, complemented by other documents such as IEEE Standards, and perceptions on the evolving consensus among the EMC community. Electromagnetic phenomena which can create electromagnetic disturbances have been classified in eighteen categories in several IEC publications. A review of these phenomena within the context of personnel protection devices (PPD) allows a further classification to establish whether they will require tests to demonstrate electromagnetic compatibility: essential, optional, or immaterial. The essential category includes those phenomena with quasi-certainty of their occurrence and potentially disruptive or destructive effects. The optional category includes those phenomena with some probability of occurrence but low risk of producing adverse effects. The immaterial category includes phenomena not occurring in the PPD environment or those for which a PPD can be deemed inherently immune. The table below presents a summary of the essential and optional tests.

EMC tests to be considered for Personnel Protection Devices

Phenomenon Description	Test Number	Necessity of performing test to demonstrate	
		Electrical shock protection	Trip-out prevention
Harmonics	1	Essential	Essential
Signaling voltages	2	Optional	Optional
Voltage fluctuations	3	Optional	Optional
Voltage sags and interruptions	4	Essential	Essential
Radiated low-frequency magnetic fields	9	Optional	Optional
Radiated low-frequency electric fields	10	Optional	Optional
Induced continuous voltages or currents	11	Optional	Optional
Conducted unidirectional transients	12	Essential	Essential
Conducted oscillatory transients	13	Essential	Essential
High-frequency magnetic fields	14	Optional	Optional
High-frequency electric fields	15	Optional	Optional
Electromagnetic fields, continuous	16	Essential	Essential
Electromagnetic fields, transient	17	Optional	Optional
Electrostatic discharge	18	Optional	Essential

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EMC tests to be considered for Personnel Protection Devices

Necessity of performing test to demonstrate		Test Number	Phenomenon Description
Trip-out prevention	Electrical shock protection		
Essential	Essential	1	Harmonics
Optional	Optional	2	Signaling voltages
Optional	Optional	3	Voltage fluctuations
Essential	Essential	4	Voltage sags and interruptions
Optional	Optional	9	Radiated low-frequency magnetic fields
Optional	Optional	10	Radiated low-frequency electric fields
Optional	Optional	11	Induced continuous voltages or currents
Essential	Essential	12	Conducted unidirectional transients
Essential	Essential	13	Conducted oscillatory transients
Optional	Optional	14	High-frequency magnetic fields
Optional	Optional	15	High-frequency electric fields
Essential	Essential	16	Electromagnetic fields, continuous
Optional	Optional	17	Electromagnetic fields, transient
Essential	Optional	18	Electrostatic discharge

Electromagnetic Immunity of Personnel Protection Devices

1. SCOPE

This document is aimed at providing guidance on electromagnetic compatibility of single-phase Personnel Protection Devices (PPDs) used in North America for supplying ac power to the chargers of electric vehicle batteries from the premises wiring of a building. It covers the normal operating conditions of the charger as well as some malfunctions of the charger, each resulting in applying electromagnetic disturbances to the PPD, against which the PPD is expected to respond in a manner that will not compromise the safety function of the PPD, nor cause spurious trip-out.

The following basic operational requirements for a PPD are not included in the scope of the present document as they are not electromagnetic compatibility issues:

- Performing the protective function upon occurrence of a leakage current in the connected load:
    - Isolation and grounding monitor/interrupter
    - Consideration of a frequency factor in the human reaction
- Maintaining operational capability over the expected range of normal line voltage
- Dielectric voltage withstand
- Overload, short circuit, low impedance to ground
- Endurance

Furthermore, some of the electromagnetic environment parameters affecting the PPD might depend on the type of charger design, especially the type of coupling to the vehicle (conductive or inductive). Appropriate consideration must be given to these differences in requiring specific tests only where they are applicable.

2. REFERENCE DOCUMENTS

A section entitled "Reference documents" usually consists of a list of publications which are supposed to be available to the reader, this list being introduced by a statement to the effect that the listed publications, by the mere fact of their citation, form an integral part of the document. In the present document, such a list would be excessively lengthy and it would be impractical for the reader to acquire all these publications. In fact, the purpose of the present document is to develop a synthesis of the vast array of publications concerned with EMC in general, from which recommendations specific to PPDs can then be developed.

The present considerations have been developed primarily on the basis of available IEC publications concerned with equipment EMC. As discussed in more detail in section 4.2 of the present document, there is a hierarchy in the IEC publications for EMC: when the fast-moving technology has allowed product committees to develop specific standards for their products, these take priority. In the absence of such product standards, the basic ("horizontal") standards are applicable. In the PPD case, there is a mixture of well-defined requirements and "under consideration" clauses in the IEC standards covering what the IEC calls "residual current-operated devices" (RCD), the generic name for the subject PPD addressed in the present document.

Given the evolution of applicable standards, the EMC requirements identified in the present document are based on a synthesis of the product standards for RCDs and the basic EMC publications, plus some other reference documents identified in the text as needed. Test procedures to be followed for demonstrating electromagnetic compatibility of the PPD are generally specified in IEC publications of the 1000 Part 4 series (Testing and measuring techniques), and in some cases with additional or alternate reference to other test protocols such as defined in ANSI C62.45 or UL 943.

In the absence of specific data in the product standards for RCDs, the severity levels proposed in the present document are derived from the data presented in the IEC publications of the 1000 series, Part 2 (Environment), Part 3 (Limits) as well as those proposed as guides or implied specifications in Part 4 (Testing and measurement techniques). Specific publication sources are cited in the section presenting the test protocol, while a general listing of documents consulted in developing the present document, with comments, is given in Appendix A, Annotated Bibliography.

3. DEFINITIONS

Technical terms used in the present document are defined in the following standards:

- IEEE Standard Dictionary of Electronic and Electronics terms, IEEE Std 100
- International Electrotechnical Vocabulary - Chapter 161: Electromagnetic Compatibility, IEC 50(161) : 1990
- Electromagnetic compatibility (EMC) - Part 1 : General - Section 1 : Application and interpretation of fundamental definitions and terms, IEC 1000-1-1 : 1992
- National Electrical Code, Article 100, NFPA 70: 1996

4. GENERAL CONSIDERATIONS ON EMC

4.1 Phenomena and disturbances [1]

Electromagnetic (EM) disturbances are caused by conducted or radiated phenomena. Figure 1 depicts in a general manner how EM disturbances may affect sensitive apparatus. An apparatus can be both the emitter and susceptor (potential victim) at the same time. One essential aspect of an EMC standard is the availability of suitable tests to verify compliance with the standard. In the case of EMC requirements for PPDs, the IEC publications series 1000 offers a comprehensive "menu" of tests procedures, each having received approval of a wide body of experts in specialized fields. For this reason, the present document is based primarily on these IEC publications. The process adopted for ensuring electromagnetic compatibility of equipment may take two approaches, depending on how early in the design the EMC specialist is offered an opportunity to contribute:

a) At the early stages of equipment design, each compatibility level (specific for a given electromagnetic disturbance) can be assigned for the particular environment of the equipment being developed. Through specification of appropriate mitigation schemes, equipment and their installation practices are then specified with immunity and emission levels corresponding to the predetermined compatibility level.

b) At later stages of the design, a mismatch may occur between the overall, de facto compatibility level of the site and the capability of the equipment. In such a case, mitigation methods must be retrofitted to close the gap between the environment and the equipment immunity levels to a minimum.

Clearly, the first approach is more rational and is likely to be more cost-effective than the second. History, however, is replete with examples of application of the second approach. It is one of the goals of the present document to establish a climate and consensus where the first approach will prevail.

1 *Parts of this section paraphrase IEC Publication 1000 - Part 5: Mitigation methods and installation guidelines - Section 1: General considerations.*

The relationship between sources of disturbances ("emitters") and the equipment onto which the disturbances impinge ("susceptor") is shown by the schematic of Figure 1. Some ambiguity might be created by misunderstanding the term "disturbance." In the EMC world, this term is understood as a ***disturbance in the environment***, not a disturbance of the operation of the equipment. The equipment operation may or may not be affected, depending upon the relationship between the level of the disturbance and the susceptibility level of the equipment.

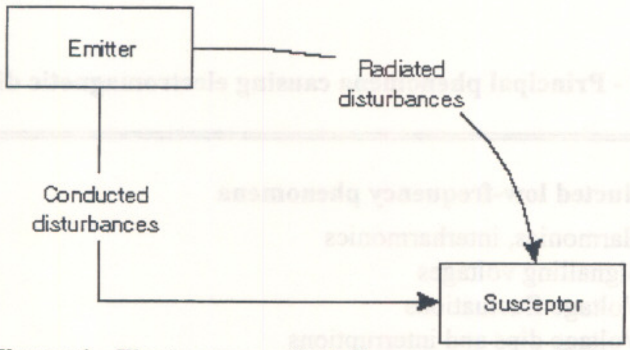


Figure 1 - Electromagnetic influence representation

In the case of PPDs, the effect of the disturbances may produce a variety of responses, with corresponding acceptable or unacceptable consequences:

- Disturbances with no effect on the operation of the PPD -- an acceptable response;
- Disturbances that might cause erroneous tripping of the PPD, not a direct safety hazard but a severe annoyance that might lead to some users by-passing the device in an unauthorized manner, or create ill-will for the industry -- an unacceptable response;
- Disturbances (of highly unusual severity) that might cause the PPD to fail in an open mode, maintaining safety but losing power delivery to the load - a tolerable response.
- Any failure mode that might allow continuous delivery of power to the battery charger but with loss of the personnel protection function is ***not acceptable***.

Disturbances in the electromagnetic environment are caused by many phenomena, man-made or natural. Table 1, overleaf, has been widely used in IEC publications concerned with EMC, and is reproduced here as it appears in these publications.

For the sake of comprehensive treatment of the subject, the present document will follow the sequence of possible phenomena listed in Table 1. Such sequence does not imply ranking by order of importance. For each phenomenon, a subsection will present a rationale on whether the particular phenomenon is relevant to PPD applications, and in the affirmative appropriate severity levels for the test will be indicated, corresponding to the type of acceptable PPD response. The suggestions for PPD compatibility will be presented in two categories: an imperative ("essential") requirement for safety or absence of nuisance trip, and a requirement that may be waived ("optional") if knowledge of the PPD design indicates beyond doubt that the phenomenon in question is not relevant. This concept of matching the test protocol to the known characteristics of the equipment is central to the EPRI/PEAC System Compatibility Test Protocols, discussed in Appendix B, as opposed to a blind application of a regimen of "black-box testing" which can be motivated by a desire for uniform, "fair" evaluation of products, but which can be less than optimal and entail unnecessary consumption of resources. The choice between these two approaches will be determined by the user(s) of the present document.

The system compatibility test protocol approach may be a useful tool thanks to the iterations between test results and product design for a fast-developing technology, in contrast with mature technologies for which black-box testing is generally accepted. Given on the one hand the present situation where the information on design details of the battery chargers and the resulting electromagnetic environment they create appears incomplete, and on the other hand the need for developing a generic standard for approval or listing of specific brands or models of PPD, it is likely that the black-box testing mode will have to be implemented in the near future.

Table 1 - Principal phenomena causing electromagnetic disturbances

Conducted low-frequency phenomena Harmonics, interharmonics Signalling voltages Voltage fluctuations Voltage dips and interruptions Voltage unbalance Power-frequency variations Induced low-frequency voltages D.C. in a.c. networks
Radiated low-frequency phenomena Magnetic fields Electric fields
Conducted high-frequency phenomena Induced continuous-wave voltages or currents Unidirectional transients Oscillatory transients
Radiated high-frequency phenomena Magnetic fields Electric fields Electromagnetic fields - continuous waves - transients
Electrostatic discharge phenomena (ESD) Contact Air Discharge to adjacent objects

Source: IEC Publication 1000-2-5

4.2 Hierarchy of IEC Publications

The IEC publications concerning EMC have been classified in four categories, for several reasons outlined below. The categories are:

- Basic EMC Publications
- Generic EMC Standards
- Product Family EMC Standards
- Product EMC Standards

The motivation for this approach includes several aspects:

- Establish a uniform system promoting a consistent and well-coordinated set of documents
- Provide guidance on EMC matters to specialized product committees developing their own standards
- Make it possible for fast-moving technologies to be covered by some form of standard until the cognizant product committee can develop an appropriate standard.

In the absence of a product standard, the recommendations of basic standards may be applied. When product standards containing EMC recommendations have been developed, they become the relevant EMC standard.

At this time, product family standards have been developed by the IEC for Residual Current Devices (RCDs), although some still contain the holding pattern of "under consideration."

IEC 1008-1:1990	Residual current operated circuit-breakers without integral overcurrent protection for household and similar uses (RCCB's) Part 1: General rules
IEC 1009-1:1991	Residual current operated circuit-breakers with integral overcurrent protection for household and similar uses (RCBO's) Part 1: General rules
IEC 1543:1995	Residual current operated devices (RCDs) for household and similar use - Electromagnetic Compatibility

4.3 PPD interface with the battery charger

It is essential to recognize that in the evolving technology of battery charger systems, information on the electromagnetic environment created by the normal operation and any abnormal operation of the charger is not definitive at this time. There is a need to establish close coordination among all parties to ascertain that the assumptions made in the present document on the environment created by the charger will in fact be applicable in specific cases. Thus, this document can only be considered as a snapshot in time on the EMC of the total system including all components.

As an example of this situation, the spectrum and levels of harmonic currents drawn by a specific battery charger are not known. As discussed in the "Rationale" paragraphs of the harmonics test procedure, two approaches are possible to fill this lack of information. One is to speculate what these levels might be on the basis of the expected principle of operation of an AC-DC converter circuit, the other is to make the bold assumption that the present emission limits of specific products developed by the IEC for the international market will take hold in the North American environment. There is no guarantee that such assumption will be realized.

To place the situation in perspective, Figure 2 illustrates the chain of power flow, from the plant where electric power is generated, to the vehicle motor where the electric energy is converted into mechanical energy. Several possibilities exist for defining boundaries of interactions between the PPD and the adjacent elements of the total system and the related EMC requirements, in particular whether the charger would be on-board the vehicle or off-board, and whether the coupler is of the conductive or inductive type. These issues need to be resolved for specific cases, rather than by a generic mandate.

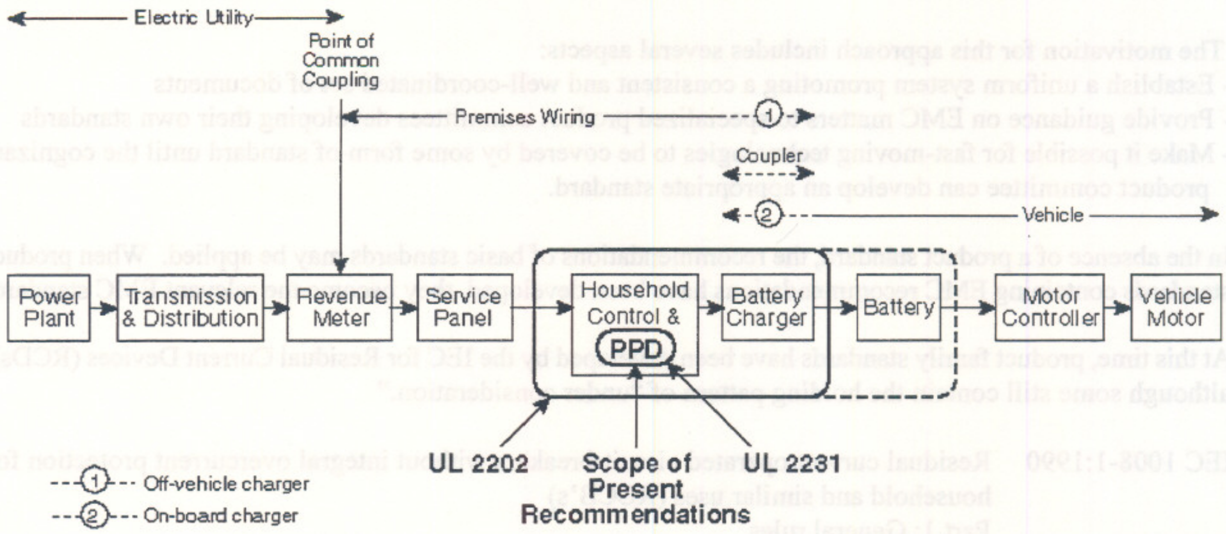


Figure 2 - Role of the PPD in total system

The present document presents basic concepts that should be applicable to North American installations as well as installations in other industrialized countries. However, the details of implementations such as grounding practices (TT, TN and IT configurations as defined in IEC publications 364), directives of the National Electrical Code, ready availability of three-phase supply in some countries versus the single-phase supply that prevails in the U.S. residential environment, etc., might restrict the applicability of detailed requirements for the PPD. Therefore, the present document is primarily intended for the North American environment.

Figure 2 shows graphically the location of the Point of Common Coupling (PCC) in the relationship between the supplying utility and the premises wiring of an installation. The PCC concept will be particularly important when discussing harmonic emission limits because the IEC approach has been to define limits at the level of individual equipment (eventually to be considered as mandated requirements), while the IEEE approach has been to promote (as a Recommended Practice) the control of harmonic currents at the PCC.

Another important distinction to be made in the PPD-charger interface is the nature of the electrical parameter to be considered. In most cases, the conducted EMC parameters can be expressed in terms of applied voltage. However, for the PPD-charger interface (the output power port), both voltage and current must be considered because the PPD port is exposed to voltages created by the charger while being required to carry-through the harmonic currents drawn by the (compensated or not compensated) AC-DC converter.

5. DISTURBANCES IN THE TN-C-S SYSTEM

The IEC has defined classes of power system network configurations according to the type of grounding practices at the distribution level and at the end-user level. The three major categories are the IT system, where there is no direct grounding of the system, the TT system where grounding is applied outside of the premises wiring, and the TN system where grounding is applied at one or more points of the distribution system ***and*** the premises wiring. A further classification is the TN-C-S system widely used in North America, where the distribution system uses a common conductor for the functions of current-carrying neutral conductor and of grounding conductor, while the premises wiring uses a separate protective grounding conductor (PE in IEC documents), designated as "equipment grounding conductor" in the National Electrical Code. The concept of a PPD is applicable downstream of the point where the grounding conductor has been split into a neutral conductor and an equipment grounding conductor.

This general use of the TN-C-S system has noteworthy implications on the details of test circuits and the level of disturbances that may impinge upon connected equipment. For this reason, a brief review of the characteristics of such a system and its implications in the application of PPD will be useful. The publication by Biegelmeier, Skuggevig, and Takahashi, cited in Appendix A, contains information on these application considerations. Figure 3 below is excerpted from this publication, with permission from the publisher.

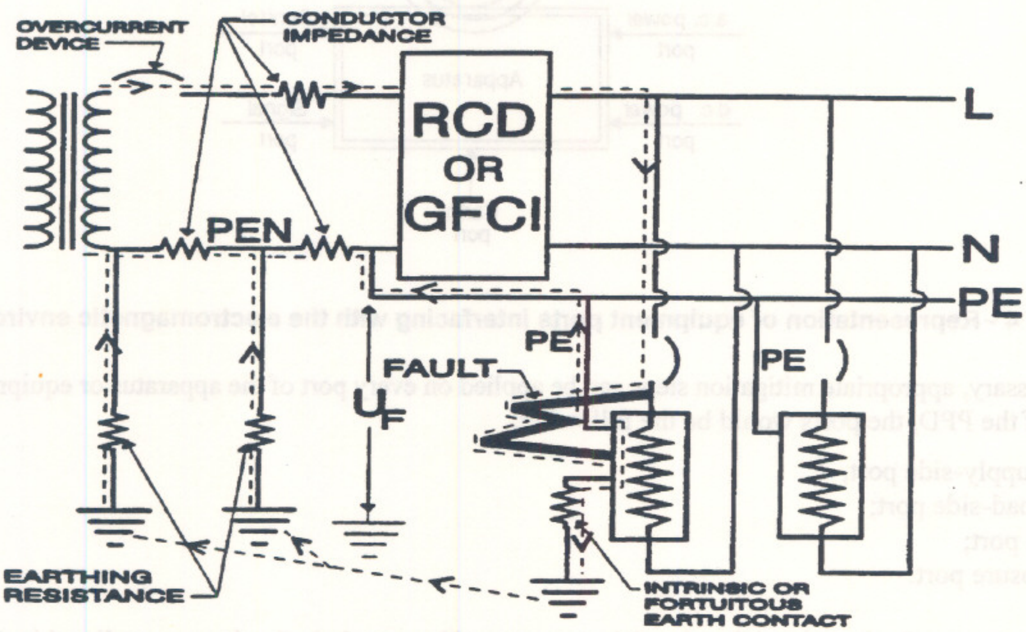


Figure 3 - The TN-C-S system for a single-phase circuit

Many documents refer to "common mode" and "normal mode" when specifying severity levels for the EM disturbances to be considered. However, the definitions of these two modes originated from the telephone industry where the grounding practices are different from the TN-C-S system of interest here. There are also competing definitions, such as "symmetrical" or "unsymmetrical" which can create confusion. To avoid such confusion, the IEEE standards on surge-protective devices (notably C62.41 and C62.45) have encouraged the use of "line-to-line," "line-to-neutral" and "neutral-to-ground" to describe the coupling or propagation mode of impinging surges.

This designation definition is adopted in the present document. For instance, a surge originating in the low-voltage distribution system, outside of a building, as a result from an indirect lightning strike, may have equal components for all conductor-to-earth combinations. However, when reaching the service entrance where the grounding conductor (PEN) is bonded to the local ground, further propagation of this surge will only be in the line-to-neutral and line-to-ground modes; there will not be a neutral-to-ground surge at the origin of branch circuits.

Electromagnetic disturbances will impinge upon the PPD through several "ports" of the device. In IEC documents, a representation has been given to illustrate the concept of port, with the following definition:

"**port** : Specific interface of the specified apparatus with the external electromagnetic environment."

By identifying such ports, protective steps can be specifically related to the nature of the EM phenomenon, its coupling path, and its impact on the functional elements of the apparatus (immunity) or its impact on the environment (emissions). Figure 4 shows the case of EM disturbances impinging on the apparatus through six ports, for immunity evaluation. Conversely, the case for emissions evaluation, such as those associated with the operation of the battery charger, would be obtained by reversing in the figure the direction of the arrows and the orientation of the radiation.

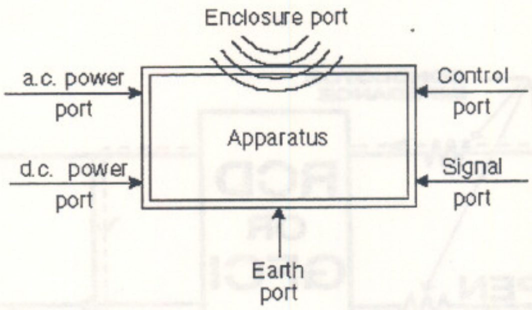


Figure 4 - Representation of equipment ports interfacing with the electromagnetic environment

If necessary, appropriate mitigation steps can be applied on every port of the apparatus or equipment. In the case of the PPD, the ports would be the following:

- AC supply-side port,
- AC load-side port;
- Earth port;
- Enclosure port.

References to a "safety circuit" and to "charger control" are made in the documents listed in Appendix A. It may be appropriate, in further expansion of the present document, to review the implications of these other circuits when considering the ports of the PPD, and add control and signal ports, if any, to the preceding list.

For the AC power ports, this protection typically involves the use of surge-protective devices, sometimes complemented by filters. The concept of earth port is not as simple as for the other conducted ports because it can involve a deliberate earthing, which is apparent when materialized by an external grounding strap, as well as inherent connections included in the cables connected to the equipment, such as the equipment grounding conductor. In the present document, compliance with the NEC directive concerning grounding (Article 625-24) has been postulated.

Depending upon the case, the enclosure port is always present: as a metallic envelope, as a non-conductive envelope or even as just a conceptual, immaterial envelope. However, a metallic envelope should not be considered implicitly as an effective mitigation element, unless specifically designed for that purpose.

6. OVERVIEW OF EMC PHENOMENA AND TESTS

This section presents a summary synthesis of the array of published or in-preparation EMC-related documents, which are not always coordinated or harmonized, addressing immunity of equipment to the disturbances defined in Section 4. For the sake of clarity, the phenomena and the related immunity tests are listed in the same order as they appear in Table 1. This order is a logical classification of the phenomena, but its sequence does not imply ranking by importance. To avoid such misunderstanding, Table 2 presents a summary of all the phenomena listed in Table 1 and a ***proposal*** as to whether an EMC test specific to the PPD applications is essential, optional, or immaterial.

The decision on including in the test regimen a test identified here as "optional" should be made with due consideration of the particular design or installation conditions of the PPD, in close coordination with designers of PPDs as well as designers of battery chargers. Such coordination could be achieved under the sponsorship of the National Electric Vehicle Infrastructure Working Council.

Our readers will recognize here another aspect of the dilemma concerning the choice between "black-box tests" and "dedicated tests" discussed under Section 4.1. Clearly, the proposed classification of essential, optional, or immaterial requires a peer-review before it can be promulgated as a definitive approach. Such a review will require interactions between all stakeholders: manufacturers of battery chargers, manufacturers of PPDs, and consumer safety advocates. At that time, the present draft document may then be a useful input to the process, turning it into a consensus document.

To facilitate this peer-review process, the basic information presented in Table 2 has been extended to include numerical information on the levels of immunity for those parameters identified as "Essential" or "Optional" in Table 2. This extension is shown in Table 3, ***which should be the focus of the peer-review process***. As a further input to the process, Table 4 shows a comparison of the levels derived in the present document (derived independently from the draft of UL 2231) to those proposed in the current issue (Part 2, July 1, 1996) of UL Subject 2231. Further harmonization may be achieved in the process of the Industry Advisory Group convened by the Underwriters Laboratories.

In the following Section 7, the tests associated with each of these phenomena are listed, including a rationale for performing or not performing the test, guidance information -- a proposed basic specification as the case may be -- on immunity requirements, and a statement of expected results which may be the basis of pass/fail criteria to be developed by listing agencies such as the Underwriters Laboratories.

Table 2
EMC tests to be considered for single-phase Personnel Protection Devices [1]

Phenomenon Description	Test Number	Necessity of performing test to demonstrate		Relevant Reference Standards	
		Shock protection	Trip-out prevention	Test methods	Levels
Harmonics	1	Essential	Essential	IEC 1000-4-7	IEC 1000-3-4
Signalling voltages	2	Optional	Optional	IEC CDV 77A/147A	IEC 1000-2-5
Voltage fluctuations	3	Optional	Optional	IEC 1000-4-..	3%, 5%, 10%
Voltage sags and interruptions	4	Essential	Essential	IEC 1000-4-11	Down to zero
Voltage unbalance	5	Immaterial	Immaterial		
Power frequency variations [2]	6	Immaterial	Immaterial		
Induced low-frequency voltages	7	Immaterial	Immaterial		
DC in AC systems	8	Included in Test 1		-	-
Radiated low-frequency magnetic fields	9	Optional	Optional	IEC 1000-4-8	To be determined [3]
Radiated low-frequency electric fields	10	Optional	Optional	IEC 1000-4-..	To be determined [3]
Induced CW voltages or currents	11	Included in Test 16		UL 943	Extend range?
Conducted unidirectional transients	12	Essential	Essential	IEC 1000-4-5 ANSI C62.45	ANSI C62.41
Conducted oscillatory transients	13	Essential	Essential	IEC 1000-4-12 ANSI C62.45	ANSI C62.41
High-frequency magnetic fields	14	Optional	Optional	IEC 1000-4-9 CISPR ?	To be determined [3]
High-frequency electric fields	15	Optional	Optional	IEC 1000-4-.. CISPR ?	To be determined [3]
Electromagnetic fields, continuous	16	Essential	Essential	IEC 1000-4-6 UL 943 [4]	0.5 V 10 MHZ to 450 MHZ
Electromagnetic fields, transient	17	Optional	Optional	IEC 1000-4-.. CISPR ?	To be determined [3]
Electrostatic discharge	18	Optional	Essential	IEC 1000-4-2	IEC 1000-4-2

NOTES:

1. *Temporary overvoltage immunity is not considered an EMC parameter, but an operational characteristic associated with input voltage range such as noted in ANSI C84.1*
2. *For North American environments.*
3. *By default, select a level from IEC 1000-2-5, in the appropriate location category.*
4. *Based on the successful experience incorporated in the GFCI standard UL 943 which specifies immunity to radiated electromagnetic fields through a substitute immunity test for "Resistance to environmental noise" instead of the "conducted disturbances induced by radio-frequency fields," the subject of IEC 1000-4-6.*

Table 3
EMC tests to be considered for Personnel Protection Devices

Phenomenon Description	Necessity of performing test to demonstrate		Relevant Reference Standards		Proposed PPD EMC Test Level	Section 7 Test Number
	Shock protection	Trip-out prevention	Test methods	Levels		
Harmonics	**Essential**	**Essential**	IEC 1000-4-7 IEC 1000-4-13	Under consideration	Twice the relevant IEC emission limit for the battery charger	**7.1**
Signalling voltages	Optional	Optional	IEC CDV 77A/147	IEC 1000-2-5	IEC 1000-2-5 as applicable to USA (Subject to review)	7.2
Voltage fluctuations	Optional	Optional	IEC 1000-4-..	Under consideration	3%, 5%, 10%, modulated	7.3
Voltage sags and interruptions	**Essential**	**Essential**	IEC 1000-4-11	Extend range	Down to zero, including recovery	**7.4**
Radiated LF magnetic fields	Optional	Optional	IEC 1000-4-8	To be determined	To be determined	(7.9)
Radiated LF electric fields	Optional	Optional	IEC 1000-4-..	To be determined	To be determined	(7.10)
Induced continuous voltages or currents	Optional (see 7.16)	Optional (see 7.16)	UL 943	UL 943	0.5 V injection, frequency range to be determined	(7.16)
Conducted unidirectional transients	**Essential**	**Essential**	IEC 1000-4-5 IEC 1000-4-4 ANSI C62.45	ANSI C62.41	EFT: 2 kV no trip Combination: 3 kV no trip 6 kV no damage	**7.12a** **7.12b**
Conducted oscillatory transients	**Essential**	**Essential**	IEC 1000-4-12 ANSI C62.45	ANSI C62.41	Ring Wave: 3 kV no trip 6 kV no damage Cap Switch: 1.8 p.u. no trip*	**7.13a** **7.13b**
High-frequency magnetic fields	Optional	Optional	IEC 1000-4-9	To be determined	To be determined	(7.14)
High-frequency electric fields	Optional	Optional	IEC 1000-4-.. CISPR ?	To be determined	To be determined	(7.15)
Electromagnetic fields, continuous	**Essential**	**Essential**	Substitute UL 943. Par 26	UL 943	Conducted 0.5 V 10 MHZ to 450 MHZ	**7.16**
Electromagnetic fields, transient	Optional	Optional	1000-4-.. CISPR ?	IEC 1000-2-5	To be determined	(7.17)
Electrostatic discharge	Optional	**Essential**	IEC 1000-4-2	IEC 1000-4-2	6 kV contact, 8 kV air - no trip 8 kV contact 15 kV air - no damage	**7.18**

* Need for no-damage demonstration under consideration

Table 4
Comparison with UL 2231 July 1, 1996 Draft

Phenomenon Description		Present Document: Need to perform test — Electrical shock Protection	Present Document: Need to perform test — Trip-out Prevention	Present Document: Level	UL 2231 Draft * Reference and Level Neither false trip nor loss of shock protection
Harmonics		Essential	Essential	Odd: "Twice IEC limits" or rectifier load Even: Half-wave rectifier spectrum ***Current*** generated by dummy load connected at ***output*** of PPD - No impaired shock protection - No trip	UL 24.2: Per EN 60204-1 (Ref to IEC 801, where no harmonics are mentioned) n = 2 to 5: 10% n = 6 to 30: 2% ***(V or I **)*** distortion on ***input***
Signaling voltages		Optional	Optional	For frequencies and levels to be determined - No impaired shock protection - No trip	None
Voltage fluctuations		Optional	Optional	3%, 5%, and 10% modulated change at 50% duty, 2 Hz to 30 Hz modulation No trip-out permissible Shock protection not an issue, but verify	None
Sag & interruptions		Essential	Essential	Progressive reduction to zero Duration from short to permanent (CBEMA) Consider source impedance during loss Shock protection maintained down to low line voltage level Trip is OK if automatic reset is provided Related charger issues: - Phase angle of sag to be considered - Restoration overshoot to be considered	UL § 24.6: EN 55104, IEC 1000-4-11 100% @ 10 ms 60% @ 200 ms 30% @ 1 s Trip is OK if automatic reset at 85% is provided
Radiated LF magnetic fields		Optional	Optional	To be determined ***	UL § 24.7 IEC 1000-4-8 30 A/m @ 60 Hz
Radiated LF electric fields		Optional	Optional	To be determined	None
Induced continuous voltages and currents		Optional	Optional	Similar to UL 943 Environmental Noise Test, but extend frequency range?	None at lower part of frequency range. See "Continuous fields."
Conducted unidirectional transients	EFT	Essential	Essential	Per IEC 1000-4-4, Level 3 (2 kV setting) - No trip - No permanent impairment of protection, - Momentary disabling of protection tolerable	UL § 24.5: EN 50082-2, IEC 1000-4-4 Level 3 (2 kV on power lines) No false trip Shock protection maintained
	Combi-nation	Essential	Essential	Per ANSI C62.45 (only on L-N and L-G) - 3 kV OCV, 1.5 kA SCI - no trip - 6 kV OCV, 3 kA SCI - no damage - Damage at >6 kV permissible if output remains open (de-energized)	UL § 21 On line conductor(s): 6 kV OCV , 3 kA SCI, no flashover 3 kV OCV, no trip

* Paragraph 23 identifies "Resistance to False Tripping Test" as reserved for future use.

** *Note that during review process with UL, agreement was reached that immunity to conducted current through the PPD would be added to immunity to input voltage distortion.*

*** *Note that during the review process with UL, agreement was reached that the LF magnetic field test proposed by UL would be maintained.*

Table 4 - Continued

Phenomenon Description		Present Document: Need to perform test — Electrical Shock Protection	Present Document: Need to perform test — Trip-out Prevention	Present Document: Level	UL 2231 Draft: Reference and level — Neither false trip nor loss of shock protection
Conducted oscillatory transients	Ring Wave	Optional	Essential	Per ANSI C62.45, all conductor combinations L-N and L-G - 3 kV - no trip - 6 kV - no damage - Damage at > 6 kV permissible if output remains open (de-energized) N-G: 2 kV - No trip	None **
	Capacitor switching	Optional	Essential	1.8 p.u. @ 1000 Hz 1.6 p.u. @ 700 Hz 1.4 p.u. @ 400 Hz - No trip - Monitor energy deposition - Verify no shock protection impairment	UL § 24.8 Variable ringing wave at less than 0.4 p.u. No source impedance defined 1 kHz, 2 kHz, 3 kHz, 4 kHz, 5 kHz
HF magnetic fields		Optional	Optional	To be determined	None
HF electric fields		Optional	Optional	To be determined	None
EM fields, continuous		Optional	Essential	Per UL 943, Section 26 0.5 V superimposed to line voltage in frequency steps from 10 MHZ to 450 MHZ	UL § 24.4.1: EN 60601-1-2, IEC 1000-4-3 20 V/m @ 150 kHz to 1000 MHZ
EM fields, transient		Optional	Optional	None (Presumed to be covered by UL 943) *	UL § 24.4.2: ENV 50204 (Digital phones) 20 V/m @ 895 MHZ to 905 MHZ
Electrostatic discharge		Optional	Essential	IEC 1000-4-2 Levels - No trip at 6 kV contact, 8 kV air discharge - Shock protection maintained after test of 8 kV contact, 15 kV air discharge Related charger issue: Control cables	UL § 24.3: Per IEC 1000-4-2 8 kV direct contact 15 kV air discharge - See Note ***

* The application of this environmental noise test was catalyzed by spurious trip-out observed for portable GFCI used in the construction industry where "walkie-talkies" were extensively used. The test, developed by UL and NEMA has successfully demonstrated immunity for the millions of GFCIs now installed in the United States. Adopting this test method will at the same time cover the upper range of the "Signalling voltages" phenomenon listed as item 2 in the IEC tabulation of disturbance sources.

** *Note that during review process with UL, agreement was reached that immunity to conducted ring wave would be added.*

*** *Note that the Report of the Meeting by UL, dated November 27, 1996 states that a revision will be made to the proposed UL test.*

7. SPECIFIC EMC PHENOMENA AND TESTS

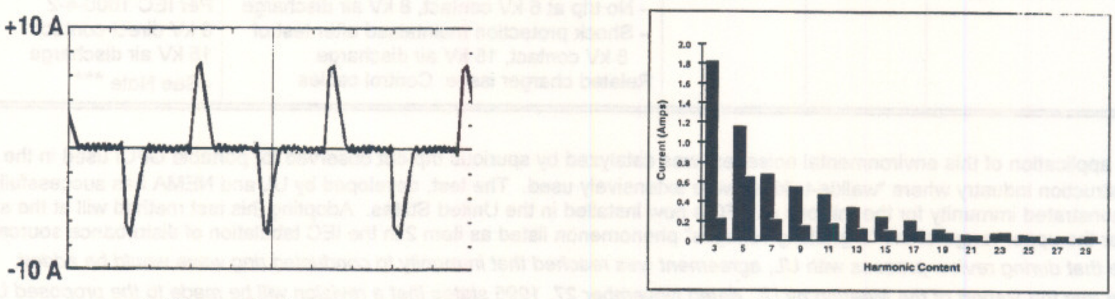
7.1 HARMONICS

7.1.1 Rationale

The EMC tests for this phenomenon listed in IEC 1543 (1995-04 issue) are still under consideration. For this reason, the rationale for the present document concerning this phenomenon includes a discussion of the operating conditions for a PPD controlling an electric vehicle battery charger. This discussion should be the subject of a peer review, until such time when IEC 1543 will be updated to include harmonic test specifications. The following is presented for consideration:

Given the battery-charging load of the PPD, normal operation of the system involves a harmonic-rich current waveform, depending upon the design of the charger. In a simple full-wave rectifier system, current pulses will be drawn only when the instantaneous voltage of the supply is greater than the battery voltage. Such nonlinear operation is known to be a generator of odd harmonics, the third harmonic being the major component. Emission limits for individual equipment have been developed by the IEC, in the 1000 Part 3 series. On the other hand, IEEE Std 519 addresses limiting harmonics at the point of common coupling. For a residential installation, one might rationalize that other loads in the residence might offer some relief at the point of common coupling. One could also rationalize that the charger is likely to be operated during the night, at a time when other loads would be light. Thus, one can expect that the consensus process among vehicle and charger manufacturers and the electric utilities will eventually result in some harmonic emission limitation, settling either on the IEC approach such as IEC 1000-3-2 (input current ≤ 16 A per phase) or IEC 1000-3-4 (input current > 16 A per phase), or on some North American application of IEEE 519.

Figure 5 (a) shows the current pulses drawn by a battery or capacitor circuit, and (b), the resulting spectrum of harmonics. In (b), the high bars at each harmonic correspond to the current drawn by the circuit without a filter, and the low bars to the current with a filter has added to satisfy a given requirement for harmonics emission limitation.



(a) Current pulses (b) Harmonics spectrum

Figure 5 - Typical AC current waveform and harmonics spectrum of a simple DC supply rectifier

Therefore, we can expect that a typical battery charger would include some form of harmonic emission limitation to bring it in compliance with either the requirements of IEC 1000-3-2 or IEC 1000-3-4, or the recommendations of IEEE 519. Thus, the harmonic content for which the PPD must be immune would be the greatest of the two limits. Because the IEEE 519 approach is based on levels achieved at the point of common coupling, the resultant limits for individual equipment can be expected to be less stringent than those promulgated by the IEC. In the absence of agreed-upon limits from the battery charger industry, a conservative approach might be taken by postulating that battery chargers will be built to satisfy the published and to-be-published IEC limits for battery chargers, and then specify a PPD immunity level equal to two times the level(s) of these IEC limits.

However, because the levels are still being debated within the IEC, there is some uncertainty on what level should be retained for this "twice the IEC limit" selection. IEC 1000-3-2, issued in 1995 for equipment rated less than 16 A per phase, clearly specifies current levels for the equipment, not percentages of the load current. The future IEC 1000-3-4, for equipment rated more than 16 A per phase is still being developed, and proposes limits expressed in percentage of the fundamental current. There are also indications that the limits may be negotiated to reflect other loads and system impedances, not unlike the IEEE 519 PCC approach. Table 5 is based on the assumption that the percentages proposed in the future IEC 1000-3-4 will be adopted. See Appendix A (page 41) for further comments on the "stages" of application of that document, including the source upon which Table 5 is based.

Table 5
Maximum harmonic levels expected at the output power port of the PPD under normal operation

Harmonic number	3	5	7	9	11	13	≥15
Current level, % of fundamental	42	22	15	8	6	4	2

In the IEC 1000-3-4 limits, even harmonics drawn by equipment appear to be presumed negligible, with a percentage limit for every even harmonic set at less than 1/8 of the rank, or 0.6. However, the situation created by the normal operation of the rectifier supply must be complemented by the scenario of a charger that would have failed into a half-wave rectifier mode. That type of operation produces a harmonic spectrum with the second harmonic as high as 42% of the total, as well as a DC component.

Should the scenario of a half-wave rectifier mode be retained as necessary, Table 6 shows the percentage of harmonics (including a DC component) which might be involved in the absence of mitigation in the charger circuitry. These levels are substantially higher than the levels of odd harmonics associated with a pulsed charging current from a full-wave rectifier circuit provided with a modicum of harmonic control. Therefore, there is a need for the electric vehicle industry to address the issue of abnormal operation of a charger as well as the normal, expected and controlled emission of harmonics for the various types of AC-DC converters under consideration.

Table 6
Possible emission of even harmonics during half-wave operation of a battery charger

Harmonic number	0	2	4	6	8	10	∑n≥10
Current level, % of fundamental	50	50	40	20	5	5	5

7.1.2 Immunity Test Requirement and Procedure

a) Normal operation

With the PPD input power port energized at the rated voltage from the laboratory 60 Hz power supply, a dummy harmonic-generating load must be connected to the output power port of the PPD to simulate the current that would be drawn by a generic battery charger. This simulation may be achieved by one of the following methods:

1) With the input power port of the PPD energized at its rated voltage (and supplied by a power supply of appropriate short-circuit current capacity), inject a harmonic current on the output power port circuit by

means of an isolated power amplifier driven by an arbitrary waveform generator with a spectrum of harmonics as specified in IEC Publication 1000-3-4, at a level equal to two times the level specified in this IEC publication.

2) Establish a generic load-simulation circuit as shown in Figure 6, with a full-wave rectifier circuit and a combination of resistors, inductors, and capacitors such that the spectrum shown in Table 6 will be approximately obtained for the rated current of the generic charger of interest. The variable inductance L controls the amount of harmonics (the smaller the inductance, the more peaked the current pulses and consequently the harmonic content). With no inductance, the worst case is obtained, with third harmonic content substantially greater than the expected IEC limits. Likewise, the greater the capacitor C, the higher the harmonic content. The load resistance R is to be sized to obtain the rated current of the charger.

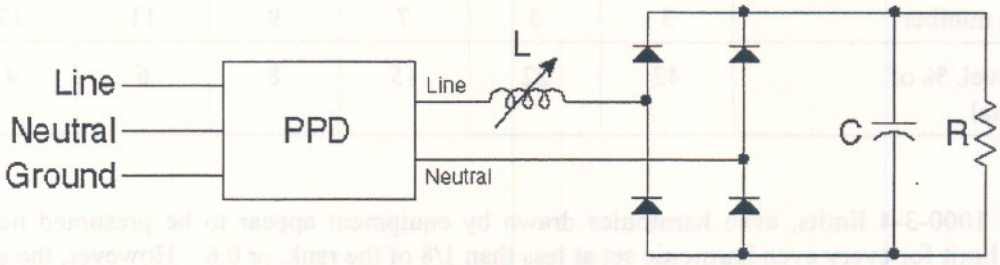


Figure 6 - Typical test circuit for generating a harmonic spectrum in the load current

Method 1) might require a current-compliance amplifier which may not be readily available. However, it offers the advantage of performing a test with more closely controlled (and therefore more repeatable) harmonic spectrum.

Method 2) has been successfully applied for testing line filters in the presence of specified harmonics, but it becomes a hardware-defined test method rather than a generic percentage method. This characteristic might make the test less repeatable and more involved if many dummy loads must be implemented to match the ratings of a diversity of battery charger applications.

Having selected either Method 1) or Method 2), create a leakage current on the load side of the PPD with an rms value equal to the rated threshold of PPD trip.

b) Half-wave operation

With the PPD input power port energized at the rated 60 Hz voltage, apply to the PPD output power port a half-wave load with peaks corresponding to the current pulses drawn by a fully discharged battery.

Create a leakage current on the load side of the PPD, upstream of the half-wave rectification, with an rms value equal to the rated threshold of PPD trip.

7.1.3 Expected Results

Depending on the design of the PPD and its interface, if any, with the control circuitry of the charger, either one of two results can be considered as acceptable, both for normal and abnormal operation of the charger:

a) The protective function (trip-out) of the PPD is not impaired, and no trip-out occurs until the leakage current is created, for the case of a charger which does not have a visible indication or alarm of malfunction.

b) The protective function of the PPD is not impaired, and trip-out is permissible for abnormal charger condition, in the case of a charger which provides the user with a visible indication or alarm of the charger malfunction so that the PPD trip-out will not be misconstrued as a spurious PPD tripping that might lead the user to bypass the PPD.

For the scenario of normal charger operation, the harmonic spectrum is defined in 7.1.2 above.

In the case of an abnormal charger operation, such as a half-wave mode, the levels at which these results should be obtained are still to be determined by a review of the actual harmonic emission levels under conditions to be identified by manufacturers of battery chargers.

7.2 SIGNALLING VOLTAGES

7.2.1 Rationale

One can speculate that a household including an electric vehicle is likely to contain an array of equipment using signalling voltages for remote control of various appliances, distributed speakers, etc. Thus, demonstrating immunity of the PPD to such injection of signaling voltages would be prudent, but not essential; therefore, this test is classified as "Optional." IEC 1000-2-5 cites a wide range of signal frequencies and their corresponding levels among different countries. To define a realistic test applicable to the North American environment, specific data must be obtained on the frequencies and levels that should be considered. Obtaining such information remains an action item for the Personnel Protection Devices Committee as of the date of the present document.

7.2.2 Immunity Test Requirement and Procedure

Apply to the input power port of the PPD a sine wave voltage at the rated value, with the appropriate superimposed signalling voltage.

Create a leakage current on the load side of the PPD with an rms value equal to the rated threshold of PPD trip.

7.2.3 Expected Results

a) No trip-out should occur under realistic conditions of signal injection.

(Note: The applicable frequency range and amplitude are still under consideration by the PPD Committee)

b) The detection of a leakage current and the corresponding intentional trip-out should not be disabled in the presence of the injected signaling voltages.

7.3 VOLTAGE FLUCTUATIONS

7.3.1 Rationale

In lighting loads, voltage fluctuations typically affect light output with quite noticeable results, sometimes even irritating to the human eye. Thus, this phenomenon is primarily associated with flicker of light sources and is not very likely to affect PPDs. Common causes of voltage fluctuations are pulsating reactive loads and the switching on and off of resistive loads. Typical pulsating reactive loads are arc welders, affecting a single service, or large arc furnaces, which can affect an entire distribution system. However, in the absence of information on the generic response of PPDs to voltage fluctuations, it may be prudent to ascertain that they have achieved some degree of inherent immunity. For this reason, testing for this type of disturbance is proposed as an optional test.

7.3.2 Immunity Test Requirement and Procedure

1. Apply a 60 Hz sinusoidal supply voltage with a 3% modulated RMS change, having a duty cycle of 50%. The modulation waveform should be a square wave, crossing the zero axis 45 degrees after the supply voltage crosses zero. The frequency of modulation should be swept from 2 Hz to 30 Hz in the following sequence: [2, 3, 4, 5, 6, 10, 12, 15, 20, and 30] Hz.

2. Repeat test guideline 4 at modulation amplitudes of 5% and 10%.

3. After completion of 1 and 2, create a leakage current of appropriate value at the power output port and verify that the shock protection has not been impaired.

7.3.3 Expected Results

No trip-out should be observed for the voltage fluctuations described above .
While damage (loss of shock protection after the test) is not expected, it will be a simple matter to verify integrity of the protection function by creating a leakage current.

7.4 VOLTAGE SAGS AND INTERRUPTIONS

7.4.1 Rationale

The folklore and literature are replete with anecdotes of blinking clocks and lost programming of VCRs following a sag or an interruption. The scenario of the recharging of the vehicle battery being aborted by a sag, tripping out the PPD, caused by an early evening lightning storm and having the user find the vehicle battery still discharged the following morning, is ***absolutely unacceptable***. Therefore, the highest possible immunity is required for the PPD, not only against a sag, but against any transient response of the battery charger following power restoration. The latter disturbance is not defined in environment characterization documents and should be the subject of a joint review with the manufacturers of battery chargers so that such power restoration transient, if any, can be correctly identified and included in the sag immunity requirements for PPDs. While not a likely scenario, and somewhat outside of the scope of EMC considerations, a long-term voltage reduction should be considered for those PPD designs where trip-out is contingent upon having the line voltage available at the input power port of the PPD. For instance, shock protection should be maintained down to a voltage where a leakage in the output power port would not be a shock hazard.

7.4.2 Immunity Test Requirement and Procedure

For the purpose of establishing immunity to sags, the exacting specifications of IEC 1000-4-11 might not be necessary for this test, however, for the sake of repeatability, it may be prudent to follow these. A progressive reduction of the voltage at the AC input port, down to zero, should be performed, as well as an abrupt loss of power. The revised "CBEMA Curve" should be applied to define the envelope of duration versus depth of the sags, rather than the IEC 1000-4-11, because this revised curve reflects a more recently developed consensus based on actual tests.

Power quality investigations have revealed that the power-frequency angle at which the sag originates may have an influence on the outcome of the sag. Therefore, this aspect of the sag test procedure requires a review of the design of battery charger controls to assess whether the angle of the sag origin is a relevant parameter in subjecting PPDs to sags.

The response of the battery charger to restoration of power might also create transient disturbances which might produce spurious trip-out of the PPD. This is another example of the need for coordinating the PPD immunity specifications with the yet-to-be-defined generic or specific behavior of the battery charger.

The issue of whether this loss of power is associated with loss of utility power (the impedance upstream of the PPD remains low) or trip-out of the branch circuit breaker supplying the PPD (open circuit upstream of the PPD) does not appear to be significant. However, it should be reviewed by the manufacturers of PPDs for comment. After the manufacturers have characterized the behavior of the battery charger during power recovery, appropriate simulation of such behavior should be defined for application to the AC output port of the PPD.

Create at the power output port a leakage current path corresponding to the threshold of protection first at a nominal line voltage, then at 85% of nominal, and verify opening of the circuit for each case.

7.4.3 Expected Results

Considering the importance that the response be free of any spurious trip-out, the PPD response, unlike other electronic devices concerned with ride-through capability, should be that while loss of power during the sag or interruption is perfectly acceptable, the power delivery to the charger must resume when the supply voltage returns to the normal level. Note that this flexibility does not include permission to stop supplying power, nor impair shock protection, during any long-term low line-voltage condition such as those defined in ANSI C84.1. That consideration is not generally included in EMC specifications, but is necessary as one of the operational specifications of the PPD.

7.5 VOLTAGE UNBALANCE

7.5.1 Rationale

This EMC requirement concerns polyphase power systems. Because residential power systems in North America are single-phase TN-C-S systems, this phenomenon is immaterial for residential use of as far as electric vehicle battery chargers and their PPDs are concerned. Should the industry introduce public recharging stations, then a three-phase supply may be considered and a suitable immunity level should be selected.

Should the peer-review process indicate interest in performing such a test, those parties interested in the test should provide information on appropriate levels to be applied.

7.6 POWER FREQUENCY VARIATIONS

7.6.1 Rationale

Given the frequency stability of the North-American power grid, this type of phenomenon is not expected to have levels that could affect the safety function of the PPD, hence a classification of "immaterial."

7.7 INDUCED LOW-FREQUENCY VOLTAGES

7.7.1 Rationale

This phenomenon does not appear to represent a threat to the operation of PPDs and therefore has been classified "immaterial." Some interaction might still occur, so that if in the experience-based opinion of reviewers this phenomenon should still be considered, it might be upgraded to the rank of "under consideration."

Should the peer-review process indicate interest in performing such a test, those parties interested in the test should provide information on appropriate levels to be applied.

7.8 DC IN AC NETWORKS

7.8.1 Rationale

The effects of this phenomenon are included in the half-wave rectifier test (as part of the harmonics immunity test) and no other test is suggested for immunity against this phenomenon.

7.9 LOW-FREQUENCY RADIATED MAGNETIC FIELDS

7.9.1 Rationale

It is not expected that this phenomenon is likely to occur at significant levels in the PPD environment for direct coupling into the internal PPD circuits, except in the case where a charger would be installed near a strong source of magnetic fields. Consequently, no test is suggested in the present document for immunity against this phenomenon. However, peer-review may reveal a need for such a test, hence a classification of "optional."

Should the peer-review process indicate interest in performing such a test, those parties interested in the test should provide information on appropriate levels to be applied [1].

1 *Note that during the review process at UL, agreement was reached that such a test should be included.*

7.10 LOW-FREQUENCY RADIATED ELECTRIC FIELDS

7.10.1 Rationale

It is not expected that this phenomenon is likely to occur at significant levels in the PPD environment for direct coupling into the internal circuits of the PPD; consequently, no test is suggested in the present document for immunity against this phenomenon. However, peer-review may reveal a need for such a test, hence a classification of "optional."

Should the peer-review process indicate interest in performing such a test, those parties interested in the test should provide information on appropriate levels to be applied.

7.11 INDUCED CONTINUOUS-WAVE HIGH-FREQUENCY VOLTAGES OR CURRENTS

7.11.1 Rationale

In the context of Table 1, this phenomenon is limited to the conducted aspects, that is, induction of high-frequency voltages or currents into the power system conductors, resulting in the input power port of the PPD being exposed to the presence of some high-frequency signal. In Publication IEC 1000-2-5, Table 8 proposes three distinct frequency ranges: 10 kHz to 150 kHz, 150 kHz to 27 MHZ, and 27 MHZ to 150 MHZ, presumably reflecting the frequency bands of various types of transmitters. The respective levels in those three ranges, however, are identical except for one low-exposure (degree 1 in IEC parlance) in the 10 kHz-150 kHz range, but that difference is only a factor of 3, hardly significant given the uncertainty of the assumptions made on the presence of transmitters in that range.
By comparison, the conducted high-frequency test included in UL 943 ("environmental noise test"), as discussed in Section 7.16 of the present document, covers the range of (only) 10 MHZ to 450 MHZ.

The test 7.16, derived from the UL 943 environmental noise test, would include that the upper frequency range of this phenomenon. It is not apparent that the lower frequency range would present a larger immunity problem than the higher frequency range. Thus, unless it can be shown that the PPD would be more susceptible at the lower frequencies, a separate test is unnecessary in view of test 7.16.

Should the peer-review process identify the need to include the lower range of the high-frequency, then the range of the 7.16 could be extended downward. Thus, a separate test under the IEC listing (Table 1 of the present document) appears unnecessary, hence the notation of "included in Test 7.16" appearing in Tables 2, 3 and 4 of the present document, with a question mark on extending the frequency range.

7.12 CONDUCTED UNIDIRECTIONAL TRANSIENTS

Several phenomena have been identified as occurring in low-voltage AC power systems, which can be described as producing unidirectional transients (impulses). IEC Publication 1000-2-5 suggests three ranges for the time scale of unidirectional transients: nanoseconds, microseconds, and milliseconds. The nanosecond range is addressed by the so-called Electrical Fast Transient (EFT) burst, an interference test, for which test procedures and implied severity levels are given in IEC 1000-4-4. The microsecond range is addressed by the Combination Wave. As discussed in ANSI C62.41, the purpose the Combination Wave is to demonstrate immunity against insulation breakdown (for high impedance EUTs) and current-handling capability (for low impedance EUTs). The millisecond range, where consensus has not been achieved, includes proposals for "Long Waves" such as the 10/1000 additional wave of ANSI C62.41 or the 10/350 under consideration in IEC TC 37.

Consequently, two of the IEC tests, the EFT Burst in the nanosecond range, and the Combination Wave in the microsecond range are proposed here. Because of the lack of consensus on the millisecond range for unidirectional transients, and the fact that the millisecond range is covered by the capacitor switching transient (in the next section), the millisecond range for unidirectional transients is not considered here.

NOTE: If the design of the connection between the premises power supply and the vehicle involves control lines such as interlocks, state of charge, etc. which might not involve the PPD, an EFT test applied to the connections (such as by means of the IEC 1000-4-4 "Coupling Clamp") would seem appropriate, albeit outside of the scope of the present document.

7.12-a EFT Test

7.12-a.1 Rationale

The EFT test was initially developed for industrial process control equipment, because industrial installations include many relays and contactors, the prime sources of fast transients. In a residential environment, there are still many loads controlled by electromechanical relays, an excellent source of EFT bursts. Therefore, a test for immunity against EFT bursts is essential in ensuring compatibility and operational reliability of PPDs in the residential as well as commercial environments.

7.12-a.2 Immunity Test Requirement and Procedure

Because the EFT test is a test aimed at demonstrating immunity against upsets, not damage, it is inherently presumed to be performed with the equipment under operating conditions. This means that surges applied to the incoming AC port should be applied line-to-neutral and line-to-ground, with the output AC power port connected to a dummy load, as discussed in ANSI C62.45. The details of the test set-up are specified in IEC 1000-4-4, with test levels defined in its Subclause 5. For the PPD environment, the level 3 ("Typical industrial environment") with open-circuit voltage of 2 kV should be adequate. It is noteworthy that the Informative Annex A which contains the description of the environment still uses the original titles developed at the time when the standard (IEC 801-4) was limited in scope to industrial process control equipment.

7.12-a.3 Expected Results

- No trip-out should occur for a test level of 2 kV open-circuit voltage for the procedure defined in IEC 1000-4-4.
- Verify that the protective function has not been impaired by creating a leakage current of appropriate value on the output power port of the PPD. (Momentary disabling of the shock protection function is tolerable during the burst.)

7.12-b Combination Wave

7.12-b.1 Rationale

The Combination Wave Test has a dual purpose in the case of the PPDs. One is to demonstrate adequate insulation and implies application in the line-to-ground mode, the other is to demonstrate both adequate voltage withstand and current-handling capability in the line-to-neutral mode. As discussed in Section 5, in a TN-C-S, there are no "high-energy surges" (originating outside of the building) propagating in the neutral-to-ground mode beyond the service entrance.

It is somewhat unlikely that the line-to-neutral and line-to-ground input port of the PPD will be inherently capable of withstanding the full stress of a 6 kV open-circuit voltage, so that one can expect some form of surge-protective device (SPD) to be provided at this input. That SPD then becomes a low-impedance input so that the 3 kA 8/20 μs short-circuit current stress becomes the relevant test. Of course, the transition from a voltage stress to a current stress is inherent to the use of a Combination Wave surge generator.

While the garage location may be somewhat distant from the service entrance in the general case, there is some likelihood that it could be located quite close to the service entrance. Furthermore, the Cascade Coordination studies, a popular topic of the nineties, have demonstrated that the stress of a surge event is applied to the SPD which has the lowest clamping voltage in an installation. It is likely that well-intentioned designers of PPDs might have selected for protection of the input port an SPD with low clamping voltage, making it the winning candidate in a bid to attract most of the surge current impinging on the installation.

7.12-b.2 Immunity Test Requirement and Procedure

Apply the procedure described in IEEE C62.45 to subject the input power port of the PPD to a Combination Wave surge coupled in the line-to-neutral mode, and later in the line-to-ground mode. The highlights of the procedure include: with the surge produced at the peak of the sine wave, in additive polarity, proceed by 500 V increments of the open-circuit voltage, starting at 1000 V (to ferret out any blind spots) up to the full 6000 V. Allow sufficient time between surge application to allow any internal SPD to cool down. In a preliminary test, a dummy load should be connected to the output power port to determine whether the impinging surge passes through the PPD or is diverted by an internal SPD. This monitoring, as explained in C62.45, is important in assessing the test results. After each application of the surge for the no-trip-out criterion, verify that the protective function of the PPD has not been impaired by creating a leakage current of appropriate level on the output port of the PPD. Subject the PPD to even greater surge stress if no failure has occurred at the 6 kV open-circuit voltage level to ascertain that the ultimate failure mode (for unlikely but possible extreme surge levels) will indeed lead to a permanent interruption of power delivery to the output port. For further details on the surge coupling and instrumentation, see C62.45.

7.12-b.3 Expected Results

- Neither damage nor trip-out should occur for a test level of up to and including 3 kV open-circuit voltage (1.5 kA short-circuit current)
- Trip-out is tolerated above 3 kV open-circuit voltage, but no damage or impairment of the protective function.
- Damage is permissible above 6 kV open-circuit voltage, but the output port must then become permanently disconnected from the input port to maintain the protective function, albeit requiring replacement of the PPD to restore service.

7.13 CONDUCTED OSCILLATORY TRANSIENTS

The oscillatory transients occurring during load switching or stimulated within a building by impulsive unidirectional surges are addressed by the 100 kHz Ring Wave originally defined in UL 943 and IEEE 587-1980. In addition, lower frequency oscillatory transients can be produced by the switching of capacitor banks used for power-factor compensation or voltage control. The Ring Wave has now been adopted in IEC 1000-4-12, but capacitor switching transients have not been the subject of a test standard in the IEC 1000-4 series. The guidance provided in IEEE C62.41-1991 is now questioned as the result of field measurements that indicate that lower frequencies (500 Hz to 1000 Hz) are more likely than the 5 kHz suggested by C62.41. Therefore, two tests are suggested: the "classical" 100 Hz Ring Wave, and a proposed simulation procedure for capacitor switching. These two are discussed below, respectively in part a) and b) of this section 7.13.

7.13-a 100 kHz Ring Wave

7.13-a.1 Rationale

This test is primarily concerned with the effects of the rate of voltage change which can produce upsets. When used in conjunction with the Combination Wave at the same peak value of the open-circuit voltage, the damage potential is assessed by the Combination Wave, not the Ring Wave. On the other hand, as discussed in ANSI C62.41, the Ring Wave can occur in all three modes, line-to-neutral, line-to-ground, and neutral-to-ground. For the latter, the severity of the stress increases for increasing distances from the service entrance, so that the envelope of stresses for surge tests must consider the short distance from the service entrance as the worst case for the Combination Wave, while for the Ring Wave in neutral-to-ground mode (potentially an upsetting event for PPDs) the worst case is the longest likely distance from the service entrance.

7.13-a.2 Immunity Test Requirement and Procedure

The Ring Wave should be applied, in turn, to the three combinations of line-to-neutral, line-to-ground, and neutral to ground. See C62.45 for details of how these combinations are applied, for single-phase three-wire circuits (120 V) as well as for single-phase four-wire circuits (240 V). The highlights of the procedure are similar to those given above in the case of the Combination Wave.

7.13-a.3 Expected Results

For line-to-neutral and line-to-ground surge coupling:
- Neither damage nor trip-out permitted for a test level of up to and including 3 kV open-circuit voltage (100 A short-circuit current)
- Trip-out is tolerated above 3 kV open-circuit voltage, but no damage or impairment of the protective function.
- Damage is permissible above 6 kV open-circuit voltage, but the output port must then become permanently disconnected from the input port to maintain the protective function, albeit by requiring replacement of the PPD.

For a 2 kV open-circuit voltage application neutral-to-ground:
- No trip-out of the PPD.

7.13-b Capacitor switching transients

7.13-b.1 Rationale

Capacitor bank switching is a common practice on utility power transmission and distribution systems. System power factor and voltage regulation can be improved by switching in capacitor banks. Strategically placed capacitor banks provide capacitive reactance to offset the inductive reactance of the system wiring and transformers and to improve overall distribution system performance during normal loading conditions.

When an uncharged capacitor bank is switched onto the line, the instantaneous charging of the bank causes a transient current inrush which in turn causes a transient voltage drop across the switched conductors. As the system recovers from this transient voltage drop, a damped oscillatory response is experienced at frequencies that may be as high as 5 kHz at the location of the switched capacitors, or may be as low as a few hundred hertz on the wiring inside of a building many miles away from the switched bank. The theoretical maximum transient voltage of the first full oscillation is 2 per unit (p.u.) with respect to the peak voltage of the distribution system. However, larger magnitudes (3 or more p.u.) have been recorded on the load side of a second capacitor bank already on line when the transmission or distribution banks are switched in. This magnification effect is observed mainly at locations where local capacitor banks have been installed to improve the power factor of the facility.

Recent power quality survey data suggests that up to 95 percent of all locations experience capacitor switching transients with magnitudes ranging from 1.1 p.u. to 1.8 p.u. The frequency range for 95 percent of all locations is between 400 Hz and 1 kHz, while the median event was observed near 700 Hz.

As the frequency of the switching transient increases, its magnitude increases also, so the worst-case expected event for 95% of all locations would be a 1.8 p.u. ring decaying at 1 kHz, while 400 Hz events would likely have magnitudes of 1.4 p.u. or less. Higher magnitude events at higher frequencies have been recorded, but these are the exception and occur at fewer than 5% of all locations.

Many electronic loads have sensing and/or protection circuitry that will trip out in the presence of capacitor switching transients. Peak detection circuits may interpret the potential high magnitudes during the ringing oscillatory transient to be an unacceptable overvoltage or in some cases a nominal line voltage higher than it really is. Transient dv/dt sensing circuits may interpret the transient rise or fall times of the voltage as an unacceptable event. Zero crossing detection circuits may be fooled by the potential additional zero cross overshoots observed during severe capacitor switching transients. AC to DC converters can experience DC overvoltage conditions due to the oscillatory voltage swell above the nominal line peak during the first few ringing cycles of a capacitor switching event. Phase-angle controlled rectifiers may experience failure due to multiple devices turning on simultaneously during capacitor switching events. Consequently, for the case of a PPD (as well as the associated battery charger), it would be prudent to demonstrate immunity against this type of disturbance, both for false tripping and possible damage.

7.13-b.2 Immunity Test Requirement and Procedure

Because present standards do not provide information on how to conduct this test, the following procedure is suggested. It is based on availability of a linear power amplifier, as suggested in ANSI C62.45.

1. Select an arbitrary function generator and amplifier capable of generating transients up to 2 p.u. of the peak nominal voltage (340 V measured from zero to peak on a 170 V measured from zero to peak sinewave for a 120 V application, and prorated levels for higher input voltage ratings). To provide a test condition emulating the presence of a switched capacitor near the location of the building, it is recommended but not mandatory that the amplifier be rated for at least 10 times the steady state VA requirement of the load under test, in this case the presumed load of the battery charger.

2. Apply an additive 1.8 p.u. 1000 Hz oscillatory decaying transient at the 90 degree peak of the voltage sine wave. The applied transient should decay to zero over 180 degrees of the sine wave or by the 270 degree negative peak of the same sine wave cycle. Record the effect on the unit under test and/or its output power port. Repeat the test at 0 degrees and again at 270 degrees of the voltage sine wave. Repeat the entire procedure at the high level of the voltage specification for the unit under test. Repeat the entire procedure at the low level of the voltage specification for the unit under test. If the high and low specifications are unavailable, repeat the entire procedure at plus 10 percent of nominal voltage and at minus 10 percent of nominal voltage.

3. Repeat step 2 with a 1.6 p.u. 700 Hz oscillatory decaying transient.

4. Repeat step 2 with a 1.4 p.u. 400 Hz oscillatory decaying transient.

5. Other levels may be applied at the test engineer's discretion. For example, a 1.2 p.u. 200 Hz oscillatory decaying transient or a 2.0 p.u. 1200 Hz oscillatory decaying transient may be applied. Additionally the procedure may include identifying an upset matrix by sweeping the frequency band between 400 Hz and 1 kHz and by sweeping the magnitude between 1.1 p.u. and 2 p.u. in a search for potential upset modes.

6. After each of the tests 2, 3, 4, and 5 above, create a leakage current on the output power port of the PPD to ascertain that the protective function has not been impaired by the test.

NOTE: Because capacitor switching is a daily utility activity, it may also be prudent to do "repetitive hits" testing to assess exposure over time to this event. However, such testing is more an issue of device ageing, to be conducted during the design phase of the PPD, rather than an EMC test procedure.

7.13-b.3 Expected results

It is common to find that the unit under test (UUT) will reduce the observed applied transient unless the amplifier is significantly oversized with respect to the power requirement of the UUT. If the UUT does reduce significantly the applied capacitor switching transient, for instance as the result of the action of a built-in surge-protective device, the results of this test may not be a reliable assessment of the UUT's response to a real-world event involving a switching transient generated by a "large" capacitor bank. Unfortunately, there are no reliable data available on typical magnitudes of the equivalent source impedance of a capacitor switching transient. Therefore, it is important to monitor the applied transient during the actual test to verify that the amplitude and ring frequency are not substantially reduced by the presence of the UUT in the test circuit. This is another example of a test procedure where a strict application of the black-box testing philosophy might not produce meaningful results, unless some knowledge of the internal circuits is available.

- For all the steps listed in 2, 3 ,4, and 5 above, no trip-out should occur.

NOTE: It is assumed, but not demonstrated, that questions on device damage resulting from energy deposition under the conditions of a capacitor switching transient may have been addressed by the Combination Wave test. In particular, the voltage clamping of an SPD incorporated in the PPD will have a profound effect on the current delivered by the power amplifier, or the surge source in actual installations, to the SPD. In contrast with the Combination Wave test with its high driving voltage, switching transients in the 1.4 to 1.8 p.u. range might not produce large currents in SPDs with moderate to high clamping voltages and thus not be a threatening stress. Monitoring the surge current and voltages will provide useful information on the validity of the assumption.

7.14 HIGH-FREQUENCY MAGNETIC FIELDS

7.14.1 Rationale

It is not expected that this phenomenon is likely to occur at significant levels in the PPD environment and no test is suggested in the present document for immunity against this phenomenon. However, peer-review may reveal a need for such a test, hence a classification of "optional."

Should the peer-review process indicate interest in performing such a test, those parties interested in the test should provide information on appropriate levels to be applied.

7.15 HIGH-FREQUENCY ELECTRIC FIELDS

7.15.1 Rationale

It is not expected that this phenomenon is likely to occur at significant levels in the PPD environment and no test is suggested in the present document for immunity against this phenomenon. However, peer-review may reveal a need for such a test, hence a classification of "optional."

Should the peer-review process indicate interest in performing such a test, those parties interested in the test should provide information on appropriate levels to be applied.

7.16 ELECTROMAGNETIC FIELDS, CONTINUOUS

7.16.1 Rationale

Given the expanding use of mobile telephones (cellular or cordless), exposure of PPDs to the electromagnetic field created by these devices is very likely. The telephone user may well be near the battery charger system when using the telephone, so that protection against electric shock as well as prevention of spurious trip-out are imperative requirements for the PPD immunity.

7.16.2 Immunity Test Requirement and Procedure

A very simple test might be to verify the absence of trip-out and the integrity of the electric shock protection while operating a high-performance mobile telephone near the PPD. However, to cover more thoroughly the EMC aspects of this phenomenon, and obtain reproducible results, more formal test procedures should be applied. IEC Publications 1000-4-3 and 1000-4-6 cover such tests.

However, the equipment, set-up and procedures for conducting the IEC tests are complicated, and lack of repeatability has been alleged. Instead of specifying the IEC test procedure, an alternative procedure has been successfully applied for the so-called "ground fault circuit interrupters" (GFCI) which are the predecessors of the PPD [1]. The test procedure for this alternate method is specified as Environmental Noise Test in UL 943, Section 26, including the construction of the test equipment. The ready availability of this test equipment and the demonstrated effectiveness of the test in avoiding false tripping of GFCIs successfully subjected to this Environmental Noise Test justify the selection of the alternate method.

Essentially, the tests consist of injecting a 0.5 V signal in discrete frequency steps from 10 MHZ to 450 MHZ. Refer to UL 943 Section 26 for the details of the procedure and test equipment.

7.16.3 Expected Results

- No trip-out under the specified conditions.
- No loss of protective function under the specified conditions.

1 *The application of this environmental noise test was catalyzed by spurious trip-out observed for portable GFCI used in the construction industry where "walkie-talkies" were extensively used. The test, developed by UL and NEMA, involves injection of a 0.5 V signal over the frequency range of 10 MHZ to 450 MHZ, resulting in demonstrated immunity for the millions of GFCIs now installed in the United States. Adopting this test method will at the same time cover the upper range of the "signalling voltages" phenomenon listed as item 2 in the IEC tabulation of disturbance sources.*

7.17 ELECTROMAGNETIC FIELDS, TRANSIENT

7.17.1 Rationale

It is not expected that this phenomenon (mostly associated with utility substation environments) would occur at significant levels in the PPD environment and no test is suggested in the present document for immunity against this phenomenon. However, peer-review may reveal a need for such a test, hence a classification of "optional."

Should the peer-review process indicate interest in performing such a test, those parties interested in the test should provide information on appropriate levels to be applied.

7.18 ELECTROSTATIC DISCHARGE

7.18.1 Rationale

Typical environments where electric vehicles PPDs will be installed would be expected to be free from the clean, dry conditions that lead to electrostatic charge build-up, except perhaps for a car just pulled in a garage where the sliding motion of the driver on the seat might have displaced some charges. In such a scenario, the driver would engage the battery charger so that a visible trip-out might not be a major issue[1]. Nevertheless, it would be prudent to establish that the PPD is immune to ESD exposure in order to avoid the unpleasant perception from the user that the system could be prone to malfunctions. A more likely scenario is the driver sliding out of the seat, then touching the vehicle body and producing an indirect discharge, radiating a field toward the PPD. Such a scenario is likely to be less severe than the air discharge and direct contacts to the PPD enclosure suggested in this section.

Depending on the design and enclosure of the PPD, it seems unlikely that enough ESD energy could be coupled into the PPD circuitry to cause damage.

7.18.2 Immunity Test Requirement and Procedure

IEC publication 1000-4-2 provides a comprehensive description of the calibration procedures for the ESD generator, but acknowledges the difficulty of specifying in detail the test set-up. A specific test procedure can only be determined on the basis of the installation practice of the PPD if it is a part of the power supply system or part of the battery charger system. As a separate component, testing for ESD immunity might provide some reassurance that the device is suitable, but the effort might be an unnecessary consumption of resources because the ultimate immunity will be determined by the complete package into which the PPD is to be incorporated. Until more detailed information is available on the configuration of the environment where the PPD is to be incorporated, a specific test procedure -- point of application of the discharge and definitive levels -- can only be left as "under consideration."

When an appropriate ESD immunity procedure, for either an isolated PPD or an integrated PPD is determined to demonstrate immunity to spurious trip-out, it will become a simple matter to raise the test level to explore damage immunity, if deemed necessary.

In this test procedure, monitoring the behavior of the PPD includes both a no-trip-out criterion and a verification that the protective function has not been impaired, by creating a leakage current on the output power port of the PPD.

7.18.3 Expected Results

The first level of immunity to be determined is that of a threshold of spurious trip-out, which should be high enough to withstand the test level 3, for both air discharge (8 kV) and contact discharge (6 kV) as defined in IEC 1000-4-2.

For damage immunity, a test level 4 (8 kV contact, 15 kV air discharge) should not impair the protective function after application of the discharge, but permanent damage beyond this level might be permissible, as long as the damage does not result in loss of shock protection by allowing continuing power delivery to the load, that is, in the failed condition the output power port must remain de-energized regardless of the presence or absence of power at the input port.

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1 *It is assumed that the battery charger system includes some visible indication that the charger is being energized when the coupler is engaged by the vehicle operator. Thus, a trip-out associated with this operation might be tolerable as the operator could reset the PPD upon observing the trip-out, albeit creating a nuisance factor in the user's perception.*

APPENDIX A

ANNOTATED BIBLIOGRAPHY

The documents listed in this annotated bibliography have been consulted in preparing the EMC considerations of this report. In addition to the identification of the document, brief comments are given by this author concerning the scope of each document and its use in developing consensus on the EMC requirements for Personnel Protection Devices.

These documents are available in the United States from the following sources:

IEC publications:	American National Standards Institute 1430 Broadway New York NY 10017
or	Global Engineering 15 Inverness Way East Edgewood CO 80112 800 854 7179
European Standards:	Global Engineering 15 Inverness Way East Edgewood CO 80112 800 854 7179
UL Standards:	Underwriters Laboratories 333 Pfingsten Road Northbrook IL 60062-2096 708 272 8800
IEEE Standards:	IEEE Service Center 445 Hoes Lane Piscataway NJ 08855-1331
SAE Standards:	Society of Automotive Engineers 400 Commonwealth Drive Warrendale PA 15096-0001
NFPA - NEC	National Fire Protection Association Batterymarch Park Quincy MA 02269
IWC Minutes	EPRI Distribution Center 207 Coggins Drive Pleasant Hill CA 94523 510 934 4212

A1 - IEC PUBLICATIONS

A1.1 - EMC PUBLICATIONS (1000-X-X) SERIES

A.1.1 - EMC Environment Publications (1000-2-X Series)

The publications in this part have been developed by different working groups of TC77 and its subcommittees with some effort, but not complete success at consistency. They should be used as a last resource only when no other information is available to make a recommendation on the immunity levels to be considered.

IEC 1000-2-1:1990 Electromagnetic Compatibility (EMC)
Part 2: Environment
Section 1: Description of the environment - Electromagnetic environment for low-frequency conducted disturbances and signalling in public low-voltage power supply systems

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IEC 1000-2-2:1990 Electromagnetic Compatibility (EMC)
Part 2: Environment
Section 2: Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems

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IEC 1000-2-3:1992 Electromagnetic Compatibility (EMC)
Part 2: Environment
Section 3: Description of the environment - Radiated and non-network-frequency-related conducted phenomena.

IEC 1000-2-4:1994 Electromagnetic Compatibility (EMC)
Part 2: Environment
Section 4: Compatibility levels in industrial plants for low-frequency conducted disturbances

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IEC 1000-2-5:1995 Electromagnetic Compatibility (EMC)
Part 2: Environment
Section 5: Classification of electromagnetic environments

Comment: This particular publication in the series was to be the comprehensive reference for all electromagnetic disturbances in a wide variety of locations. However, the development of the document and its final approval as a Technical Report raised many objections or proposals for alternate recommendations, decreasing the consensus value of the publication.

A.1.2 - EMC Limits Publications (1000-3-X Series)

IEC 1000-3-2:1995 Electromagnetic Compatibility (EMC)
Part 3: Limits -
Section 2: Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)

Scope summary: Specifies limits of harmonic components of the input current which may be produced by equipment having an input current up to and including 16 A per phase, and intended to be connected to public low-voltage distribution system.
Comment: This document specifies limits expressed in current levels, not percentages, and has been the subject of debate within the engineering community. It is offered as superseding the earlier series of IEC Publications 555, long held as the seminal publications on harmonic control. However, as it applies only to equipments with input current of 16 A or less, it is probably not applicable to vehicle battery chargers. Instead, IEC 1000-3-4, listed below, is more likely to be applicable.

IEC 1000-3-4 Draft Electromagnetic Compatibility (EMC)
Part 3: Limits -
Section 2: Limits for harmonic current emissions (equipment input current > 16 A per phase)

Scope summary: Applicable to electrical and electronic equipment having a rated input current exceeding 16 A per phase and intended to be connected to the public low-voltage AC distribution system.
Connection of this type of equipment to the supply usually needs notification to or consent by the supply authority. This consent depends among other factors on the expected levels of disturbances caused by the equipment and the actual situation at the connection point to the power supply system
Comments: The scope and philosophy of this document are in sharp contrast with the rigid specification of current levels found in IEC 1000-3-2, which is offered as "replacement of the old IEC 555 series" when inquiries are made at Global Engineering. Reference to the point of common coupling appears in the scope, reflecting an evolution in the philosophy away from the 1000-3-2 philosophy which focused exclusively on the equipment emission.

Because one can expect that a vehicle battery charger is likely to draw more than 16 A in a 120 V single-phase system, it is likely that such a charger would fall within the scope of this 1000-3-4 document -- when the draft will emerge as an approved IEC standard. In the latest available version of the draft document (October 1996), three "stages" of EMC assessment are proposed for ensuring compatibility, in part to take into consideration elements such as the short-circuit ratio of the power system, the actual load current level of the equipment (which can be considerably greater than the lower boundary of 16 A stated in the document title), and mutual agreement between provider and user of electrical power. The three stages proposed are:

Stage 1: Simplified connection
Stage 2: Connection based on network and equipment data
Stage 3: Connection based on the consumer's agreed power

In the case of mass-produced and broadly applied electric vehicle battery chargers, it seems doubtful that enough data will be available for the manufacturer, consumer, and utility partnership to develop consensus on applying Stage 2 or Stage 3 in the near future. This would then leave the tabulated values of Stage 1, reproduced in Figure 7, overleaf, as the baseline on which to apply the "2 × IEC limits" philosophy developed during the review process of the present document.

Table 7 - Harmonic emission levels proposed for "Stage 1" in draft IEC 1000-3-4 (October 1996)

Harmonic number n	Admissible harmonic current I_n/I_1 (%)	Harmonic number n	Admissible harmonic current I_n/I_1 (%)
3	21.6	21	≤ 0.6
5	10.7	23	0.9
7	7.2	25	0.8
9	3.8	27	≤ 0.6
11	3.1	29	0.7
13	2	31	0.7
15	0.7	≥33	≤ 0.6
17	1.2		
19	1.1	even	≤ 8/n or ≤ 0.6

Table 1 - Stage 1 current emissions values for simplified connection of equipment ($S_{equipment} \leq S_{cc}/33$)
I_1 = Rated fundamental current; I_n = Harmonic current component

A.1.3 - EMC Test Methods Publications (1000-4-X Series)

The overt intent of the Part 4 series is to define test methods. However, by including severity levels, test levels, and immunity levels either in the normative parts of the standards or in informative annexes, these documents can be construed as specifications for immunity ***levels***. This inference is stronger in the documents developed at the beginning of the process, with documents published in the early nineties. After 1995, words begin to appear either in the text or in the scope, drawing attention that the actual selection of immunity levels for specific equipment is the responsibility of the cognizant product committees. Therefore, a review of these documents is appropriate when seeking information on the consensus process.

IEC 1000-4-1:1992 Electromagnetic Compatibility (EMC)
Part 4: Testing and measurement techniques
Section 1: Overview of immunity tests

Scope summary: Listing of immunity tests for electric and/or electronic equipment connected to power, control and communications networks, for both conducted and radiated phenomena
Comment: This publication provides a list of the phenomena and associated immunity tests under consideration at the time of publication. The intent was to give a general and comprehensive reference to the technical committees of IEC or other bodies, users and manufacturers of electrical and electronic equipment concerning EMC immunity specifications and tests. Since its 1992 publication issue, some tests have been removed from the list, and some have been added. A new work item proposal has been submitted to update the publication.

IEC 1000-4-2:1995 Electromagnetic Compatibility (EMC)
Part 4: Testing and measurement techniques
Section 2: Electrostatic discharge immunity test - Basic EMC Publication

Scope summary: Immunity requirements, test methods for electrical and electronic equipment subjected to static electricity discharges from operators and to adjacent objects. It additionally defines ranges of test levels which relate to different environmental and installation conditions. This standard does not intend to specify the tests to be applied to particular apparatus or systems. The product committees (or users and manufacturers of equipment) remain responsible for the appropriate choice of the tests and the severity level to be applied to their equipment.
Comment: The scope text makes it clear that levels are not specified. However the ***normative*** part of the standard (Clause 5) provides a table with a range of levels, thereby implying some degree of severity, although the overt intent is only to provide a common and standardized basis for test methods and measurements. A comprehensive description of the calibration procedures for the ESD generator, but acknowledges the difficulty of specifying in detail the test set-up. The illustrations of test set-up are oriented toward the evaluation of process-control equipment and table-top computers rather than a device that may be part of the premises wiring, such as the PPD of interest here. ***Informative*** Annex A provides guidance on the selection of test levels and the point of application of the discharge, which may be useful in defining a specific test procedure for PPDs.

IEC 1000-4-3:1995 Electromagnetic Compatibility (EMC)
Part 4: Testing and measurement techniques
Section 3: Radiated, radio-frequency, electromagnetic field immunity test

Scope summary: Immunity of electrical and electronic equipment to radiated electromagnetic energy. It establishes test levels and the required test procedures. This standard does not intend to specify the tests to be applied to particular apparatus or systems. The product committees (or users and manufacturers of equipment) remain responsible for the appropriate choice of the tests and the severity level to be applied to their equipment.
Comment: This document draws attention to the effects that hand-held transmitters may induce disturbances directly into the PPD, which might cause spurious tripping and possible temporarily disable the electric shock protection. The scope text makes it clear that levels are not specified although "preferred test levels" are cited in the normative part of the standard. The ***informative*** Annex F defines three classes of levels, low, moderate, and severe. The conclusion is then inescapable that a Class 3 is necessary for the electric vehicle PPD environment.

IEC 1000-4-4:1995 Electromagnetic Compatibility (EMC)
Part 4: Testing and measurement techniques
Section 4: Electrical fast transient/burst immunity test

Scope summary: Immunity requirements and test methods for electrical and electronic equipment to repetitive electrical fast transients. It additionally defines ranges of test levels and establishes test procedures. The test is intended to demonstrate the immunity of electrical and electronic equipment when subjected to types of transient disturbances such as those originating from switching transients (interruption of inductive loads, relay contact bounce, etc.) The product committees (or users and manufacturers of equipment) remain responsible for the appropriate choice of the tests and the severity level to be applied to their equipment.
Comments: After pointing out in the scope that users and manufacturers remain responsible for selecting severity levels, the normative text defines numerical values of test levels (Table 1, Section 5) and an informative annex describes categories of environments where ***it is recommended*** that these levels be selected. Thus, for practical purposes, readers of the document are directed to select a particular severity level on the basis of the environment characteristics. The attributes listed for these environments point toward a Level 3 ("Typical industrial environment") more than a Level 2 ("Protected environment").

IEC 1000-4-5:1995 Electromagnetic Compatibility (EMC)
Part 4: Testing and measurement techniques
Section 5: Surge immunity test

Scope summary: Immunity requirements, test methods and range of recommended test levels for equipment to unidirectional surges caused by overvoltages from switching and lightning transients. Several test levels are defined which relate to different environments and installation conditions.
This standard does not intend to specify the tests to be applied to particular apparatus or systems. The product committees (or users and manufacturers of equipment) remain responsible for the appropriate choice of the tests and the severity level to be applied to their equipment.
Comment: The scope text makes it clear that levels are not specified. However the ***informative*** Annex provides tables with a range of levels, thereby implying some degree of severity, although the overt intent is only to provide a common and standardized basis for test methods and measurements.

IEC 1000-4-6:1996 Electromagnetic Compatibility (EMC)
Part 4: Testing and measurement techniques
Section 6: Immunity to conducted disturbances, induced by radio-frequency fields.

Scope summary: Conducted immunity requirements for electrical and electronic equipment to electromagnetic disturbances coming from intended radio-frequency (RF) transmitters in the frequency range 9 kHz up to 80 MHZ. This standard does not intend to specify the tests to be applied to particular apparatus or systems. The product committees (or users and manufacturers of equipment) remain responsible for the appropriate choice of the tests and the severity level to be applied to their equipment.
Comment: This document draws attention to the effects that hand-held transmitters may induced disturbances into the power line, which in turn might cause spurious tripping of the PPD. The ***informative*** Annex provides a range of levels, thereby implying some degree of severity, although the overt intent is only to provide a common and standardized basis for test methods and measurements.

IEC 1000-4-7:1991 Electromagnetic Compatibility (EMC)
Part 4: Testing and measurement techniques
Section 7: General guide on harmonics and interharmonics measurements and instrumentation for power supply systems and equipment connected thereto

Scope summary: This guide is applicable to instrumentation intended for measuring voltage or current components with frequencies in the range of DC to 2500 Hz which are superimposed on the voltage or current at the power supply frequency. The test procedure for measurements and test conditions for emission testing are not dealt with in this guide; these requirements are included in the particular standards.
Comment: Primarily an instrumentation guide

IEC 1000-4-8:1993 Electromagnetic Compatibility (EMC)
Part 4: Testing and measurement techniques
Section 8: Power frequency magnetic field immunity test
Scope summary: Immunity requirements of equipment, only under operational conditions, to magnetic disturbances at power frequencies related to residential and commercial locations, industrial installations and power plants, medium voltage and high voltage sub-stations. This standard defines recommended test levels, test equipment, set-up and procedure.
Comment: The domain of applicability includes residential locations, but the phenomenon is likely to become significant only when high power-frequency currents are involved, such as steady-state currents in industrial installations, power plants and substation, and under fault conditions. Given the low probability that such conditions would occur in the environment of an electric vehicle battery charger, the test has been given an "optional" category in the ranking of test priorities.

IEC 1000-4-9:1993 Electromagnetic Compatibility (EMC)
Part 4: Testing and measurement techniques
Section 9: Pulse magnetic field immunity test
Comment: The title offers no clue to the limited scope "... related to industrial installations and power plants, or medium voltage and high-voltage substations ..." which makes this publication irrelevant to the subject of electric vehicle PPDs.

IEC 1000-4-10: 1993 Electromagnetic Compatibility (EMC)
Part 4: Testing and measurement techniques
Section 10: Damped oscillatory magnetic field immunity test

Scope summary: Relates to the immunity requirements of equipment to damped oscillatory magnetic disturbances related to medium-voltage and high-voltage substations.
Comment: The title offers no clue to the limited scope of the document "... related to medium voltage and high-voltage substations ..." which makes this publication irrelevant to the subject of electric vehicle PPDs.

IEC 1000-4-11:1994 Electromagnetic Compatibility (EMC)
Part 4: Testing and measurement techniques
Section 11: Voltage dips, short interruptions and voltage variations immunity tests

Scope summary: Immunity test methods and range of preferred test levels for electrical and electronic equipment (not exceeding 16 A per phase) connected to low-voltage power supply networks for dips, short interruptions, and voltage variations.
Comment: This document contains several statements which are not entirely consistent. The closing sentence of the Introduction reads "This part is an international standard which gives immunity requirements and test procedures related to voltage dips, short interruptions and voltage variations." Then, a significant sentence is inserted near the end of Clause 3, "This test is to be used only for particular and justified cases, under the responsibility of product specifications or product committees." The ***informative*** Annex provides a table with a range of levels, thereby implying some degree of severity specification -- hence immunity of equipment. The Clause 3 sentence signals the beginning of a response to concerns about possible increased burdens on manufacturers caused by the fact that a standard happens to be available. In the next standard of the series, the 1000-4-12 reviewed below, the cautionary note on applicability has been made more prominent by including it in the wording of the scope rather than buried at the end of clause 3.

IEC 1000-4-12: 1995 Electromagnetic Compatibility (EMC)
Part 4: Testing and measurement techniques
Section 12: Oscillatory waves immunity tests

Scope summary: Immunity requirements and test methods for electrical and electronic equipment, under operational conditions, to oscillatory waves represented by non-repetitive damped oscillatory transients (ring wave) occurring in low-voltage power, control and signal lines supplied by public and non-public networks. *[A second type of test wave concerning repetitive surges occurring in HV and MV substations is also cited, but is not relevant for electric vehicle PPDs.]* This standard does not intend to specify the test levels to be applied to particular apparatus or systems.

Comment: This document signals acceptance of the 100 kHz Ring Wave by the IEC EMC community, long after (more than 20 years) its initial definition in the US -- for the UL 943 Standard, no less. The last sentence cited in the scope summary above is also a new addition to the usual wording of the 1000-4-x scopes, reflecting a growing anxiety among manufacturers that the "proliferation" of documents describing immunity tests might lead to unnecessary requirements imposed by their customers. In the case of the Ring Wave, however, this requirement is realistic -- even if it took 20 years to acknowledge it by making it the number 12 in the 1000-4-X series.

77A/147A/CDV March 1996	Electromagnetic Compatibility (EMC) Part 4: Testing and measurement techniques Section 13: Test for immunity to harmonics and interharmonics including mains signalling at a.c. power port, Immunity tests. Basic EMC publication.

Scope summary: Immunity test methods and range of basic test levels for electrical and electronic equipment with rated current up to 16 A to spurious frequencies [and] to harmonics and interharmonics on low-voltage power networks. Product-, Product family- or Generic-standards will indicate whether this standard applies and decide, for each phenomenon, on the immunity test levels required for a specific environment together with the performance criteria. However, most product groups do not have a history of being susceptible to distorted power frequency "Sine Wave" voltage phenomena caused by other loads. Consequently, testing for these phenomena is often not required. Therefore, product committees should exercise great care in specifying this standard.

Comment: This document is still at the CDV stage and might not receive approval by the required number of national committees. The additional wording in the scope, compared to other standards of the 1000-4-x series, might be a reflection of the controversies that have recently marked the development of emission and immunity level for harmonics. While providing guidance on test and measurement techniques -- the original intent of the 1000-4-x series -- the citation of test levels (subclause 5.1), which was a general practice in the other 1000-4-x series documents, appears a rather moot point in view of the footnote statement "All of the levels can be proposed by the product committees ...." Thus, the burden of specifying immunity levels for PPDs will return to the product committees, in this case the documents IEC 1008 and IEC 1009 and their subsequent amendments.

IEC / CISPR PUBLICATIONS

These publications address primarily the high-frequency domain, specifying emissions (and even immunity limits of equipment not associated with broadcasting, the charter scope of the CISPR committee). There may be some overlapping, hopefully not conflicts, with the recommendations of TC77 in its publications of the 1000 series. The following CISPR publications have not been reviewed for this draft

CISPR 11: 1990 Limits and methods of measurement of electromagnetic disturbance
Amendment 1:1996 Characteristics of industrial, scientific and medical (ISM) radio-frequency equipment
Scope summary:
Comment:

CISPR 11 Limits and methods of measurement of electromagnetic disturbance
Amendment 2:1996 Characteristics of industrial, scientific and medical (ISM) radio-frequency equipment
Scope:
Comment:

CISPR 14:1993 Limits and methods of measurement of radio disturbance characteristics of electrical motor-operated and thermal appliances for household and similar purposes, electric tools and electric apparatus

Scope:
Comment:

CISPR 22:1993 Limits and methods of measurement of radio disturbance characteristics of information technology equipment

Scope:
Comment:

OTHER IEC PUBLICATIONS

IEC 364 Series Electrical installations of buildings

Scope summary: Comprehensive set of recommendations, but not quite as detailed as the NEC.
Comment: This series of publications covers many aspects of electrical installations, from the IEC point of view. However, in the United States, the National Electrical Code, NFPA 70, generally takes precedence

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IEC 664-1: 1992 Insulation coordination for equipment within low-voltage systems
Part 1: Principles, requirements and tests

Scope summary: Specifies requirements for clearances, creepage distances and solid insulation for equipment based upon their performance criteria. Includes methods of electric testing with respect to insulation coordination.
Comment: The 1992 edition is a revision of the initial publication issued in 1980 where the concept of "Location Category" was introduced. According to this concept, a descending staircase of voltage withstand level requirements would apply from the service entrance onward to equipment connected further into the building. Subsequently, that concept was changed into a classification of "Equipment Category" which no longer reflects the location of the equipment within a building, but rather takes into consideration risk factors to assign a withstand level requirement consistent with the nature and mission of the equipment.

IEC 1008-1: 1990 Residual current operated circuit breakers without integral overcurrent protection for household and similar uses (RCCB's) - Part 1: General rules

Scope summary: Residual current operated circuit breakers without integral overcurrent protection functionally independent of, or functionally dependent on, line voltage for household and similar uses.
Comment: Within the context of application to PPDs for electric vehicle battery chargers, the EMC considerations in this documents are similar to those stated in IEC 1009. Because it is assumed that the PPDs for electric vehicle battery chargers will integrate the overcurrent protection function, only the IEC 1009 has been reviewed.

IEC 1009-1: 1991 Residual current operated circuit breakers with integral overcurrent protection for household and similar uses (RCBO's) - Part 1: General rules, including 1995 Amendment 1

Scope summary: Residual current operated circuit breakers with integral overcurrent protection functionally independent of, or functionally dependent on, line voltage for household and similar uses.
Comment: The 1991 issue includes a list of tests (Table 10, Clause 9) which are presented as type tests rather than EMC tests. The 1995 Amendment 1 refers back to IEC 1543, but its appeared that there might be some circularity in the cross-references. The behavior of the RCBO during and after voltage sags or interruptions is described in some detail. While "resistance to impulse voltages" is addressed as an insulation coordination issue (to wit the 500 Ω source impedance of the surge generator) the "resistance against unwanted tripping due to an impulse voltage" is "under consideration" in the 1991 issue and cross-referred back to IEC 1543 in the 1995 amendment. These cross-references leaves the reader in a state of confusion as to what is required, hence the reliance on other considerations which have been applied in defining test requirements in the present document.

IEC 1543: 1995 Residual current operated devices (RCDs) for household and similar use - Electromagnetic Compatibility

Scope summary: Intended to ensure EMC of devices providing residual current protection, for voltages not exceeding 440 V AC, intend principally for protection of persons against shock hazards ... applies for environmental conditions which occur in installations connected to low-voltage public networks or similar.
Comment: Contains three tables listing low-frequency and high-frequency phenomena, and ESD. The test levels for some of the phenomena, however, are still "under consideration" or are cross-referred to publications IEC 1008-1 and IEC 1009-1

A2 - IEEE STANDARDS

IEEE/ANSI C62.41-1991 Recommended Practice on Surge Voltages in Low-Voltage AC Power Circuits

Scope summary: A **description** of the voltage and current surges that may be expected in unprotected low-voltage AC power systems.
Comment: This document has become one of the primary reference standards in North America as a description of the surge environment in low-voltage AC power systems. The intent was indeed to provide a ***description*** of the surges that might be expected in an unprotected environment. However, two development have occurred to confuse the situation: many uninformed parties have attempted to use this description as a ***product specification*** for surge-protective devices (SPDs) or other equipment, and the very proliferation of surge-protective devices installed by end-users or incorporated into equipment has changed the notion of "unprotected environment" to the point that contemporary surveys of surge occurrences indicate -- misleadingly -- that surge ***voltages*** are a relatively rare occurrence. In spite of this seemingly benign surge voltage environment resulting from the presence of some unknown SPD, surge ***currents*** do occur, and are attracted to whichever SPD offers the lowest clamping voltage to divert a surge. Therefore, if a PPD is provided with an SPD at its input terminals, and that SPD happens to have the lowest clamping voltage in the installation, it will attract the impinging surge and therefore must be sized to accommodate the largest surge likely to impinge on the installation to ensure its reliability. Consequently, notwithstanding the contemporary reports of low surge activity, a PPD depending on an SPD for surge immunity must be capable of surviving the full brunt of the surges described in C62.41 for the corresponding location category, Category B in this case. This is a marked and noteworthy departure from the specification of only a Ring Wave for the GFCIs of the seventies where the sensitive electronics were connected in series with the trip coil which served as a buffer to limit the energy that a surge could deposit in the GFCI components.

IEEE/ANSI C62.45-1992 Guide on Surge Testing for Equipment Connected to Low-Voltage AC power Systems

Scope summary: Procedures for surge testing of equipment, powered or unpowered.
Comment: This guide provides generic information on test procedures, from the point of view of obtaining accurate results as well as ensuring safety of the operators. It is highly recommended that all laboratories where surge testing is performed be well acquainted with this Guide. In Sections 7.12 and 7.13 of the present document, specific reference is made to this guide for the procedures to be applied when surge testing.

IEEE Std 519-1992 IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems

Scope summary: Establish goals for the design of electrical systems that include both linear and nonlinear loads. The interface between sources and loads is described as the point of common coupling ....
Comment: After the somewhat unassuming title of the 1992 version which appeared to limit its scope to static power converters, the 1992 update of this document has emerged as a major reference on harmonics emissions in general. Unlike the IEC 1000-3-2 approach which stipulates strict emission limits for various power ratings of equipment, the IEEE 519 takes the point of view of a power distribution system as seen at the point of common coupling (PCC). From the point of view of the PPD controlling an electric vehicle battery charger, the emission limits cited in that standard are not directly applicable because they take into consideration the averaging effect of other loads at the point of common coupling. At the point of supply of the battery charger, one can expect higher harmonic current level than those considered by IEEE 519.

IEEE P519A - Draft 5, May 1996 Guide for Applying Harmonic Limits on Power Systems

Scope Summary: Provide general harmonic evaluation procedures for different classes of customers (industrial, commercial, residential) and for the application of equipment on the utility system ....
Comments: The table of contents lists a section 7.4.3, "Electric Vehicle Battery Chargers" but the subject has not yet been developed in the May 1996 iteration of the draft document. Establishing a liaison with the 519A Task Force would be an appropriate action.

IEEE 1159-1995 IEEE Recommended Practice for Monitoring Electric Power Quality

Scope Summary: Encompasses the monitoring of electric power quality of single-phase and polyphase ac power systems. As such, it includes consistent descriptions of electromagnetic phenomena occurring on power systems. The document also presents definitions of nominal conditions and of deviations from these nominal conditions ....
Comments: This standard was initially envisioned as a guide to promote more uniformity in the instrumentation used for monitoring power quality. During the process of its development, it evolved into a tutorial including a review of power quality and EMC definitions in an attempt to bridge the differences between definitions developed by the IEC and the informal use of power quality descriptors among various groups of the power quality stakeholders in North America. While it does not lead to specific levels of EMC immunity, it is still a useful reference document for clarifying some of the definitions in the context of EMC for PPDs.

A5 - SAE STANDARDS

SAE J1773-1995 Surface Vehicle Recommended Practice
Electric Vehicle Inductive Charge Coupling Recommended Practice

Scope: This SAE Recommended Practice covers the minimal physical, electrical, and performance requirements for the electric vehicle inductive charge coupling in the United States. The intent of the Recommended Practice is to define a common electric vehicle inductive charging inlet and its mating coupler. Application and compatibility requirements for the coupler and vehicle inlet are stated herein.
Comment: This document was reviewed in a quest to obtain information on the configuration and relative position of the PPD and the battery charger, to define the characteristics of the load-side of the PPD. No directly applicable information was found on that subject. The compatibility requirements mentioned in the scope concern mechanical and electrical compatibility, not EMC.

SAE J1772

Scope: This Recommended Practice covers the general physical, electrical, and performance requirements for the electric vehicle conductive charging system and coupler for use in North America. The intent of the Recommended Practice is to define a common electric vehicle conductive charging system architecture and the functional requirements of the vehicle inlet and mating connector. Application and compatibility requirements for the coupler and vehicle inlet are stated herein.
Comment: This document was reviewed in a quest to obtain information on the configuration and relative position of the PPD and the battery charger, to define the characteristics of the load-side of the PPD. No directly applicable information was found on that subject. The compatibility requirements mentioned in the scope concern mechanical and electrical compatibility, not EMC.

A6 - IWC MEETINGS MINUTES

The meetings of the National Electric Vehicle Infrastructure Working Council (IWC) contain a comprehensive record (hundreds of pages) of the issues that were discussed in that forum. An all-inclusive review of this large body of information was not possible within the required schedule and delivery date for developing the present document. However, a rapid scan of tables of contents indicated some useful references, as follows.

National Electric Vehicle Infrastructure Working Council, *Record of Consensus*, June 1996
Comment: This document provides definitions on four items, implying that specific issues are within the scope of the Council's concerns:
- Connector & Connecting stations, including description of "Levels of charging"
- Health and safety - No items in the June 20, 1996 update except references to the NEC
- Load Management, Distribution, & Power Quality, including EMC recommendations
- Data Interface, including the concept of control of the charger by on-board system

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Meeting #95-1 - March 6-8, 1995
Comments: Section 2, Health and Safety, records the postulate that personnel protection is for muscle tetanization and ventricular fibrillation, leaving out concerns about startle effects. Presumably, this postulate has been imbedded in the PPD functional specifications. Mention is also made of reviewing a research plan for EMC of PPDs with a due date of May 1995

Section 3, Load management, Distribution & Power Quality records a discussion of a test protocol which might be based on EPRI/PEAC SC-320. A table of test parameters for susceptibility includes for surge voltage a level of only 1 kV 1.2/50 wave, in contrast with the consensus recommendations of the EMC community.

A3 - UL STANDARDS

UL 943, August 1993 Standard for Safety Ground-Fault Circuit-Interrupters

Scope summary: These requirements cover ground-fault circuit-interrupters intended for use only in alternating-current circuits wherein one of the wires is grounded in accordance with the National Electrical Code ....
Comments: The first edition of this standard, dating back to 1972, pioneered the introduction of the concept of an oscillatory voltage surge test, which became the 100 kHz Ring Wave of IEEE 587 and eventually ANSI C62.41. Because at the time it seemed that all GFCI featured a trip coil which could limit the surge current applied to the electronic part, the classical 1.2/50 μs voltage waveform was not considered. (The concept of the 1.2/50 μs - 8/20 μs Combination Wave had not yet been developed.) The prime concern was to provide immunity against false tripping, with some side benefit of insulation withstand demonstration by requiring a 6 kV surge level. Another innovation was the concept of two levels of immunity, a first one below which no false operation was permitted, and a second one below which false operation was tolerated but damage not permitted, and finally an acceptable (fail-safe) failure would be accepted above 6 kV -- a high level still considered very conservative to this day. A test circuit was developed and became part of the standard (Section 23), in contrast with other surge test standards where the waveform is specified but the details of the surge generators are left to manufacturers of commercial surge generators. Subsequent field experience revealed that portable GFCI were susceptible to interference from transceivers used on construction sites. Corrective design was undertaken, and a "Resistance to Environmental Noise Test" was developed to demonstrate immunity against the high-frequency interference radiated from the transceivers. Rather than go to a ***radiated*** immunity test (a rather involved procedure), and considering that the interference from transceivers could well result from the power leads acting as an antenna and in turn presenting the GFCI with ***conducted*** disturbances, this environmental noise test was defined as injection of a voltage onto the power line at 22 set frequencies over the range of 10 MHZ to 450 MHZ. Requiring this level of immunity essentially solved the false-tripping problem, as attested by the millions of GFCIs now installed in the United States. Based on that successful field experience, the present suggestions for demonstrating PPD immunity to high-frequency electromagnetic fields (Phenomenon 16 in the list of disturbances) have adopted the UL 943 approach rather than the IEC series 1000 approach.

UL 2202, November 1994 Outline of investigation for Electric Vehicle Charging System Equipment

Scope summary: These requirements cover electric vehicle charging system equipment .... either conductive or inductive. These chargers may be either cord and plug connected or permanently connected. The battery charger can be located on or off board the vehicle.
Comments: We were advised that the standard is undergoing substantial revision, but were unable to obtain an advance copy in time to review it before the deadline for this Draft 2. A rapid visual scanning of the 1994 version did not reveal the occurrence of "GFCI" or "2231" in the text, with the exception of Section 46, which refers the reader to UL 943. From the EMC point of view, only the Harmonic Distortion Test (Section 46) appears to address one of the EMC concerns, but its language is ambiguous. Consequently, no further effort was allocated to assessing the impact of this standard on the forthcoming UL 2231 PPD standard. When the revision becomes available, it may be appropriate to revisit these comments.

UL 2231 Draft, July 1996

Scope summary: General safety requirements for PPDs
Comments: Because this document is at the draft stage, and the present document is intended as an input to the process, the UL document was deliberately not reviewed in order to provide an independent set of suggestions. The comparisons of Table 4 were made only after these independent suggestions were developed.

A4 - EUROPEAN STANDARDS

Some of the documents reviewed in the process of developing the present document refer to European Standards (EN's) rather than IEC standards or standards in general use in North America such as IEEE standards. For that reason, copies of these European Standards have been obtained for review, but have not yet been thoroughly reviewed, under the rationalization that they might not be readily adaptable or acceptable for the North American environment. These available documents include:

EN 50082-2:1995	Electromagnetic compatibility - Generic immunity standard - Part 2. Industrial environment
EN 55104: 1995	Electromagnetic compatibility - Immunity requirements for household appliances, tools and similar apparatus- Product family standard
DDENV 50204:1996	Radiated electromagnetic field from digital radio telephones - Immunity tests
EN 60204-1: 1993	Safety of machinery - Electrical equipment of machines Part 1. Specifications for general requirements

A7 - MISCELLANEOUS DOCUMENTS

National Fire Protection Association: *National Electrical Code®* - NFPA 70, 1996.

Scope Summary: This Code is the fundamental reference for minimum performance of electrical installations used as the basis for local authorities in approving electrical installations.
Comment: It is essential to recognize that the goal of the NEC is to ensure satisfactory minimum performance requirement and safety of installations. It does not guarantee electromagnetic compatibility. Conversely, some organizations have in the past advocated "remedies" to EMC problems by making recommendations that amount to a violation of the NEC. Such practices are of course highly objectionable, even illegal.
Article 625 is an addition to the Code for the 1996 Edition, reflecting the progress of electric vehicle developments. Its scope covers the electrical conductors and equipment external to an electric vehicle that connect an electric vehicle to a supply of electricity by conductive or inductive means, and the installation of equipment and devices related to electric vehicle charging. Paragraph 625-22 mandates the incorporation of a listed system of protection against electric shock of personnel -- designated "Personnel Protection Device" (PPD) in the present document. When cord and plug-connected equipment is used, the PPD is required to be part of the attachment plug or be located in the power supply cable not more than 12 in from the attachment plug. ***This provision seems at odds to the perception that a PPD can be incorporated in the enclosure of the household control device and should be clarified.***

Wyle Laboratories, *"Durability Testing of Six EV Conductive Couplings"* June 1996.

Scope: The purpose of the Test Procedure is to present the test methods and procedures to be used during the Durability Testing of six Electrical Vehicle (EV) Conductive Charging System Connectors and Vehicle Inlets. The 40-cycle Durability Test will be performed in various environments such as rain, dust, low and high temperatures.
Comment: This document makes reference to a "Safety Pilot circuit" which appears to serve the purpose of monitoring the integrity of the connection, rather than performing a personnel protection function. This remark needs confirmation, but the limited time available for developing the present document did not allow obtaining such confirmation. However, it can serve notice that some EMC aspects of the overall system (per UL 2202) need to include any control or signal leads that might exist in the coupling.

T.P. Singh, M.L. Rockfield, and C.J. Dana, *Test Protocol for System Compatibility - Single-Phase Battery Chargers for Electric Vehicles*, SC-320 Draft, PG&E/PEAC, 1995.

Scope: This document defines procedures for comparisons of commercial battery chargers suitable for electric vehicles. Methods of evaluating their charging characteristics, response to supply-side voltage variations, effect on supply-side power quality, and protection features will be described.
Comment: The family of PEAC "Test Protocols for System Compatibility" provide a procedure for performing test on a wide range of appliances. In general, the tests described in these documents have been defined with the intent that they can be performed at the PEAC facility, or at some other facility of a "Power Quality Testing Network" organized by PEAC. The documents reflect the experience acquired by PEAC in developing industry-accepted test protocols in anticipation of consensus test standards to be developed by standards-writing bodies. Reference is made to this protocol in the IWC Minutes, Section 3 of the March 6, 1995 meeting.

G. Biegelmeier, W. Skuggevig and T. Takahashi, "*The Influence of Low-voltage Network Systems on the Safety of Electrical Energy Distribution,*" Underwriters Laboratories, 1995.

Summary: This publication is intended for instructional purposes only. It should not be used as a substitute for the requirements of Underwriters Laboratories.
Comment: The document presents a comprehensive description of the IEC classification of the network systems (TN, TT, and IT) including a specific description of the TN-C-S system in general used within the USA. For each system, the principle of operation (or inapplicability) of residual current devices is described.

E.W. Roberts, "*Overcurrents and Undercurrents*" Mystic Publications, 1996

Comment: A tutorial book written in layman's English and dedicated to Charles Dalziel, providing a technical and historical overview of the need for and development of Ground Fault Circuit Interrupters (GFCI), and how these devices and their related offspring have created a revolution in electrical shock and electrical fire protection.

E.L. Owen, "Power System Grounding -- Part II: RCD & GFCI," to be published in the *IEEE/IAS Magazine*, July/August 1996.

Comment: A historical perspective and review of the development of GFCI

IEEE Task Force on Harmonic Limits for Single-Phase Equipment

Comment: This Task Force was initiated in January 1995, in part in response to concerns that IEEE 519 is unlikely to be applied to residential loads. Its charter document, the Minutes of the January 30, 1995 meeting, defines the scope of the work, including electric vehicle battery chargers. It is included in the present document as Appendix C. The task force is sponsoring panel discussions at various IEEE meetings which may be of interest to the readers of the present document. Perhaps a formal liaison could be established. Contact Arshad Mansoor at the Power Electronics Applications Center for further information.

Cascade Coordination studies

An emerging concern in the application of surge protective devices is the proliferation of SPDs installed without particular attention been paid to the need for a coordinated operation of the devices if they are to perform as intended, in a cost-effective manner. F.D. Martzloff has compiled an initial, incomplete and unpublished annotated bibliography on that subject, and would welcome inquiries and contributions to that project.

APPENDIX B

DEVELOPMENT OF SYSTEM COMPATIBILITY TEST PROTOCOLS

System compatibility test protocols have been developed in response to the growing need for ensuring equipment compatibility at the interface between utility and end-user load. The increasing sophistication and penetration of microelectronics devices has resulted in a new generation of equipment that may be more sensitive than their predecessors to electromagnetic disturbances such as surges, sags, swells, harmonics, voltage fluctuations, etc. These documents form a generic family of system-compatibility protocols, each applicable to a specific end-user load equipment, including power-conditioning equipment that may serve as interface between the point of common connection and the end-use equipment. In contrast with equipment or component performance standards aimed at enforcing a set of regulations or specifications, these protocols represent a set of performance objectives aimed at enhancing compatibility between the equipment and the power supply.

Original equipment manufacturers (OEM) typically do not have sufficient knowledge base or incentives to allocate limited resources to research all aspects of system compatibility for equipment that will be installed by third parties. Individual users might not have the appreciation of potential problems nor the leverage necessary to bring about changes in equipment design. Architectural and engineering firms, while understanding the potential incompatibilities, might lack incentives or leverage to obtain the redesign of load equipment or reconfiguration of the power supply. The purpose of these system compatibility test protocols is to facilitate coordination of the realities of the power system environment with the needs of electronic loads, by providing a uniform approach to compatibility.

This approach is based on defining the electrical characteristics of the environment, leading to a set of performance criteria tests demonstrating that specific equipment is capable of operating in that environment, will not by itself degrade that environment, and involves a minimum of undesirable side effects. These performance criteria tests are by necessity limited to the major aspects of compatibility and do not propose to replace more comprehensive tests performed by others, such as manufacturers engineering departments, regulatory compliance agencies, or customer acceptance departments. A unique aspect of the system compatibility protocols is the iteration of test results and design modifications aimed at enhancing compatibility, rather than a rigid pass/fail assessment. This iteration is particularly useful for emerging technologies where the relatively slow pace of the usual consensus process for developing standards lags the need for having some acceptable reference documentation of appropriate test protocols. In the context of developing PPDs to suit the needs of electric vehicle battery chargers, applying the iterative process may produce a more readily acceptable performance standard when the concepts have reached sufficient maturity.

APPENDIX C

TASK FORCE ON HARMONIC LIMITS FOR SINGLE-PHASE EQUIPMENT

Meeting Minutes
January 30, 1995
New York, New York

The first meeting of the Task Force on Harmonic Limits for Single-Phase Equipment was held at the Winter Power meeting in New York. The meeting was chaired by Dan Ward of Virginia Power.

1. **Introductions.** Attendees introduced themselves.

2. **Attendance.** An attendance list is attached.

3. **Presentation of Scope and Objectives.** Dan Ward welcomed the group and announced that future meetings will be scheduled so as to not conflict with other harmonics related committee work. Dan then gave a brief presentation on the scope and objectives of the task force. One of the main concerns for single-phase equipment is that it is unlikely IEEE 519 will be applied to residential loads. The following is a brief summary of the presentation:

   Scope
   -- Establish harmonic current limit at point of use.
   -- Initially address single-phase equipment only.
   -- Primarily focus on 120 V and 240 V equipment up to 30 A.

   Equipment to Consider
   -- Variable speed drive A/C and heat pumps
   -- Compact fluorescent lamps
   -- PC's and computer peripherals
   -- EV battery chargers

   Initial Plan
   -- Make use of existing IEC work
   -- Issues
   1. Review scope regarding V&I
   2. Determine equipment to include
   3. Determine acceptable and consistent source impedance
   4. Current THD limits

4. **Discussion of Objectives.** The objectives were discussed and the following concerns and comments were made:

   -- Previous IEC work is a good starting point.
   -- Expand the scope to include sensitivities to voltage sags and transients. (The group discussed this issue at length and determined that it would be best not to

expand the scope at this time. It was acknowledged that these are important issues and should be noted as such in any document that the task force drafts.)

-- Classify equipment according to size and type of power supply.

-- Need to create incentive for standards to be effective. (Energy Star/Green label marketing strategy was given as an example).

-- Need to coordinate activities with Industry Applications Society.

5. **Panel Session.** The discussion lead to a recommendation to create a panel session at the summer meeting that will represent various points of view from the manufacturers and utilities. The tentative title of the session will be "System Issues from Single-phase Harmonics." Ralph Ferraro volunteered to plan the session which will tentatively include:

-- Manufacturer of battery charger

-- Representative from a utility that has or is applying some form of charger standard or requirements - PG&E or SCE)

-- Lighting manufacturer

-- UPS/PC manufacturer

-- Additional utility representative to address needs for standards

6. **High Frequency Noise Discussion.** Bryce Hesterman with Magnetek addressed the group about high frequency noise problems occurring when using active power factor correction to reduce harmonics from electronic ballasts. Interference with carrier frequencies is a common problem. A main concern of some manufacturers is that efforts to meet certain standards may create unforeseen additional problems.

7. **Closing Remarks and Action Items.** Dan Ward shared a letter from the EEI Working Group on Harmonics asking the task force to address electric vehicle battery chargers. The following action items were identified:

   1. Distribute copies of the latest IEC Harmonics standards to the task force members.

   2. Coordinate panel session on single-phase equipment issues for summer meeting.

   3. Communicate with IAS to see where this task force fits in with work already underway outside of the PES.

   4. Identify list of equipment that will be targeted for harmonic limits.

8. **Next Meeting.** Summer Power Meeting in Portland, Oregon. Time TBA.