U.S.NRC
United States Nuclear Regulatory Commission
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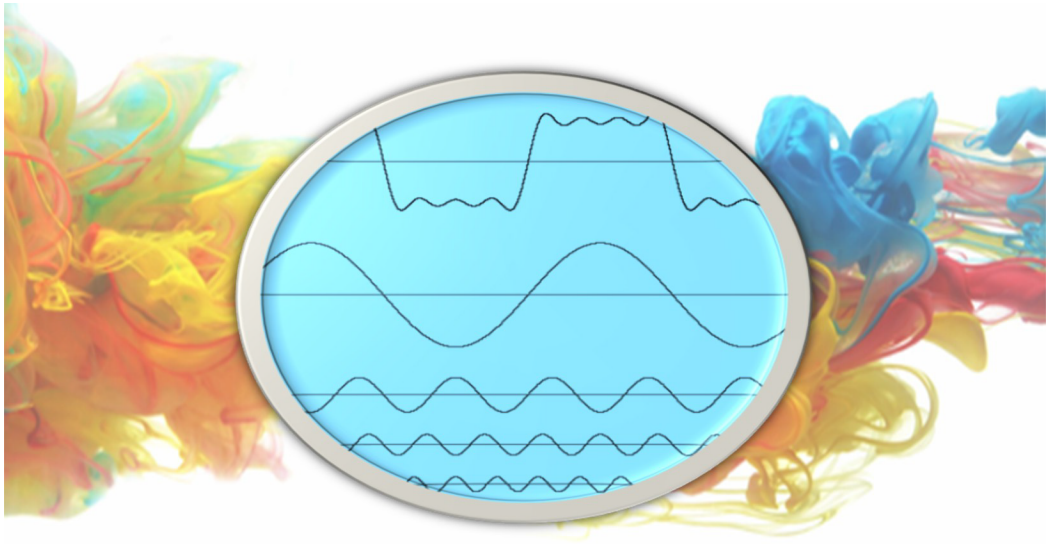
RIL 2023-09

An Assessment of the Harmonics Effects on Undervoltage Relays in Nuclear Power Plants



Date Published: January 2024

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Research Information Letter
Office of Nuclear Regulatory Research

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1. Introduction

Research assistance request (RAR) NRR-2022-03, “An Assessment of the Harmonics Effects on Undervoltage Relays in Nuclear Power Plants (NPPs),” dated February 14, 2022, requested the U.S. Nuclear Regulatory Commission (NRC), Office of Nuclear Regulatory Research (RES) to conduct a literature search and develop the project scope related to harmonic and subharmonic waveforms (referred to as “harmonics” hereafter). Specifically, the RAR requested that RES assess and examine the impacts of persistent harmonics that are produced by the electrical system, test sources, non-linear loads, and transient operation of equipment on undervoltage relays, degraded voltage relay (DVR) and loss-of-voltage (LOV) relays.

This research aimed to study how harmonics can potentially offset the DVR and LOV relay setpoints and preclude safety-related equipment from performing the intended safety functions during emergency or shutdown events.

RES awarded task order 31310022F0122 to Information Systems Laboratories (ISL) under enterprise-wide contract 31310020D0004 to conduct a literature search study and analysis on this topic, including the following areas:

- identifying operating experience, codes and standards, and generic communications pertaining to the issue;
- examining potential impacts of this phenomenon to improve the understanding of its effects in NPPs; and
- discussing the technical basis to support potential updates to licensing and oversight guidance.

ISL completed the study in June 2023 and submitted the final deliverable, which subsequently led to development of the technical letter report (TLR), TLR-RES-DE-2023-015, Revision 0, “An Assessment of the Harmonics Effects on Undervoltage Relays in Nuclear Power Plants,” issued September 2023 (Ref. 3). The purpose of this research information letter is to evaluate the findings of the TLR and discuss the results and potential regulatory implications.

2. Method of Investigation

ISL conducted a literature search of pertinent codes, standards, literature, articles, reference materials, and regulatory documents, as well as operating experience reported by the industry. Findings were categorized, evaluated, and ranked for relevance to applications in NPPs and potential impacts on DVRs and LOV relays.

ISL’s report discussed the theory behind harmonic distortion phenomenon, potential sources, and the possibility of impacts on LOV relays and DVRs. Additionally, the TLR included anticipated magnitudes of the potential impact of harmonics on DVRs and LOV relays, and acceptable values in accordance with pertinent standards.

3. Discussion of Results

The emergency buses at NPPs are equipped with DVRs and LOV relays that initiate transfer from the normal power supply to the standby (emergency) power supply (e.g., diesel generators). A combination of LOV relays and DVRs, with associated setpoints and time delays, constitutes a double scheme of protection against both instantaneous loss of offsite power (low voltage below a set limit) and long-duration, degraded voltage events.

Each U.S. NPP has performed a set of comprehensive calculations to determine the voltage setpoints and the appropriate time delays for LOV relays and DVRs that ensure high-reliability class 1E power, consistent with assumptions made in the analysis of design-basis accidents. These calculations are performed assuming that the offsite power is at the base fundamental frequency of 60 cycles per second (CPS), which excludes any effect from harmonic components.

The calibration and testing of these relays are typically performed with a power source free from harmonic contamination, that is, at the fundamental frequency of 60 CPS. In addition, all DVRs and LOV relays in operating U.S. NPPs are recommended to be equipped with harmonic filters to eliminate the higher frequency harmonics before voltage measurements for actuation or for established setpoints. As such, these relays are designed and calibrated, and will be actuated, based on the voltage magnitudes at the fundamental frequency. However, it is fair to assume that these relays will operate as intended with a small amount of total harmonic distortion.

In actual service applications, all class 1E equipment is exposed to electrical power contaminated by harmonics of varying magnitude. The equipment is expected to operate based on the aggregate voltages resulting from all harmonic components, rather than just the voltage at the fundamental frequency. Class 1E equipment is protected by DVR and LOV relays and will respond properly, even in the presence of some harmonic contamination (e.g., total harmonic distortion < 5 percent). A limit on the magnitude of sustained harmonics on emergency buses, therefore, is necessary to ensure the proper response of class 1E components. Such a requirement is not currently imposed for NPPs, although some plants have voluntarily performed calculations to show that sustained harmonics, from both the offsite grid and internal loads, are controlled.

Mitigation practices during calibration of DVRs and LOV relays are generally applied to ensure accurate trip setpoints. Many plants already employ digital versions of these relays that have capabilities of filtering out harmonic waveforms. External filtering devices are also available and used in some instances to avoid potential negative impacts.

In addition to sustained harmonics, transitory harmonics may exist, from sources such as power system transients (e.g., switching surges) or external causes, like geomagnetic storms. The duration of transient harmonics and their magnitudes can vary, and separation from the offsite power supply during periods of excessive harmonics may be necessary.

4. Conclusions

Several NRC documents discuss the presence of harmonics and mitigation practices, as

well as the requirements related to LOV relays and DVRs in General Design Criterion (GDC) 17, “Electric power systems,” of Appendix A, “General Design Criteria for Nuclear Power Plants,” to Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, “Domestic Licensing of Production and Utilization Facilities” (Ref. 1). For example, Regulatory Issue Summary 2011-12, Revision 1, “Adequacy of Station Electric Distribution System Voltages,” dated December 29, 2011 (Ref. 4), summarizes the most relevant NRC guidelines and acceptable methods and practices as they relate to LOV relays and DVRs. The NRC incorporated the staff positions to meet GDC 17 requirements and additional guidance in branch technical positions (BTPs) in NUREG-0800, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition” (Ref. 2). These include BTP 8-3, “Stability of Offsite Power Systems,” and BTP 8-6, “Adequacy of Station Electric Distribution System Voltages.” Information Notice 95-05, “Undervoltage Protection Relay Settings Out of Tolerance Due to Test Equipment Harmonics,” dated January 20, 1995 (Ref. 5), also discusses the following:

- Test equipment for undervoltage relay setting should be equipped with a power supply with low harmonic distortion in peak voltage (clean supply).

- Peak voltage changes rather than root mean square values are more indicative of harmonic distortion for undervoltage relay operation.

- A relay manufacturer (ABB Ltd.) recommends an alternating current voltage test source to be free from harmonics.

A review of the operational experience with the current designs of these relays has not shown any adverse impact on plant safety. The safety significance of this issue is currently considered small due to its low frequency of occurrence. The TLR provided a suggested formal risk evaluation of the impact of harmonics that licensees could use as a model if desired.

Based on the findings of this study, and as supported by the available operating experience, further research or study concerning this issue is not warranted. Adequate regulatory generic communications, as well as industry standards and manufacturer recommendations and bulletins, already exist to highlight the potential presence of harmonic distortion, prescribed limits, and likely impact on plant equipment to draw attention to the importance of this issue. However, the staff should consider including in future applicable regulatory guide (RG) revisions or new RGs cautionary statements to highlight the presence of harmonic distortion and potential impacts on LOV relays and DVRs. Section 5 discusses this recommendation further.

5. Regulatory Implications

Based on the results of the study and the conclusions described in Section 4, a new generic communication or RG is not deemed necessary. However, the staff should consider adding clarification and cautionary statements to two RGs under development as follows:

- The staff is currently preparing a new revision of RG 1.32, Revision 3, “Criteria for Power Systems for Nuclear Power Plants,” issued March 2004 (Ref. 6), which addresses Institute of Electrical and Electronics Engineers (IEEE) Standard

(Std.) 308-2020, “IEEE Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations” (Ref. 7). The NRC should clarify section 4.5 of IEEE Std. 308-2020 by adding the following suggested statement:

> For monitoring schemes for undervoltage and degraded voltage relays, provisions should be implemented to mitigate the effects of harmonic distortion on emergency buses. Use of harmonic distortion filters or digital undervoltage and degraded voltage relays eliminates the potential for malfunction or false indications under actual degraded voltage conditions and mitigates the harmful effects of harmonics caused by events such as nonlinear loads, grid disturbances, lighting strikes, and geomagnetic storms.

- The staff is preparing new RG 1.238, “Criteria for the Protection of Safety-Related (Class 1E) Power Systems and Equipment for Production and Utilization Facilities” (Ref. 8), which addresses IEEE Std. 741-2022, “IEEE Standard for Criteria for the Protection of Class 1E Power Systems and Equipment in Nuclear Power Generating Stations” (Ref. 9). The staff should clarify section 5.1.2 d of IEEE Std. 741-2022 in RG 1.238 by adding the following suggested statement:

  > For monitoring schemes for undervoltage and degraded voltage relays, provisions should be implemented to mitigate the effects of harmonic distortion on emergency buses. Use of harmonic distortion filters or digital undervoltage and degraded voltage relays eliminates the potential for malfunction or false indications under actual degraded voltage conditions and mitigates the harmful effects of harmonics caused by events such as nonlinear loads, grid disturbances, lightning strikes, and geomagnetic storms.

  The staff should also clarify section 6.1 of IEEE Std. 741-2022 in RG 1.238 by adding the following suggested statement:

  > Care must be taken during calibration of monitoring devices and undervoltage and degraded voltage relays to ensure proper functioning and accurate setpoints by mitigating the effects of potential harmonic distortion from the calibrating equipment. Power supplies capable of eliminating harmonic waveforms should be employed during calibration and testing of these devices.

No further regulatory changes or actions are recommended.

REFERENCES[1]

1. U.S. Nuclear Regulatory Commission (NRC), Title 10 of the *Code of Federal Regulations* (10 CFR) Part 50, "Domestic Licensing of Production and Utilization Facilities"

2. NRC, NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition"

3. NRC, TLR-RES-DE-2023-015, Revision 0, "An Assessment of the Harmonics Effects on Undervoltage Relays in Nuclear Power Plants," September 2023 (Agencywide Documents Access and Management System Accession No. ML23264A152).

4. NRC, Regulatory Issue Summary 2011-12, Revision 1, "Adequacy of Station Electric Distribution System Voltages," December 29, 2011 (ML113050583).

5. NRC, Information Notice 95-05, "Undervoltage Protection Relay Settings Out of Tolerance Due to Test Equipment Harmonics," January 20, 1995 (ML031060397).

6. NRC, Regulatory Guide 1.32, Revision 3, "Criteria for Power Systems for Nuclear Power Plants," March 2004 (ML040680488).

7. Institute of Electrical and Electronics Engineers (IEEE), IEEE Standard (Std.) 308-2020, "IEEE Standard Criteria for Class 1E Power Systems for Nuclear Power Generating Stations."

8. NRC, Draft Guide (DG) 1354, Proposed new Regulatory Guide 1.238, "Criteria for the Protection of Safety-Related (Class 1E) Power Systems and Equipment for Production and Utilization Facilities."

9. IEEE, IEEE Std. 741-2022, "IEEE Standard for Criteria for the Protection of Class 1E Power Systems and Equipment in Nuclear Power Generating Stations."

[1] Publicly available NRC published documents are available electronically through the NRC Library on the NRC's public website at https://www.nrc.gov/reading-rm/doc-collections/ and through the NRC's Agencywide Documents Access and Management System (ADAMS) at http://www.nrc.gov/reading-rm/adams.html. For problems with ADAMS, contact the Public Document Room (PDR) staff at 301-415-4737 or 1-800-397-4209, or email pdr.resource@nrc.gov. The NRC PDR, where you may also examine and order copies of publicly available documents, is open by appointment. To make an appointment to visit the PDR, please send an email to PDR.Resource@nrc.gov or call 1-800-397-4209 or 301-415-4737 between 8 a.m. and 4 p.m. eastern time, Monday through Friday, except Federal holidays.