

IEEE Guide for Economic Loss Evaluation of Sensitive Industrial Customers Caused by Voltage Sags

IEEE Power and Energy Society

Developed by the
Transmission and Distribution Committee

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IEEE Guide for Economic Loss Evaluation of Sensitive Industrial Customers Caused by Voltage Sags

Developed by the

Transmission and Distribution Committee
of the
IEEE Power and Energy Society

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Abstract: The production process of sensitive users is easy to interrupt due to voltage sag, resulting in a lot of economic losses. A method to evaluate the economic losses of sensitive industrial users due to voltage sag is provided in this guide. This document specifies the costs of power quality monitoring and voltage sag mitigation projects for power users, proposes the economic loss indexes due to voltage sag, and introduces the technical and economic evaluation method of voltage sag mitigation projects. This document gives the process of evaluating the economic loss due to voltage sag and the decision-making of mitigation scheme, and recommends the experimental method of testing user equipment and production line.

Keywords: economy evaluation, economic loss, equipment trip, IEEE 2938™, industry process, power quality, sensitive equipment, sensitive industry, voltage sag, voltage sag mitigation, voltage tolerance curve

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Introduction

This introduction is not part of IEEE Std 2938-2023, IEEE Guide for Economic Loss Evaluation of Sensitive Industrial Customers Caused by Voltage Sags.

IEEE Std 2938™ is a non-industry-specific recommended practice for electric power end users and service providers to evaluate economic loss due to voltage sags. This document is appropriate for sensitive industrial users to calculate economic loss indexes due to voltage sags, or estimate the cost and economic loss before and after voltage sag management and select optimal mitigation schemes. This document is also applicable to the utilities to efficiently collect useful data of customers for evaluating and selecting the providers of high-quality power supply services.

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IEEE Guide for Economic Loss Evaluation of Sensitive Industrial Customers Caused by Voltage Sags

1. Overview

1.1 Scope

This guide provides a method to evaluate the economic loss impact of voltage sags on sensitive industrial customers. It describes how to carry out cost and loss economic-assessment of voltage sags, what economic indexes and assessment flowcharts can be considered, how to efficiently collect useful data for evaluation, and recommended experimental methods for testing users' equipment and production line.

1.2 Purpose

The purpose of this guide is to provide a technique for evaluating economic-losses of sensitive industrial customers caused by voltage sags, and further provides mathematical means, e.g., economic indexes and assessment flowcharts, to quantify the losses of sensitive customers.

1.3 Word usage

The word *shall* indicates mandatory requirements strictly to be followed in order to conform to the standard and from which no deviation is permitted (*shall* equals *is required to*).^{6,7}

The word *should* indicates that among several possibilities one is recommended as particularly suitable, without mentioning or excluding others; or that a certain course of action is preferred but not necessarily required (*should* equals *is recommended that*).

The word *may* is used to indicate a course of action permissible within the limits of the standard (*may* equals *is permitted to*).

The word *can* is used for statements of possibility and capability, whether material, physical, or causal (*can* equals *is able to*).

⁶The use of the word *must* is deprecated and cannot be used when stating mandatory requirements; *must* is used only to describe unavoidable situations.

⁷The use of *will* is deprecated and cannot be used when stating mandatory requirements; *will* is only used in statements of fact.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

IEEE Std 1159™-2019, IEEE Recommended Practice for Monitoring Electric Power Quality.

IEEE Std 1250™-2018, IEEE Guide for Identifying and Improving Voltage Quality in Power Systems.

IEEE Std 1564™-2014, IEEE Guide for Voltage Sag Indices.

IEEE Std 1668™-2017, IEEE Recommended Practice for Voltage Sag and Short Interruption Ride-Through Testing for End-Use Electrical Equipment Rated Less than 1000 V.

3. Definitions, acronyms, and abbreviations

3.1 Definitions

For the purposes of this document, the following terms and definitions apply. The *IEEE Standards Dictionary Online* should be consulted for terms not defined in this clause.⁸

annual value: Cash flow of each year.

benchmark payback period: The maximum allowable value of payback period.

cost of voltage sag management: Economic cost of carrying out voltage sag management for sensitive users, including cost of power quality monitoring and cost of voltage sag mitigation.

direct (economic) loss: The loss of personnel, equipment, and property and the cost of waste products caused by industry process trip.

discount rate: A ratio used to convert future cash flow into present cash flow.

economic loss: The sum of direct economic loss and indirect economic loss of sensitive customers caused by voltage sag.

industry process: The continuous production process susceptible to voltage sag of sensitive customer.

indirect (economic) loss: The loss with invisible influence and accumulated over a long period of time due to voltage sag.

(industry) process trip: The industrial process of sensitive customer is stopped due to voltage sag, resulting in minutes to hours of production disruption.

net cash flow: The difference between annual cash inflow and annual cash outflow.

net present value: The present value of all incoming cash flows minus the present value of all cash outflows.

⁸*IEEE Standards Dictionary Online* is available at: <http://dictionary.ieee.org>. An IEEE Account is required for access to the dictionary, and one can be created at no charge on the dictionary sign-in page.

payback period: The time required for the cash inflow caused by investment to accumulate to equal the investment amount.

power quality economic evaluation: The analyzing and calculation of the economic loss of power quality problems and evaluates the cost and benefit of voltage sag management.

power quality monitoring: The process of measuring and collecting voltage and/or current measurements for the purpose of assessing power quality characteristics.

present value: The current value of a future incoming or outgoing cash flow given a specified rate of return.

sensitive equipment: Electrical equipment that is prone to trip, fault, or restart when the power supply is affected by voltage sag.

sensitive industry: The industry of which production process is sensitive to voltage sag. When voltage sag occurs in the power supply of users in sensitive industries, the production process is easily affected.

sensitive (industry) customer: Power customer in sensitive industries.

sensitive user: *See:* **sensitive customer.**

voltage sag management: The measures taken by sensitive customers to alleviate voltage sag problem, including power quality monitoring and voltage sag mitigation.

voltage sag mitigation: The concept of reducing the susceptibility of sensitive equipment and processes to the disruptive effects of voltage sags.

voltage sag tolerance characteristics: The performance of sensitive equipment during voltage sags, commonly represented by the voltage tolerance curve.

3.2 Acronyms and abbreviations

ACC	alternating current contactor
ASD	adjustable speed drives
CI	cash inflow
CO	cash outflow
DVR	dynamic voltage restorer
HPSL	high pressure sodium lamp
LCC	life cycle cost analysis
LVR	low voltage release
MHL	metal halide lamp
NPV	net present value method
PC	personal computer
PCC	point of common coupling
PLC	programmable logic controller
SIC	standard industry classification

SSTS	solid state transfer switch
UPS	uninterruptible power supply
VTC	voltage tolerance curve

4. Principles and process of economic loss evaluation for voltage sag management

4.1 General

This guide provides the economic loss evaluation method for sensitive industrial customers under voltage sag. The flowchart in [Figure 1](#) shows the critical procedures for the economic loss evaluation. [Clause 5](#) presents the data and the information to be collected for the evaluation. The items of costs for voltage sag management of sensitive industrial customers are listed in [Clause 6](#). [Clause 7](#) proposes the indexes of the cost and economic loss of voltage sag management. The economy of cost-investment evaluation methods for voltage sag management are in [Clause 8](#). [Annex A](#) gives typical test results of sensitive equipment tolerance against voltage sag. [Annex B](#) gives two practical test methods for the tolerance of sensitive equipment to voltage sags. [Annex C](#) gives examples of data collection. [Annex D](#) gives examples of voltage sag information statistics. [Annex E](#) gives the calculation equation of capital equivalent. [Annex F](#) gives example of trip probability of industry process evaluation. [Annex G](#) gives the calculated trip probability of sensitive equipment under different sag characteristics. [Annex H](#) and [Annex I](#) give examples of economic loss evaluation and economy evaluation of voltage sag management. [Annex J](#) lists the bibliographic references.

4.2 Process of economic loss evaluation for voltage sag management

This guide recommends a four-step procedure as follows:

- a) Obtain the information and data from user side and establish the database.
- b) Calculate the items of costs of voltage sag management for sensitive industrial customers.
- c) Calculate the indexes of the cost and economic loss of voltage sag management.
- d) Evaluate the economy of cost-investment of schemes for voltage sag management.

A flowchart for economic loss evaluation is shown in [Figure 1](#).

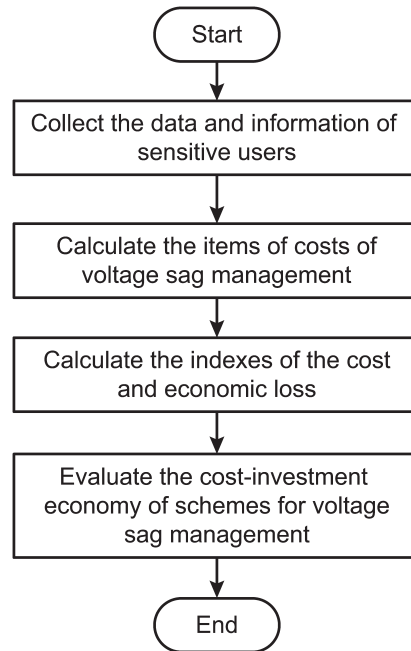


Figure 1—The procedure for economic loss evaluation

5. Method of data and information collection

5.1 General database for economic loss evaluation

5.1.1 Classification of sensitive industries

To facilitate the collection of user information, this guide uses standard industry classification (SIC) code to describe the types of industrial users. SIC codes were created by the US government in 1937 to help analyze economic activity across various industries and government agencies.

For example, a semiconductor company located in Taiwan, China, whose main product is mobile phone chips, is a typical sensitive industry, and SIC code is 367. Another example, the SIC code of a dairy manufacturers and suppliers in the United States is 202.

5.1.2 Economic loss database

This guide investigates several sensitive industries to form a loss database for different industries, including SIC code, industry description, the area, typical sensitive equipment, economic loss of single trip, and annual economic loss, as listed in [Table 1](#). The economic loss database can make a preliminary estimation of economic loss for different industries under voltage sag. For example, a sausage processing plant located in the United States, with SIC code of 201, and its typical sensitive equipment are adjustable speed drive (ASD) and AC contactor (ACC). Typical sensitive equipment also includes a programmable logic controller (PLC), personal computer (PC), and low voltage release (LVR), etc. The economic loss of single trip of the plant is approximately three to five thousand dollars per MW, and the annual economic loss caused by voltage sag and short interruption is approximately 80 to five hundred thousand dollars per MW.

The data in the table is collected from the Power Quality Applications (PQA) and Advanced Distribution Automation (ADA) project of the Electric Power Research Institute (EPRI) from the United States, as well as investigations on industries in some provinces by China's electric power institutions. The information in the

current table does not represent all. The production scale, process technology, labor cost, raw material cost, product price, and the location led to different economic losses, but it can still be used as a reference.

Table 1—Economic loss database for different industry

SIC code	Industry description	Area	Typical sensitive equipment	Economic loss of single trip (thousand dollar/MW)		Annal economic loss (thousand dollar/MW)
				Direct loss	Indirect loss	
109	Metal ore mining	United States	ASD	2.5~7.5	—	10~40
138	Petroleum processing	United States	PC	3.0~5.0	—	10~35
149	Non-metallic mining	United States	ASD, ACC	2.0~4.0	—	30~100
201	Sausage processing	United States	ASD, ACC	3.0~5.0	—	80~500
201	Pork processing	United States	ASD, ACC	3.0~5.0	—	10~30
204	Grain processing	China	ASD, ACC, PLC	10	—	30
206	Sugar processing	China	ASD, ACC, PLC	30	—	30
208	Beverage processing	United States	ASD, PLC	3.0~5.0	—	10~30
224	Cotton mill	United States	ASD, PLC	2.5~7.5	—	10~50
228	Wool processing	China	ASD, PLC	20	—	200
229	Dolls, textile toys	United States	ASD, PLC	2.0~4.0	—	10~40
232	Garment mill	United States	ASD, PLC	2.0~4.0	—	5~40
243	Wood mill	United States	ASD, PLC	3.0~6.0	—	15~80
251	Plate mill	China	ASD, PLC	6~14	—	60~140
251	Furniture mill	United States	ASD, PLC	5~15	—	10~30
262	Paper Mill	China	ASD	2.0	—	17
262	Paper Mill	United States	ASD	1.5~2.5	—	10~30
273	Book printing	United States	ASD	1.5~4.5	—	5~40
275	Printing mill	United States	ASD	1.0~2.0	—	15~50
283	Pharmaceutical mill	United States	ASD, PLC	5.0~50	—	10~40
286	Chemical processing mill	China	ASD, ACC, LVR	10	—	20
286	Organic material processing	United States	ASD, ACC, LVR	5~15	—	20~75
289	Petrochemical mill	China	ASD, ACC, LVR	30~40	3	150~200
302	Rubber products mill	United States	ASD, ACC	3~4.5	—	4~16
308	Plastic toys mill	United States	ASD, ACC	2.0~7.5	—	20~75
311	Leather shoes mill	United States	ASD	2.0~4.0	—	10~60
322	Glass window production	China	ASD	8.0	2	40
322	Glassware production	United States	ASD	4.0~6.0	—	20~400
324	Cement production	United States	ASD, ACC, relay, LVR	0.5~1.5	—	10~40

Table continues

Table 1—Economic loss database for different industry (continued)

SIC code	Industry description	Area	Typical sensitive equipment	Economic loss of single trip (thousand dollar/MW)		Annual economic loss (thousand dollar/MW)
				Direct loss	Indirect loss	
325	Structural Clay Products	China	ACC	8	2	20
331	Steel processing Mill	United States	ASD, PLC, LVR	1.0~6.0	—	5~30
344	Metal products mill	United States	ASD, PLC, LVR	2.0~7.5	—	10~40
352	Garden Machinery production	China	ASD, PLC, PC, ACC, LVR	2.5~3.0	0.5	10.0~15.0
354	Metalworking machine production	United States	ASD, PLC, PC, LVR	4~10	—	15~50
357	Computer production	China	ASD, PLC, PC, ACC, LVR	10~20	—	5~50
363	Household appliances production	United States	ASD, PLC, PC, ACC, LVR	2.5~7.5	—	15~50
366	Communication equipment production	China	ASD, PLC, PC, ACC, LVR	10	—	30
367	Semiconductor processing	China	ASD, PLC, PC, ACC, LVR	4.0~5.0	2	50
367	Chip production	United States	ASD, PLC, PC, ACC, LVR	2.0~6.0	—	10~60
371	Automobile mill	United States	ASD, PLC, PC	4~12	—	10~60
384	Medical materials production	China	ASD, PLC	4	—	32
384	Hospital Equipment production	United States	ASD, PLC, PC, ACC, LVR	5~15	—	10~40

5.2 The information and data collection from user side

5.2.1 The list of information

To evaluate the economic loss of users by voltage sag, it is necessary to analyze the consequences of sensitive equipment and industrial process suffering from voltage sag, estimate the economic loss combined with output value and production capacity, and formulate the mitigation scheme according to the power network information. Therefore, three aspects of information need to be collected, namely basic information, industrial process information, and power network information.

Among the information to be collected, some is necessary information, which is indispensable in the process of economic loss evaluation. Some of the information is assistant information, which can help with economic loss evaluation and make the results more accurate.

Before collecting the information from user side, it is necessary to clarify the implementer of economic loss evaluation of voltage sag, and the responsibilities of the implementers to help ensure the smooth

implementation of this guide. The possible implementers of the economic loss evaluation of voltage sag and their responsibilities are as follows:

- a) The utilities. When the utilities carry out the economic loss evaluation for power users caused by voltage sag, it is necessary to sign an agreement with the users. The users provide the information required for the evaluation. The utilities execute the evaluation based on the collected information, give the corresponding voltage sag management scheme, and keep the collected information confidential.
- b) The third-party companies. The same as the utilities, the third-party companies also need to sign corresponding agreements with the users, and both parties should perform corresponding responsibilities.
- c) The power users. Power users can evaluate the economic loss caused by voltage sag based on the existing information using this guide and decide whether to carry out voltage sag management.

The information to be collected is listed in 5.2.1.1 through 5.2.1.3.

5.2.1.1 The basic information

The basic information is recommended to include, but is not limited to, the following contents:

- a) The basic information. Name of Customer, address, telephone number, email address, and number of employees.
- b) The production information. Industry type, main products, and annual output value (assistant information).

5.2.1.2 The industrial process information

The industrial process information is recommended to include, but is not limited to, the following contents:

- a) The sensitive equipment. Capacity/power/contact current, numbers, series parallel connection mode, type of the equipment (whether it contains typical sensitive components such as PLC, frequency converter, ac contactor, computer control, release system, etc.), and any relevant information such as protection threshold of sensitive equipment.
- b) The industrial process. The links included in the industrial process, the work content of each link. A link represents a production step, such as wood cutting in paper making, or filling in beverage production, etc. The general coordination mechanism and connection relationship of each link in the industrial process, and the typical electrical equipment included in each link.
- c) The economic losses due to voltage sag. Calculation of product scrap loss, raw material loss, equipment damage, etc., and economic loss caused by whole production stop.

5.2.1.3 The power network information

The power network information is recommended to include, but is not limited to, the following contents:

- a) The voltage sag monitor information of the PCC (assistant information). The customer's record and analysis of voltage sag, any customer history of power quality problems, the frequency of occurrence and the causes of the voltage sag, and the number of plant shutdowns caused by voltage sag in recent years.
- b) The power network topology of the customer's area. Ways for customers to access power grid (name and length of power supply line, cable or overhead line, whether the line supplies power to other