Power Quality Challenges Data Centers Face Today and How to Address These Issues

William Brown ,
Chief Technology Officer, Schneider Electric & Member, IEEE Data Center Subcommittee

Qais Alsafasfeh,
Power System Domain Leader, Schneider Electric & Member, IEEE Data Center Subcommittee

Life Is On | Schneider Electric

Public

1

Introduction

What is Power Quality?

→

Power Quality (PQ) refers to the characteristics of the electrical power supply, including voltage, frequency, and waveform stability. Good PQ means that the power supply is stable, clean (free from harmonics or noise), and within standard tolerances.

✅ **What Constitutes Good Power Quality?**

- *Consistent voltage levels without sags or surges*
- *Stable frequency (typically 50/60 Hz)*
- *Minimal electrical noise or harmonic distortion*
- *Reliable delivery without interruptions*

📈 **Why PQ Matters in Data Centers?**

Data centers rely on continuous and clean power to operate thousands of servers and sensitive equipment. Poor PQ can:

- *Cause system crashes or reboots*
- *Damage hardware*
- *Lead to data corruption or loss*

Public

2

Role of Data Centers in Modern Infrastructure

- ***Backbone of cloud computing, financial systems, e-commerce, healthcare, etc.***
- ***Operate 24/7 with high performance and uptime requirements***
- ***Host mission-critical applications and vast amounts of data***

Impact of Poor Power Quality

- ***Operational Disruptions: Server outages and system failures***
- ***Reduced Reliability: Downtime can affect SLAs (Service-Level Agreements)***
- ***Increased Costs: Equipment wear, higher maintenance, backup system use, and potential data loss***

Maintaining high power quality is essential for operational continuity, cost-efficiency, and protecting infrastructure in data centers.

3

Overview of Data Centers and Their Power Demands

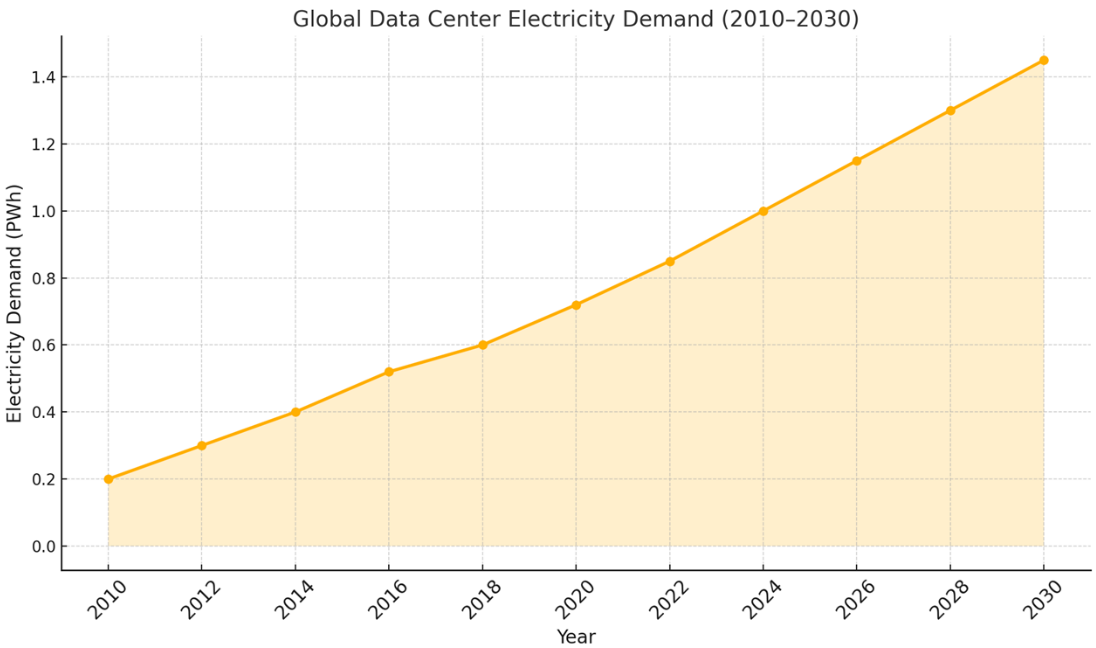
Evolving Role of Data Centers

- Data centers have transformed from basic physical spaces to **core digital infrastructure**, enabling cloud computing, AI, and IoT.
- They are essential for processing, storing, and managing the vast data generated by modern applications and services.
- Defined as facilities centralizing IT operations – housing servers, storage systems, cooling units, and redundant power systems

Rising Energy Demands

- Increasing reliance on high-bandwidth applications and AI has led to **significant power demand**.
- A single modern data center can consume over **100 MW** of electricity.
- By 2030, global data center energy use is projected to exceed **1 PWh annually** and could reach **4.5%-9%** of global electricity consumption.

4



5

Critical Components Dependent on Power Quality

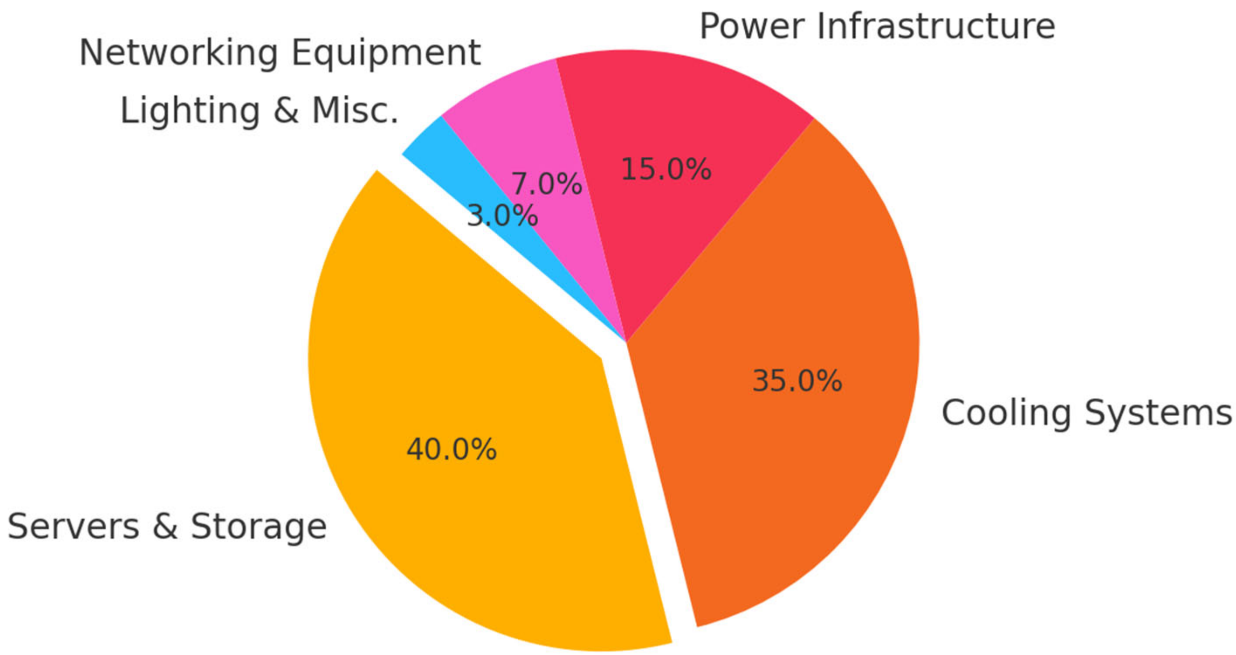
Power-Dependent Components in Data Centers

- **Servers and Storage Devices**: Continuous power is vital for uptime, performance, and data integrity.
- **Cooling Systems**: Maintain optimal thermal conditions; sensitive to voltage fluctuations or power interruptions.
- **Power Distribution & Backup Systems**: Advanced electrical infrastructure ensures **uninterrupted and clean power delivery**, critical for Tier 3 and Tier 4 level fault tolerance.

Infrastructure and Tier Classification

- Components include: servers, networking gear, power storage, software, and security systems.
- Uptime Institute’s **Tier Classification (1–4)** reflects operational continuity and redundancy standards, all heavily reliant on stable and quality power supply.

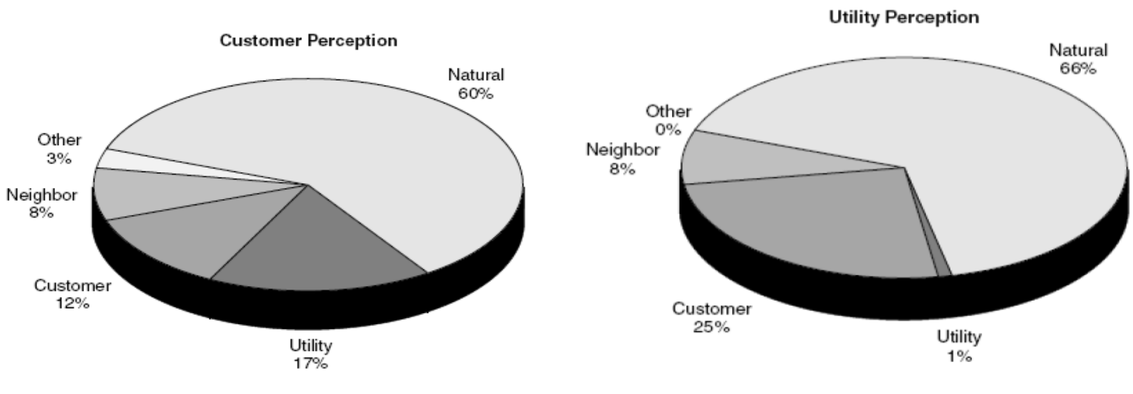
6



U.S. Department of Energy – Lawrence Berkeley National Laboratory
Reference: Masanet et al., *"Recalibrating Global Data Center Energy-Use Estimates"*, *Science*, 2020.

7

Sources of Power Quality Problems



Confidential Property of Schneider Electric | Page 8

Life Is On | Schneider Electric

General

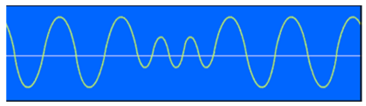
8

Key Power Quality Challenges

Voltage Sags and Surges

- **Definition (IEEE 1159):**

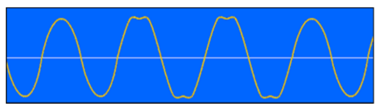
•A **voltage sag** is a **reduction in RMS voltage** between 0.1 to 0.9 per unit for a duration from **0.5 cycles to 1 minute**.
•A **voltage surge (or swell)** is an **increase in RMS voltage** between 1.1 and 1.8 per unit within the same time range.



Harmonics

- **Definition (IEEE 519):**

Harmonics are **voltage or current waveforms** with frequencies that are **integer multiples** of the fundamental (50/60 Hz), caused by **non-linear loads**.



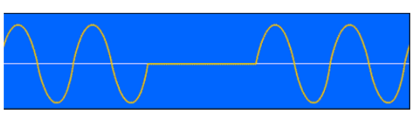
Public

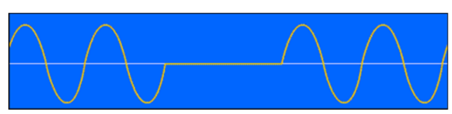
9

Power Interruptions

- **Definition (IEEE 1159):**

A **power interruption** is a **complete loss of voltage** at a particular point in the electrical system, classified as momentary (≤5 seconds), temporary (≤1 minute), or sustained (>1 minute).





Load Imbalances

- **Definition (IEEE Std 1159):**

A **load imbalance** occurs when **current or voltage magnitudes differ** among the phases in a multi-phase system.

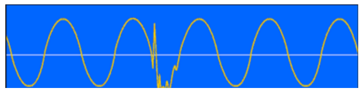
Public

10

Transients

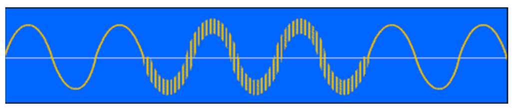
- **Definition (IEEE 1159):**

Transients are **fast, high-frequency disturbances** in voltage or current, often **lasting microseconds**, resulting from sudden changes in power flow.



Noise

- Description: An unwanted electrical signal of high frequency from other equipment
- Duration: Sporadic
- Causes: Electromagnetic interference: from appliances, microwave and radar transmissions; radio and TV broadcasts; arc welding; heaters; laser printers, thermostats, loose wiring; or from improper grounding
- Effect: Disturbs sensitive electronic equipment, but is usually not destructive. It can cause processing errors and data loss.
- Possible Solutions: Isolation transformer, power conditioner, uninterruptible power supply, motor generator

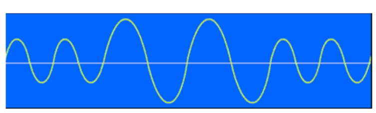


Public

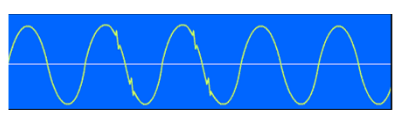
11

Swell or Overvoltage

- Description: An increase in voltage
- Duration: Milliseconds to a few seconds, overvoltages are swells that are longer than a few seconds
- Causes: Major equipment start-up or shutdown, short circuits (fault clearing), undersized electrical circuit
- Effect: Memory loss or data errors, dim or bright lights, shrinking display screens, equipment shutdown
- Possible Solutions: Relocate computer to a different electrical circuit, voltage regulator, power conditioner, uninterruptible power supply, motor generator



Q rwfk



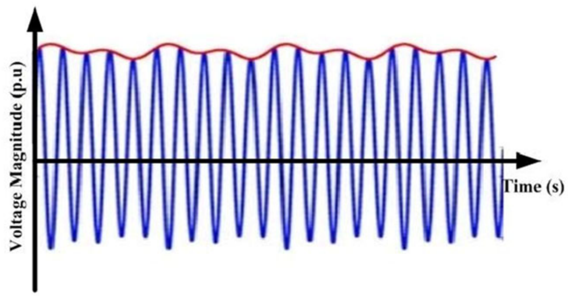
- Description: A disturbance of opposite polarity from the waveform
- Duration: Microseconds
- Causes: Utility switching operations, starting and stopping equipment or machinery, static discharges, lightning
- Effect: Processing errors, data loss, burned circuit boards
- Possible Solutions: Surge suppressor (for transients), power conditioner, motor generator

Public

12

Voltage Flicker

According to the IEEE, flicker, or voltage flicker, is the perceptible change in the intensity of electric light sources due to voltage fluctuations of the input voltage. IEEE 1453-2022 provides specifications for measuring this phenomenon and recommends acceptable levels



Public

13

Power Quality Monitoring Challenges Faced by Data Centers

Challenge	Description	Proposed Solution	Benefits	Enabling Technologies
1. Lack of Granular Power Quality Data Visibility	Power quality assessments are often one-time events, missing ongoing issues like harmonic distortion, overheating, and false alarms caused by non-linear loads.	Implement real-time power quality monitoring systems with high-frequency data sampling and advanced visualization tools.	• Faster fault detection and resolution • Reduced equipment failure rates • Improved uptime and reliability	• High-resolution sensors • Power quality analyzers • Real-time dashboards • Edge computing devices
2. Difficulty in Enhancing Efficiency and Infrastructure	Limited visibility hinders the ability to detect inefficiencies, such as zombie servers and stranded power capacity, which waste resources.	Deploy intelligent monitoring tools with detailed analytics on power usage effectiveness (PUE), server activity, and outlet-level current loads.	• Improved energy efficiency • Optimal resource utilization • Support for high-density IT deployment	• Advanced rack PDUs with analytics • AI-driven energy monitoring software • Predictive maintenance tools
3. Lack of Power Quality Monitoring Tool Integration	Existing intelligent PDUs often lack compatibility with broader BMS or DCIM systems, reducing centralized control.	Use PDUs and monitoring tools that support open APIs and standard protocols for seamless integration.	• Unified infrastructure management • Simplified monitoring and automation • Increased flexibility and scalability	• APIs: Redfish, JSON-RPC, SNMP • Integration with BMS/DCIM • Vendor-neutral interoperability

Public

14

Impact of Power Quality Issues in Data Centers

Operational Impact

Server and System Downtime:

- Voltage sags, surges, and interruptions can cause sudden shutdowns or restarts, interrupting mission-critical processes.
- Power-related problems are responsible for **43% of data center outages**, leading to unexpected server and system downtimes.

Increased Latency and Failed Transactions:

- Unstable power can slow down response times, impact user experience, and lead to transaction or data processing failures.

Automatic System Shutdowns:

- Sensitive equipment may trigger protective shutdowns in response to unstable conditions, affecting availability.

15

Financial and Business Consequences

Revenue Loss:

- Every minute of downtime can result in substantial financial loss, especially for cloud services and e-commerce platforms.
- The **average cost of data center downtime** is approximately **$9,000 per minute**, with larger organizations potentially losing hundreds of thousands of dollars per hour.

SLA Violations:

- Service-Level Agreements (SLAs) may be breached due to poor uptime, leading to compensation claims and client churn.
- Service Level Agreement (SLA) breaches due to downtime can result in substantial penalties. For instance, some organizations have incurred over $1 million in penalties for SLA violations.

Equipment Replacement Costs:

- Frequent exposure to poor power quality shortens equipment lifespan and increases costs for maintenance and replacement.
- Power quality issues contribute to approximately **33% of data center outages**, often necessitating costly equipment repairs or replacements

16

Long-Term Reliability and Efficiency

Accelerated Equipment Aging:

- Frequent power disturbances wear out sensitive electronics, leading to increased failure rates over time.

Reduced Energy Efficiency:

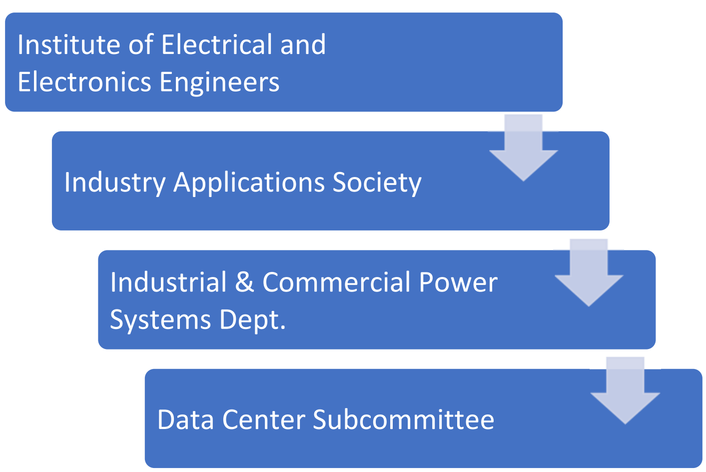
- Issues like harmonics and imbalanced loads cause inefficient energy use and increase operational power consumption.

Increased Maintenance Needs:

- Unstable power conditions necessitate more frequent checks, diagnostics, and system calibrations, raising operational complexity.
- Data centers located near significant data center activity have shown higher instances of power quality distortions, necessitating more frequent maintenance and monitoring.

17

Mitigation Strategies and IEEE Color Book and the 3000 series standards



Public

18

IEEE Advancing Technology for Humanity

Introduction to IEEE
(Institute of Electrical and Electronics Engineers)

IEEE is the world's largest technical professional organization dedicated to advancing technology for the benefit of humanity.

- ***Mission:*** IEEE's core purpose is to foster technological innovation and excellence for the benefit of humanity.
- ***The IEEE Today:*** IEEE and its members inspire a global community through its highly cited publications, conferences, technology standards, and professional and educational activities.
  - ***460,000 + Members in over 190 countries***
  - ***39 IEEE Societies/8 Technical Councils***
  - ***10 Regions***
  - ***Publishes approximately a third of the world's technical literature in electrical engineering, computing, and electronics.***
  - ***Holds more than 2,000 annual conferences and events worldwide***
  - ***Has more than 1,144 active standards, with 1,018 under development***

19

Industry Application Society (IAS)

IAS IEEE INDUSTRY APPLICATIONS SOCIETY ® Linking Research to Practice

- IAS: a global organization focusing on the needs of industry and commerce within the IEEE. The IAS mission is to advance the theory and practice of electrical systems, equipment, and services.
- IAS offers many benefits to its members, including:
  - **Professional Connections**: Build relationships with other professionals and access a global network
  - **Professional Development**: Members can grow their skills and qualities.
  - **Publications**: IAS produces or contributes to the IAS Newsletter, *Industry Applications Magazine*, and IEEE Transactions on Industry Applications.
  - **Events**: Members can attend IAS's regional, national, and international events and conferences.
  - **Mentorship Program**: The IAS offers online resources and tools to help young professionals advance their careers.

20

Industrial & Commercial Power Systems Dept. (I&CPS):

Part of IEEE's Industry Applications Society (IAS)

Focus: electric power generation, transmission, and distribution technology in industrial, commercial, and institutional facilities. It also includes rural or agricultural applications.

I&CPS's annual technical conference brings together both experienced and younger engineers. It features papers and industry presentations on many aspects of industrial and commercial power systems.

I & CPS
Industrial & Commercial Power Systems

IEEE IAS I&CPS Department

I&CPS is responsible for many IEEE standards. The largest effort recently has been converting the "Color Books" to the IEEE 3000 Standards Collection

- PSE | Power Systems Engineering Committee
- PSP | Power Systems Protection Committee
- ESC | Energy Systems Committee
- C&S | Codes & Standards Committee
- REPC | Rural Electric Power Committee
- SDC | Standards Development Committee

Property of Schneider Electric | Page 21

Public

21

About the Industry Applications Society's *Data Center Subcommittee*

IAS Links Research to Practice: We meet the engineering needs of industry and commerce through the advancement of theory and practice in design, manufacturing, and application.

Scope of the IAS Data Center Subcommittee: The treatment of all matters within IAS that specifically relate to Data Center "Gray Space."

- This encompasses electrical supply, distribution, and utilization of equipment on the customer side of the utility meter.
- We are the data center authority for the IAS' Industrial and Commercial Power Systems Dept.

We Seek Your Subcommittee Participation: Give back to our industry while raising your profile! Contribute to technical papers, application guides, industry application presentations, thought leadership activities, and learn about many industry-specific topics. We work in cooperation with the Society Standards Department.

Property of Schneider Electric | Page 22

22

Color Books and 3000 Standards:

The IEEE Color Book standards series include 13 books with each one focusing on different aspects of electric power.

The Working Groups responsible for Color Book standards, development and revisions are sponsored by the IAS's Industrial & Commercial Power Systems Dept.'s technical committees.

23

Color Books and 3000 Standards:

Color Book	IEEE Std. No.	Topic
Red	141-1993 [2]	Electric Power Distribution for Industrial Plants
Green	142-2007 [3]	Grounding of Industrial and Commercial Power Systems
Gray	241-1990 (R1997)[4]	Electrical Power Systems in Commercial Buildings
Buff	242-2001[5]	Protection and Coordination of Industrial and Commercial Power Systems
Brown	399-1997 [6]	Industrial and Commercial Power Systems Analysis
Orange	446-1995 (R2000)[7]	Emergency and Standby Power Systems for Industrial and Commercial Applications
Gold	493-2007, [8]	Design of Reliable Industrial and Commercial Power Systems
White	602-2007, [9]	Electrical Systems in Health Care Facilities
Bronze	739-1995 (R2000) [10]	Energy Management in Industrial and Commercial Facilities
Yellow	902-1998, [11]	Guide for Maintenance, Operation, & Safety of Industrial and Commercial Power Systems
Blue	1015-2006 [12]	Applying Low-Voltage Circuit Breakers Used in Industrial & Commercial Power Systems
Emerald	1100-2005 [13]	Powering and Grounding Electronic Equipment
Violet	551-2006 [14]	Short-Circuit Calculations in Industrial and Commercial Power Systems

24

Color Books and 3000 Standards:

The IEEE GOLD BOOK: Provides sufficient information so that reliability analysis can be performed on power systems without requiring cross-references to other texts; contains many reliability aspects

The IEEE YELLOW BOOK: Provides a reference source for the fundamentals of safe and reliable maintenance and operation of industrial and commercial power systems, regardless of system size or complexity.

IEEE 3000 Standards Collection™

IEEE Standards Collection designed for Industrial and Commercial Power Systems.

IEEE 3000 Standards Collection™ is the trademarked name of the family of industrial and commercial power systems standards formerly known as IEEE Color Books. The IEEE 3000 Standards Collection overall includes the same content as the Color Books but is now organized into approximately 60 IEEE "dot" standards that cover specific technical topics.

IEEE 3000 Standards Collection™ Standards and Projects

- IEEE 3001™ Standards: Power Systems Design
- IEEE 3002™ Standards: Power Systems Analysis
- IEEE 3003™ Standards: Power Systems Grounding
- IEEE 3004™ Standards: Protection & Coordination
- IEEE 3005™ Standards: Energy & Standby Power Systems
- IEEE 3006™ Standards: Power Systems Reliability
- IEEE 3007™ Standards: Maintenance, Operations & Safety

IEEE 3001™ Standards: Power Systems Design

Standards:

IEEE 3001.2™-2017

IEEE Recommended Practice for Evaluating the Electrical Service Requirements of Industrial and Commercial Power Systems

IEEE 3001.4™-2020

IEEE Recommended Practice for Estimating the Costs of Industrial and Commercial Power Systems

IEEE 3001.9/IES RP-48™-2023

IEEE/IES Recommended Practice for the Design of Power Systems Supplying Lighting Systems in Commercial and Industrial Facilities

IEEE 3001.11™-2017

IEEE Recommended Practice for Application of Controllers and Automation to Industrial and Commercial Power Systems

Projects:

P3001.1™

Recommended Practice for the Planning and Design of Industrial and Commercial Power Systems

IEEE P3001.3™

IEEE Draft Recommended Practice for the Design of Industrial and Commercial Power Systems: Voltage Considerations

Public

27

How are Standards Developed?

The IEEE Standards Association (SA) even provides a style guide. This helps ensure that everyone is on the same page when it comes to understanding how a standard is implemented.

- At IEEE SA, the development of technical standards can be broken down into six main stages:

Property of Schneider Electric | Page 28

Public

28

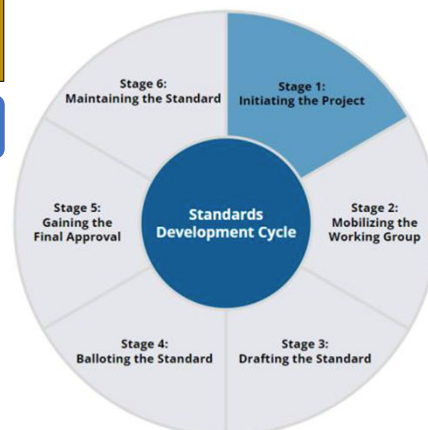
How are Standards Developed?

The development of an IEEE standard begins with an idea. Individuals, companies, or other entities may contact each other and discuss the need for a standard.

If a need for a standard is identified, the project's **Standards Committee** assumes responsibility for that area of standards development, including the organization of a Working Group and its activities. The Standards Committee will submit a formal request to IEEE SA to begin the project.

Types of IEEE Standards Projects are classified as:

- **Standards** – documents with mandatory requirements
- **Recommended Practices** – documents in which procedures and positions preferred by IEEE are presented
- **Guides** – documents in which alternate approaches to good practices are suggested but no explicit recommendations are made
- **Trial-Use** – documents in effect for no more than three years. The documents can be a Standard, Recommended Practices, or Guide.



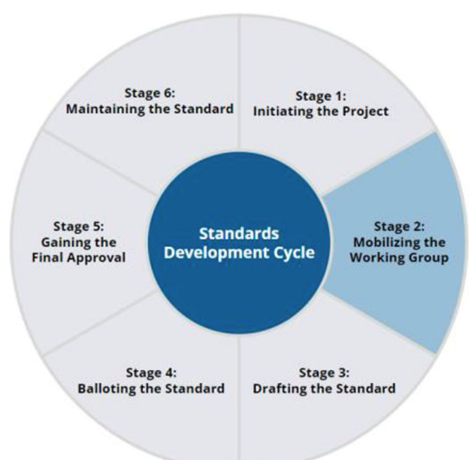
How are Standards Developed?

Working Groups are composed of individuals or entities (companies, organizations, non-profits, government agencies) who volunteer to participate in the development of the standard. These volunteer participants have an interest in a specific area of the development of the standard (e.g., producers, sellers, buyers, users and/or regulators of a particular material, product, process or service).

All participants in Working Groups should have technical expertise, knowledge and/or an interest in the technology being standardized.

For individual standards projects, IEEE or IEEE SA membership is not required to participate.

For entity standards projects, IEEE SA advanced corporate membership is required to be a member of the working group.

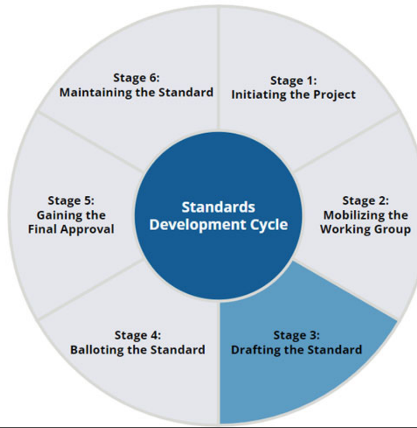


How are Standards Developed?

- The IEEE SA provides editorial draft development support to more than 500 Working Groups and publishes more than 100 standards a year.
- Generally, Working Groups interact with editorial staff three times during their standards development journey: The drafting stage, the balloting stage (MEC), and the post-SASB approval publishing stage.
- The IEEE SA professional staff includes two types of Program Managers: staff liaisons and staff project editors.

Contact your staff project editor for help with the following:
- Editorial requirements
- Figure requirements
- Guidance with copyright permission

Please contact your staff liaison for help with the following:
- PAR submittal/revision
- Draft submittal for MEC
- Draft submittal for balloting and recirculation
- Draft submittal to RevCom



Public

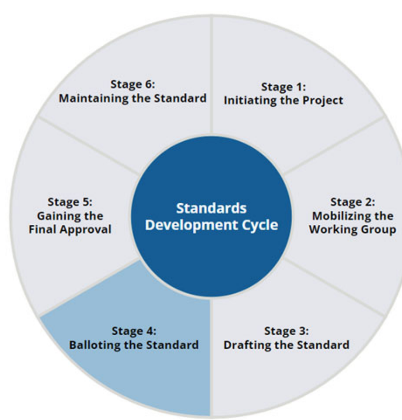
31

How are Standards Developed?

- Once a draft standard has been reviewed, finalized, and approved by the Working Group, it is submitted to the Standards Committee for approval to move forward to the IEEE SA Ballot
- Upon successful completion of the IEEE SA Ballot process, the draft standard is submitted to the Review Committee (RevCom).
- The balloted draft standard is reviewed by RevCom and then submitted to the IEEE SASB for approval. After final approval by the IEEE SASB, the approved standard is published and made available for distribution and purchase.

The IEEE SA balloting process is an important part of the strength of IEEE SA consensus standards. All stakeholders have an opportunity to participate.

Those who join the ballot group have an obligation to submit ballot responses.



Public

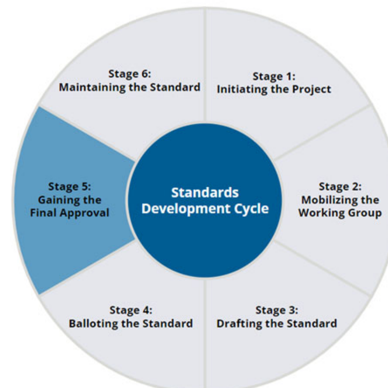
32

How are Standards Developed?

- The IEEE SA Standards Board (SASB) approves or disapproves draft standards based on the recommendation of its Standards Review Committee (RevCom).
- Once a standard has been approved by the IEEE SASB, it receives a thorough, detailed edit from a professional IEEE Standards editor. The role of the editor is to ensure that the standard is grammatically and syntactically correct using American English. It is not an editor's role to make any changes that affect the technical meaning of the standard.

The IEEE SA balloting process is an important part of the strength of IEEE SA consensus standards. All stakeholders have an opportunity to participate.

Those who join the ballot group have an obligation to submit ballot responses.



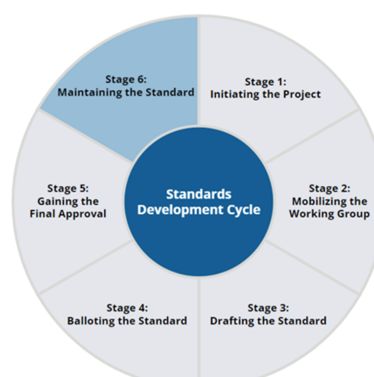
How are Standards Developed?

- An IEEE standard is active for 10 years from the IEEE SA Standards Board approval year.

Within the 10-year period, Standards Committees can take the following actions:

- Revise the standard by opening the entire document for updates, changes, or additions
- Submit Amendments for additional material to the standard
- Submit Corrigenda for corrections to the standard that does not introduce new material
- Withdraw the standard from active to inactive-withdrawn status through an SA Ballot

If a standard has not been revised before the end of the 10-year maintenance cycle, it may be administratively withdrawn by the IEEE SASB.



IEEE P3710
"Guide for the Design of Modular Data Centers"

Scope

- Provides guidance for North American (NA) standards-based designs of Modular Data Centers (MDCs).
- Covers three types:
  - Power Distribution Only
  - IT Installation Infrastructure Only
  - Power/IT Combined
- Focuses on electrical considerations consistent with installation codes and product safety standards.
- Does not include IT components.

35

IEEE P3710
"Guide for the Design of Modular Data Centers"

Purpose

- Establishes guidelines for the electrical design of MDCs.
- Enhances safety, reliability, and efficiency.
- Facilitates integration with existing infrastructure or development of new infrastructure for MDCs.

36

IEEE P3710
"Guide for the Design of Modular Data Centers"

Need for the Project

- Rapid expansion of data centers creates demand for flexible and scalable modular solutions.
- Current lack of consistent design standards causes variability in safety and quality.
- Project provides standardized guidelines to:
  - Reduce design/installation errors
  - Improve safety
  - Enable seamless integration with traditional data centers
- NA-specific design and installation codes make a combined global standard impractical, but global concepts can be applied.

37

We Welcome You to Join the Data Center Subcommittee!

Industry professionals are warmly welcomed to join the Data Center Subcommittee.

- You can help set standards that affect the entire industry.
- Contact Chair Daleep Mohla at dcmohla@comcast.net or Vice Chair Keith Waters at keith.waters@se.com to join or ask questions.

38