

# Reliability Models for Electric Power Systems

## White Paper 23

Revision 1

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### > Executive summary

This white paper explains the sources of downtime in electric power systems and provides an explanation for site-to-site variations in power availability. The factors affecting power quality from generation to the utilization point are summarized. There is a qualitative description of a model, which can be combined with data to provide a method for estimating down time based on site-related factors.

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## Introduction

The availability of business systems is significantly impacted by AC mains power quality. The degree to which power quality affects business systems depends on many factors, which include:

1. The quality of the electrical power
2. The downtime caused by factors unrelated to power
3. The ability of the business systems to recover from power problems

These factors vary greatly from site to site and from business to business and therefore it is inappropriate to make general statements regarding the impact of power on business process availability. Nevertheless, it is possible to take into account the specific issues of a site and a business and determine the quantitative effect of power problems on business operation.

This white paper explains the components needed to model power quality focusing on power events that lead to the malfunction of information technology equipment. Of the three factors listed above, this note only addresses the first factor. Factors 2 and 3 and the general problem of overall business process availability are the subject of separate white papers.

### The electrical power distribution system

For purposes of understanding the distribution of electrical power, the system is typically separated into the following four levels:

Distribution level	Equipment
Bulk power	Power plants
Area power	High voltage lines
Distribution network	Neighborhood power lines
Utilization equipment	Building wiring

**Table 1**

*The four levels of power distribution*

A failure at any of these levels can lead to a failure of equipment operation at the user site. In the following sections the common problems at each of these distribution levels will be described.

### What constitutes a power problem?

AC power is imperfect. All AC power exhibits defects almost continuously including harmonic distortion, sags, swells, RF noise etc. Fortunately, information equipment is immune to the overwhelming majority of these problems. Common citations regarding power quality and the frequency of power problems can be highly misleading because they often include power defects that do not affect information equipment.

For a meaningful discussion of the effect of power problems on information equipment, a power problem must be defined as a condition where the AC power does not meet the necessary and sufficient conditions required to provide equipment operation. The generally accepted definition of necessary and sufficient power quality is provided by the Computer and

Business Equipment Manufacturers Association, which describes the magnitudes and durations of power problems which are likely to affect information equipment.

## Bulk power

Bulk power is defined as a composite of the generating stations and the very high voltage transmission network.

Problems with bulk power affect the largest number of users. These problems are caused by

1. Fuel shortages
2. Human error
3. Plant shutdowns
4. Planned conservation
5. Earthquakes

The statistics for bulk power availability vary widely. For example, on a small island bulk power may be a major contributor to down time. In Western Europe, the USA and Japan, the bulk power system is highly fault tolerant and a bulk power loss may occur only once every ten years or less.

## Area power

Area power is defined as the transformer stations and substations supplying a given area.

Problems with Area power affect large blocks of people such as entire towns or cities. These problems are caused by:

1. Equipment failure/wear out
2. Overloads
3. Weather
4. Earthquakes

The statistics for area power availability vary widely. For example, some countries routinely employ interconnected stations with fail over capability while others employ a single path system. Systems with fail over capability provide a much lower mean time to repair and hence higher availability.

## Distribution network

The distribution network is the local network of wiring which feeds buildings. This wiring typically follows streets and operates in the range of 5 kV to 30 kV and includes the transformers at the user's site, which convert the power to the final utilization voltage.

For many sites distribution is the primary cause of power problems. The distribution network is highly complex and exposed to many factors which can cause a power problem, including:

1. Ice
2. Trees
3. Wind
4. Lightning

5. Vehicular accidents
6. Overloads
7. Animals
8. Construction accidents
9. Earthquakes
10. Tornados

The statistics for power problems in distribution networks are most strongly affected by local weather. In systems where distribution wiring is underground these affects are reduced dramatically. In some cases, a significant degree of fail over redundancy is designed into the local distribution system, which reduces mean time, to repair and therefore increases availability.

## Utilization system

The utilization system consists of building wiring, circuit breakers, and internal building transformers.

Power problems arising in the customer's utilization system are mainly independent of the geographic location of the site and are caused by factors that are typically in the control of the customer, including:

1. Overloads
2. Construction accidents
3. Scheduled electrical work
4. Electrician errors
5. Heavy equipment startup
6. Poor wiring connections

The statistics for power problems in utilization systems are most strongly affected by the existence of construction or wiring changes in the building, the nature of the business (industrial vs. knowledge workers) and the age of the building and wiring. In situations where the quality of the power supplied by the utility company is high, such as in suburban Western Europe, power downtime may be dominated by utilization system problems within the customer's own facility.

### Developing a quantitative model for power availability

Making general quantitative statements about power availability is not helpful in predicting the experience at a given site because the variations are so great. However, by collecting a limited amount of basic information about the customer site, and combining it with the available statistical data on power quality, it is possible to make reasonable predictions about power quality a specific customer site. The types of data that are required include:

1. Geographic location
2. Type and age of building
3. Nature of the business
4. Above or underground distribution
5. In-building construction plans
6. Neighborhood construction plans

From this information it is possible to develop a profile for the site and apply available statistical data to predict power availability in percent, frequency of events, and the distribution of mean times to repair.

## Conclusion

This note has explained the logical foundation for predicting power availability for information systems. Due to the wide site-to-site variation in power availability, prediction of availability requires that geographic location and other information about the site be used.

Such a predictive model can be used in combination with a model of how business processes react to and recover from power problems in order to predict the likely business consequences of power problems.



### About the author

**Neil Rasmussen** is a Senior VP of Innovation for Schneider Electric. He establishes the technology direction for the world's largest R&D budget devoted to power, cooling, and rack infrastructure for critical networks.

Neil holds 19 patents related to high-efficiency and high-density data center power and cooling infrastructure, and has published over 50 white papers related to power and cooling systems, many published in more than 10 languages, most recently with a focus on the improvement of energy efficiency. He is an internationally recognized keynote speaker on the subject of high-efficiency data centers. Neil is currently working to advance the science of high-efficiency, high-density, scalable data center infrastructure solutions and is a principal architect of the APC InfraStruXure system.

Prior to founding APC in 1981, Neil received his bachelors and masters degrees from MIT in electrical engineering, where he did his thesis on the analysis of a 200MW power supply for a tokamak fusion reactor. From 1979 to 1981 he worked at MIT Lincoln Laboratories on flywheel energy storage systems and solar electric power systems.



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## Related reading

1. Endrenyi, *Reliability Modeling in Electric Power Systems*, Wiley & Sons, 1978  
(A detailed description of the probabilistic models used to analyze the Bulk, Area, and Distribution System levels of a power system).
2. Sabin, Larnoree, and Sundaram, *Final Results from the EPRI Distribution System Power Quality Monitoring Project and New Power Quality Monitoring Tools*.  
(A description of the 1995 EPRI study of Distribution power quality in the USA, including quantitative data).



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