Oxygen Delivery Toolkit
Resources to plan and scale medical oxygen

Electricity Planning Guide

Assisting countries in planning for deployment and use of medical devices in an environment where access to electricity is intermittent

For use by:

Decision-makers

Implementers

June 2020

This resource is part of the **Oxygen Delivery Toolkit: Resources to plan and scale medical oxygen.** The materials provided within the toolkit can be used together or separately, as needed. The complete Oxygen Delivery Toolkit includes the following resources:

- *Oxygen is Essential: A Policy and Advocacy Primer*
- *Health Facility Standards Guide*
- *Baseline Assessment Manual*
- *Consumption Tracking Tool*
- *Procurement Guide*
- *Quantification and Costing Tools*
- *Reference Pricing Guide*
- *Electricity Planning Guide*
- *Asset Management Guide*

The toolkit is available at www.path.org/oxygen-delivery-toolkit.

Acknowledgments

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Oxygen Delivery Toolkit disclaimer

Contents

Abbreviations

AC	alternating current
CT	computerized tomography
DC	direct current
Hz	hertz
IEC	International Electrotechnical Commission
ITI	Information Technology Industry Council
LMIC	low- and middle-income country
ms	millisecond
RMS	root mean square
SE4ALL	Sustainable Energy for All
SPA	Service Provision Assessment
UPS	uninterruptible power supply
USAID	US Agency for International Development
V	volt
W	watt

1. Introduction

Access to consistent, reliable, and high-quality electricity is important for any economy, but it is especially critical for health systems that rely on electromedical devices for patient diagnosis and treatment. A simple transformer failure, for example, can leave a rural health facility without power for six months, turning away thousands of patients who require proper diagnostics and treatment or who are seeking vaccines, snakebite antivenom, or lifesaving uterotonics, which require cold storage. There are countless examples of facilities across developing countries that cannot properly carry out their work without access to electricity or that have lost expensive electromedical devices, lab equipment, and critical oxygen equipment due to poor power quality.

The *Electricity Planning Guide* is designed to inform country stakeholders on how to improve the way electromedical devices are deployed and used at health care facilities in low- and middle-income countries (LMICs). The guide provides information on electricity availability, quality, and cost in selected countries, and includes recommendations for deployment of electromedical devices. Though the guide focuses on examples that are specific to medical oxygen delivery devices and pulse oximeters, the recommendations hold general applicability to other electromedical devices.

2. Current state of electricity access

Globally, there is little comprehensive data on electricity access in LMICs and a near complete lack of data on electricity quality. Throughout this guide, a clear distinction is drawn between issues of electricity access and quality.

Electricity access is defined as electricity that can be used or obtained.

Quality is the state of the electricity that is being consumed.

The few existing studies that have been conducted to capture data on electricity access and quality in LMICs typically generalize data across large geographies, making it difficult to respond to facility-specific power challenges. The largest known study is the Electricity Supply Monitoring Initiative, which is led by the Indian nonprofit organization Prayas Energy Group. The Electricity Supply Monitoring Initiative monitors electricity interruptions and voltage levels in 434 locations within 23 Indian states, as well as in Indonesia, Kenya, Tajikistan, and Tanzania. Power quality data are collected in aggregate and summarized across regions, making it difficult to target practical recommendations for selecting and effectively using electromedical devices in different settings. Understanding electricity access and, when available, electricity quality is crucial for broader health systems planning.

Access to electricity across LMICs

The World Bank's Sustainable Energy for All database reports on the current status of electricity access by country and according to the country's income-level classification (i.e., high income, upper-middle income, lower-middle income, and low income). In high-income and upper-middle-income countries, access to electricity is reported as being available for over 96 percent of the population. By comparison, electricity access is still limited in LMICs, with only 78 percent of the population having access to electricity in lower-middle-income countries and 41 percent of the population in low-income countries. Further, when examined by urban versus rural communities in low-income countries, not surprisingly, electricity access is 70 percent for urban populations but drops considerably to 25 percent for rural populations.

How electricity impacts firms conducting business

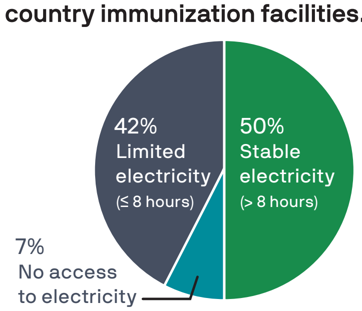
Consistency and reliability of electricity are also major constraints for companies doing business in developing countries. The World Bank's Enterprise Surveys data show that an average of 46 percent of firms in low-income countries and 29 percent of firms in lower-middle-income countries identify with these challenges. Countries with more frequent outages also face outages of longer duration. This challenge has tremendous economic impact in LMICs, including an adverse effect on private companies that produce mass quantities of medical oxygen—whether liquid oxygen and/or gas oxygen at large production sites. It also has a direct impact on the ability to provide advanced care in both the public and private health sectors. (Refer to Appendices 3 and 4 for the Enterprise Surveys data specific to Kenya and Senegal.)

How electricity impacts health facilities

Poor electricity access affects all electromedical devices. While the degree of impact may vary, it is particularly devastating with vaccines in the case of cold chain equipment, timely diagnosis of a variety of infectious diseases in the case of diagnostic equipment, and sustaining life in the case of oxygen delivery devices and pulse oximeters. Women and children are often disproportionately affected by electricity challenges, as complications in pregnancy and birth often require advanced care with more than one electromedical device. Gavi, the Vaccine Alliance's Cold Chain Equipment Optimisation Platform inventory data from 30 countries (60,251 vaccines storage and immunization facilities) reveal that 50 percent of births are served by facilities with unstable electricity (less than 8 hours per day) or no electricity. This places women and newborns at risk if complications occur that require electromedical equipment and no backup power source is in place.

The aggregated results from the Gavi Cold Chain Equipment Optimisation Platform data show that approximately 50 percent of facilities have on-grid and stable electricity; 7 percent have unstable, on-grid electricity; and 42 percent have no access to electricity (Figure 1).

Figure 1. Electricity availability breakdown for all Cold Chain Equipment Optimisation Platform country immunization facilities.



The Service Provision Assessment (SPA) survey, performed by the Demographic and Health Surveys Program of the US Agency for International Development (USAID), is a health facility assessment that provides a comprehensive overview of a country's health service delivery. SPA data are analyzed to get an overview of electricity availability rate, electricity continuity rate, and the link between electromedical devices owned by facilities and continuity rate for a specific country. SPA data illustrates the importance of investigating both access and quality to understand a country's health facility electricity situation. For example, while Nairobi health facilities had high rates of access, continuity was low (19%). Similarly, in Senegal health facilities, while electricity access was around 60% across the country, the highest rates of continuity were noted in Dakar and Diourbel at 21%, but went as low as 10% in other areas. (Refer to Appendices 3 and 4 for the SPA data analysis specific to Kenya and Senegal.)

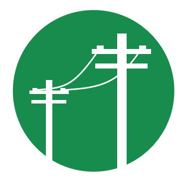
3. Understanding power sources and requirements for electromedical devices

Deployment of electromedical devices requires a suitable electrical infrastructure to support daily operation. The requirements of this infrastructure revolve around two key questions: (1) Is the amount of power sufficient? (2) Is the quality of power sufficient?

What are the different power supply sources?

Grid-connected electricity

Grid electricity is an interconnected network for delivering electricity from producers to consumers, often from a central power source. Grid networks often include a generation station (coal/natural gas/oil-fired power plant, nuclear power plant, solar or wind-generation farms, hydroelectric dam, etc.), high-voltage transmission lines that carry electricity over long distances, transformers to convert the high voltage used in transmission to safer distribution levels, and distribution lines that connect to individual consumers. Problems with any segment between the customer and the source can lead to power-quality issues and outages.

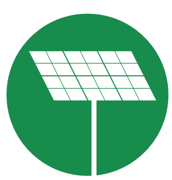


Off-grid electricity

When not connected to a country's power grid, especially in remote areas, electricity is generated locally or not generated at all. Some options for generating electricity locally are outlined below. Each of these electricity-generation systems can also be used to provide electricity in the event of a grid-connected electricity outage or disruption.

Solar power

Solar power is the conversion of sunlight into electricity. Solar energy is usually generated by photovoltaic cells, which are grouped into modules that absorb light and convert it into energy. Facilities may have solar panels to support the electricity they use from grid-connected sources.

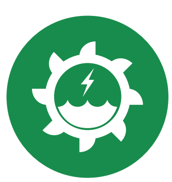


Wind power

Wind power is the conversion of the kinetic energy from wind into electricity. Although often associated with large farms that connect to a country's power grid, it is possible for facilities to use smaller wind turbines to generate local electricity.

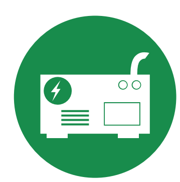
Hydroelectric power

Hydroelectric (sometimes referred to as "hydro") power is the conversion of kinetic energy from flowing water into electricity. Although often associated with large dam projects (such as those that connect to a country's power grid), examples have been found of facilities using smaller-scale dams to produce local, off-grid electricity.



Generator

These are machines that burn fossil fuels, such as gas or oil, to produce electricity. These are often smaller machines that can run in the event of a disruption of electricity supply from the grid, ensuring consumers still have electricity to power homes or facilities.



Most off-grid electricity sources (with the exception of generators) produce lower-voltage direct current (DC) energy, which can be used to charge batteries. A battery is a container that stores electricity in a chemical state, which can be converted into electricity to use as a source of power. To use electrical equipment that run on grid power, a device called an inverter is required. Inverters range in output from 50 watts (W) up to several thousand watts. An inverter and a battery must be sized so that neither is overloaded when operating anticipated electrical devices (see Table 1).

What power factors should be considered for electromedical devices?

There is a large variety of electromedical devices, from small handheld devices that are used in rural outposts to large diagnostic imaging machines that are found occasionally in top-level hospitals. The amounts of power they require for standard operation also vary greatly (see Table 1).

When connected to grid power, the power usage of individual pieces of equipment is not critical. However, power consumption over time will lead to incurred costs for power billing.

Off-grid sources of power are typically much more limited in terms of total output. As such, off-grid sources of electricity must be appropriately sized to accommodate equipment usage during peak demand times. Off-grid electricity is challenging and expensive to use with higher-power equipment that is not designed to run on DC power. For example, a single solar panel may be rated for a peak output of 275 W, and a given day may have 5 hours of peak sun depending on geography and weather. Given efficiency losses of inverters and batteries, this solar system may only be able to power a 350 W oxygen concentrator for about 3 hours per day in good weather (see Figure 2). In addition, devices that use electric motors (such as concentrators and refrigerators) can have starting power requirements that are several times the average running power. The power system also must be oversized to match these startup power requirements, increasing system cost. This class of devices may have mobile or off-grid versions that are more energy efficient and can accept DC power directly from solar panels or automotive batteries without needing an inverter, which would reduce system cost and complexity. As such, devices designed for off-grid use are preferable from a device selection standpoint if a facility is planning to use a DC system.

Table 1. Medical devices and their power supply requirements.[1–3]

Device	Approximate average power usage (watts)
Handheld pulse oximeter	1
Laptop	40
Ventilation fan	161
Oxygen concentrator	350
Anesthesia unit	302
Refrigerator/freezer	725
CT (computed tomography) machine	20,000

Figure 2. Off-grid electricity can be challenging and expensive to use.

4. Integrating electricity monitoring into routine health system data

Robust electricity monitoring systems are important for governments to ensure that their health systems are operating as effectively as they can in treating patients. If they are not, decision-makers should plan and respond to mitigate roadblocks to efficient operations.

What electricity information is helpful to know?

Power systems are inherently dynamic entities that are expected to fluctuate during normal operation. Whether or not these fluctuations damage equipment that are connected to the power system depends on the duration and magnitude of the fluctuations. The Information Technology Industry Council (ITI), formerly known as the Computer and Business Equipment Manufacturers Association, has defined the industry standard for acceptable voltage excursions based on duration and severity of the excursion (see Figure 3). Figure 3 serves as a benchmark for determining if a particular power event would likely result in electromechanical damage to an electrical device or not. A key limitation of this standard is that it was only defined for 120 V systems, so 240 V system thresholds may not be as applicable. Different types of power fluctuations are defined below as well as their acceptable limits.

Outages

An electrical outage is the loss of electrical power for longer than 20 milliseconds (ms). Outages are represented at any point greater than 20 ms on the x-axis [0 volts (V)] of Figure 3. Short-duration outages can come from the grid or may happen when switching between grid electricity and backup generator. Short-duration outages may cause disruptions in equipment without battery backup, such as desktop computers. Longer-duration outages can prevent electrical equipment use, which would lead to issues for services that require electricity. Battery backup or an uninterruptible power supply (UPS) can be used to prevent disruption of short-duration power outages. Electricity generators are common for providing power during longer grid outages.

Voltage sags

Voltage sags are reductions in the mains voltage (typically 90 percent of nominal voltage) that last longer than 20 ms. Sags less than 10 seconds represent the no-damage region in Figure 3, and sags greater than 10 seconds are in the prohibited region. Voltage sags longer than 1 minute (steady state) are sometimes called brownouts. Sags are often caused by large electrical loads being switched on. Sags can cause lighting to dim. Brownouts are typically from disruptions in the electricity grid, such as overloading. Brownouts are harmful to electric motors, as they can lead to overheating and burnout over time. Electric motors are commonly found in refrigerators, fans, and air compressors (e.g., oxygen concentrators) in health care facilities. Voltage stabilizers are devices that can adjust output voltage provided to equipment in order to prevent these issues. There are also automatic switching devices that cut power to equipment when the voltage drops too low, preventing damage.

Voltage surges

Voltage surges (or swells) are increases in the mains voltage (typically 110 percent of nominal voltage) that last longer than 20 ms. Surges form the majority of the prohibited region (20 ms to steady state) in Figure 3. Surges are often caused by large electrical loads being switched off. Surges can cause lighting to brighten, and severe surges can cause equipment to draw too much power, leading to damage. Voltage stabilizers are devices that can adjust output voltage provided to equipment in order to prevent these issues. There are also automatic switching units that cut power to equipment when the voltage rises too high, preventing damage.

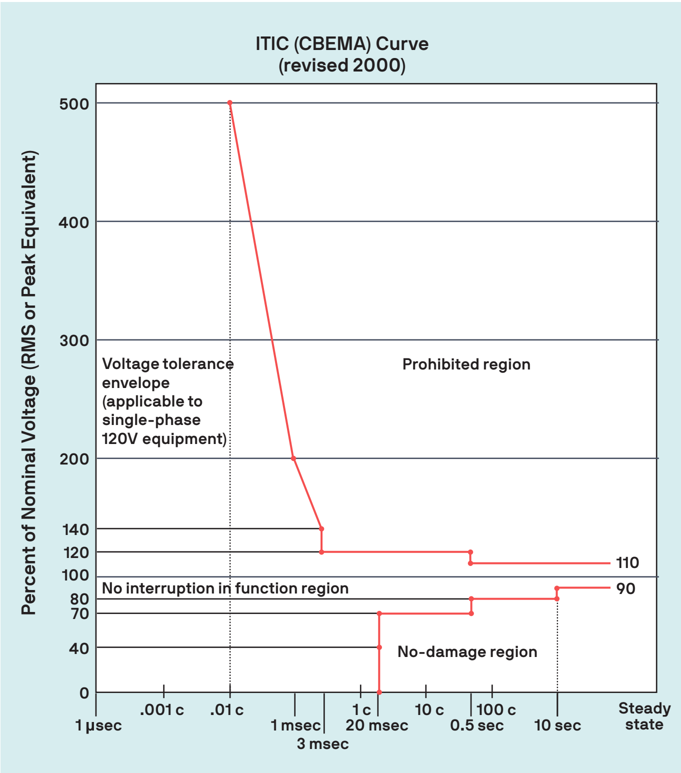
Voltage spikes

Voltage spikes or impulses are extremely short-duration (less than 10 ms), transient voltage disruptions. Spikes (less than 20 ms) also encompass the prohibited region in Figure 3. Voltage spikes on grid electricity can come from industrial equipment or from lightning strikes. Spikes (especially when greater than 500 percent of the nominal voltage) can be damaging to sensitive electronics, such as circuit boards in electronic equipment. Surge suppressors can reduce harmful voltage levels and prevent damage to equipment from these spikes.

Frequency deviations

Frequency deviations are fluctuations in the cycling rate of the alternating current (AC) voltage, which is nominally 50 cycles per second (hertz or Hz is the unit for cycles per second). These deviations do not cause changes in nominal voltage, and as such they are not applicable to Figure 3. Frequency can fluctuate higher or lower if the power grid is mismanaged. Frequency can also experience a loss of synchronization if two power generators in a system are not sufficiently matched before connection. Changes in frequency can affect the rotation speed of electric motors and can also cause some clocks to be inaccurate.

Figure 3. Information Technology Industry Council curve.[4]



Note: CBEMA, Computer and Business Equipment Manufacturers Association; ITIC, Information Technology Industry Council; RMS, root mean square.

How to collect information on current electricity quality

To better understand the state of electricity, it can be helpful to collect data on outages, voltage sags, voltage surges, voltage spikes, and frequency deviations. This can be done via an electricity audit of health facilities. Electricity audits can take many forms; some approaches are outlined below. The audits are ordered from less resource-intensive and time-intensive to most resource- and time-intensive.

1. Electricity providers

a. **Overview:** Electricity providers often have data on electricity availability and quality for those they supply electricity to.

b. **Data collection:** Connect with the energy provider to inquire what facility- or region-specific electricity access and quality data they have and are willing to share.

c. **Advantages:** Contacting electricity providers would be a low-resource and simple way to gain insight on facility power quality.

d. **Disadvantages:** The availability, level of detail, and willingness to share data (due to political barriers) may vary widely among providers. Data may be considered sensitive and therefore confidentially managed.

2. Generator usage logging

a. **Overview:** For facilities that use a generator, valuable data and information on power continuity can be gleaned from logging generator use.

b. **Data collection:** Record the time and duration of generator use.

c. **Advantages:** Requiring facilities to track usage logging would be a decentralized way to collate information on power quality. This would require limited oversight and reduce resources required by leveraging biomedical engineers within individual facilities or counties that already work on power generators.

d. **Disadvantages:** This is only applicable at facilities with a generator that is used during power outages. It is also only applicable to power outages and does not allow data to be captured on power quality. Generator downtime (due to costs or maintenance) will not show unless other means of manual recording are in place. It could be time intensive to train individual facilities on how to capture this information.

3. Health care facility survey (self-reporting)

a. **Overview:** This is the simplest method to collect information on electricity availability and quality. A primary advantage includes data specificity as it relates directly to health care facilities and a low up-front cost.

b. **Data collection:** Construct a basic survey that can be sent to facility directors, who can complete the survey or instruct someone to complete the survey. A wide range of basic qualitative and quantitative data can be collected, including but not limited to general questions on power availability, power quality (if qualitative methods for observing power quality can be decided), and how devices have been affected by electricity issues.

c. **Advantages:** Data collection may be paired with existing tasks in electromedical device management to minimize the burden to staff in obtaining this information. If it is possible to invest in and create a culture around facilities reporting electricity data via a survey, it may be seamlessly integrated into health system reporting with fewer resources required.
d. **Disadvantages:** Data are self-reported and therefore potentially subjective. For example, it can be difficult to recall the availability of power accurately from memory. There can also be hidden costs due to the time required of individuals to fill out the survey. Additionally, it could be a time-intensive operation to create a survey, disseminate the survey, and to ensure facilities are reporting information via the survey.

4. Spot checks

a. **Overview:** Another way to check electricity quality in each facility is to deploy devices that collect data on power quality. PATH used PowerWatch energy-tracker (or "power logger") device monitors in facility-level data collection activities in order to better understand electricity quality. See Appendices 2, 3, and 4 for the results.
b. **Data collection:** Power loggers are devices that plug into electrical outlets and track data on energy events (such as brownouts, blackouts, and power surges of mains power) over a period of time or up to a specified number of energy events. Data are downloaded onto laptops or mobile devices and may be analyzed to observe key trends over time.
c. **Advantages:** Spot-checking allows for ample flexibility, allowing users to move spot-check devices among different facilities. A low number of spot checkers can service a wide geographic area in a facility-by-facility approach over a longer time horizon.
d. **Disadvantages:** Spot checks can be time and resource intensive, as data must be collected in individual facilities over a period of time (which involves multiple visits to each facility). Additionally, investing in spot-check equipment could be costly at the onset.

5. Continuous remote monitoring

a. **Overview:** This is a form of automated data collection from remote devices that can be accessed from a central location. This usually is accomplished via cellular data transfer from monitoring devices to a cloud server.
b. **Data collection:** Install a remote monitoring device within select facilities and monitor the data remotely. When implementing remote monitoring, consider how reliable and sustainable data collection will be ensured.
c. **Advantages:** Once the up-front investment is made, data collection would require minimal time and resources. Capturing data outages that are longer than 30 minutes as separate events can allow for clearer data, as no characterizing data are available during prolonged outages.
d. **Disadvantages:** There can be a high up-front cost to installing remote monitoring equipment. Accurate reporting of electricity data may be compromised in the case of data outages, when data connectivity is interrupted.

An important consideration is that electricity quality can vary widely over time for several reasons. In many places, the power grid is continually evolving as more generation sites, transmission equipment, and customers are brought online. Also, seasonal variations exist due to changes in weather and electricity demand. Rain can wash out power lines and lighting can introduce voltage spikes. Warmer temperatures increase air conditioner usage, potentially leading to brownouts or rolling blackouts. Additionally, when collecting data, it is good to keep in mind hours of operations of various industries that could be tapping into the power grid during facility hours of operations. For example, if an industrial operation in the same town is operating during a health facility's primary operating hours, power fluctuations could be more prevalent. In short, there are many important considerations for decision-makers, including that power quality over a certain period of time may or may not be indicative of the future quality.

Given the many factors that can lead to fluctuations in quality, it is important to collect data for at least two weeks. Although implementing a long-term monitoring program is the ideal, data collection for a minimum of two weeks may capture some weather variations as well as fluctuations in daily business. If there are prominent weather/atmospheric changes from season to season (i.e., rainy versus dry season), data collection during each season is recommended to better understand seasonal variations.

> Biomedical engineers are well positioned to collect and monitor electricity data. Their roles in maintaining electromedical devices, as well as generators and other power systems, allow them to log these data and respond with or advocate for solutions.

Why collect this information?

Having data on the availability and quality of electricity in health facilities can inform operational decision-making in several key areas.

Device selection

Understanding the power context allows for more insights into what equipment or electromedical devices best fit the facility infrastructure, especially as it relates to oxygen therapy devices. If power surges and sags are persistent issues, it may be worth evaluating if devices that do not rely on steady and clean electricity are suitable for the facility (such as oxygen cylinders). Having consistent and clean power can help inform the decision to purchase more intricate medical devices (e.g., oxygen concentrators may have prolonged longevity). (More information on device selections and mitigation devices that can be procured in conjunction with device selection can be found in Sections 5 and 6 below.)

Implementing mitigation solutions

Supplemental technologies to deal with power issues are available. For example, if power surges are significant issues for the facility, it may be worth investing in surge protectors. If brownouts are common, investing in a voltage stabilizer may be worthwhile.

Stakeholder advocacy

Having clear data on the availability and quality of electricity, as well as key challenges and subsequent effect on public health, is critical to advocate for change. Sharing evidence of power quality issues with local, regional, or national health care decision-makers can provide compelling rationale for increased investment in solutions and/or relevant policy change (see Table 2 below). Alternatively, this evidence can be a useful tool for electricity providers so that they may have the most up-to-date information on existing constraints.

National health facility infrastructure and medical device standards (health facility standards) are guidelines on infrastructure and medical device specifications that are recommended in each health facility level in a country. These documents may include requirements on the location of facilities, staffing requirements, information on wards and health services provided, other infrastructure requirements, and lists of suggested medical devices. In some cases, these exist as a single document per country, covering all levels of the health system. In other cases, these are presented as a package of separate documents, one for each level of the health system. They are often designed to help ministry of health and hospital officials understand what each level of health facility should look like in a country. They can be used when opening new health facilities, certifying existing health facilities, or comparing facilities to a set standard. These documents could also outline electricity requirements and have the potential to outline technologies that could be put into place to audit electricity at given levels of health care systems.

In addition to country-level facility infrastructure and medical device standards guides, there are global standards and recommendations specifically for electricity as well. These are concerned with power quality and practices for power quality monitoring. Table 2 outlines some of these policy documents, their sources, and their purpose.

Table 2. Global standards and recommendations for electricity.

Standards and policy body	Specific guidelines
The Institute of Electrical and Electronics Engineers (IEEE)	• Power quality: IEEE 1366. • Power quality monitoring: IEEE 1159.
The International Electrotechnical Commission (IEC)	• Power quality conditions for power distribution systems: EN 50160. • Electricity supply system and equipment (including limits for power quality disturbances, limits for withstanding non-ideal power conditions): IEC 61000. • Testing device immunity to voltage dips and interruptions: IEC 61000-4-11; limits used for testing: IEC 61000-6-1.
World Health Organization; Performance, Quality and Safety Secretariat (PQS)	• Standards for voltage stabilizers used with cold chain equipment: PQSVS01.

5. Power continuity and electromedical device selection

Power continuity describes the number and duration of power interruptions experienced in health facilities. The requirements for continuity are primarily driven by the criticality of the electromedical devices present in a facility. For example, for oxygen concentrators or oxygen-generation plants that are used to sustain life in surgery or critical care, there is little acceptable (often 30 seconds or less) margin for power outage durations. However, for devices that do not require continuous operation, their usage can be flexed according to power availability; therefore, they are less reliant on power continuity. Although unplanned power interruptions can affect electrical devices, devices will typically not sustain physical damage from these events.

Table 3. Oxygen equipment and their power summary.

Equipment type	Approximate average power usage (watts)	Size	Power continuity options
Gas cylinder	0	Portable cylinder that can be moved with ease	No power needed
Liquid oxygen tank	0	Tank that requires piping	No power needed
Oxygen concentrator	350	Small device that requires electricity to produce bedside oxygen	Generator/solar
Pressure swing adsorption plant*	500 kW/ton of oxygen[5]	Full system the size of a shipping container	Industrial-scale generator
Air separation unit plant*	200 kW/ton of oxygen[5]	Industrial-scale manufacturing plant	Industrial-scale power plant

Note: kW, kilowatt.

*Both pressure swing adsorption and air separation unit plants can be used to fill cylinders that can be used as backup when there are power interruptions.

Technologies to support power continuity

Battery backups: For facilities that experience frequent and/or lengthy power outages, battery backups can be used as the local power supply. Some devices, such as benchtop pulse oximeters, come with internal battery backups. Unfortunately, most battery backups are not well suited to support electrical devices with high power operating requirements, such as oxygen concentrators, for more than a few minutes.

Uninterruptible power supply (UPS): This type of device can be used to provide backup power to electromedical devices when primary power is disrupted for a short duration of time (typically less than 1 hour); it can be used long enough until a backup generator can be started. These devices typically operate using batteries and an inverter, similar to components of off-grid systems. UPS devices contain circuitry to detect problems with grid power (e.g., overvoltage, undervoltage, outages) and determine whether to draw power from batteries or grid power. These devices can be used with any standard mains-supplied medical device, but they cannot be used with non-mains-connected battery-powered devices, such as a fingertip pulse oximeter. Some UPS devices have built-in voltage stabilizers and/or surge suppressors. Similar to battery backups, most UPS devices are not well suited for supporting electrical devices with high power operating requirements, such as oxygen concentrators, for more than a few minutes.

It is important to note that batteries that are used in off-grid systems or UPS devices have a finite life span and must be replaced when performance starts to degrade. Lead acid batteries (the most common large battery chemistry) may have a life span of three years when used within manufacturer specifications, and lithium batteries may last ten years. The lithium batteries have a higher up-front cost but lower maintenance costs over the life span of the system.

Generators: As mentioned in Section 3, generators are machines that burn fossil fuels, such as gas or oil, to produce electricity. These are often smaller machines that can run in the event of a disruption of electricity supply from the grid, ensuring consumers still have electricity to power homes or facilities in the event of a grid outage. Generators are a widely used technology that support power continuity in the event of a power outage (especially a grid-connected power outage). Generators are helpful in the event of prolonged power outages to ensure services that rely on electricity can continue. Generators do, however, take seconds or minutes to turn on and are not helpful with short blips of power failure or sags of power quality. Generators also require fuel to operate, which needs to be procured and on standby. Although many facilities have generators, budgeting for and procuring fuel is a challenge for many health facilities.

Oxygen-generation plants and liquid oxygen plants require large amounts of electricity in order to operate efficiently. Oxygen concentrators also require electricity to deliver oxygen to patients. Regardless of whether a health facility has a backup power supply, having a backup or buffer stock of oxygen cylinders is recommended in cases of emergency.

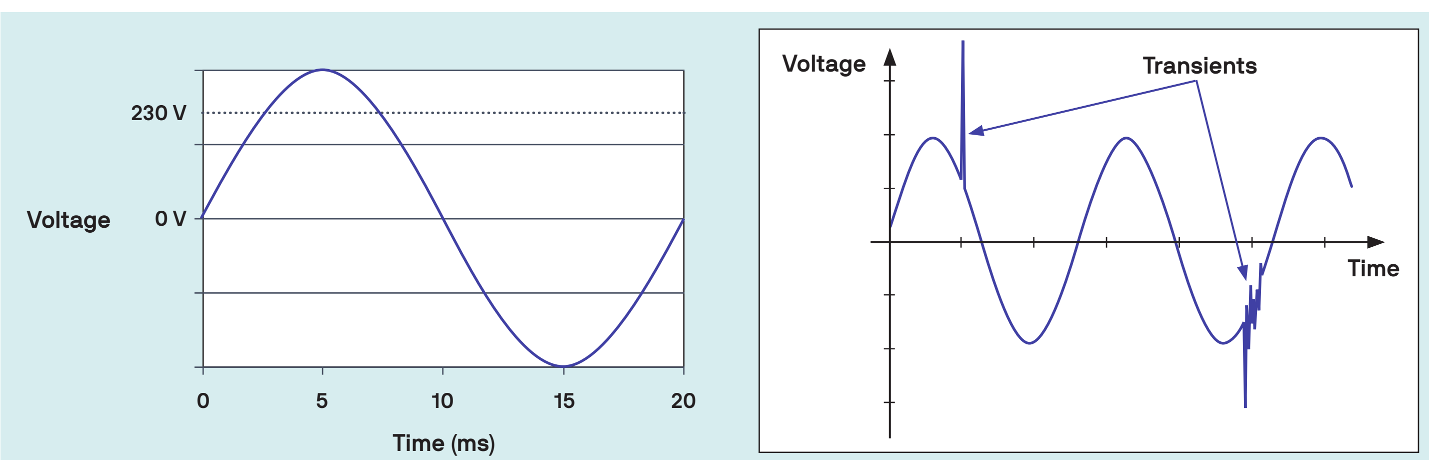
Fuel-based generators have a large capacity for power production; as such, they are better suited for providing extended backup power to devices with higher power requirements than UPS devices. The drawback of fuel generators is that they require an adequate reserve of fuel to ensure operation throughout power outages, which is both expensive and requires logistics for planning deliveries and storage of fuel on premises.

Solar power: Solar power is another category of power backup that can offset power outages and has significant environmental advantages over fuel generators. However, practical use requires system implementation with batteries and a charge controller to provide power when the sun is not out. Additionally, simple solar power systems do not have the power generation capacity to power devices with high power (> 100 W) operating requirements (such as oxygen concentrators) without installing larger, more complex, and expensive systems.

6. Power quality and methods for extending the life of electromedical devices

Power quality describes the characteristics of the mains power signal when it is available at the facility. Power available on the grid is delivered to customers with AC, in which voltage polarity constantly alternates. Throughout most of the world, this frequency is 50 times (cycles) per second (Hz). Figure 4 below shows one cycle of AC voltage. Since voltage alternates between negative and positive values, AC voltage is usually measured as the root mean square (RMS) voltage, represented below by the dashed line. The preferred conditions for power delivery are steady voltage and frequency over time that fall within device specifications. Power quality issues can be characterized by voltage magnitude (surges and sags), continuity (outages), transients (spikes), and harmonics (frequency).

Figure 4. Left: Alternating current (AC) voltage waveform. Dashed line represents root mean square (RMS) voltage. Right: Example of voltage transients (spikes).



What is the impact of power quality on electromedical devices?

Poor power quality can reduce the longevity of electromedical devices. Specifically, spikes and surges can harm sensitive circuitry commonly found in most electronic devices. Certain components on a circuit board may be more susceptible to damage than others. Circuit boards can be designed to be robust, but this typically increases costs for manufacturers and is often not needed for many settings that electromedical devices are designed for. Passive devices with basic circuitry, such as incandescent lights and fans, are generally not impacted by voltage spikes but may still burn out prematurely during a longer or more extreme power surge event.

Which specifications for electromedical devices are important to consider?

Electromedical devices will have specifications from the manufacturer regarding power requirements. These may include voltage, frequency, current, power, and plug type. This information will often be provided in the product information or data sheet, in the user manual, and/or on the device itself. Unless otherwise noted, voltage supply tolerance is typically ± 10 percent based on the International Electrotechnical Commission (IEC) 60038 standard.

Some devices may have several models for different regions around the world. Specifications should always be reviewed before procurement to ensure the power available at facilities will meet the device requirements. There are three main types of device voltage inputs, which are outlined below.

Single voltage

These devices are specified at a single voltage. Most devices will fall under this category unless they have an internal power supply. Most of these devices will be specified at a single frequency as well, but some may have dual-frequency (50/60 Hz) capabilities.

Dual voltage

These devices have a mechanism to switch between different input voltages. In most cases, this is with some sort of a switch. If there is no switch, devices may offer a method to change the wiring internally. These devices will typically be dual frequency as well. Operating these devices in the incorrect voltage range may cause permanent damage.

Universal

These devices will be specified for a wide range of voltages and frequencies, often from 100 V to 240 V and 47 Hz to 63 Hz. This type of device can operate worldwide without modification when provided with the correct plug adapter. Common examples include battery-operated devices or units with DC power connections, such as coaxial “barrel” type plugs (IEC 60130-10) or USB. A summary can be found in Table 4 below.

Table 4. Example of electrical specifications for three different electromedical device types. Specifications below are nominal with a ± 10 percent tolerance.

Type	Standard device (single voltage)	Dual-voltage device	Universal power supply
Voltage	230 VAC	110/220 VAC	100–240 VAC
Frequency	50 Hz	50/60 Hz	47–63 Hz
Current	1.5 A	1.5/3 A	1.5–3 A

Note: A, ampere; Hz, hertz; VAC, volts of alternating current.

Power considerations are also important for UPS and off-grid applications.

Specific technical specifications on oxygen devices can be found in the *WHO-UNICEF Technical Specifications and Guidance for Oxygen Therapy Devices*.[6]

What device-specific requirements for power quality should be understood in selection?

Devices with electrical motors are susceptible to damage from undervoltage conditions. These include refrigerators, fans, air compressors, and oxygen concentrators. Undervoltage and overvoltage cause these devices to draw higher electrical currents, which can lead to overheating and premature failure. Voltage stabilizers can help improve motor life span. As reported in an assessment conducted by Kenya, voltage stabilization improved voltage conditions by three.[7] In Nigeria, there was determined to be a 15 percent increase in usability of electricity if stabilized.[7] (More information on these findings can be found in Appendix 1.)

Technologies to protect against power spikes

Surge suppressors

Surge suppressors (or surge protectors) help protect equipment from power spikes. Their mode of operation is to reduce high transient voltages to safer levels. Most inexpensive surge suppressors use metal-oxide varistor units to accomplish the transient voltage reduction. These devices have several different common specifications, including clamping or let-through voltage, joule rating, and response time.

- Clamping or let-through voltage: The threshold at which the device activates or begins reducing the line voltage. Lower thresholds offer better protection for equipment but may wear equipment out faster.
- Joule rating: The amount of energy that a surge suppressor can absorb before failure. Higher joule ratings indicate that the unit can absorb a greater number of spikes and/or more severe spikes.
- Response time: The amount of time it takes for a surge suppressor to respond to a voltage spike. Transients shorter than the response time of the suppressor can pass through to the equipment.

Surge suppressors may also be tested to one or several normative standards. These products may wear out over time depending on the number or severity of spikes. Most surge suppressors have a light to indicate that the device is working as intended; they should be replaced if the light does not illuminate when powered. It is important to note that most surge suppressors are not able to completely protect equipment from a direct lightning strike to power lines. It is always safest to unplug equipment during a lightning storm, when reasonable to do so.

Technologies to protect against voltage magnitude issues

Voltage stabilizers

Voltage stabilizers help to keep the supply voltage within specified tolerances of the device, specifically addressing voltage sags and surges. Some voltage stabilizers may have some surge suppression capabilities as well. Devices operated outside of their specified voltage range may be damaged for a number of reasons, and some types of equipment are more susceptible to damage than others.

Certain types of equipment (e.g., laptops or a handheld pulse oximeter) may operate on power from a universal power supply, which can accept a wide range of voltages (100 V to 240 V is common). As a result, this type of equipment does not benefit from voltage stabilizers. Device specifications should state the input voltage range.

Voltage cutoff devices

Voltage cutoff devices help protect devices by cutting off power during voltage sags and surges. This prevents device damage, but also prevents the device from being used during times of poor power quality. These devices are simpler and less expensive than stabilizers and can be suitable alternatives for devices that are not needed for time-sensitive care (e.g., lab centrifuge or ice-lined refrigerator). These devices may have surge suppression capabilities as well. As with stabilizers, electromedical devices with universal power supplies will not benefit from these devices, and their use may actually be impaired if power is cut off.

Routine maintenance

Changes or more conscientious efforts in standard operating procedures can also extend life span of devices in circumstances where electricity is a challenge. While this guide describes selection and implementation considerations for electromedical devices and accessory components, such as voltage stabilizers and surge protectors, electricity challenges may also be addressed, at least in part, by changes in standard device operation. For example, disconnecting devices from the main power supply during times of unstable, under or over, voltage during high industry demand or during an electrical storm could increase electromedical device life span.

To properly implement behavior changes, it is important that practices are informed by an understanding of electricity challenges and how they present. For example, some protective accessory devices that disconnect electromedical devices during times of harmful voltage conditions might cause a large device like a generator to appear broken or shut down, while a nearby lamp continues to function because it operates at a much lower line frequency. In this case, if the generator continues to operate at the line frequency of the lamp, it might incur damage. Even though the protective accessory is performing its job, if the observer does not understand this, they may inadvertently undo its protective effect.[6]

7. Conclusions

Access to electricity is critical for diagnosing and treating patients, allowing health systems to carry out their mission. Sensitive and costly electromedical devices are also reliant on stable electricity to operate effectively and to not break down prematurely. Unfortunately, access to high-quality electricity remains a challenge in many LMICs. This impacts not only health systems and the people they serve, but also economic growth over time.

An improved understanding of electricity access and quality at health facilities is important to efficient operation, including appropriate electromedical device selection, use of supporting technologies to mitigate electricity challenges, and advocacy to improve a given electricity situation. This ensures electromedical devices are protected from periods of poor electricity quality and investments are maximized. This guide should inform decision-makers, health care facility managers, biomedical engineers, and other stakeholders to better understand their electricity situation and strategies to improve access to lifesaving electromedical devices, including those to ensure reliable oxygen delivery and beyond.

For more information, contact oxygen@path.org.

Appendix 1. Global Good study summary

In December 2019, Global Good published *Power Quality Challenges in Low-Resource Settings*,[7] a robust analysis of electricity quality in Nigeria and Kenya. Global Good purchased, distributed, and installed specially designed vaccine refrigerators in health facilities and monitored voltage and other power measurements via World Health Organization–prequalified mains-powered vaccine refrigerators over the course of several months. The study yielded three main conclusions: First, many health facilities experience power interruptions. Second, voltage fluctuates significantly from nominal values and voltage stabilizers could be used to increase the range of usable voltage for devices. And lastly, extreme voltage conditions, while less common than interruptions, can severely damage devices. Selected analyses that are most relevant to the *Electricity Planning Guide* are highlighted below.

Figure A1. Percentage of time that mains voltage was usable without a stabilizer, usable if stabilized, and unusable (Kenya, left; Nigeria, right).[7]

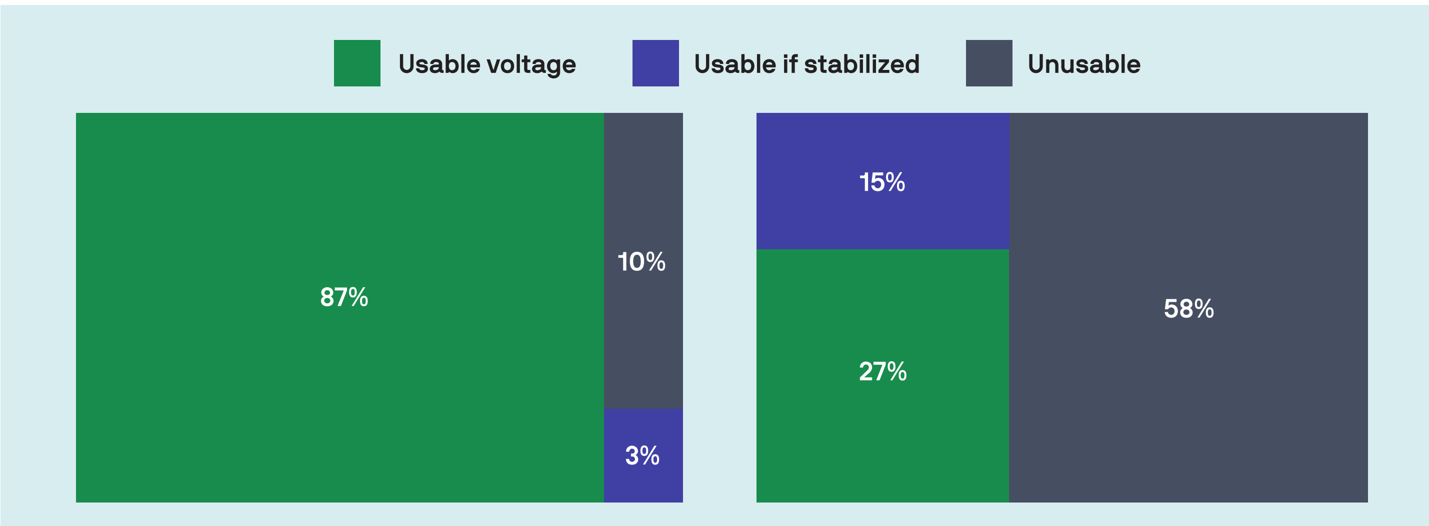


Figure A2. Percentage of devices reporting interruptions longer than 48 hours per year, on average (Kenya, left; Nigeria, right).[7]

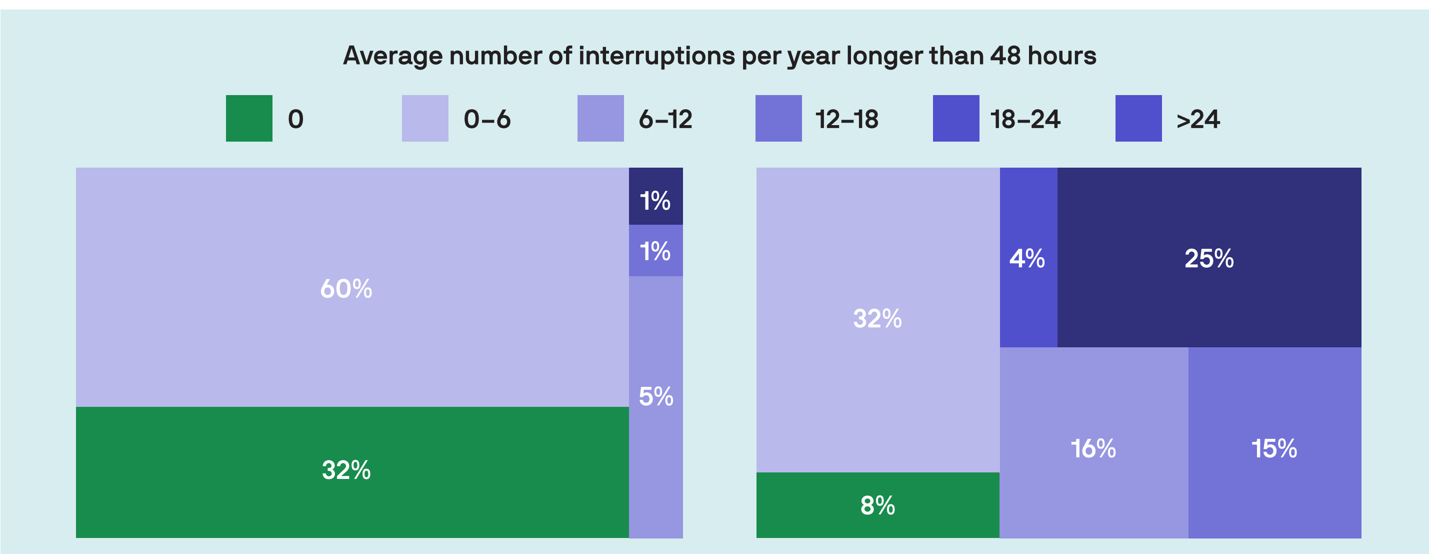
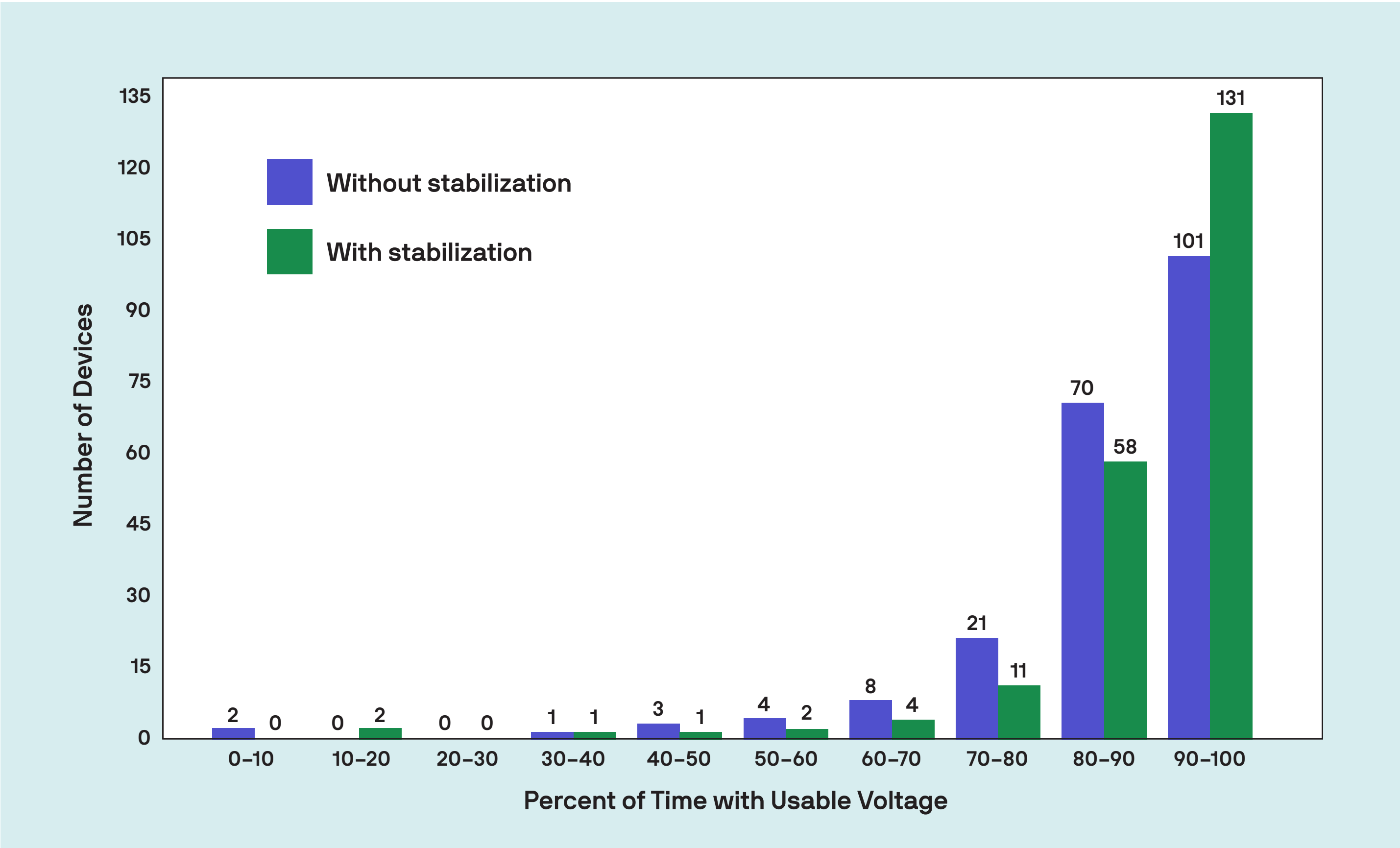


Figure A3. Impact of voltage stabilization on percentage of time devices experienced usable voltage conditions in Kenya.[7]



Appendix 2. Primary and secondary analysis

PATH conducted both secondary and primary data analysis to understand overall power availability, power interruption, power sources distribution, and facility-specific power quality. For the secondary data analysis, PATH analyzed the World Bank Sustainable Energy for all (SE4ALL) database, World Bank Enterprise Survey data, US Agency for International Development (USAID) Service Provision Assessment (SPA) data, and Gavi, the Vaccine Alliance Cold Chain Equipment Optimisation Platform data to get an overview of country power conditions.

World Bank data of access to electricity (percentage of population) are first summarized by World Bank income levels: low income, lower-middle income, upper-middle income, and high income. Other than data on general access to electricity, SE4ALL also has data on access to electricity by the urban and rural population. After getting the summary of electrification by income level, the same data are used to indicate the electrification rate in the country.

World Bank Enterprise Surveys data are from firm-level surveys of a representative sample of an economy's private sector. Four indicators under the infrastructure section are selected to understand barriers to electricity access that businesses or firms experience. The four indicators are: (1) percentage of firms that experience electrical outages, (2) number of electrical outages in a typical month, (3) average duration of a typical outage, and (4) percentage of firms that identify electricity as a major constraint to doing business. This dataset is also summarized by income levels and used to view country-specific electricity conditions for businesses.

The SPA survey is a health facility assessment that provides a comprehensive overview of a country's health service delivery. Electrification rate, electricity continuity rate, and the link between having continuous electricity and owning electromedical devices are explored with this dataset. These rates are also mapped out by subnational level (region or district) to easily visualize the distribution of electricity access and electricity continuity.

The Cold Chain Equipment Optimisation Platform was established by Gavi, the Vaccine Alliance in January 2016 to support countries in improving their cold chain. Countries submitted cold chain inventory data to apply for funds to invest in new cold chain equipment. The data show power availability, power continuity, and power sources for each vaccine supply point in country for 30 countries in total. The data indicate the power condition for immunization facilities.

For the primary data analysis, PATH collected data on electricity quality in 39 health facilities in Kenya and Senegal between December 2019 and April 2020 to understand the quality of electricity when available. The project team used ten PowerWatch energy trackers (or "power loggers") to conduct the data collection. These devices monitor energy events, such as outages, sags, and surges of mains power. Working with ministries of health and regional health authorities in each country, the project team identified a sample of urban, semi-urban, and rural health facilities from each level of the health care system. PATH collected data over a period of two weeks in each facility.

PATH gave each facility that was included in data collection activities a two-page overview of their facility's electricity quality. PATH included a power quality summary template in (see Appendix 5) as an example for ministries of health that were interested in monitoring power quality in their facilities.

Appendix 3. Kenya data summary

World Bank data

According to 2017 World Bank data, approximately 64 percent of the population in Kenya has access to electricity. The electrification rate in urban areas is roughly 81 percent and 58 percent for rural areas. Of the over 1,000 Kenyan firms interviewed as part of the World Bank Enterprise Surveys between May 2018 and January 2019, 83 percent reported experiencing electrical outages. In a typical month, firms experienced an average of four electrical outages lasting close to 6 hours in length. Of the firms interviewed, 21 percent identified electricity as a major constraint to doing business in Kenya.

Data from the SPA, Demographic and Health Surveys Program, USAID

The Kenya SPA surveyed 695 health facilities in 2010. This survey was conducted before the reorganization of administrative structures in 2010, which divided eight regions into 47 counties. Since the sampling process was done by region, results were reported in this way. Data at that time suggested that approximately 86 percent of all facilities sampled had access to electricity. Nairobi region had the highest electrification rate (97 percent) and the highest on-grid rate (97 percent). However, it had a lower continuity rate (19 percent) than many other regions with power sources other than the central supply. This suggests that central power supply does not guarantee continuous power. Power continuity was a common issue across regions. The continuity rates for facilities with access to electricity in each region were all lower than 40 percent.

The SPA survey also collected data on the medical devices and equipment owned by interviewed health facilities. CT (computerized tomography) scanners, incubators, refrigerators, ultrasound devices, and X-ray machines were the five electromedical devices selected for subsequent analysis. The relationships between existing electromedical device access and electricity continuity were explored. Of the facilities that owned any of the devices, 70 to 80 percent reported facing issues with electricity continuity.

Since the survey was done in 2010, the situation and environment may have improved. Regardless, it is an indication that electromedical devices, some of which are costly to own and operate, are installed within facilities where electricity continuity is an issue and may cause the devices to fail quickly because of unstable power quality.

Electricity quality findings from PATH's primary data analysis

PATH collected electricity quality data in 24 facilities in Kenya between December 2019 and March 2020. The 24 facilities are located in three counties: 5 facilities in Nairobi, 10 facilities in Kisumu, and 9 facilities in Kajiado.

We first analyzed the average outage duration and maximum outage duration between facilities with generators and without generators. For facilities in Nairobi and Kajiado counties, owning generators significantly shortened the average and maximum outage duration. However, there was only little improvement with generators

Figure A4. Availability of electricity in health facilities in Kenya, by region.[8]

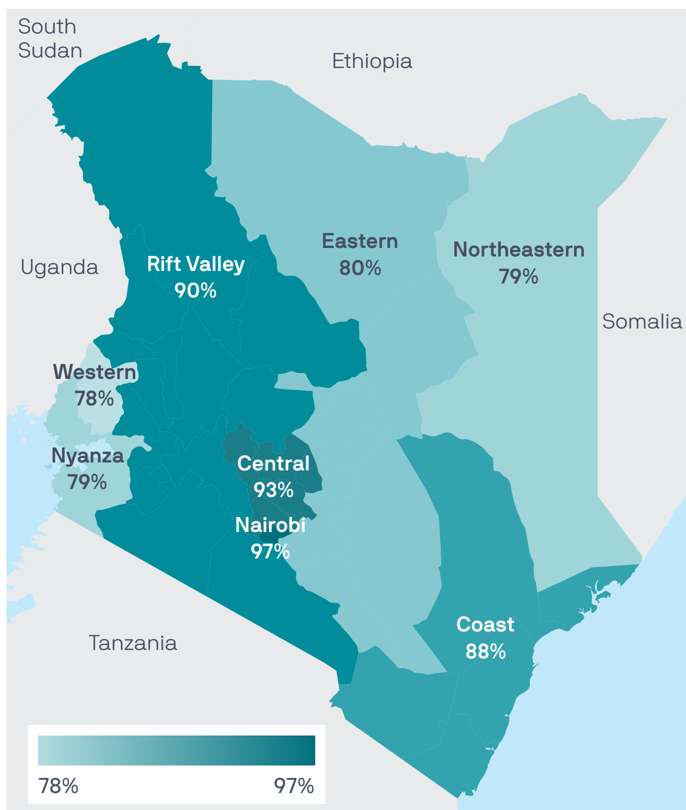


Table A1. Electricity quality in three counties in Kenya.

County	With generator		Without generator	
	Average outage duration	Maximum outage duration	Average outage duration	Maximum outage duration
Kisumu	20 min 13 sec	19 hr 06 min 14 sec	29 min 42 sec	09 hr 17 min 36 sec
Nairobi	00 min 07 sec	00 min 23 sec	27 min 21 sec	16 hr 45 min 00 sec
Kajiado	00 min 05 sec	00 min 16 sec	25 min 29 sec	09 hr 25 min 10 sec

Note: hr, hours; min, minutes; sec, seconds.

in Kisumu county. Implementing and abiding by an effective generator use protocol could make better use of generators in certain settings.

Prevalence of outages varies across facilities and counties. Facilities experiencing common outages should consider battery backup if justified by criticality and applicability of the use situation, as described in the *Electricity Planning Guide*.

Many power spikes were observed, but only a few were damaging to sensitive electronics and could have the potential to adversely affect unprotected circuit boards/ control units. The damaging power spikes were observed in all three counties without significant differences by county and facility level. As mentioned in the *Electricity Planning Guide*, surge protectors are key to protecting equipment in settings with electricity quality issues. Inclusion of surge protectors in the procurement of electromedical devices are recommended, especially for facilities with common power spikes.

Analysis in each county suggests that electricity quality was extremely variable across facilities and regions, and between urban and rural areas. Generally, higher-level health facilities (such as Level 4 and 5 facilities) had more stable electricity quality. However, some urban facilities (such as major health centers in Nairobi) experienced poor power quality. This is likely due to higher industrial demand for electricity in these settings, where industries draw large amounts of power. In rural facilities, power surges, spikes, and sags were much more prevalent.

Appendix 4. Senegal data summary

World Bank data

According to 2017 World Bank data, approximately 62 percent of the population in Senegal had access to electricity. The electrification rate in urban areas was roughly 92 percent and 35 percent in rural areas. Of the over 600 Senegalese firms interviewed as part of the World Bank Enterprise Surveys between May 2014 and February 2015, 84 percent reported experiencing electrical outages. In a typical month, firms experienced an average of six electrical outages lasting around 2 hours in length. Of firms interviewed, 48 percent identified electricity as a major constraint to doing business in Senegal.

Data from the SPA, Demographic and Health Surveys Program, USAID

The most recent SPA in Senegal was conducted in 2017 in 781 facilities, 158 of which were in urban areas and 623 of which were in rural areas. Facilities that reported any type of power accessibility, regardless of continuity, were categorized as having available electricity. Of the sampled facilities, 63 percent reported having access to electricity. All surveyed facilities in Dakar reported having access to electricity. Kolda region reported the lowest electrification rate, with 45 percent of facilities having access to electricity. In addition to electricity availability, an electricity continuity rate was calculated to indicate the percentage of facilities in the region with continuous electricity. Dakar and Diourbel had the highest continuity rates, each at 21 percent. The rest of the regions had continuity rates lower than 10 percent.

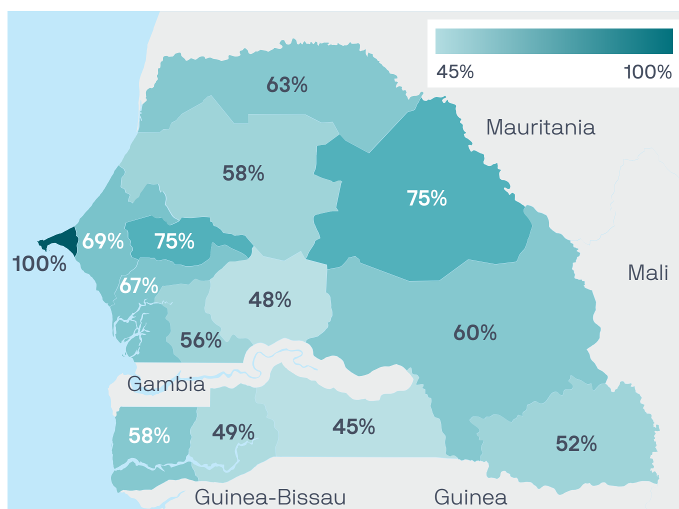
PATH also used the 2017 Senegal SPA data to analyze the link between owning electromedical devices and electricity continuity. Of the facilities without continuous electricity, 15 percent reported having incubators, 33 percent reported having X-ray machines, and 52 percent reported having electrical refrigerators. Both World Bank Enterprise Surveys data and SPA survey analysis indicated that electricity continuity was a common problem.

Electricity quality findings from PATH's primary data analysis

PATH collected electricity quality data in 17 facilities in Senegal between December 2019 and April 2020. The 17 facilities were located in five regions: 6 facilities in Dakar, 8 in Kaolack, and 1 each in Thiès, Louga, and Saint-Louis districts. Data collection for this workstream was suspended early due to domestic travel restrictions in light of the COVID-19 pandemic.

All facilities but one in Senegal were equipped with generators. Nevertheless, the result of minimizing impact of power outages was only observed in some facilities. There are few facilities in Dakar, Thiès, Louga, and Saint-Louis still experiencing long duration and high frequency of electricity outage even with a generator on site. Implementing and abiding by an effective generator use protocol could make better use of generators in certain settings. Facilities that experience common outages should consider battery backup if justified by criticality and applicability of the use situation, as described in the *Electricity Planning Guide*.

Figure A5. Electricity availability and continuity in health facilities in Senegal.[9]



Damaging power spikes, greater than 500 percent of nominal voltage, were not commonly observed in Senegal. They were only recorded in four facilities in four different regions, with only one occurrence for three of the facilities and five occurrences for a facility in Dakar within the two-week monitoring window. Surge protectors are recommended to protect equipment in settings with electricity quality issues. Inclusion of surge protectors in the procurement of electromedical devices is suggested, especially for facilities with common power spikes.

Power sags were commonly observed, but sags longer than 60 seconds were less common than we anticipated. Power sags were only observed in three facilities in Thiès, Louga, and Saint-Louis. Sites that regularly experience sags/brownouts run the risk of overheating equipment; this is particularly true for refrigerators/concentrators or other devices with motors. Power sags were often observed when there was more industrial competition for power.

Generally, analysis in Senegal suggests that electricity quality was extremely variable across facilities and regions, and between urban and rural areas. Generally, higher-level health facilities (such as EPS2 and EPS3) had more stable electricity quality. However, some urban facilities (such as a major hospital in Dakar) experienced poor power quality. This was likely due to higher industrial demand for electricity in these settings, where industries draw large amounts of power.

Appendix 5. Facility power quality summary

PATH gave each facility included in power quality data collection activities a two-page overview of their facility's electricity quality. PATH included a data summary template as an example for ministries of health that were interested in monitoring power quality in their facilities. This format for collating data around power quality can be replicated when conducting spot checks in facilities in other contexts.

Facility power quality summary

Overview and methods

PATH monitored power at a selected facility in Kenya between December 3, 2019, and December 17, 2019. The electrical logger used was an ACR Systems PowerWatch 220 event logger.[10] A power socket outlet in the facility maintenance unit office was used for this monitoring.

Results

Outages

An electrical outage is the loss of electrical power for longer than 20 milliseconds (ms). Short-duration outages can come from the grid or may happen when switching between grid electricity and backup generator. Short-duration outages may cause disruptions in equipment without battery backup, such as desktop computers. Longer-duration outages can prevent electrical equipment use, leading to issues for services that require electricity. Battery backup or uninterruptible power supply (UPS) can be used to prevent disruption of short-duration power outages. Electricity generators are common for providing power during longer grid outages.

During the monitoring period, a total of 27 outages were observed. Twenty outages were less than 2 minutes, and 7 outages were between 2 and 30 minutes in duration.

Voltage sags

Voltage sags (or dips) are reductions in the mains voltage (typically 90 percent of nominal voltage) that last longer than 20 ms. Voltage sags longer than 1 minute (steady state) are sometimes called brownouts. Sags are often caused by large electrical loads being switched on. Sags can cause lighting to dim. Brownouts are typically from disruptions in the electricity grid, such as overloading. Brownouts are harmful to electric motors, as they can lead to overheating and burnout over time. Electric motors are commonly found in refrigerators, fans, and air compressors (e.g., oxygen concentrators) in health care facilities. Voltage stabilizers are devices that can adjust output voltage provided to equipment in order to prevent these issues. There are also automatic switching units that cut power to equipment when the voltage drops too low, preventing damage.

A total of 254 voltage sags were recorded at or below 208 volts (V) (90 percent of nominal 230 V, the voltage for which most motors are rated). All voltage sags were less than 4 seconds in duration.

Voltage surges

Voltage surges (or swells) are increases in the mains voltage (typically 110 percent of nominal voltage) that last longer than 20 ms. Surges are often caused by large electrical loads being switched off. Surges can cause lighting to brighten, and severe surges can cause equipment to draw too much power, leading to damage. Voltage stabilizers are devices that can adjust output voltage provided to equipment in order to prevent these issues. There are also automatic switching units that cut power to equipment when the voltage rises too high, preventing damage.

A total of ten surge events were recorded at or above 252 volts (V) (110 percent of nominal 230 V) were recorded during the monitoring period. All of these events were less than 1 second in duration, and the most extreme was 282 V.

Voltage spikes

Voltage spikes or impulses are extremely short-duration (less than 10 ms) transient voltage disruptions. Voltage spikes on grid electricity can come from industrial equipment or from lightning strikes. Spikes (especially when greater than 500 percent of the nominal voltage) can be damaging to sensitive electronics, such as circuit boards in electronic equipment. Most spikes occur on the "line" (powered) wire, but spikes may also be present on the protective earth wire. Protective earth wire spikes can be indicative of outlet or building wiring issues. Surge suppressors can reduce harmful voltage levels and prevent damage to equipment from these spikes.

A total of 307 spikes above 200 volts (V) were observed throughout the monitoring period on the line wire. The most extreme spike was 470 V, or approximately 200 percent of the nominal voltage. In addition, there were 5 spikes above 100 V observed on the protective earth wire.

Frequency deviations

Frequency deviations are fluctuations in the cycling rate of the AC voltage, which is nominally 50 cycles per second (hertz or Hz). Frequency can fluctuate higher or lower if the power grid is mismanaged. Frequency can also experience a loss of synchronization if two power generators in a system are not sufficiently matched before connection. Changes in frequency can affect the rotation speed of electric motors and can also cause some clocks to be inaccurate.

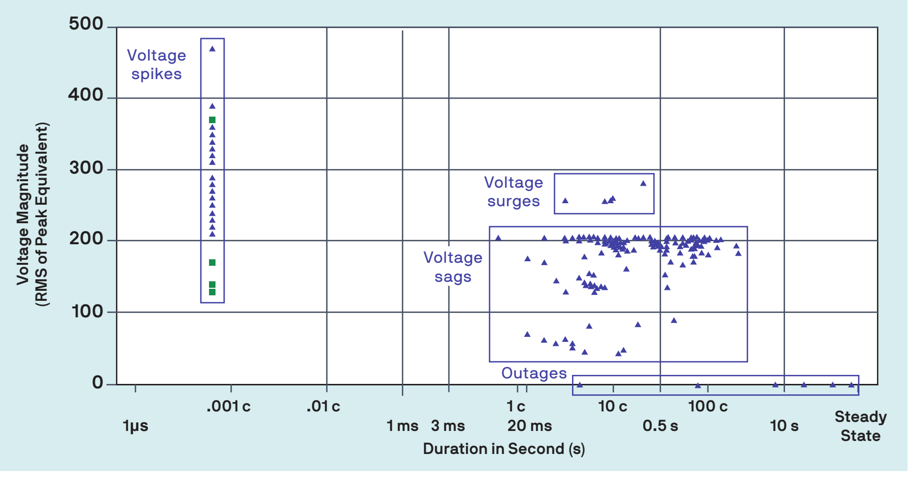
Throughout the monitoring period, 857 high-frequency deviations were observed. Of these, 849 deviations were less than 2 minutes and 8 were between 2 and 20 minutes. The most extreme deviation was 52.7 Hz.

Data collection caveats

The two-week duration of the evaluation period was relatively short. Power quality can change from week to week. Further, power quality may vary by season. While the data collected serve as a helpful starting point, long-term conclusions about power quality in this facility cannot be made with certainty and without further investigation, following recommendations in the *Electricity Planning Guide*.

Figure A6 shows a summary of the recorded electrical disturbances during the monitoring period, with each event represented by a triangle. The y-axis describes the voltage magnitude (severity). For reference, the nominal voltage is 230 V. The x-axis represents duration, with increasing duration toward the right side. Voltage sags, outages, and spikes are highlighted in different areas below. Squares indicate protective earth events. Figure A6 does not show frequency deviations.

Figure A6. Power event distribution at a selected health facility in Kenya, December 3, 2019–December 17, 2019.



Note: c, cycle = duration of one AC cycle (20 ms); ms, millisecond; RMS, root mean square; µs, microsecond.

References

1. Black DR, Lanzisera SM, Lai J, Brown RE, Singer BC. *Evaluation of Miscellaneous and Electronic Device Energy Use in Hospitals*. Berkeley, CA: Ernest Orlando Lawrence Berkeley National Laboratory; 2012. https://buildings.lbl.gov/sites/default/files/lbnl-6084e.pdf.
2. Hu SC, Chen JD, Chuah YK. Energy cost and consumption in a large acute hospital. *International Journal on Architectural Science*. 2004;5(1):11 –19.
3. Sheppy M, Pless S, Kung F. *Healthcare Energy End-Use Monitoring*. Golden, CO: National Renewable Energy Laboratory; 2014. https://www.nrel.gov/docs/fy14osti/61064.pdf.
4. Power Quality In Electrical Systems website. ITIC curve - power acceptability curve for information technology equipment page. http://www.powerqualityworld.com/2011/04/itic-power-acceptability-curve.html. Accessed April 7, 2020.
5. Banaszkiewicz T, Chorowski M, Gizicki W. Comparative analysis of cryogenic and PTSA technologies for systems of oxygen production. *AIP Conference Proceedings*. 2014;1573(1):1373–1378. https://doi.org/10.1063/1.4860866.
6. *WHO-UNICEF Technical Specifications and Guidance for Oxygen Therapy Devices*. Geneva: World Health Organization and the United Nations Children's Fund (UNICEF); 2019. WHO Medical Device Technical Series. Licence: CC BY-NC-SA 3.0 IGO. https://apps.who.int/iris/bitstream/handle/10665/329874/9789241516914-eng.pdf?ua=1.
7. Hinman R, Jónsson P, Kreyche T, et al. *Power Quality Challenges in Low-Resource Settings*. Glenwood, MD: The Global Good Fund; 2019.
8. Demographic and Health Surveys (DHS) Program. Service Provision Assessment survey. Rockville, MD: DHS Program; 2010. https://dhsprogram.com/data/available-datasets.cfm. Accessed December 5, 2019.
9. Demographic and Health Surveys (DHS) Program. Service Provision Assessment survey. Rockville, MD: DHS Program; 2017. https://dhsprogram.com/data/available-datasets.cfm. Accessed December 5, 2019.
10. ACR Systems website. https://www.acrdatasolutions.com/product/powerwatch-european-shuko-220v/. Accessed April 7, 2020.

For more information

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