Energy & Petroleum Regulatory Authority

Mini-grid Technical Guidelines: Power Quality, Service Quality, Grid Interconnection and Distribution Network

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1. Definition of terms

a. Delivery Point

"Delivery Point" means the interface point between an electric power system and a user of electric energy[1].

b. Distribution Network

"Distribution Network" means a power delivery system that delivers electric power from electrical substations or generation plants at medium and low-voltage levels to consumers.

c. Generation

''**Generation**" means the production of electricity from a generating station to be fed into a distribution network.

d. Generation capacity

"Generation capacity" means the guaranteed active power that any generation plant can supply to a load or network at any point in time under given environmental constraints (temperature, humidity, etc.) and a power factor of 0.8 (inductive) for at least one hour under the assumption that the plant is well maintained and fully functional.

e. Harmonics

"**Harmonics**" means a voltage or current at a multiple of the fundamental frequency of the electrical system.

f. Interconnected mini-grid

"**Interconnected mini-grid**" means a mini-grid connected to a Distribution Network which is operated by a third party under a separate licence.

g. Isolated mini-grid

"**Isolated mini-grid**" means a mini-grid not connected to any Distribution Network operated by a third party under a separate licence.

h. Metering point

"**Metering point**" or "point of measurement" is the point in an electric power system (in this case in the mini-grid electric infrastructure), where flow of energy and, when applicable, the flow of electric power is metered.

i. Mini-grid definition

"**Mini-grid"** refers to any electricity supply infrastructure with or without its own generation capacity, supplying electricity to more than one consumer and

[1] The user may be the end user or an organization for the distribution of electric energy to end users.

which can operate in isolation from or be connected to a third party's distribution network with an installed capacity of up to 1 MW.

j. Power quality

"**Power quality**" means a wide variety of electromagnetic phenomena that characterise the voltage and current at a given time and at a given location on the power system.

k. Service quality

Service quality is a multidimensional quantitative description of the quality of the service supplied, it can be divided in the following main components:

- **Electricity Rating** (or electricity available) is defined as the number units of electricity (Wh or kWh) per day required for the different end-user tiers as per their needs, regardless of the quality of the electricity during these hours.
- **Power Rating** (or power draw) is the maximum power provided for consumption regardless of the power quality provided.
- **Daily Availability** is the total number of hours electricity service is provided, expressed per day (daily availability) or per evening (evening availability).
- **Power Reliability** (or interruptions) can be defined as the total unplanned and planned interruptions in comparison to the agreed service availability.

l. System interruptions

Two common measures for system interruptions are used in this document:

- **SAIDI** is the System Average Interruption Duration Index.
- **SAIFI** is the System Average Interruption Frequency Index.

m. Voltage imbalance

"**Voltage imbalance**" means the deviation from the average of the three-phase voltage or current divided by the three-phase voltage or current, expressed in percentage.

2. Introduction

These technical guidelines provide a series of recommendations for the minimum power quality, power service availability, and operational standards in a **demand-driven approach**, or in other words, for off-grid electricity categories as per the end-user's requirements for both DC and AC mini-grids, and more in general for off-grid assets (such as autonomous renewable energy plants or SHS). This document **categorises the service level provided to the end-user, from least to most technically demanding**.

The power quality and service quality are regulated by defining the outputs of the electricity service (voltage, frequency, interruptions, hours of service) rather than by defining the input of the service (section of the cable, height of the power poles, minimum wattage of the PV modules, etc.).

Scope of this guidelines

Following the Energy Act 2019 (Mini-grid) regulations, the scope of this document is for mini-grids with a **generation capacity up to 1 MW.**

Norms and reference documents

These technical guidelines follow some international norms and reference documents, namely the following:

- IEC Technical Specification 62257: Recommendations for renewable energy and hybrid systems for rural electrification.
- IEEE Recommended Practice for Monitoring Electric Power Quality, Standard 1159-2019.
- Quality Assurance Framework for Mini-grids by NREL and US Department of Energy, November 2016.
- Kenya National Distribution Grid Code, April 2017

Nonetheless, the consultants have adapted the values, categories, and information from these documents for the Kenyan context and the context of off-grid electricity supply.

3. Power quality

Power quality refers to the diversion from the nominal values of the electricity attributes (mainly voltage, frequency, and harmonics) and how they affect the interoperability between generation sources, distribution networks, and consumption loads (receivers of electricity).

Power quality is usually linked to compatibility with appliances and the potential damage to these appliances or receivers if some or any of the electricity attributes changes or exceeds certain thresholds. Historically these standards were created to protect appliances that were highly sensitive to changes in voltage, frequency, or harmonics from the rated value at which they were manufactured to operate. However, technology developments in the last decade has made appliances more robust and sturdier in responding to these variations.

When regulating power quality in off-grid settings it is important to understand and recognize the end-user requirements and regulate accordingly. Three categories of end-user power quality are presented in the following table:

Table 1: Power Quality Categories (TTA, 2020)

PQI	PQII	PQIII
DESCRIPTION		
The most basic category: for those users that consume electricity mainly for lighting, appliance charging, and other similar low-consumption and high-tolerance devices, and therefore technical regulation is minimal. Frequency regulation is not restricted here.	This intermediate category provides tighter power technical requirements than the previous category, like surge protection for transients or frequency regulation that are not regulated in PQI.	The most demanding power quality category: for those users and appliances that require the least disturbances (i.e., have the least tolerance to disturbances) in the electricity supply.
EXAMPLES		

- Basic rural households consuming several lighting points and charging loads. - Street lighting. - Appliance charging stations (such as phones). - Dedicated source-to-power solutions (i.e., stand-alone systems).	- Basic commercial customers. - Places of worship. - Community centres. - Health centres without sensitive equipment.	- Low tolerance health facilities equipment, such as respirators - Electric motors. - Light industries. - Rural households with heavier consumptions. - Telecom stations. - Other critical loads.

For each of the above-presented power quality categories, this section sets power quality thresholds on voltage variations, frequency, harmonics, and other electricity phenomenon.

Voltage

In Kenya, the nominal voltage level for AC LV distribution is:

- 230 Volts in single -phase line
- 400 Volts from phase to phase in a 3-phase line

The table below proposes the maximum voltage variation permitted on the end-user side depending on the power quality category provided to the end-user for AC and DC distribution networks:

Table 2: Voltage Variation thresholds per PQ category

PQ CATEGORY	PQI	PQII	PQIII
AC LV VOLTAGE VARIATION	NA	< ± 10%	< ± 10%
DC LV VOLTAGE VARIATION	< +25%, -10%		< ± 10%

Voltage level deviation

The mini-grids shall maintain a voltage level deviation within the allowed tolerances at least for 97% of the time. During the remaining 3 % of the time, voltage deviations shall not exceed 50% of the allowed tolerance values[2].

Voltage imbalance

[2] KNDGC 2017

In 3-phase AC distribution networks, the voltage unbalance is defined as the deviation from the average of the three-phase voltage or current divided by the average three-phase voltage or current, expressed in percentage. Voltage unbalance occurs only in three-phase networks and this can cause motor damage due to excessive heat.

Table 3: Voltage Imbalance thresholds per PQ category

PQ CATEGORY	PQI	PQII	PQIII
AC LV VOLTAGE IMBALANCE	< 10%	< 5%	< 4%

Frequency

Frequency oscillations allow renewable energy control systems to adjust power generation to match demand (among other features) through "frequency-based active power control". This a very important characteristic as it is relied on by most solar PV mini-grids and autonomous renewable energy generation power plants to adjust generation based on the battery state of charge and demand. To allow for the operability of these controls, wide ranges of frequency need to be permitted in AC grids.

Table 4: Frequency thresholds per PQ category

PQ CATEGORY	PQI	PQII	PQIII
Frequency variation	NA	< +4 Hz, -2 Hz	< +2 Hz, -1 Hz
If 50 Hz	NA	48 Hz < f < 54 Hz	49 Hz < f < 52 Hz

Harmonics distortions

The proposed maximum total harmonic distortions for each power quality category are as follows:

Table 5: THD requirements per PQ category

PQ CATEGORY	PQI	PQII	PQIII
THD REQUIREMENTS	< 10%	< 5%	< 3%

Transients

The proposed guidelines for transients are as follows:

Table 6: Transients per power quality category

PQ CATEGORY	PQI	PQII	PQIII
Transients protection requirements	No protection	Surge protection	Surge protection

For specific induced transients on the PV array, IEC 60364-7-712 provides guidelines for electrical surge protection devices (SPD), while IEC 62305 provides general requirements for protections against lightning.

Power quality summary

Table 7: Power Quality categories summary table

	PQI	PQII	PQIII
AC			
Voltage variation	NA	< ± 10%	< ± 10%
Voltage Imbalance (only 3-phases)	NA	< 5 %	< 3 %
Frequency variations	NA	48 Hz < f < 54 Hz	49 Hz < f < 52 Hz
Harmonics	< 10%	< 5%	< 4%
Transients	No protection	Surge protection	Surge protection
DC			
Voltage variation	< +25%, -10%		< ± 10%
Transients	No protection	Surge protection	Surge protection

Time resolution of measurements

In order to place a sample of measurements under PQI, PQII or PQIII categories, minimum time interval measurements are defined. Following the IEC 61000-4-30:2015 "*Electromagnetic compatibility (EMC) - Part 4-30: Testing and measurement techniques - Power quality measurement methods*" standard, the minimum time interval measurement is set to 10 minutes.

4. Service quality

Service Quality has the following four dimensions as per the definition in the first section of this document:

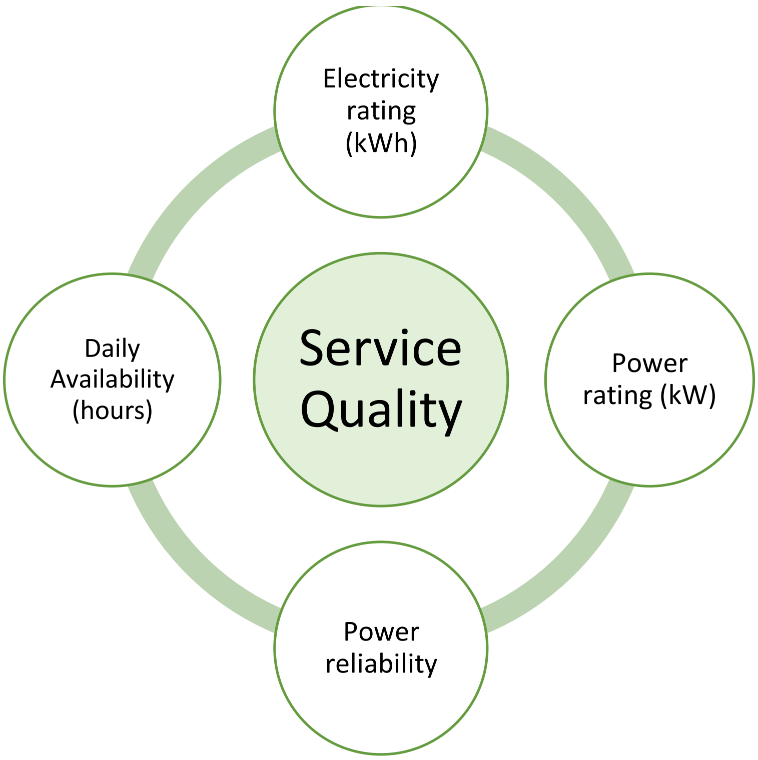

Figure 1: Service quality dimensions

The first three components of service quality can be categorised into five levels or "Tiers" as per the Multi-Tier Framework from ESMAP:

Table 8: Dimensions of the Multi-tier Framework (MTF) by ESMAP

MTF ESMAP	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Daily availability	-	> 4 hours		> 8 hours	> 16 hours	> 23 hours
Evening availability (7PM to 7AM, hours)	-	> 1hour	> 2 hours	> 3 hours	> 4 hours	
Power rating	-	≥ 3 W	≥ 50 W	≥ 200 W	≥ 800 W	≥ 2 kW
Minimum daily electricity ratings	-	≥ 12 Wh/d	≥ 200 Wh/d	≥ 1 kWh/d	≥ 3.4 kWh/d	≥ 8.2 kWh/d

Levels of service / tiers / energy packages

Electricity service supply does not have to match with 24h/7 days a week necessarily, but it should match with the level of service required by the end-user (in other words, the end-user expectations). In RE mini-grids, the continuous supply of electricity throughout the night is usually coupled to the battery size, a critical component in the cost of service through any storage-based infrastructure[3]. Non 24/7 service levels should therefore be considered, as per end-user requirements, as this can lower the cost of electricity to the end-user.

This section uses the term "tier" as an energy service category of a customer or connection from the service availability and capacity perspective, rated from the most basic category (Tier 1) to the most demanding category (Tier 5).

Nonetheless, it is possible to have end-users with a different daily energy demand (because they have different needs or ability to pay) but the same tier in terms of daily service availability. These technical guidelines introduce and define energy packages (EP), as a "decoupled" dimension from the Tiers, that can cater for different set of appliances (energy packages or EP).

Table 9: Packages of daily energy

Energy package (EP)	Indicative service	Indicative daily energy (Wh/day)
EP 1	Lights, phone, radio	140
EP 2	Lights, phones, fan, radio, TV, other small appliances	550
EP 3	Lights, phones, fans, TV, other small appliances, fridge	2,200
EP 4	Lights, phones, fans, TV, other small appliances, freezer, and productive use appliance	3,850

The following table is based on the existing MTF and IEC 62257-2 categorization for availability and capacity of the different end-user tiers of electricity and TTA's EPs.

Table 10: Tiers of electricity service with energy packages de-coupled (TTA, 2020)

MTF ESMAP	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Tier 5
Daily availability	-	> 4 hours		> 8 hours	> 16 hours	> 23 hours
Evening availability (7PM to 7AM, hours)	-	> 1hour	> 2 hours	> 3 hours	> 4 hours	
Power rating	-	≥ 3 W	≥ 50 W	≥ 200 W	≥ 800 W	≥ 2 kW
Minimum daily electricity ratings	-	≥ 12 Wh/d	≥ 200 Wh/d	≥ 1 kWh/d	≥ 3.4 kWh/d	≥ 8.2 kWh/d
TTA Energy packages	-	EP1	EP1 EP2	EP1 EP2 EP3	EP1 EP2 EP3	EP1 EP2 EP3

[3] The use of other RE technologies such as wind, pico-hydro, biomass and non-RE technologies can offset the need for energy storage, but will not replace it

					EP4	EP4

Power Reliability

The last component, power reliability, can be categorised into three levels:

Table 11: Power Reliability Categories

PRe category	PReI	PReII	PReIII
Planned and unplanned SAIDI [4](h/year)	<876 (90% reliability)	<438 (95% reliability)	<175 (98% reliability)
Planned and unplanned SAIFI[5] (interruptions per year)	<52	<12	<6

The System Average Interruption Duration Index (SAIDI) is defined as:

$$\mathrm{SAIDI} = \frac{\text{total minutes (or hours) of interruptions for a group of customers}}{\text{Number of all customers served}}$$

The System Average Interruption Frequency Index (SAIFI) is defined as:

$$\mathrm{SAIFI} = \frac{\text{total number of interruptions for a group of customers}}{\text{Number of all customers served}}$$

The contractual agreement between the mini-grid customer or end-user and the mini-grid developer shall specify the agreed Tier and PRe categories.

[4] In KNDC the values established are 7h/year for rural and 3.5h/year for urban, the consultant proposes to relax these values to the proposed values in the table for a realistic requirement

[5] In KNDC the values established are 6 per year for rural and 3 per year for urban, the consultant proposes to relax these values to the proposed values in the table for a realistic requirement

5. Interconnection

When the main grid extends to an area where a mini-grid is operating, uncertainty arises about what to do with the existing infrastructure. The possibility of interconnecting to the main grid is an opportunity to take advantage of previous efforts and investments, while also taking advantage of the electric demand that the mini-grid has "developed" over the course of the years operating in that location. Nevertheless, this opportunity also presents technical and non-technical challenges.

Interconnection Readiness Level (IRL)

Mini-grids can be categorised into two IRLs depending on the likelihood of the grid arrival to the mini-grid's location, directly related to the distance from the KPLC distribution system, and on the voltage level:

Table 12: Interconnection Readiness Level (IRL) Categories

IRL	Description	Grid expansion plans (short-term, medium-term, and long-term)	Voltage level of the mini-grid's distribution network	Compliance with interconnection standards
IRL0	Mini-grids that are unlikely to be interconnected to the main grid, located beyond the area to which KPLC service could be expanded.	Medium and long-term; site and communities that are within the medium to long-term plans of grid expansion[6]	Low Voltage (230 V)	Not required.
IRL1	Mini-grids that may be interconnected to the main grid at some point in the future.	Short-term; sites and communities that are within the short-term grid expansion plans	Low Voltage (230 V) or Medium Voltage (11, 33 or 66 kV)	Following a minimum of 1-year notice, the mini-grid shall comply with the Kenya National Distribution Grid Code, especially with Chapter 5

[6] KNES 2018 suggests 15km, however as the national electrification plans may be reviewed in the near future this document uses the short, medium and long-term plans instead of distance. This will have to be reviewed by EPRA as the electrification plans are reviewed

				“Connections”.

6. Distribution network and end-user connection

Distribution network

Distribution network standards exist in Kenya, as well as a grid code. The purpose of this section is:

1. To classify mini-grids into two categories depending on whether they need to comply with the Kenya National Distribution Grid Code or not
2. Recommend low-cost distribution standards for those mini-grids that do not need to comply with KNDC

The mini-grid's distribution network shall comply with the Kenya National Distribution Grid Code if the mini-grid is likely to be interconnected to the grid (IRL1) as presented in the previous section. On the other hand, if the mini-grid is likely to remain isolated from the main grid, the distribution network design can make use of low-cost rural electrification construction strategies such as :

Low-cost distribution standards

- Single-phase MV reticulation via phase-phase taps. If the distribution network consists of a backbone three-phase three-wire MV line as per KPLC standards, the branches can be done via two-wire single-phase MV lines by tapping into two phases. This allows the usage of single-phase transformers to supply the LV network.
- Single-phase MV reticulation via phase-neutral taps. A four-wire three-phase MV system backbone can be used instead of the standard three-phase three-wire MV backbone. The MV branches can be done via tapping the phase and neutral wires. The neutral may be either a fourth physical wire installed on the poles or an earth return without an additional wire, also known as the Single-Wire Earth Return (SWER).
- Split phase LV lines. This three-wire system with 460 V between phases and 230 V between phase and neutral offers a lower voltage drop than the traditional two-wire LV line, hence allowing for lower cable cross sections.
- Aerial Bundled Cables (ABC) in LV lines.
- Split-type prepayment meters. These meters allow for the physical separation between the customer interface and the measurement unit, the latter being installed at the top of the LV pole. This configuration simplifies the hardware required.

Connection inside the customer premises

Service drop connections between the low-voltage distribution line and the customer shall be made at the poles rather than along the span. The service connections shall be anchored to a solid surface to be mechanically secured.

A connection board shall be installed between the distribution line and the internal house wiring. The board shall be tamper-proof and shall contain the necessary elements to satisfy the following **minimum functionalities: overcurrent protection, switching and earth leakage detection** (e.g., residual current circuit breaker). The electrical installation and all the components shall comply with the IEC standards or their equivalent national standards, including:

- IEC 60364. Low-voltage electrical installations
- IEC 60947. Low-voltage switchgear and control gear
- IEC 61439-1, -2 and -3. Low-voltage switchgear and control gear assemblies
- IEC 61008. Residual current operated circuit-breakers without integral overcurrent protection for household and similar uses (RCCBs)
- IEC 60898. Electrical accessories - Circuit-breakers for overcurrent protection for household and similar installations

All components shall be designed, manufactured, and tested in accordance with the quality assurance requirements of the ISO 9000 family.

The customer connection and inhouse wiring shall be done by an EPRA authorized technician.

7. Other provisions

A. Energy Meters

Standards

The metering system employed by mini-grids shall comply with the requirements set by the local regulations[7], considering the following international standards as well:

- IEC 17025: General requirements for the competence of testing and calibration laboratories
- IEC 61869 – Instrument transformers - Part 2: Additional requirements for current transformers
- IEC 61869 – Instrument transformers - Part 3: Additional requirements for inductive voltage transformers
- IEC 61869 – Instrument transformers - Part 4: Additional requirements for combined transformers
- IEC 61869 – Instrument transformers - Part 5: Additional requirements for capacitor voltage transformers
- IEC 61000 - Electromagnetic compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current ≤16 A per phase)
- IEC 62052 - Electricity metering equipment – General requirements, tests, and conditions – Part 11: Metering equipment
- IEC 62053 - Electricity metering equipment - Particular requirements - Part 21: Static meters for AC active energy (classes 0,5, 1 and 2)
- IEC 62053 - Electricity metering equipment - Particular requirements - Part 23: Static meters for reactive energy (classes 2 and 3)
- IEC 62054 – Electricity metering (AC) - Tariff and load control - Part 21: Particular requirements for time switches
- IEC 62056 - Data exchange for meter reading, tariff, and load control - Part 21: Direct local data exchange
- IEC 62059: Electricity Metering Equipment Dependability

Anti-tampering features shall be included in the design of the energy meter.

STS optional compliance

Following the main energy regulations section 20(2), "all meters installed shall be at least IEC 62055-41 compliant", mini-grid operators are not obliged to comply with STS compliant standards. STS standard is an application layer

[7] Kenya National Distribution Grid Code, April 2017

protocol for one-way token carrier systems for pre-paid mechanisms, however there are many other protocols and payment systems that are equally valid (including post-paid meters) and already working in the market, therefore keeping this standard will only restrict the market.

Different types of meters exist in the market with different functionalities and payment methods, such as post-paid meters, pre-paid (PAYG) meters and smart meters. With post-paid meters, the mini-grid operator sends a worker to read the meter of each household and determine how much energy has been consumed. Pre-paid meters allow the users to pay for energy in advance via mobile money platforms or scratch cards and allow to show the expenditures in real time. Smart meters are usually pre-paid meters with more advanced functionalities, such as remote monitoring and meter reading, algorithms to limit the daily energy consumption and peak power, real-time theft detection, report on the power quality and reliability for an optimized troubleshooting process and ancillary services (e.g., automated tariff modification for variable smart pricing, demand-side management, load shedding).

End-user visualization of energy consumption

As many of all the customers mini-grids are serving and will serve, have not had reliable and high-quality electricity before, it is important that the meters implemented in mini-grids provide basic information to the end-user on their energy consumption or energy balance (if prepaid methods, credits or similar) through a user-friendly interface (LCD display or similar).

B. Data management and protection

There is a Data Protection Act, 2019[8] that contains provisions on the management of personal data, that would be useful for operators of sites to be familiar with as they handle customer information.

[8] http://kenyalaw.org/kl/fileadmin/pdfdownloads/Acts/2019/TheDataProtectionAct__No24of2019.pdf