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Review

A Review of Grid Code Requirements for the Integration of Renewable Energy Sources in Ethiopia

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Abstract: Rapid integration of renewable energy into the electric grid has ramifications for grid management and planning. Therefore, system operators have formulated grid code requirements to ensure that the grid continues to operate in a secure, safe, and cost-effective manner. The current state of grid code in Ethiopia, as well as the need for it, is discussed in this article. It lays out the technological grid integration requirements, with a focus on small and microgrids, which are especially important for the integration of renewable. The barriers to grid code normalization and renewable energy grid compatibility testing are identified, and suggestions for continued grid code development in Ethiopia based on Danish observations are provided. Further, a detailed comparative analysis of the Ethiopian grid code with the IEEE 1547-2003 and IEEE 1547-2018 standards is presented.

Keywords: grid code; minigrid; microgrid; renewable energy integration

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1. Introduction

The availability of energy is a major factor in global economic shifts. Energy security is a vital problem for industrialization and economic progress, as it helps to alleviate poverty, improve food production, improve clean water availability, update healthcare centers, raise standards of education, and generate work opportunities for young people, especially women. One out of every five individuals in the world does not have access to power. Several individuals still use charcoal, wood, agricultural waste, as well as other solid fuels for cooking and other daily activities; consequently, they suffer from several health problems that shorten their lives. Inadequate power availability has an impact on a family's income, industrial productivity, education, and health. Due to emissions from greenhouse gases, contemporary energy-producing units based on fossil fuels have an adverse impact on the climate and the environment [1]. At a national and international level, these atmospheric shifts cause water and food problems. Security of energy supply from renewable energy sources is crucial for sustainable development. Although there has been a significant improvement in alternative sources of energy, there are still several constraints that must be resolved in order to achieve large-scale sustainable growth. Many breakthroughs in technology, financial strategy, marketing strategies, regulatory, and governance frameworks are essential for sustainable power generation. In terms of global growth, African countries have a relatively low rate of sustainable development due to insufficient energy generation and availability [2]. There are three major energy concerns in sub-Saharan Africa: inadequacy of energy generation, insufficient energy access, and global warming. To limit the effects of global warming, these difficulties must be handled so that 100% availability of power may be achieved via renewable energy-producing infrastructure.

1.1. Ethiopian Energy Sector

Ethiopia is a nation in the Horn of Africa region. The Ethiopian government is adamant about increasing power generation and accessibility for all of its 130 million citizens. Various international organizations such as World Bank, African Development Bank, etc., contribute to various energy and electricity initiatives [3]. In order to determine the impact of rural grid extension on various degrees of deprivation, a thorough and comprehensive investigation is essential. There are several proofs known on the consequences of poverty on Asian nations, but comprehensive empirical evaluations for African countries are scarce [3].

1.1.1. Background

The majority of people in Africa reside in rural areas and carry out subsistence farming and other activities linked to agriculture. Oil seeds, legumes, fruits, flowers, natural gum, spices, textiles, and mineral products are among Ethiopia's exports in addition to coffee, leather, live animals, and meat. Ethiopia's economy is among the most rapidly developing in the African region, and the nation's economy is being stabilized and rehabilitated [3]. Ethiopia, like other sub-Saharan African nations, needs enough power generation and fair access to power. The urban population has extensive access to energy, while the rural areas have limited access to electricity. Ethiopia has one of the least power usage rates in the world, with some of the urban areas such as Addis Ababa, Hawassa, Jimma, Bahirdar consuming the majority of it. The administration is addressing the longstanding issue of a lack of energy supply in rural regions and expanding access to modern energy. As a result, a variety of initiatives are being undertaken in collaboration with foreign governments. The rural electrification connectivity initiative has been continuously funded by the Ethiopian government, with other financial institutions such as World Bank, etc., since 1998, with the goal of achieving nationwide electrification of 90%. Apart from conventional energy production, non-conventional power generation units such as photo-voltaic, wind, and geothermal have been built and procured [4].

1.1.2. Overview

Ethiopia's government wants to improve energy availability from 26% in 2014 to 60% by 2040. Another goal is to improve the effectiveness of current power production facilities. To carry out such specific goals, the Ethiopian government is constantly organizing fresh monetary capacity from China, in addition to traditional World Bank funds. The Universal Power Access Program (UEAP) was created to ensure that most rural communities have reliable electricity. The entire cost of the UEAP is estimated to be around USD 920 million. The Ethiopian Electric Power (EEP) has devised an integrated plan to achieve these objectives [4]. Ethiopia has a huge power grid that is integrated (ICS). There are 13 hydro, 6 diesel standby, 1 geothermal, and 4 wind farms in this ICS. Ethiopia now has 23 power plants that use hydropower, wind energy, geothermal energy, and diesel to generate electricity. In the fiscal year 2020–21, energy output is expected to be about 4523.77 MW [1].

1.1.3. Ethiopia's Renewable Energy Sector

Ethiopia now has a total installed capacity for electricity generation of about 4238 MW. Nearly 90% of the electricity is produced by hydropower plants (3807 MW). In concert, 324 MW (7.65%), 7.3 MW (0.17%), and 99.17 MW (2.34%) are produced by wind, geothermal, and diesel energy facilities, respectively. Alternative energy sources, such as hydropower, wind, solar, and geothermal energy as well as diesel, have a lot of promise in Ethiopia. Despite the enormous potential for producing renewable energy, only a small amount of green energy is generated as a result of a lack of funding and other important problems. Ethiopia continues to be on the cusp of a renewable power revolution. Significant support is needed in the wind, geothermal, solar, and biomass industries to fully fulfill this immense potential. These resources can be used to produce power over the long term for both domestic and international industries [5]. The Ethiopian Electric Power Company has devised a number of programs aimed at achieving 75% electricity availability by the end of the decade. Ethiopia, like other sub-Saharan African nations, lacks enough power generation and fair access to energy. The urban population has extensive electricity access, whilst the rural areas have limited availability of power. Ethiopia, like other sub-Saharan African nations, suffers a slew of issues that place it towards the bottom of the energy rankings. In recent years, Ethiopia has significantly aided in the electrification of cities and villages, but resources such as micro-hydro, wind, and solar energy are still not being fully used. Hydropower is Ethiopia's main form of energy generation, which reduces carbon emissions (less than three percent of the total emission). Thanks to new hydropower and wind power facilities, Ethiopia's energy production rose by more than 250 percent between 2008 and 2016. In addition, work is now being undertaken on the Grand Ethiopian Renaissance Dam, which will have a 6000 MW capacity. However, the extra power generation is not being utilized efficiently because of the inadequate electrical grid [5].

1.1.4. Renewable Energy-Based Minigrid Clusters in Ethiopia (REMCE)

The REMCE project, which was supported by the Danida Project, includes this paper. The primary goal of this endeavor is to complete this paper. The REMCE project intends to increase access to electricity in Ethiopia's rural areas while addressing the difficulties associated with the large-scale implementation of sustainable power minigrids. In order to carry this out, REMCE will gather and analyze the pertinent data and information in order to assess and choose the best minigrid designs and locations in Ethiopia. To meet the need for electricity in Ethiopia's distant locations, REMCE will suggest the appropriate activities and procedures. The project will focus on solar and wind resources in combination with diesel generators, or preferably battery energy storage systems and micro-hydropower systems to implement multiple minigrids. These minigrids will be interconnected forming clusters with high levels of efficiency, scalability, and expandability. The main objectives of this project are the development of the grid code for the incorporation of the minigrid and microgrid into the utility grid, develop minigrid and microgrid clusters for the remote areas of the remote Ethiopian areas, optimal controlling of the proposed mini and microgrids and integrate them to the utility grid.

1.2. RPP's Classification Based upon Size/Type

The grid code defines specific requirements for the RPPs depending upon their size and type. Accordingly, the RPPs can be classified into six categories as follows:

(1) 0–100 kVA: Alpha (α) renewable power plant;
(2) 100 kVA to 1 MVA: Beta (β) renewable power plant;
(3) 1 to 20 MVA: Gamma (γ) renewable power plant;
(4) Greater than 20 MVA: Delta (δ) renewable power plant;
(5) Less than 1 MVA: Eta (η) synchronous generator-based renewable power plant;
(6) 1 to 20 MVA: Mu (μ) synchronous generator-based renewable power plant.

1.3. Related Work

The grid code requirement was proposed by many academics from various national viewpoints. How to match utility demand in Peninsular Malaysia with bulk level grid-linked solar power generation is demonstrated in [6]. This study describes the development and validation of an alternative method (the generation-demand matching model, or GDMM) for assessing the widespread adoption of grid-connected PV power plants in Peninsular Malaysia in relation to the current network. In order to support widespread solar energy use, grid code modifications are examined from the utility grid perspective in [7]. This paper looks at grid code changes that would allow PV to be widely used in the distribution grid. Furthermore, three reactive power injection strategies are taken into account, as well as the significance of low voltage ride-through (LVRT) for 1Φ PV electrical networks under grid faults, based on the fact that Italy and Japan recently finished a significant review of standards for PV systems connected to low-voltage systems. The requirements of island grid regulations for extensive incorporation of renewable energy are examined in [8]. This study focuses on the grid code provisions for huge renewable energy integration employing dispersed generation in island power systems. The report also discusses other demands, such as "virtual" wind inertia for better wind farm operating characteristics and energy storage solutions for greater performance from renewable energy sources. In [9], authors presented the comprehensive review on various issues and advancements in grid integrated PV systems. An analysis of international grid integration standards for wind power is presented in [10]. The authors in [11] provide research concerning the grid code specifications and control strategies for wind generating system participation in network frequency control. This research looks at the primary frequency regulation and synthetic inertia control methods utilized by wind turbines in addition to the grid codes' requirements.

Further, various researchers have presented the different clustered micro and minigrid-related literature, for their better control and utilization. The authors presented a scalable and flexible hybrid AC/DC microgrid clustering structure in [12], with distributed systems for coordinated operation. A solar–wind correlation-based efficient utilization of distributed sources for island microgrid clusters is presented in [13]. For the best energy management of interconnected clusters of microgrids with net-zero energy multi-greenhouses, model predictive control is detailed in [14]. In [15], the authors present interactive multi-level planning for managing the energy in clustered microgrids with changing demands. For a coordinated cluster of connected microgrid-powered multi-greenhouses to operate at its best, the authors of [16] propose a central controller.

The Indian grid codes that have been approved by the Ministry of Power of the Indian Government are listed in [17]. A full description of the many rules governing the connection of energy-generating equipment to Denmark's public electricity supply system is provided in [18]. To make it easier for electric production and storage systems to be integrated, interconnected, and interoperable, the National Renewable Energy Laboratory (NREL) sets standards and recommendations [19].

Manuscripts relating to Ethiopia's grid code requirements and the sub-Saharan region's grid code requirements are still few, which is the basis for this study.

1.4. Requirement of Grid Code

Integration of the available renewable energy sources is the one of main characteristics of a grid system and this code help utility to incorporate these renewable energy sources that is why we call it smart. Therefore, the smart grid code is required from the utility point of view to incorporate available energy sources into the grid system.

The government is pushing for the penetration of solar sources into the main electrical grid since Ethiopia has a sizable capacity for renewable energy generation. The grid code should promote the deeper penetration of renewable generation and technology requirements while ensuring the safe and secure functioning of the electrical grid network. Different criteria and requirements for renewable power plants and their potential to link to an expanded network in the future should be included in the grid code.

1.5. Contribution

This manuscript presents the grid code requirement for adequately solving several difficulties such as reliability, stability, and power quality, which are related to sustainable power production and system integration at the distribution level. The major contributions of this manuscript are as follows:

1. Presents the technical specifications for the integration of renewable power plants at the distribution level.
2. A detailed comparative analysis of the proposed Ethiopian grid code with the Danish grid code and the IEEE 1547-2003 and IEEE 1547-2018 standards is presented.
3. Presented the pros and cons of the recommended Ethiopian Grid code
4. Classified RPPs based on their capacities into different categories.

5. Presented the evaluation and recommendation of the Ethiopian grid code modifications, which are based on the comparative analysis for the improvement of the existing Ethiopian grid code.

1.6. Organization of the Manuscript

The manuscript is organized as follows. Section 2 presents the existing Ethiopian grid code under various operating conditions. Section 3 presents the comparative analysis of the Ethiopian grid code with the Denmark grid code and the IEEE 1547-2003 as well as IEEE 1547-2018 standards. Section 4 presents the summary of the Ethiopian grid code. Section 5 presents the evaluation and recommendation of the Ethiopian grid code modifications. Section 6 presents the pros and cons of the recommended Ethiopian Grid code, followed by the conclusions.

2. Existing Ethiopian Grid Codes for the Integration of Renewable Energy Sources

The Grid Code (GC) outlines the regulations required for the overall administration and evaluates the Ethiopia National Distribution System Grid Code's (ENDS-GC) various aspects.

Grid codes' technical standards establish the electrical characteristics that generating assets must meet in order to acquire the necessary permission for grid integration. As a result, establishing grid code compliance and obtaining a grid connection agreement are critical benchmarks in the evolution of RPP projects.

An authority in charge of system integrity and network functioning specifies and implements the grid code. Its execution often involves system operators including distribution grid operators, consumers, and the governmental entity. The contents of a grid code vary based on the utility company's needs.

The needed performance of linked RPPs under network disruptions will specify the technical validity of a GC. Voltage control, power factor restrictions and reactive power requirement, reaction to network failures, responsiveness to frequency variations on the grid, and the necessity of ride-through capabilities for small interruptions of the connection are all examples.

2.1. Technical Specifications for Renewable Energy Sources Integration at Distribution Level

A renewable power plant (RPP) should have the capabilities to fulfill future grid requirements, but until the RPP reaches a certain size of MW capacity or is connected to the main grid, some of the requirements of the grid code can be less strict. Such requirements can be voltage band, frequency band, disconnection times during under voltage, etc. The technical requirements, limits, and ranges of constraints are described below.

2.1.1. Normal Operating Conditions

RPPs of β category can be linked to the Ethiopian national distribution supply system at the point of consumption (POC). The difference in installed capability among phases in multi-phase supply linkages must not exceed 4.6 kVA/phase.

(a) RPPs of the category β and γ must be capable of running consistently within the POC operating voltage (0.9–1.1 p.u. at 66 kV, and 0.9–1.08 p.u. for voltages lower than 66 kV).
(b) RPPs of the category β and γ are only permitted to interface to the ENDS for a maximum of 3 s once the preceding criterion is met:

1. The potential at the POC is between the maximal and lowest allowed ranges set out in item (a) above;
2. ENDS's frequency is between 49.0 and 50.2 Hz.

RPPs of α category are only permitted to link to the ENDS power network for a maximum of 60 s just after succeeding criteria are met:

1. The allowable variation in potential at the point of consumption is between −15% and +10% of the normal voltage
2. The ENDS frequency is between 49.0 and 50.2 Hz, unless so approved by the regional dispatch center.

(c) The ENDS' nominal frequency is 50 Hz, and it is generally regulated by the regulations of the Ethiopian national distribution grid code specifications. The RPP must be configured to operate within the minimal operating ranges shown in Figures 1 and 2 at the time of network frequency issues.

(d) The RPP may be eliminated if the ENDS frequency exceeds 51.5 Hz for more than 4 s or if it dips below 47.0 Hz for more than 200 milliseconds. The RPP shall continue to be connected to the ENDS even if the system frequency varies up to and including 1.5 Hz per second as long as it continues within the minimal level operational range shown in Figures 1 and 2.

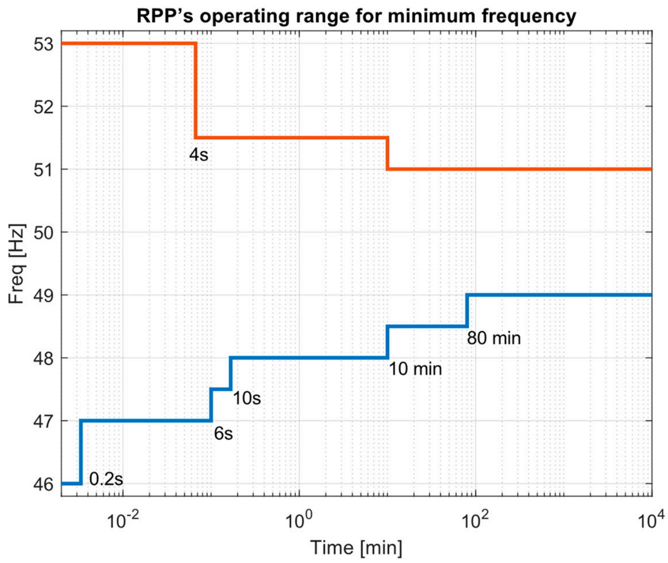

Figure 1. Minimum frequency operating range for RPP.

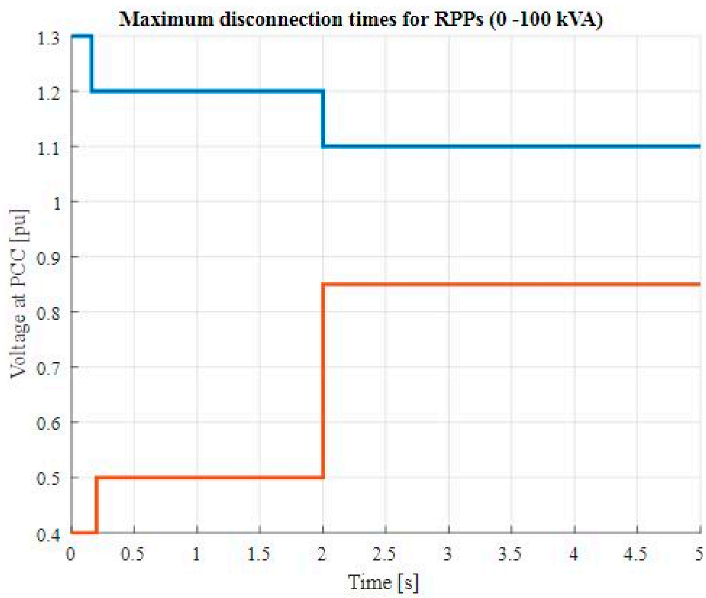

Figure 2. Maximum disconnection times for RPPs of α category.

2.1.2. Operating Conditions under Disturbance

At the point of consumption, the RPP must be able to withstand fast phase jumps of up to 20 degrees while still remaining connected and functional. No later than 5 s after the operating conditions in the point of consumption have returned to normal, the RPP must start regular production.

A. Voltage Response

RPPs of the category of α must be able to resist and satisfy voltage ride-through capabilities (VRTCs) as shown in Figures 3 and 4 at the point of use.

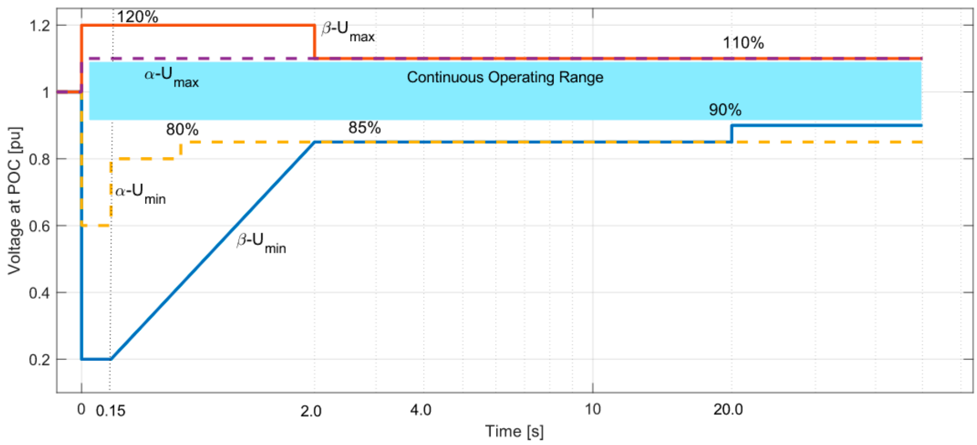

Figure 3. VRTC for the RPPs of α, β, and γ categories RPPs.

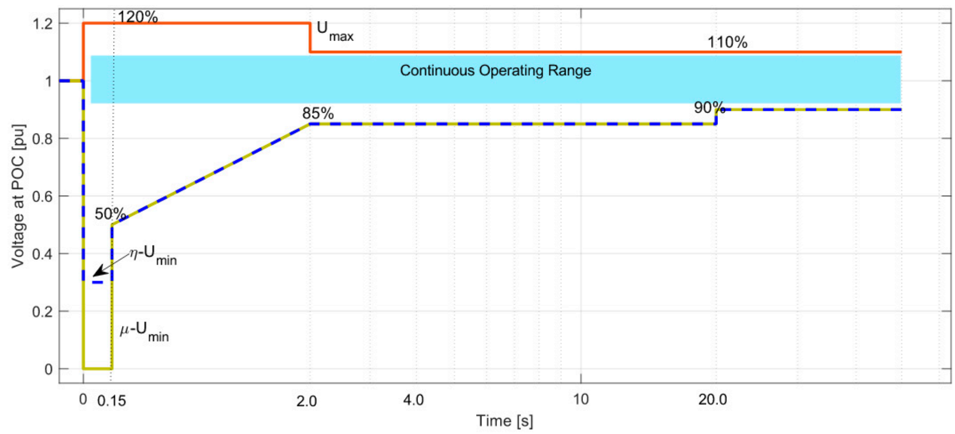

Figure 4. VRTC for the RPPs of μ, δ, and η categories RPPs.

RPPs having different capacities such α, β, γ, δ, μ, and η must be able to resist and meet the voltage conditions indicated in this section, as well as those depicted in Figures 3 and 4. Without disconnecting, the RPP must endure voltage decreases and peaks, as shown in Figures 3 and 4, and provide or absorb reactive current. As shown in Figures 3 and 4, the RPP must be able to withstand voltage drops to zero, measured at the point of consumption, for a minimum of 0.150 s before detaching, with the exception of synchronous generator-based RPPs of μ (1–20 MVA) during symmetrical three-phase failures. The RPP category of δ must be capable of withstanding voltage peaks up to 120 percent of the normal voltage measured at the point of consumption for a minimum of 2 s without disconnecting, as shown in Figures 4 and 5.

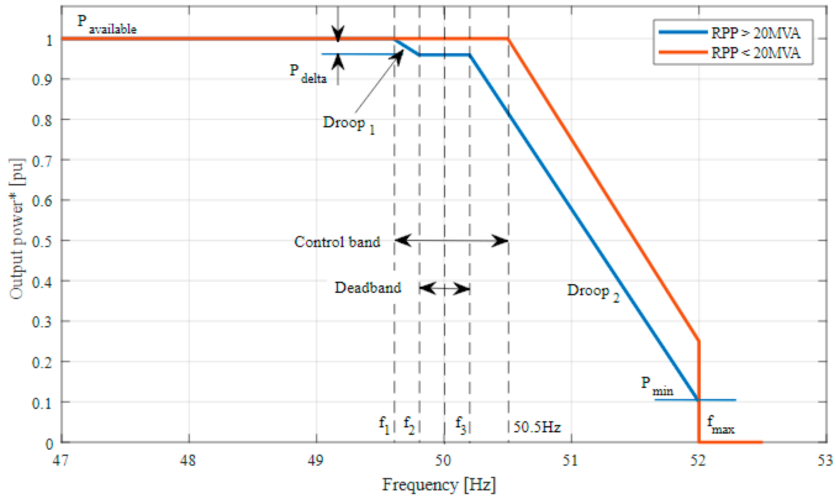

Figure 5. RPPs of higher capacity size (20 MVA and above) Frequency responses. * Power output from RPPs (20 MVA and above).

The voltage at POC is between the minimum and maximum voltage curves for the specified durations, and then the RPPs must remain connected. The RPPs must inject reactive current as a function of voltage deviation (from 80%) when the voltage is lower than 80%. Maximum reactive current should be injected when the voltage at the POC is 50% or less. Similarly, if the voltage is more than 110%, the RPPs must absorb reactive power.

B. Frequency Response

The power frequency response curve agreed upon by the system operator and regional control center must be met by the frequency response system of RPPs.

1. Power–Frequency Response Curve for RPP

In order to maintain frequency stability during high frequency operating conditions, RPPs must be able to provide necessary active power reduction needs, as seen in Figure 5. Metering accuracy for the grid frequency must be at least 10 mHz. As shown in Figure 5, the RPP must reduce active power as a function of frequency change when the frequency on the ENDS exceeds 50.5 Hz. For the sake of protecting the ENDS, the RPP is unplugged when the frequency exceeds 51.5 Hz for more than 4 s.

2. Power–Frequency Response Curve for RPP of δ category

Figure 5 shows how RPPs must be able to provide power–frequency response. The RPP is not required to execute any frequency response functions other than the mandated high-frequency response (above 50.5 Hz). Without a special agreement with the distribution network system planner (DNSP), Regional Control Center, and/or the ENTSO, no P_{Delta}, dead-band, or control-band functions shall be implemented. The term "PDelta" refers to the active power that has been reduced in order to provide reserves for frequency stability. The frequency response control function needs to be able to regulate each and every frequency point in Figure 5. With a minimum accuracy of 10 mHz, the frequencies fmin, fmax, and f1 through f6 must be able to be modified to any value between 47 and 52 Hz. Frequency points f1 through f4 operate as a dead band and a control band for RPPs contracted for the main frequency response. The requisite critical power/frequency response is provided by the frequency points f4 through f6. The frequency control droop parameters, as shown in Figure 5, must be included in the RPP. Each droop parameter must be able to be adjusted between 0% and 10%. The system operator will be consulted to decide the precise droop setting. The droop settings required to govern between the distinct frequency points must be determined by the system operator and sent to the RPP. If the active power from the RPP is managed underneath the unit's design limit Pmin, individual RPP units may shut down.

The RPP (excluding photovoltaic solar) must be able to provide a P_{Delta} of at least 3% of the total $P_{available}$. The frequency response control feature must be able to be activated and deactivated in the range of f_{min} to f_{max}. If the frequency control set point (i.e., P_{Delta}) is to be altered, the change must be started within two seconds and finished within ten seconds of receiving the change order. Regardless of which creates the highest tolerance, the accuracy of the executed control and the set point cannot deviate by more than 2 percent of the set point value or 0.5 percent of the rated power. Unless the system operator and the RPP generator agree differently, the default parameters for f_{min}, f_{max}, f_4, f_5, and f_6 are 47 Hz, 52 Hz, 50.5 Hz, 51.5 Hz, and 50.2 Hz, respectively. The system operator must approve the settings for f_1, f_2, and f_3, as per the agreement.

The Regional Control Center and/or the system operator must provide the RPP with at least two weeks' notice if any of the frequency response parameters (i.e., f1 through f6) need to be altered. The RPP shall confirm with the Regional Control Center and/or the system operator that the appropriate changes have been made within two weeks of receiving the request from the Regional Control Center and/or the system operator.

C. Reactive Power Capability

1. *RPPs of α category (below 1 MVA)*

The α Category RPPs must operate at unity power factor measured at POC unless the Regional Control Center and/or the system operator stipulate otherwise. As assessed at the POC available from 20 percent to 100 percent of rated power, RPPs of β category must be able to operate at power factors ranging from 0.95 lagging to 0.95 leading (Pn). A power factor characteristic curve that RPPs can follow will be developed by the Regional Control Center and/or the system operator. The default power factor value is unity unless the regional control center and/or system operator specify otherwise.

2. *RPPs of γ category*

The ability to operate in voltage (V), power factor, or reactive power control modes is a requirement for RPPs in this category. The distribution network system planner (DNSP) must be consulted in order to identify the precise operating point and operating mode (voltage, power factor, or reactive power regulation). Within the reactive power capability ranges shown in in Figures 6 and 7 the RPPs in γ and δ categories must be able to support varying reactive power (MVAr) at the POC when operating between 5 and 100 percent of rated power Pn (MW). Figure 7 shows the reactive power capability of the RPPs of γ and δ categories at nominal voltage.

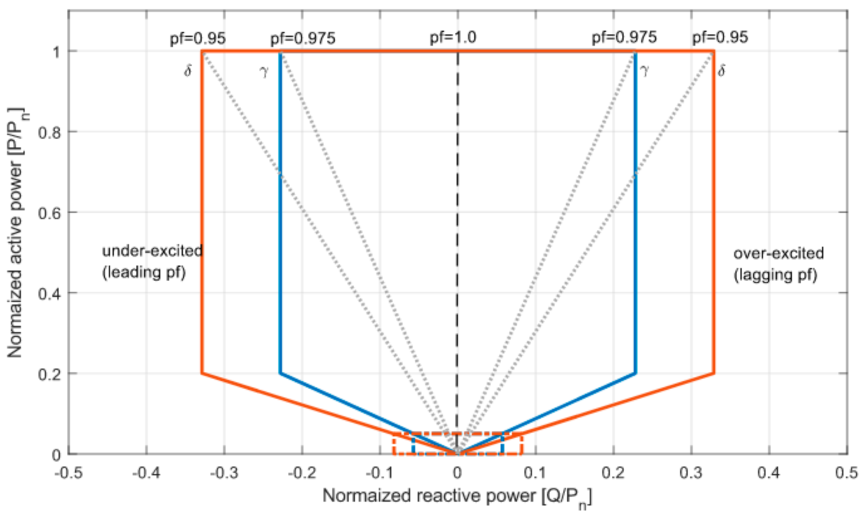

Figure 6. Reactive power requirements for RPPs of γ and δ categories at POC.

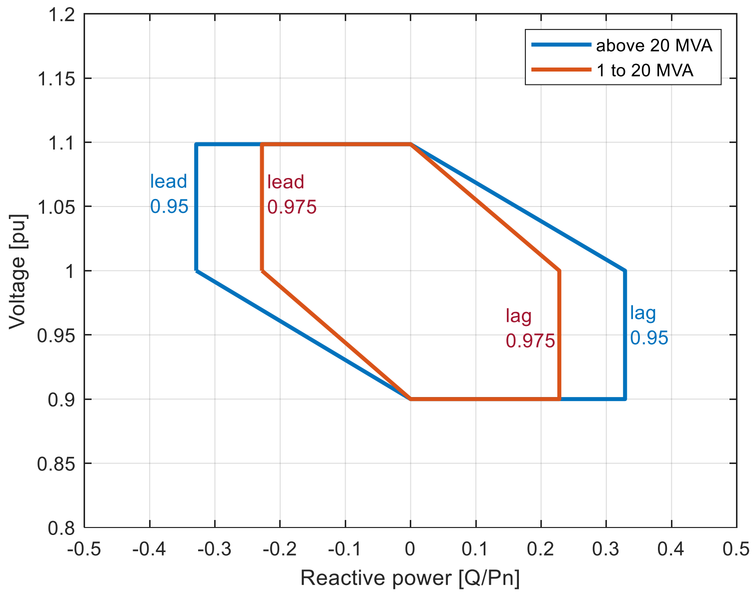

Figure 7. Reactive power and voltage control range requirements of γ and δ categories of RPPs.

Although the RPP can only operate within a reactive power tolerance range of not more than 5 percent of rated power, there is no requirement for reactive power capacity while operating below ± 5 percent of rated power Pn (MW).

3. *RPPs of δ category*

The ability to function in voltage, power factor, or reactive power control modes is required for this set of RPPs. The genuine control operational mode and the operating point must be approved by the DNSP. The RPP must be able to adjust reactive power support at the POC within the reactive power capability ranges depicted in Figure 6 where Qmin and Qmax are voltage dependent while operating between 5 percent and 100 percent of rated power Pn (MW). The required RPP reactive power capability at nominal voltage is shown in Figure 7. Although the RPP can only operate within a reactive power tolerance range of not more than 5 percent of rated power, as illustrated in Figure 6, there is no demand for reactive power capacity while running below ± 5 percent of rated power Pn (MW).

D. Reactive Power, Power Factor, and Voltage Control

The below-mentioned conditions should be implemented in renewable power plants of γ and δ with a reactive power contract with a transmission utility:

i. The RPP must have both a voltage control function and reactive power control capabilities that allow it to manage the voltage as well as the reactive power it delivers at the POC.
ii. One of the three functions—voltage, power factor, and reactive power—can only be employed at a time since the management of reactive power and voltage functions is often mutually exclusive.
iii. The control function and relevant parameter values for the reactive power and voltage control functions, which will be carried out by the RPP, shall be specified by the distribution network system planner in conjunction with the regional control center and/or the system operator. The specified control functions shall be set out in the operating agreement.

1. *Reactive Power Control*

Reactive power control, which is unrelated to active power and voltage, regulates the reactive power supply and absorption at the POC. The RPP must update its echo analog set point value within two seconds if the reactive power control set point is altered by the distribution network system planner, the Regional Control Center, and/or the system planner. The RPP must respond to the new set point within 30 s after receiving an order to change the set point. A maximum tolerance of 2 percent of the set point value or 0.5 percent of the maximum reactive power may exist between the accuracy of the accomplished control and the set point. Reactive power set points must be delivered to the RPP with a 1 kVAr degree of accuracy.

2. *Power Factor Control*

Power Factor Control adjusts the reactive power in accordance with the active power at the POC. The RPP must update its echo analog set point value within two seconds in response to any changes made to the power factor set point by the regional control center, the system operator, and/or the distribution network system planner. The RPP has 30 s to respond to the new set point after receiving a second instruction to change it. The directed control's accuracy and the set point's precision cannot be more than ±0.02.

3. *Voltage Control*

Through voltage management, the voltage at the POC is managed. After receiving the order to adjust the voltage set point, the change must start within 2 s and be finished within 30 s. According to droop characteristics, the control accuracy cannot deviate by more than two percent from the required reactive power injection or absorption. The voltage set point accuracy must be within 0.5 percent of nominal voltage. Each RPP must be able to conduct the control within the limits of its dynamic range and voltage range with the droop set up. In this application, droop is the voltage shift (p.u.) caused by a change in reactive power (p.u.). After the voltage control has reached the dynamic design constraints of the RPP, the control function must wait for likely overall control from the tap changer or other voltage control functions. Overall voltage coordination is the responsibility of the distribution network system planner, in collaboration with the regional control center and/or the system operator.

E. Power Quality

The RPP is responsible for monitoring power quality metrics (such as flicker, harmonics, and unbalanced voltages) and reporting to the distribution network system planner, Regional Control Center, and/or system operator, as needed. The RPP will use IEC standards to determine harmonics (IEC 61000-4-7 [20]) and flicker (IEC 61000-4-15 [21]). The IEC 61000-4-30 class A [22] power quality monitoring standard, which outlines methods for determining and interpreting power quality parameters in AC power supply systems, must be complied with by the RPP. The reporting will be undertaken to show that the POC is in compliance with the distribution network system planner requirements as outlined in the Purchase Power Agreement (PPA). The RPP at the POC must emit voltage and current quality distortion levels that comply with international standards such as IEC 61000-3-2:2018 [23].

Different practices and rules for harmonic control in electrical networks are specified in IEEE 519-2014 [24]. For integration and interoperability of distributed energy resources with associated power system interfaces, IEEE 1547-2018 [25] will be utilized. Communications systems and automation systems for power utilities will both utilize IEC 61850 [26]. Furthermore, the specified and established emission limit values must not be exceeded by the RPP's design, setting, and execution. The DNSP will manage any excess voltage harmonic compatibility level induced by the network harmonic impedance at the POC, which is greater than three times the base harmonic impedance for the range of benchmark fault levels at the POC, in line with the licensing criteria for the DNSP. Equipment that will produce a resonance of more than three times at the POC at any frequency is not allowed to be connected by any RPP.

The continuity and voltage quality of the connection cannot always be guaranteed by the network operators under all conditions. As a result, the RPP must follow the different IEEE and IEC standards in order to safeguard the RPP facility from losses and/or damage brought on by various power quality problems. The RPP is also accountable for taking all necessary safeguards to protect the transmission and distribution networks.

In a distribution network with only home loads, harmonic distortion created by PV generators is below industry norms. Furthermore, if the photovoltaic generators are close to the transformer, harmonic distortion is reduced even further. Furthermore, the placement of photovoltaic systems adjacent to transformers aids in the management of voltage growth in distribution lines.

2.2. Protection and Fault Levels

To protect the RPP and maintain a reliable distribution system, protection mechanisms must be provided. The RPP must have the appropriate protective functions to safeguard itself from harm caused by distribution system faults and events. For RPPs of α and β in the and categories as well as bigger RPPs, the RPP must be capable of identifying islanded operation in all system configurations and shutting down power generation in such a condition within 0.2 s. Islanded operation with a portion of the distribution system is not authorized unless the distribution network system designer has expressly consented to it.

2.3. Active Power Constraint Functions

The distribution network system planner and the system operator may limit the active power output of RPPs larger than 100 kVA for system security considerations. Constraint functions, or additional active power control functions, assist prevent distribution system imbalances and/or overloading. Absolute production constraints, delta production constraints, and power gradient constraints are among the necessary constraint functions. The following sections give more information on each of these. For small hydro power plants, the power gradient and delta production constraints are not necessary.

2.3.1. Absolute Power Constraint

The output active power of the RPP is constrained to a predetermined power MW limit at the POC using an absolute production constraint. Typically, this is undertaken to prevent overloading of the distribution system. RPPs (with the exception of small hydro power plants) must begin the alteration of the Absolute Production Constraint set point within 2 s and must complete it within 30 s of receiving the modification order.

The precision of the control executed and the set point shall not deviate by more than ±2% of the set point value or ±0.5% of the rated power, whichever provides the largest tolerance. This rule does not apply to small hydro power plants. For small hydro power plants, a modification to the Absolute Production Constraint's set point must be made within 5 s. Within the limitations of its technological design, the RPP must carry out the alteration in the least amount of time and with the highest degree of accuracy.

2.3.2. Delta Production Constraint

A Delta Production Constraint is used to limit the active power from the RPP to a required constant value relative to the potential active power. A Delta Production Constraint is frequently used to create a control reserve for control purposes in the context of frequency regulation. If the set point of the Delta Production Constraint is to be changed, the change must start within 2 s and be finished within 30 s of receiving the command to do so. It is required that the accuracy of the direct control and the set point be within ±2% of the set point value or ±0.5% of the rated power, whichever provides the largest tolerance.

2.3.3. Power Gradient Constraint

A power gradient constraint, which takes into account the availability of primary energy to support these gradients, places a cap on the maximum ramp rates by which the active power can be altered in the event of changes in the primary renewable energy supply or the set points for the RPP. When running a system, a power gradient constraint is typically used to prevent active power fluctuations from impairing the stability of the transmission or distribution systems. If the set point of the Power Gradient Constraint is to be changed, the change must start within 2 s and be finished within 30 s after receiving the modification order. Regardless of which generates the largest tolerance, the precision of the conducted control and the set point cannot deviate by more than ±2% of the set point value or ±0.5% of the rated power.

2.4. Control Function Requirements

For different capacity RPPs, different control actions are required. For the RPP with a capacity between 100 kVA and 1 MVA, control functions such as constraint of absolute production and constraint power gradient are required. Furthermore, for the RPPs of capacities between 1 MVA and 20 MVA, control functions such as constraint of absolute production, constraint power gradient, reactive power control, power factor control, and voltage control are required. Lastly for the RPPs of capacities greater than 20 MVA, control functions such as the frequency control, constraint of absolute production, constraint of delta production, constraint power gradient, reactive power control, power factor control, and voltage control are required.

The numerous control functions' objective is to guarantee that the RPP's generation is under control and monitored at all times. The maximum MW per minute ramp rate set by the RPP control system should allow the distribution system planner and operator to govern the ramp rate of the active power output.

2.5. Ramp Rates

In particular, positive ramp rate during startup, positive ramp rate only during normal operating conditions, and negative ramp rate during controlled shut down are necessary for the ramp rate parameters to be valid throughout all operational categories. They should not be used to regulate frequency. The RPP control system must be able to manage the ramp rate of its Active Power output with a maximum MW per minute ramp rate set by the Regional Control Centre and/or the system operator. There are two possible maximum ramp speeds. The average MW ramp rate over a minute will be subject to the initial ramp rate setting. A 10 min averaged MW per minute ramp rate will be covered by the second ramp rate choice. Additionally, each of these ramp rate settings has to be individually changeable between 1 and 30 MW each minute. Different ramp rate properties must be met for each of the operational conditions, such as decreasing wind speed, cloudiness, or frequency deviation. The Solar Power Generating Plant's power production must be reduced by 10% per minute, in any operational condition and from any working point, without cutting the RPP off from the network, to a maximum power value (target value), which may equate to a 100% decrease in power. The RPP operator, the regional control center, and/or the system operator must all agree on a procedure for setting and modifying the ramp rate control.

2.6. High Wind Curtailment

The wind power generating plant must remain connected to the distribution system when average wind speeds are below a preset cut-out wind speed. The cut-out wind speed must be at least 25 m/s based on the wind speed estimated as an average value over a 10 min period. In order to avoid a momentary halt of Active Power generation at wind speeds close to the cut-out wind speed, the Wind Turbine Generating Plant should be equipped with an automatic downward regulation mechanism.

The RPP Active Power must be able to be continuously reduced to a value between 100% and at least 40% of the rated power. Individual Wind Turbine Generating Plants are allowed to shut down while downward regulation is being applied in order to precisely follow the load characteristic.

There are two methods for downward control: continuous and discrete. Discrete regulation cannot have a step size more than 25% of the rated power in the space between the slanted lines in Figure 8's example of a high wind downward control chart. When downward regulation is being used, individual wind turbine-producing plant units may be shut down. The downward regulatory band will be decided upon in conjunction with the system planner when the Wind Turbine Generating Plant units are commissioned.

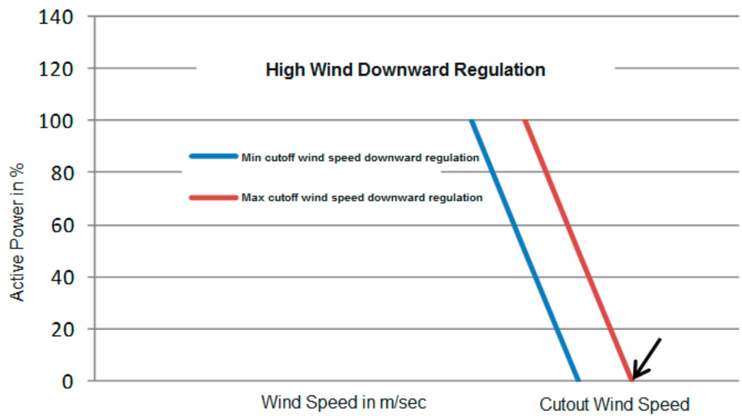

Figure 8. Illustrative High Wind Downward Regulation Chart.

2.7. RPP System Reserve Requirement

A greater requirement for various forms of reserves may result from the increased integration of wind and solar power as well as other RPPs to a lesser extent. They require larger operational and planning reserves because of the unpredictable nature of their output in order to offset the increased risk of being unavailable or going offline when they are needed. Additionally, they do not provide much inertia to the system, which makes it necessary to regulate frequencies more strictly and may call for higher levels of regulating and spinning reserve. For the purpose of calculating planned and operational bank reserves, several factors must be taken into account. RPPs must, overall:

(a) Within the design margins, maintain at least two separate set amounts of spinning reserve.
(b) Maintain the spinning reserve set level within 2% of the registered capacity with the DNSP, the regional control center, and/or the system operator for at least one hour.

3. Comparative Analysis

This section presents the comparative analysis of the existing Ethiopian grid code with the Denmark grid code and IEEE 1547-2003 and IEEE 1547-2018 standards.

3.1. Comparative Analysis of the Grid Codes (Danish versus Ethiopia)

This section compares the proposed national distribution grid code for Ethiopia with the Danish grid code. Table 1 presents the comparative analysis of the Danish and Ethiopian grid codes on the various technical standards.

Table 1. Comparative analysis between Danish and Ethiopian grid codes.

Parameter	Danish Grid Code	Ethiopian Grid Code	Comments
Voltage Phase Jump	Plant capable of withstanding up to 20-degree transient voltage phase jumps at POC without disconnecting.	The plant must be capable of withstanding abrupt phase jumps at the POC of up to 20 degrees without cutting out or lowering its output. After a phase leap of more than 20 degrees, the plant must restart regular output no later than 5 s after normal operating conditions are achieved at the POC.	Similar to Danish Code, therefore, no further correction is required.

Table 1. *Cont.*

Parameter	Danish Grid Code	Ethiopian Grid Code	Comments
Tolerance for frequency and voltage deviations	Continuous generation in the 49.0–51.0 Hz frequency range. Voltage at POC is 230 V. Continuous generation at POC when voltage is within the 85% to 110% range of nominal voltage. Continuous generation under ROCOF up to 2.0 Hz/s.	The generator will continue to operate between 48.75 and 51.25 Hz. The generator should be in operation for 3 s between 48.0 and 52 Hz but will not operate continuously outside of that range. Plant remains connected when the rate of change in frequency (ROCOF) of values up to 1.5 Hz per second Allowable voltage variation less than 1.kV for urban load is varying from ±6% to ±10% Allowable voltage variation for 1 kV and above rural load is ±5%.	Frequency and voltage deviation ranges are so similar to the Danish grid code, hence no further modifications are required.
Reduction of active power	Plant is allowed to reduce the active power within the 49-47.5 Hz frequency range by 6% of Pn/Hz—under-frequency	When the system's frequency surpasses 50.5 Hz, the plant should lower its active power in proportion to the frequency change. Plant shall be tripped to protect the network once the frequency exceeds 51.5 Hz for more than 4 s	The reduction in the active power due to frequency and voltage deviation depends on the power–frequency response curve.
Voltage drop	Plant must be designed to withstand voltage deviations during normal and abnormal operating conditions.	Except for synchronous generators (size 1–20 MVA) during symmetrical 3-phase failures, the plant withstand voltage must drop to zero for a minimum of 0.150 s without disconnecting. Active power must be maintained during voltage decreases; however, for voltages below 85%, active power must be reduced within the plant's design parameters in proportion to the voltage drop.	Voltage drops to zero are permitted in the Ethiopian grid code for a minimum of 0.150 s. The same applies to asynchronous power modules in Denmark.
Voltage rise	Plant must be designed to withstand voltage deviations during normal and abnormal operating conditions.	Plant (20 MVA and above) must be able to endure voltage peaks of up to 120 percent of the normal voltage for at least 2 s before disconnecting.	The maximum voltage rise allowed in the Ethiopian grid code is up to 120% for short time duration of 2 s.
Connection and reconnection	Start-up and reconnection of a plant are only permitted when frequency and voltage are within the 47.5 to 50.2/50.5 Hz and 85% to 110% of nominal voltage for 3 min, respectively. After connection, the maximum active power increase per minute is 20% of nominal power.	For plant, with capacity higher than 1 MVA, capable of operating continuously within voltage range 0.9 to 1.1 p.u. at 66 kV, and 0.9 to 1.08 p.u. at voltage below 66 kV. Plants greater than 1 MVA are only permitted to connect to the distribution grid 3 s after the following conditions are satisfied. (1) The voltage is within the maximum and minimum allowable limits mentioned above (2) The frequency in the distribution grid is between 49.0 and 50.2 Hz. Plant with a capacity of less than 1 MVA may only connect to the distribution grid 60 s after the following requirements have been met: (1) The voltage is in the −15% to +10% range around the normal value. (2) The distribution system's frequency is between 49.0 and 50.2 Hz.	The requirements for the starting up and reconnection of the power generating plants are more or less similar to the Danish code. It is very fast in the Ethiopian grid code

Table 1. *Cont.*

Parameter	Danish Grid Code	Ethiopian Grid Code	Comments
Absolute Power Constraints	The plant must have the ability to regulate its maximum active power. It restricts the active power coming from an RPP to a maximum power limit at POC that is determined by a set point. Control for a new value of the absolute power limit must be completed within five minutes of receiving the parameter change order.	This restriction is utilized at the POC to constrain the plant output to a predetermined power MW limit. If the set point for this limit is to be changed, the plants shall commence change within 2 s (for small hydro it should be within 5 s) and it should be completed within 30 s The precision of the conducted control and the set point should not diverge by more than ±2% of the set point value or ±0.5 percent of the rated power.	These constraints are also similar to the Danish grid code therefore no further modifications are required.
Reactive Power Control	The plant has to be able to manage its reactive power. It caps the reactive power produced by a power plant to a maximum limit determined at POC.	Plant should have a reactive power control system. The plant must update its echo analog set point value in reaction to the new value within 2 s and must finish it within 30 s if the reactive power control set point is. More than 2% of the set point value or 0.5% of the maximum reactive power can be used as the tolerance for the accuracy of the control being conducted and the set point. Reactive power set points for the plant must be accurate to at least 1 kVAr.	Based on the reactive power control function curve, reactive power control of the renewable power plants is carried out.
Power Factor control	In order to manage reactive power using a fixed Power Factor, RPP must be able to execute Power Factor control. A new Power Factor set point must be controlled within a minute after being established.	At the POC, Power Factor Control adjusts the reactive power appropriately to the active power. The plant must update its echo analog set point value in response to the new value in response to the power factor set point modification within 2 s and reply within 30 s. The precision of the set point and the control operation cannot differ by more than ±0.02.	In proportion to the active power at the POC, reactive power is managed through power factor control. The set point shouldn't vary by more than ±0.02 points.
Power Quality	The power quality requirements outlined in the various IEEE and IEC standards must be met by the plant.	IEC 61000-4-7, Harmonics Calculation Power quality monitoring for flicker: IEC 61000-4-15 Class A IEC 61000-3-2:2018 Voltage and current quality distortion levels released by the facility at the POC IEEE 519-2014 Standard for Interconnecting Distributed Resources with Electric Power Systems Recommended Practice and Requirements for Harmonic Control: IEEE 1547	The Ethiopian grid code uses many IEC and IEEE standards to specify the types of power quality issues.
Transient and Short Duration Voltage Variations	Plant must not cause rapid voltage changes exceeding the limit value d(%) = 4%.	A brief voltage variation occurs when the voltage deviates from the nominal value for a period longer than a half-cycle of the power frequency but not more than one minute. The term "transient voltages" refers to high-frequency overvoltages that typically last less time than short-duration voltage variations.	A detailed description is available related to the transient and short-duration voltage variations.

Table 1. *Cont.*

Parameter	Danish Grid Code	Ethiopian Grid Code	Comments
Current and Voltage Unbalance	The current unbalance between the three phases of a plant must not exceed 16 A. Plants above 11 kW must have balanced three-phase connections	In order to achieve average levels of negative sequence voltage that are equal to or less than the set values, the current drawn should be balanced in each phase at each of its connection points. However, at any nominal voltage, the negative sequence voltage averaged over any 1 min period shall not exceed 2 percent in any hour.	Voltage unbalance information is presented based on the nominal voltage value.
Protection System	Plant is responsible for ensuring that it is dimensioned and equipped with the necessary protection functions so that: the plant is protected against damage due to faults and incidents in the public electricity supply grid. Relay settings must not prevent specified power-generating plant functions from functioning properly. Provides protection for the public electricity supply system against unintended effects of the power plant and from harm caused by asynchronous connections. The plant is prevented from disconnecting in non-critical circumstances so that it won't be harmed or turn off when the voltage drops.	To limit the effects of faults on the distribution level and to achieve the appropriate degree of speed, sensitivity, and selectivity in fault clearing, the protection of plants linked to the distribution grid and accompanying equipment must be developed, coordinated, and tested. The protection system for the electrical equipment and facilities on each of their respective sides of the connection point shall be the exclusive responsibility of the generating licensee. The protection system and switching arrangements should be made to separate the plant after the first main breaker, recloser, or sectionalizer opening, and to remain disconnected until the system has been fully restored, if the distribution network user facilities are connected to a feeder with auto-reclosing capabilities.	A detailed description about the protection schemes and their coordination is available in the Ethiopian grid code.
Islanding protection	Plant must detect unintentional island operation and must disconnect from the grid if unintentional islanding is detected.	The plant may be purposefully isolated in order to continue serving nearby consumers even when there is an outage. ANSI/IEEE Std. 1547-2003's Prevention of Unintended Islanding Operation (Loss of Mains)	Detailed information about protection systems to detect unintentional and intentional islandings are not presented.
Information Transfer	Plant is equipped with an interface (controller) at the point of communication enabling real-time exchange of signals. Plant must be acted no later than five seconds after the command to this effect has been received.	To effectively share the necessary information, the plant and big user (more than 2 MVA) will select contact people and agree on communication methods.	Procedures, information Flow, and Coordination, related to the information exchange are presented but a detailed framework is unavailable.

3.2. Comparative Analysis between the Ethiopian Grid Code and IEEE 1547-2003 and IEEE 1547-2018 Standards

A detailed comparative analysis of the proposed Ethiopian Grid code is performed with IEEE 1547-2003 and IEEE 1547-2018 standards for finding the future requirements of the Ethiopian grid code is presented in this section. Table 2 presents the comparative analysis of the proposed Ethiopian Grid code performed with IEEE 1547-2003 and IEEE 1547-2018 standards.

Table 2. Comparative analysis of the proposed Ethiopian Grid code is performed with IEEE 1547-2003 and IEEE 1547-2018 standards.

Parameters	IEEE 1547-2003 [25]	IEEE 1547-2018 [25]	Ethiopian Grid Code	Comments
Scope	Applied to DERs having an overall rating of no more than 10 MVA	Applied to DERs with a combined rating of at least 10 MVA	Applied to 20 MVA or higher	Higher capacity RPPs are incorporated in the Ethiopian grid code
Voltage Regulation	Regulation of the voltage at DER's Point of Common Coupling was forbidden (PCC)	DERs may regulate voltage to a limited extent.	Maintained at the values stated in the Performance Standards Code for voltage regulation	According to the aforementioned criteria, the Ethiopian grid code permits voltage control.
Faults and open phases	DERs stop energizing the region There is no information on the open stages.	DERs turn off the Area's energy The PCC or DER terminals must have an open phase for DER to function.	A fault might cause the generator plant's link to the distribution network to be severed.	In Ethiopia's grid code, open phases are not discussed at all.
Power Quality	Setting basic limits for power quality issues	A new part of the IEEE 1547-2003 standard is added that addresses the concerns listed below: 1. Inter-harmonic limits 2. DER contribution in Flicker 3. Rapid voltage change 4. Transient overvoltage	IEC 61000-4-7, Harmonics Calculation IEC 61000-4-15 Class A flicker Monitoring power quality: IEC 61000-4-30 IEC 61000-3-2:2018 Voltage and current quality distortion levels released by the facility at the POC IEEE 519-2014 Standard for Interconnecting Distributed Resources with Electric Power Systems Recommended Practice and Requirements for Harmonic Control: IEEE 1547	In Ethiopian GC, many IEC and IEEE Standards are mentioned for handling Power quality concerns.
Islanding	Solely the prevention of unintended islanding was discussed	Discussions are made of both unintentional and purposeful islanding.	Discussions are made of both unintentional and purposeful islanding.	There is no detailed information provided on the protection mechanism to identify accidental and deliberate islandings.
Communications	There is no standard for information sharing.	emphasis on the need for communications and compatibility with the standard being considered	Communication networks and management systems are explored in relation to the IEC 61850 standard.	Details of the information exchange's procedures, information flow, and coordination are supplied; however, the Ethiopian GC lacks a detailed framework.

4. Summary of the Ethiopian Grid Code

The proposed Ethiopian grid code incorporated the various technical standards and specifications related to the incorporation of various capacity renewable power plants under normal and abnormal operating conditions. These technical standards and specifications are related to the operations conditions such as Voltage Phase Jump, Tolerance for frequency and voltage deviations, Reduction in active power, Voltage drop, Voltage rise, Connection and reconnection, Absolute Power Constraints, Reactive Power Control, Power Factor

Control, Power Quality, Transient and Short Duration Voltage Variations, Current and Voltage Unbalance, Protection System, Islanding protection, and Information Transfer.

Different IEEE and IEC standards are utilized to provide the specifications for the above-discussed operating conditions.

5. Evaluation and Recommendation of the Ethiopian Grid Codes Modifications

After the evaluation of the whole Ethiopian grid codes, the following points are recommended.

i. Requirements related to the reactive power compensation are required to be incorporated. Similarly, specifications related to the ancillary services are required to be incorporated.
ii. A critical issue related to the hosting capacity of the distribution network is required to be incorporated. In the presented Ethiopian grid code draft, information related to the hosting capacity of the distribution network after the incorporation of renewable energy sources is unavailable. Some general rules are required to determine hosting capacity with renewable energy integration. This will depend on the grid transformer/cable capacity such as impedance, short circuit current, etc. Further, both the power and current should be evaluated, and also the harmonics for this purpose.
iii. A detailed framework related to the procedures and implementation of the information and communication technologies, their standard, and protocols are completely missing from the existing Ethiopian grid code document.
iv. Low-voltage ride-through (LVRT) capability requirements are mentioned in the grid code document but the requirements related to the High-voltage ride-through (HVRT) capability are not available in the document. Further, Fault ride-through (FRT) capability requirements are also not clearly available in the document. The limits for these capabilities can be determined based on the type and size of the renewable energy sources utilized in the system.
v. Detailed framework related to the information transfer is unavailable.
vi. Intentional islanding criteria and other related information are available in the Ethiopian grid code, but detailed information about the protection system to detect unintentional islanding is not presented. A suitable method (active or passive) for unintentional islanding can be selected based on the requirements of the system.
vii. There is no information available regarding the DC current components' presence in the grid. If it is available, how the system will deal with certain issues should also be discussed in the Ethiopian grid code document. DC content of the current injected by the plant into the grid should be below 0.5% of the nominal current of the plant.
viii. There is no discussion available related to the automatic power factor control.
ix. Nothing in the Ethiopian GC is mentioned regarding automated synchronization. The paper is also missing information on automated reconnection. When synchronization is involved, the operation is completed within ± 5 min of the scheduled synchronization time. The synchronized generation obtained is within a tolerance limit of the reported net capacity error of 2.5%.
x. Deployment of smart meters is a critical issue to integrate renewable energy sources at the distribution level, but the existing Ethiopian grid code does not discuss any information related to the implementation of smart meter technology in the existing distribution system. Critical studies related to the status of the system are required for the adequate deployment of the smart meters.
xi. Energy management system development at the distribution level is also critical for the integration of renewable energy sources at the distribution level, but the present document does not provide any information regarding the development, type, and implantation of such system into the distribution network.

xii. Incorporation of the controllable loads at the distribution level is also one issue that could be incorporated into the existing Ethiopian grid code documents. Some regulations based on the over/under voltage and frequency controls could be implemented if problems occur.
xiii. Flexibility issues related to the integration of renewable energy sources are also missing in the Ethiopian grid code.
xiv. Discussion about the impact of electric vehicle integration and charging on distribution networks is missing.

6. Pros and Cons of Recommended Ethiopian Grid Code

The recommendation grid code has the following advantages with some limitations.

6.1. Advantages

i. The proposed grid code supports the better implementation of smart grid technology in the Ethiopian distribution system.
ii. The recommended grid code supports the incorporation of various capacity renewable energy sources (recommended in the manuscript) at the distribution level in a more adequate way.
iii. The proposed grid code adequately operates and controls the renewable energy sources (as their operating ranges are critically discussed under normal and abnormal conditions) integrated at the distribution level.
iv. The recommended grid code suggests the integration of electric vehicle technology to the distribution level in a better way.
v. The recommended grid code suggests the better implementation of ICT technologies in the Ethiopian distribution system

6.2. Limitations

i. For the implementation of the proposed recommendations, capital requirement will be the major issue.
ii. Implementation of advanced controlling techniques such as artificial intelligence techniques is still not discussed in the grid code.

7. Conclusions

This publication provided a thorough analysis of the grid code offered by Ethiopia for integrating renewable energy sources into the distribution system. The document presents several technical details pertaining to the grid integration of renewable energy sources. The grid code requirements for integrating RPPs with the utility system were described in this publication. It specified the voltage band, frequency band, and disconnection times during under-voltage operation, etc., from the perspective of the RPPs' integration to the utility grid. Furthermore, a detailed comparative analysis of the proposed Ethiopian grid code with the Danish grid code is presented under various operating conditions. Moreover, a detailed comparative analysis of the Ethiopian grid code with IEEE 1547-2003 and IEEE 1547-2018 is presented. Lastly, detailed recommendations are provided based on the comparative analysis for the improvement of the proposed grid code. The paper also includes the auxiliary services requirements, which the plant has to deliver during operation and failure conditions. Based on the detailed discussion and analysis it is concluded that for remote RPPs, some lighter requirements such as voltage range, frequency range, etc., should be considered to support weak grid operation.

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