

Non-isolated Microgrid Business Models for Low Voltage Applications: A Case Study in Southern Brazil

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Declaration of Independence

I hereby declare that this thesis is my own work, that I have not presented it elsewhere for examination purposes and that I have not used any sources or aids other than those stated. I have marked verbatim and indirect quotations as such.

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Abstract

Power systems globally are undergoing a significant transformation driven by the need to transition from fossil fuel-based systems to low-carbon and renewable energy sources. Increasing distribution energy resources penetration has led to the development of local generation and consumption ideas and, consequently, the emergence of the microgrid concept. However, the displacement of traditional power plants by distributed energy resources, especially in low voltage grids, poses new challenges for distribution grids' operation, such as voltage control. The reactive power support capability of distributed energy resources, one of the microgrid components, makes them a potentially useful source for voltage issues. However, this support should be allowed within the framework permitted by regulations.

Although the Brazilian power system is mainly based on renewable energy sources, Brazilian legislation does not support the potential service capability of distributed energy resources. Moreover, the absence of an ancillary services market and the non-remuneration of ancillary services are the main reasons for distributed energy resources and microgrids not participating in such services.

This thesis proposes developing two business models for a non-isolated microgrid in Brazil, one that considers regulations and one that can be described as innovative by not considering regulations. The business model has been developed with a reactive energy compensation approach in which PV inverters are used. Furthermore, two different remuneration mechanisms have been proposed for the innovative business model. The microgrid where the developed business models are implemented is modelled and simulated in Open Distribution System Simulator with IEEE 13-node test feeder. Since the simulated microgrid does not have any voltage issues, sensitivity analysis is performed to be able to provide more accurate results. The sensitivity analysis results show that the proposed remuneration mechanism can motivate the microgrid to provide ancillary services, resulting in a profit for the microgrid and mitigating voltage problems of the distribution grid.

Keywords: non-isolated microgrid, voltage control, distribution grid, renewable energy, distributed energy resources, business model, sensitivity analysis, OpenDSS, simulation

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List of Abbreviations

AC	Alternating Current
ACL	Free Contracting Environment
ACR	Regulated Contract Environment
ANEEL	Brazilian Electricity Regulatory Agency
AS	Ancillary Service
BESS	Battery Energy Storage Systems
BM	Business Model
BUC	Business Use Case
CCEE	The Chamber of Electricity Commercialization
CERTS	Consortium for Electricity Reliability Technology Solutions
DC	Direct Current
DER	Distributed Energy Resource
D-FACTS	Distribution Flexible AC Transmission System
DG	Distributed Generation
DRES	Distributed Renewable Energy Resource
DSO	Distribution System Operator
D-STATCOM	Distribution Static Synchronous Compensator
D-SVC	Distribution Static Var Compensator
ESS	Energy Storage Systems
GHG	Greenhouse Gas Emission
HVAC	High Voltage Alternative Current
HVDC	High Voltage Direct Current
ICT	Information and Communication Technologies Infrastructure
IEC	International Electrotechnical Commission
LTC	Load Tap Changer
ONS	National System Operator
OpenDSS	Open Distribution System Simulator
PCC	Point of Common Coupling
PRODIST	Procedures of Electric Energy Distribution in the National Electric System
PROINFA	Program to Stimulate Alternative Electricity Sources
PV	Photovoltaic
RES	Renewable Energy Source
SG	Synchronous Generator
SIN	National Interconnected System
SOC	State of Charge
TE	Energy Tariff
TR	Technical Report
TS	Technical Specification
TUSD	Use of Distribution System Tariff

1 Introduction

The increasing population day by day in the world exceeds 8 billion today, and technology and industrial development bring the need for energy [1, 2]. Although there are resources to meet this need in the world, the resources are limited and running out; thus, using these fossil-based resources leads to various problems and doubts [3]. The use of renewable energy is acknowledged as a solution for meeting energy demand and combating global warming and has become a common practice in countries worldwide [3, 4]. Figure 1.1 shows the global primary renewable energy consumption between 2000 and 2021.

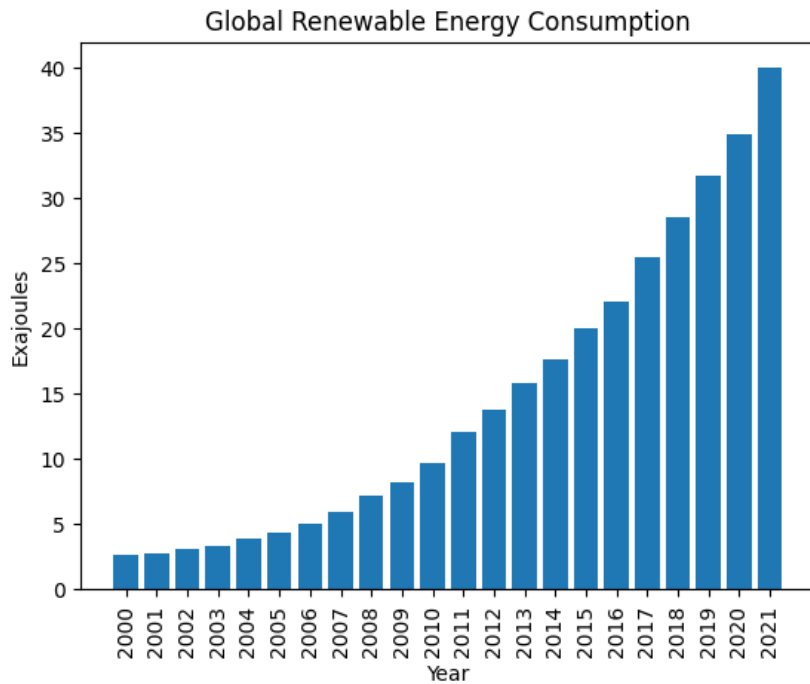


Figure 1.1: Global renewable energy consumption 2000-2021
(own illustration based on [5])

In addition to this, power systems are changing and evolving by targeting especially decarbonization, decentralization and digitalization [6]. Today, large-scale conventional power plants at high voltage levels have been replaced by distributed energy resources at lower voltage levels, leading to new concepts such as microgrids [7]. International Electrotechnical Commission (IEC) Technical Specification (TS) 62898-1-2017 refers to a microgrid as an aggregation of distributed energy resources that are capable of operation both grid-connected and off-grid [8, 9]. There are various global microgrid applications for different purposes as specified in IEC TS 62898-1:2017 [8] business use cases (BUC), and these can be listed as follows:

- **Security of energy supply (BUC A):** This business use case proposes to supply

critical loads during blackouts and provide uninterrupted electricity for microgrid customers [8]. For instance, the Thacher School microgrid project with 1 MW capacity aims to secure the energy supply by switching the microgrid to an island operation mode in case of grid outages and making electricity uninterrupted [10].

- **Service to microgrid customers with local resources (BUC B):** This business use case aims to generate profit for the microgrid through energy storage and grid services [8]. To give an example, General Motors E-Motor Factory microgrid project reduces the cost for the microgrid with energy storage systems while having revenue by providing ancillary services with the bi-directional inverter [10].
- **Providing electricity to remote areas (BUC C):** This use case has been developed to supply energy to isolated areas that cannot be supplied from the main grid [8]. In particular, Gaidouromantra microgrid, an isolated microgrid, was designed to provide electrical energy to 12 vacation houses in one of the Greek islands [11].
- **Power supply after disasters with local resources (BUC D):** This use case aims to extend the black-start ability of the electric power systems with local resources after blackouts[8]. Sendai microgrid is an application in Japan for a disaster-preparedness objective and illustrates this point clearly. After the devastating earthquake in Japan in 2011, the main grid was unavailable for days, and the backup generators and Sendai microgrid were able to energize [12].

Safe, reliable, high-quality power flow is crucial for electrical power systems, and the processes performed to ensure that flow is called ancillary services (AS) [7]. Traditionally, large-scale conventional power plants based on synchronous generators (SG) have been responsible for secure operation, and these are remunerated through various mechanisms by transmission system operators (TSO) or the corresponding AS market [13].

However, the displacement of bulk generation from large SGs to distributed energy resources (DERs) at lower voltage levels compromises the security of the power system. In many countries, especially at the distribution level, ancillary services are considered supporting services, and it is a requirement to connect distributed renewable energy sources (DRES) to the grid. In other words, these services do not generate revenue for DERs [14]. A remuneration mechanism for DERs that can provide these services could encourage systems to provide ancillary services.

This study aims to develop business models for non-isolated low-voltage microgrids to reduce the energy costs of microgrid users and provide ancillary services according to IEC TS 62898-1:2017 BUC B. In addition, it also focuses on identifying the necessary changes to achieve this goal and then analyzes the proposed model through a case study.

In this study Chapter 2 contains a comprehensive review of the technical background, including the traditional power grid, microgrid technology, ancillary service, and reactive power. Mentioning the business model canvas leads to Chapter 3, which provides information about the Brazilian electricity market and regulations. Chapter 4 describes the developed business models, and to analyze the proposed model, the Barigui Park project is simulated in Open Distribution System Simulator (OpenDSS) as a case study in Chapter 5. The study is finalized with a conclusion and provides an overview of the work that can be done in the future in Chapter 6.

2 Technical Background

In this chapter, traditional electric power grids are discussed first. Then microgrid technology is described, including its components, operation modes, types and impacts. In the following section, ancillary services and reactive power are presented. The chapter is finalized by describing the business model canvas.

2.1 Traditional Electrical Power Grid

Traditional power systems consist of generation, transmission, and distribution stages. First, electricity is produced through large conventional power plants, most commonly from synchronous generators. Then, the produced energy is transmitted to the distribution grid via a transmission system, either high voltage direct current (HVDC) or high voltage alternating current (HVAC), but mostly HVAC. Transmission can be done through overhead, underground, and underwater lines [15]. Lastly, the transmitted electrical energy is distributed to the end users in the distribution stage. These power systems are centralized, and power flow is hierarchical, from production to end users, to consumers. Figure 2.1 represents the stages of traditional power systems.

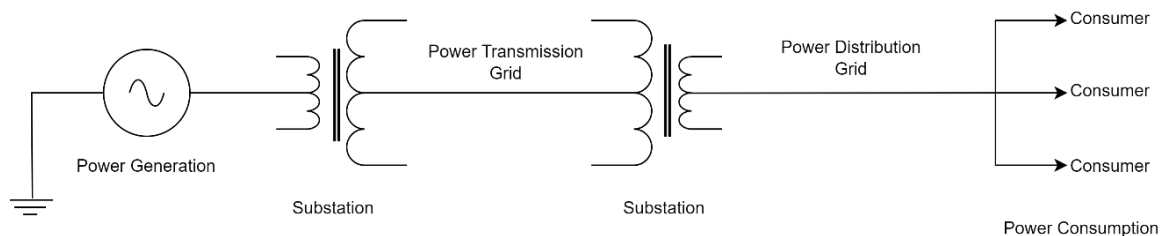


Figure 2.1: Stages of traditional power systems
(own illustration based on [16])

Reliable operation in power systems requires managing voltage and frequency within the predefined limit. It is called power system stability and can be defined as all generators in the power system having the same frequency and voltage angle differences. Synchronous generators are primarily responsible for the safety and continuity of the grid as well as the stability of traditional power grids [15, 17, 18]. However, traditional power systems in several countries, mainly predominantly reliant on fossil-based power plants, encounter significant environmental challenges. While the integration of renewable energy sources (RESs) in the grid reduces environmental problems, displacing fossil-based generations by distributed energy resources at lower voltage levels, and the constantly increasing energy demand disrupt the

supply and demand balance. Consequently, voltage and frequency issues occur in the traditional power system, leading to the evolution of the entire power system [19, 20].

2.2 Microgrid Technology

There has been considerable interest in microgrids due to their potential for enhancing power supply reliability and energy security, along with their economic benefits and the capability of clean energy integration [21, 22].

Fundamentally, a microgrid has a structure similar to the traditional grid and consists of generation, distribution, and load zones. Figure 2.2 shows the typical structure of microgrids. The generation part of a microgrid mainly comprises distributed energy sources, including photovoltaic (PV) systems, fuel cell systems, and wind power plants. Microgrids can operate as a part of the main grid, have switches to disconnect from the main grid when required, and can supply power to the islanded area independently. They can also provide energy to the main grid in cases where microgrid resources have surplus energy [23].

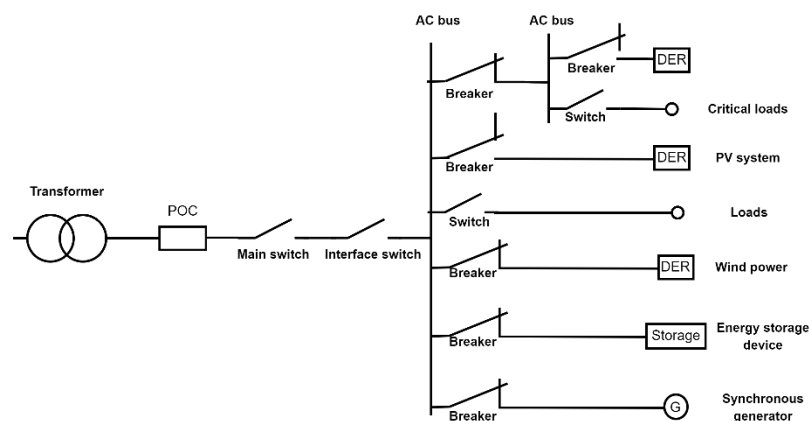


Figure 2.2: Typical microgrid structure
(own illustration based on [8])

Despite their structural similarity, microgrids differ from traditional power grids in many aspects, including size, operation, and technology. These main differences can be listed as follows [24]:

- Traditional power grids are large-scale networks with large generators serving large areas, while microgrids are smaller-scale systems with small-capacity resources serving localized areas.
- Traditional power grids are typically centralized systems, while microgrids are decentralized systems installed close to loads.

- Due to their localized nature, microgrids are more reliable and resilient than traditional power grids. During an outage, microgrids are better able to continue providing power to local loads.
- Microgrids differ from traditional power grids as they allow bidirectional power flow; they can receive electricity from the main grid and supply electricity to the grid.

Since the microgrid concept has been introduced, several standards, technical specifications and technical reports have been developed related to the concept. Furthermore, there are numerous standards, technical specifications and reports for distributed energy sources, which are the typical generation sources of microgrids [25]. The developed international specifications and reports include IEC TS 62898-1:2017, IEC TS 62898-2:2018, IEC TS 62898-3-1:2020 and IEC-TR 62898-4:2023, and Table 2.1 summarizes the scope of mentioned guidelines.

*Table 2.1: Mentioned guidelines and their scope
(own illustration based on [8, 9, 26, 27])*

Guideline	Title	Scope
IEC TS 62898-1:2017	Microgrids - Part 1: Guidelines for microgrid projects planning and specification	Guidelines for planning and specification of LV and MV AC microgrid projects, including generation and load prediction, control and communication systems, connection to the distribution system
IEC TS 62898-2:2018	Microgrids - Part 2: Guidelines for operation	Guidelines for the operation of LV and MV AC microgrids, including operation modes, anti-islanding, maintenance
IEC TS 62898-3-1:2020	Microgrids - Part 3-1: Technical requirements -Protection and dynamic control	Guidelines for fault protection and dynamic control of isolated and non-isolated AC microgrids
IEC-TR 62898-4:2023	Microgrids - Part 4: Use cases	Microgrid high-level use cases as “decentralized energy system” covering the typical application of microgrids based on IEC 62913-1

2.2.1 Components of microgrid

Components of the microgrid can be sorted as follows: Distributed generation (DG) units, energy storage systems (ESS), loads, and control systems. Typical specifications of those DGs are presented in Table 2.2.

Table 2.2: Common DG sources and their properties
(own illustration based on [28])

	Solar	Wind	Micro hydro	Diesel	CHP
Availability	Geographical location dependent	Geographical location dependent	Geographical location dependent	Any time	Dependent on source
Output power	DC	AC	AC	AC	AC
GHG emission	None	None	None	High	Dependent on source
Typical interface	Power electronic converter	Power electronic converter	Synchronous or induction generator	None	Synchronous generator

A **distributed generation unit** is a small-scale power source that is located close to the consumption area, unlike typical centralized power generation, where massive power plants are far from the end consumers. PV, wind turbines, fuel cells, micro-turbines, and small-scale hydropower generators are the most common technologies used in distributed generation systems [28]. In addition to better energy efficiency and improved power quality and reliability, DGs can also reduce transmission and distribution losses. Also, they can contribute to lower reliance on centralized power plants and offer a more flexible and reliable power system [29].

ESSs play an essential role in microgrid systems by balancing the electricity supply and load demand [30]. They can be considered a backup power source during power outages, guaranteeing the uninterrupted operation of essential facilities and services. Furthermore, ESSs can minimize the total energy expenses of microgrid systems by retaining extra energy when demand is low and dispensing it during high-demand periods [31]. Battery energy storage systems (BESS), thermal, pumped hydro, and flywheel energy storage systems are some energy storage technologies used in microgrids [32]. Figure 2.3 illustrates the energy storage technologies used in power systems.

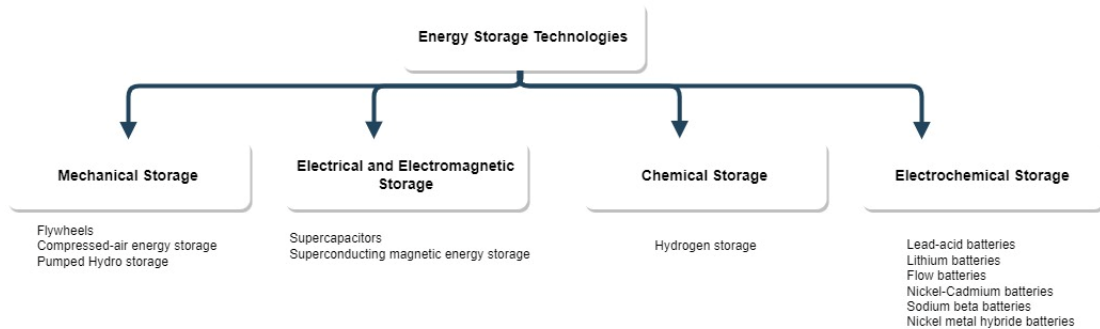


Figure 2.3: Energy storage technologies used in power systems
(own illustration based on [32])

The energy storage technology used in microgrids depends on specific grid needs, including storage duration, response time, cycle capacity, discharge time, and available resources [32]. Lower cost and energy density make electrochemical storage one of the preferred storage technologies for microgrids [31, 33].

Microgrid loads are various energy-consuming parts of the microgrid, which can be categorized concerning their importance or types [34]. According to their types, the microgrid loads can be classified as industrial, commercial or residential. Concerning their importance, they are considered critical or non-critical [34, 35].

The control system is a crucial electronic component for the effective operation of a microgrid. Its essential function is to optimize the operation of the system by utilizing data from different sources. Specifically, the unit ensures that the microgrid operates within predetermined voltage and frequency limits. Moreover, the control system monitors regularly for safe and reliable microgrid operation [36].

2.2.2 Operation modes of microgrid

The microgrids have two operating modes based on their connection to the main grid. The microgrid that operates in non-isolated mode can be considered a controllable entity from the main grid point of view as it is connected to the external grid with a switch. The non-isolated mode consists of grid-connected and islanded modes. During the grid-connected mode, the power flow is from the main grid to the microgrid through the point of common coupling (PCC) or vice versa [8, 37]. Secondly, in islanded mode operation, the microgrid is unlinked from the main grid at PCC. In this operation mode, the microgrid operates independently from the main grid; hence it is responsible for the balance between its generation and consumption. Supplying critical loads from its own generation and energy storage sources is one of the most important concerns for this operation mode. In other words, load shedding becomes a crucial aspect of the islanding operation [3].

In isolated operation mode, the microgrid is continuously operated off-grid. In contrast to the non-isolated mode, the microgrid is responsible for its frequency, voltage regulation, and power balance since there is no main grid contribution [35]. The isolated microgrids are not elaborated in the thesis' scope.

2.2.3 Types of microgrid

Depending on their connection to the common bus, microgrids consist of alternating current (AC), direct current (DC), and hybrid microgrids [34]. Their structures are shown in Figure 2.4.

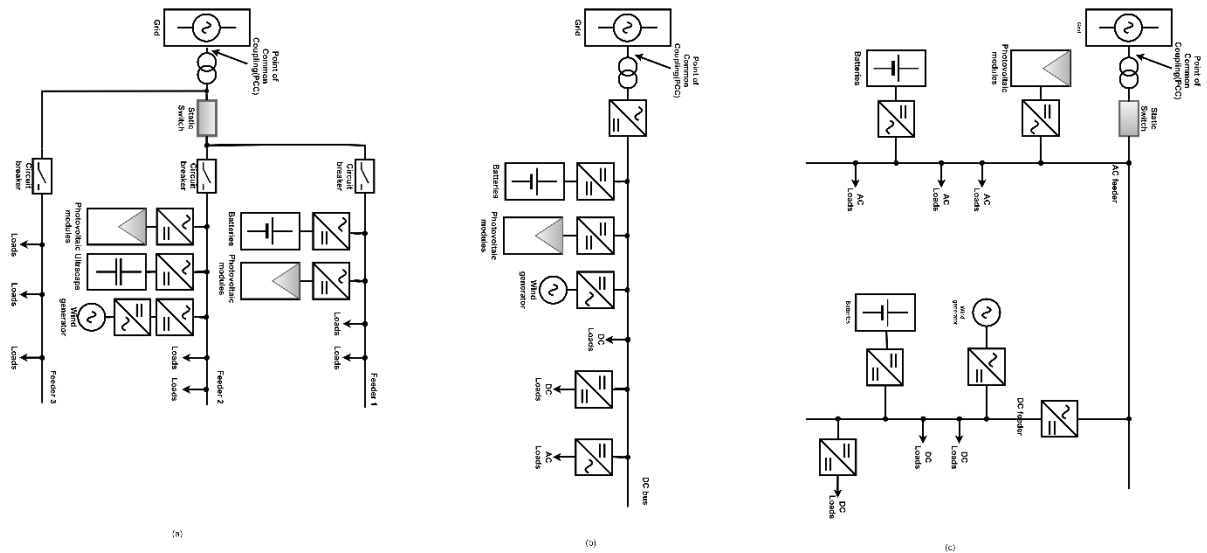


Figure 2.4: AC microgrid(a), DC microgrid(b), and hybrid microgrid structure(c),
 (own illustration based on [38])

In AC microgrids, DERs are coupled to the common bus via power electronic interfaces, while loads are linked simply to the common bus [3]. AC microgrids are the most widely implemented type of microgrid, and their resemblance to traditional power systems is one of their most essential advantages [34].

In DC microgrid architecture, all the microgrid components are coupled to the DC busbar, whereas the microgrid is linked to the AC grid at the PCC via a bi-direction converter [39]. DC microgrids have a comparably simple structure and lower losses as they have less energy conversion, and these are among the prominent advantages of DC microgrids [3].

The hybrid microgrid architecture is formed by utilizing the strengths of the other two types[38]. It is composed of DC and AC networks connected to the grid. The loads and DERs are linked to the respective bus, either in AC or DC, considering the minimization of energy conversion [34].

2.2.4 Impacts of microgrid

The microgrid concept offers environmental, economic, and technical advantages. In this context, according to [3, 15, 24, 36], the benefits of the microgrid can be listed as follows:

Environmental benefits: While traditional power utilities are fossil-based, microgrids have a minor negative impact on the environment since they are based on either renewable energy or low-emission fuels. Therefore, greenhouse gas emissions (GHG) and global temperature rise can be reduced.

Economic benefits: Using renewable energy is not only an environmental benefit but also

an economic benefit as it reduces energy costs through local production. Using own resources during peak times also reduces energy costs for microgrids. In addition, selling energy to other consumers, where possible under regulations, is another economic benefit.

Technical benefits: Since the location of microgrids and their sources are close to loads, there are shorter energy flows, and being close to loads reduces transmission and distribution losses. In addition, the possibility of the microgrid disconnecting from the main grid in case of any outages ensures continuous electricity provision for critical loads. The capability of providing ancillary services to the grid through distributed energy resources can be considered another technical advantage of microgrids.

2.3 Ancillary Service

The term “ancillary service” in the power system is described as the additional service, other than electricity generation, required for a stable and reliable electric power system [40]. These services can be evaluated under frequency response, black-start capability and voltage control through reactive power support [13].

Frequency is a characteristic related to active power, and it must be stabilized within a specific range for the proper operation of an AC power system. The frequency is maintained by matching the supplied active power to the loads in real-time [41]. Any disturbance between generation and consumption causes an increase or decrease in frequency and must be adjusted immediately to avoid instability and possible power outages [42]. Frequency control as an ancillary service comprises of maintaining the frequency at the nominal operating level [14]. Frequency-related ancillary services are additionally divided into frequency restoration, containment, and replacement reserves [13]. However, it is not investigated further in this study.

Black-start capability as an ancillary service is another critical component for the reliability of the power systems. It can be defined as the restart of a power grid experiencing a complete or partial blackout, and this service is provided by specified generators called black-start units. The power plants will be able to operate with the help of the black start units, and the power system will be restored [14]. In the scope of the thesis, the black-start capability will not be elaborated further in the study.

Voltage is a characteristic related to reactive power. It must be maintained within a specific range to ensure the proper operation of all equipments in the power system without any damage and a stable and reliable supply of electricity [14]. The most significant effect causing voltage instability in the power system is the lack of required reactive power [43]. For particular types

of loads, the consumption of active and reactive power is observed simultaneously, and increased reactive power demand of the loads causes a voltage drop at the bus. Therefore, the lines consume more reactive power and again cause voltage drops and voltage instability in the power system [43, 44]. Furthermore, the high integration of electric vehicles leads to an overload and, consequently, a voltage drop. Besides, high penetration of DER causes some voltage-related issues. For instance, high PV integration causes voltage rise, especially on long low-voltage feeders, due to its high resistivity characteristic. DERs may supply energy to the main grid, causing reverse power flow. Reverse power flow increases the voltage; this makes the operation of traditional voltage control sources more complicated. Additionally, RESs can cause voltage fluctuations due to their dependence on weather conditions for a generation [45–48]. Voltage control is an ancillary service to ensure that the voltage level in the power system remains within the required limits by supplying or consuming reactive power.

2.4 Reactive Power

Although reactive power does not correspond to actual energy consumption or supply, unlike active power, it significantly affects power systems. The reactive power flow in the power grid causes a phase difference between current and voltage. More specifically, the current fluctuates back and forth, resulting in a phase shift between the two waveforms. The increase of reactive power in the power system has a negative impact on the active power to be supplied as it leads to line losses in the grid [49, 50]. The impact of reactive power on a grid goes beyond line losses; it also significantly affects the system's voltage [49]. Reactive power injection to the system leads to a voltage rise in the grid voltage, while reactive power absorption results in a voltage drop [44]. Considering the effect of DERs on the voltage of the electric system, reactive power compensation becomes more critical.

2.4.1 Reactive power sources in distribution grids

Load Tap Changer: Although a load tap changer (LTC) is not a reactive power compensator, it can be combined with reactive power compensation technologies to regulate voltage. The LTC regulates the voltage by adjusting the ratio between the windings of a transformer with the taps. There are two types of LTCs, off-load and on-load, but since the transformers do not need to be disconnected, on-load tap changers are one of the most preferred sources in distribution power systems [51–53].

Distribution Static Var Compensator (D-SVC): A distribution static var compensator is one of the distribution flexible AC transmission system (D-FACTS) device that continuously

maintain the grid voltage at a set reference point [54]. SVCs can absorb and inject reactive power through the reactor and capacitors they comprise [55].

Distribution Static Synchronous Compensator (D-STATCOM): STATCOM is another FACTS device which compensates the reactive power. STATCOM, which has a fast reaction time, can absorb reactive power from the grid and inject it to the grid. These devices help to regulate the grid voltage by exchanging reactive power with the grid. The STATCOMs used in the distribution system are called D-STATCOMs [54, 56].

Capacitor Banks: Capacitor banks are another source that help to regulate voltage by supplying reactive power to the grid. These sources are typically located in distribution grids and can be of two types: fixed and switched [55].

Inverter-based DER: Although coupling DERs into the grid brings voltage issues, the inverter that they are connected to can inject and absorb reactive power. This ability may bring another solution for voltage issues of the distribution grid [57]. The inverters can solve voltage issues at PCC by reactive power control under various control techniques, including the function of injected active power, fixed power factor control, and voltage-dependent reactive power control (Volt-VAr). Since reactive power injection and absorption can be performed without active power generation, the Volt-VAr technique is considered in this study. In this technique, the inverter provides or consumes reactive power with respect to PCC voltage [58].

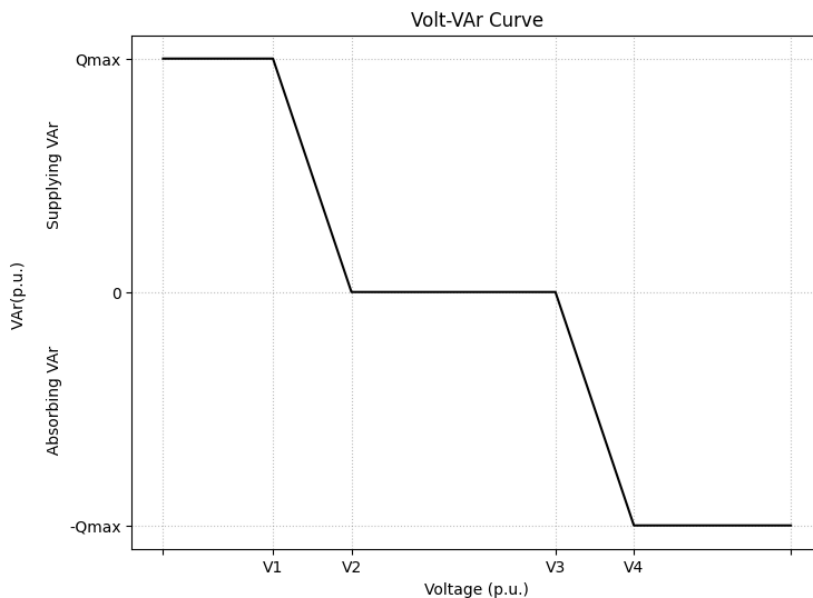


Figure 2.5: Volt-VAr curve
(own illustration based on [58])

As seen in the Volt-VAr curve in Figure 2.5, when the voltage at PCC is between V2 and V3, in the predefined limits, the inverter does not provide or absorb any reactive power. On the

other hand, the inverter absorbs reactive power when overvoltage occurs. On the contrary, if undervoltage occurs, the inverter injects reactive power to increase the voltage at PCC.

2.4.2 Remuneration structures and price types for reactive power

As stated by [59], the pricing structure for reactive power comprises three fundamental elements: the cost component, service type, and the price settlement mechanism if it is remunerated.

The cost components of reactive power can be listed as follows:

- Cost of loss: The reactive power negatively impacts the active power by reducing the amount that could flow. The amount of the decrease in “real” power is related to the cost of loss.
- Switching costs: This component occurs due to the switching lifetime of mechanically switched sources.
- Lost opportunity cost: The source must reduce the active power for every injected or absorbed reactive power. Reduced active power negatively affects sources’ revenue from providing active power to the grid.

Service types of reactive power may consist of the following:

- Fixed price: Reactive power products are remunerated regardless of demand and time.
- Availability price: Reactive power resources are remunerated for the product’s availability and capacity, whether used or not.
- Utilization payment: Reactive power source is remunerated based on the amount of the used product.
- Utilization frequency price: The source is paid by the frequency of the delivered product.
- Compensation of lost opportunity cost: It is a repayment to a resource for potential revenue they have lost by providing reactive power.

Price settlement mechanisms for reactive power can be structured as follows:

- Regulated price: The price of the reactive power is set by regulators considering various factors, including the cost and demand of the product.
- Uniform price: All bids for the quantity of product needed are ranked from cheapest to most expensive, and the highest bid prices are paid to all sources.
- Area-wise uniform price: Uniform price mechanism is implemented separately for

each area.

- Nodal price: Separate pricing is provided for each node of the grid.
- Pay-as-bid: Unlike the uniform price, this mechanism pays resources by their bid.

2.5 Business Model Canvas

A business model (BM) is a strategy for a business that outlines how a firm creates value, generates revenues, manages costs and meets customer needs [60]. It helps business owners determine how to operate their business, how to serve customers, and what kind of profit-making plan to adopt [61]. The business model canvas is an illustration of the business model. It is a one-page strategic tool comprised of nine building blocks, which can be grouped under four main categories as shown in Figure 2.6 [61].

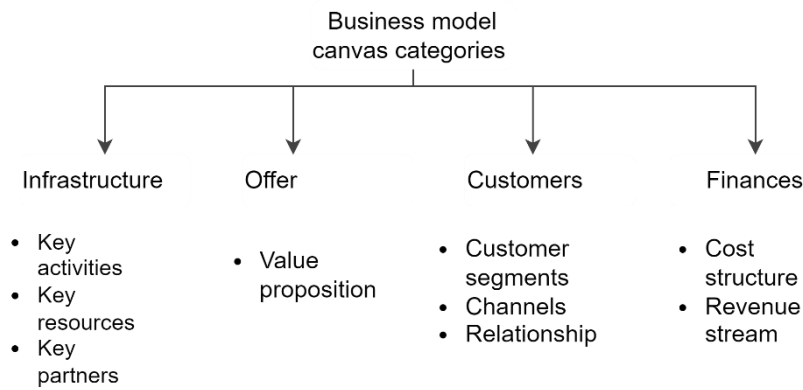


Figure 2.6: Business model canvas categories
(own illustration based on [61])

In the book [60], although the customer segment is identified as one of the most critical blocks for business model development, concerning the study’s aim, the value proposition can be considered as the most critical block of the canvas.

The Value Proposition clarifies the value a business offers to its customers and how it differentiates itself from competitors. Businesses’ understanding of customer needs makes this block an essential canvas component [60].

Considering non-isolated microgrids, the value proposition of the business model canvas may include resilience, flexibility, energy security, local consumption promotion, energy security, cost savings for microgrid users, grid services, increased energy independence and carbon emission reduction with renewable energy resources [8].

The Customer Segments is another vital block in the business model canvas. This block represents the people or organizations from whom the business will generate revenue by

meeting their needs through the value proposition. The identification and comprehension of the customer segments allow businesses to meet the needs and preferences of their customers [60].

Although it may vary according to several factors such as location, in general, residential, commercial, and industrial customers, power distribution utilities and distribution system operators can take place in the customer segment for a non-isolated microgrid business model [61].

The Channels block represents how a business interacts with its customers [62]. As the *Channels* block can be considered a bridge between the *Customer Segments* and the *Value Proposition* block, it is placed between them.

Since it connects the microgrid to its customer, the local grid is one of the key channels of a non-isolated microgrid business model. Others can be sorted as information and communication technologies infrastructure (ICT), electricity and ancillary service markets.

The Relationship block focuses on how a business will provide value to and interact with customer segments.

This block may contain energy providers, equipment suppliers, regulators and microgrid customers for the non-isolated microgrid business model canvas.

The Revenue Stream comprises the various ways the company can have revenue by delivering value to its customer segments [62].

This block may include the sale of electricity, energy production, and consumption based on energy pricing and the provision of grid services for the non-isolated microgrid business model canvas.

Key Resources block denotes the essential elements a business needs to possess to generate and provide value to its customers [60].

The key resources can be electric vehicle charging stations, control and monitoring systems, photovoltaic panels, wind turbines and energy storage systems of a non-isolated microgrid.

The block “**Key Activities**” contains the operations or processes that the business provides to generate revenue from its customers [61].

The key activities of the non-isolated microgrid business model can include energy surplus, local generation, energy storage, islanding operation and ancillary service provision.

Key Partners building block stands for the strategic relationships the organization establishes to offer value to its customers. The partnerships help to optimize resource usage, and through partnerships, risks and costs of the activities may be lowered [60, 62].

In non-isolated microgrid business models, power distribution utilities, distribution system operators, government agencies, energy traders, electricity and ancillary service markets, and prosumers can be included in the key partners building block.

Cost Structure is the costs arising in a company operating with a business model. Osterwalder and Pigneur [60] emphasize that this building block is vital in increasing profitability by optimizing cost factors.

Capital and operating expenditures of microgrid, fuel costs- if the microgrid has a fossil-based backup power source, distribution cost, and electricity purchased from the supplier may be possible cost structure elements of a non-isolated microgrid.

3 Brazilian Electricity Market and Regulations

The Brazilian power system is one of the most extensive power systems in the world, with 656.1 TWh of annual electricity production as of 2021. The country's leading source of electricity is hydropower, with more than half of the total supply [63]. However, wind and solar power have been dramatically increasing and are expected to continue to increase their share of the country's electricity production in the coming years. To express it in numbers, solar photovoltaic production increased by 55.9% in 2021 compared to the previous year and reached 16.752 TWh. Likewise, wind power generation increased by 26.7% to 86.957 TWh [64].

The Brazilian transmission system, the National Interconnected System (SIN), is a country-wide interconnected grid with 179,311 km of high-voltage transmission lines by 2022 and meets 99% of the country's total demand [65]. The SIN's operation is coordinated and controlled by the National System Operator (ONS), and SIN comprises four regions: South, Southeast/Mid-West, North-East and North region [66]. Electricity distribution is operated by 105 distributors, 52 permissionary and 53 concessionaires. Fifty-one distributors are located in the south, 35 in the southeast/mid-west, 12 in the northeast and 7 in the north region [67].

In Brazil, several bodies are involved in the electricity sector. Brazilian Electricity Regulatory Agency (ANEEL) and The Chamber of Electricity Commercialization (CCEE) are the agencies in charge of the commercialization of electricity. ANEEL is the regulator of the electric energy market created by the Brazilian government. It supervises electric energy at every stage, from generation to commercialization. It also has the authorization to issue licenses for the generation, distribution and transmission of electricity to ensure that these activities comply with the legislation. In addition, it plays an essential role in establishing electricity tariffs [68]. Besides, CCEE manages the operation of the Brazilian electricity market. In this respect, it acts as a bridge for commercial activities between producers, distributors, and consumers. Its operations are monitored and supervised by ANEEL [69].

The Brazilian electricity market is divided into contract and energy reserve markets [70]. Figure 3.1 shows the simplified structure of the Brazilian contract market.

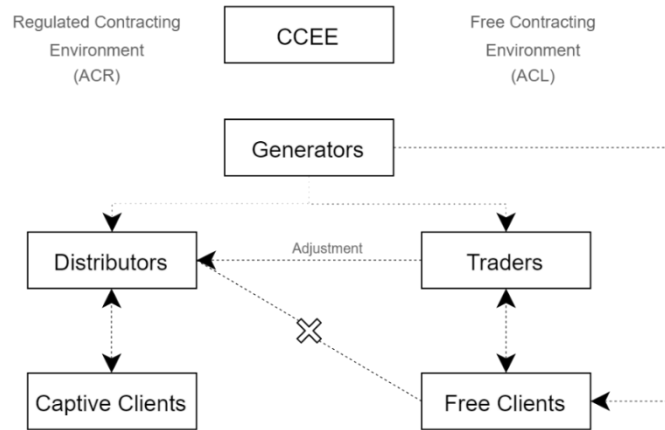


Figure 3.1: Simplified structure of the Brazilian electricity market (own illustration based on [71])

In the Regulated Contract Environment (ACR), utility companies, distributors and traders participate in auctions carried out by ANEEL [72]. In this contracting environment, consumers can not choose their suppliers; electricity is supplied by distribution companies that procure electricity through auctions [73].

In the Free Contracting Environment (ACL), the contract is executed through electric energy trading by generators, power marketers, large customers, and special-status customers. In this contracting environment, trades will be freely negotiated and governed by bilateral contracts for buying and selling energy in compliance with defined trading rules and procedures [74]. Decree 5.163/2004 and Law 9.074/1995 have defined the concepts of free consumers and special-status consumers. In this context, free consumers are defined as consumers having electricity loads equal to or greater than 3,000 kW, while special-status consumers are stated as free customers having a demand of 500 kW or higher who meet their energy use from micro-scale wind, biomass or solar-based sources [74, 75]. With Decree No. 465/2019, the entry limit to the free market has been gradually reduced to less than 500 kW by 1 January 2024; as of today, the entry limit is 500 kW [76].

Furthermore, the reserve energy market was introduced in 2008 to improve the security of supply of the interconnected system, which is one of the main objectives of the Brazilian electricity policy [70, 77]. The reserve energy is another auction-based structure in the country's electricity market, which has a similar process to ACR, with auctions organized at the government's request and managed by CCEE [70].

ANEEL also introduced the electricity compensation system, net metering, in Normative Resolution No. 482/2012 and expanded its scope in Normative Resolution No. 687/2015.

According to normative resolutions, renewable energy sources connected to the low- and medium-voltage grid are allowed to inject excess electricity into the main grid. The sold energy is defined as a credit that the consumer is able to use for up to 60 months [78].

The pricing structure for electricity consumers is regulated according to ANEEL Normative Resolution No. 1,000/2021 and Tariff Regulation Procedures [79]. Consumers are categorized into two main groups: Group A and Group B.

Group A consumers are those connected to 2.3 kV and higher voltages or have a voltage level lower than 2.3 kV and are supplied by underground cables. Group B consumers are those connected to a voltage level lower than 2.3 kV [80]. The sub-groups of consumer categories and their descriptions are represented in Table 3.1.

Table 3.1: Electricity consumer categories
(own illustration based on [80])

Group A	Group B
A1: Connected voltage level ≥ 230 kV	B1: Residential
A2: $88\text{kV} \leq$ Connected voltage level ≤ 138 kV	B2: Rural
A3: Connected voltage level = 69 kV	B3: Other classes
A3a: 30 kV \leq Connected voltage level ≤ 44 kV	B4: Public lighting
A4: $88\text{kV} \leq$ Connected voltage level ≤ 138 kV	
AS: Connected voltage level ≤ 2.3 kV with the underground distribution system	

The tariffs of both groups vary according to the hours that the distributor decides, except for certain days, including weekends and national holidays. Group A consumers are charged peak and off-peak tariffs, while Group B consumers are charged peak, intermediate, and off-peak tariffs [80]. Additionally, electricity price comprises energy price (TE) and use of distribution system (TUSD) price [81]. Based on this information, since this thesis focuses on Group A AS consumers, table 3.2 shows tariff prices for AS consumers.

Table 3.2: AS consumer's electricity tariff
(own illustration based on [81])

	TE (R\$/kWh)	TUSD (R\$/kWh)
Off-peak tariff	0.3159	0.182
Peak tariff	0.49593	0.18256

The Brazilian electricity system, which relies heavily on hydroelectric power plants, is considered comparatively green. Despite being one of the world's most carbon-free sectors, Brazil has made significant progress in the last few decades in promoting renewable energy, distributed generation, and micro generation to reduce GHG emissions [82]. It has implemented

many laws and regulations to achieve this goal, and these significant regulations and changes can be listed as follows:

Law No 9,478/1997 defines the national energy policy of the country, which comprises promoting renewable energy, using alternative energy sources and protecting the environment [83].

Law No 10438/2002 establishes the Program to Stimulate Alternative Electricity Sources (PROINFA), aiming to reach 3300 MW of renewable energy capacity [84].

Normative Resolution No 482/2012 entered into force to define net metering for small PV, wind and biomass generators in addition to general rules for the interconnection of distributed micro and mini generation in the distribution system with the Brazilian technical standards [84].

Normative Resolution No 687/2015 revises Resolution No 482/2012, furthermore introducing distributed generation into the concept of micro and mini generation. This resolution provides technical specifications for connecting distributed generators to the grid.

Normative Resolution No 792/2017 introduces a demand response mechanism and defines the consumers who may take part in this program [85].

Normative Resolution No 956/2021 settles and standardizes technical procedures for operating electricity distribution systems through Procedures of Electric Energy Distribution in the National Electric System (PRODIST), composed of 11 modules [86].

The market structure in the Brazilian electricity sector has not been introduced concerning ancillary service. The provision of frequency control and voltage control required for the grid's reliability is determined by a regulation. Normative Resolution No 697/2015 sets the rules for primary frequency control, secondary frequency control, and reactive support must be provided without any remuneration, whenever requested by ONS, from all generating units that meet the minimum requirements defined in PRODIST [87].

4 Development of the Business Models

Concerning business model development in the energy sector, business models are associated with countries' sector-related legislation and legal regulations, including promoting renewable energy, using alternative energy resources and reducing carbon emissions. In addition to the laws regulating energy production, distribution and sales, there are also technical standards for the energy sector, such as licensing energy resources and its coupling to the main grid. Hence the legal framework should be considered while developing the business model. While regulations and standards ensure that the business operates under legal obligations, the business model evolved by considering these regulations is also crucial for the sustainability and success of the business.

According to IEC TS 62898-1:2017 BUC-B [8] and as discussed in Chapter 3, the established business model for a non-isolated low-voltage microgrid is presented in Table 4.1.

Table 4.1: Established business model by considering Brazilian regulations (First BM)

Key Partners	Key Activities	Value Proposition	Relationship	Customer Segments
-Power Distribution Utility	-Energy surplus -Local generation -Energy storage -Islanding operation	-Reducing the energy cost for microgrid users -Promoting local consumption -Grid services -Facilitating renewable energy integration	-Energy providers -Regulators	-Distribution power utility
	Key Resources		Channels	
	-PV -BESS		-Local grid -ICT	
Cost Structure			Revenue Stream	
-Capital and operating expenditure of microgrid -The distribution system use tariff -Electricity purchase from supplier			-Electricity surplus	

The fundamental barrier to the developed business model is the lack of an ancillary service market in the Brazilian electricity market. Introducing such a market by regulators would make distribution system operators another element of customer segments. Consequently, the microgrid can provide ancillary services to offer its value propositions through the ancillary service market, making the system operator one of the key partners. Lastly, and most importantly, the microgrid generates revenues by providing ancillary services, precisely voltage control through reactive power provision.

If an ancillary service market had been introduced and DG participation in this market is regulated, the business model outlined in Table 4.1 could be evolved to the business model indicated in Table 4.2.

Table 4.2: Developed business model canvas by not considering Brazilian regulations (Second BM)

Key Partners	Key Activities	Value Proposition	Relationship	Customer Segments
-Power Distribution Utility -DSO	-Energy surplus Local generation -Energy storage -Islanding operation -Reactive power provision	-Reducing the energy cost for microgrid users -Promoting local consumption -Grid services -Facilitating renewable energy integration	-Energy providers -Regulators	-Distribution power utility -Distribution system operator (DSO)
	Key Resources		Channels	
	-PV -BESS		-Local grid -AS market -ICT	
Cost Structure			Revenue Stream	
-Capital and operating expenditure of microgrid -The distribution system use tariff -Electricity purchase from supplier			-Electricity surplus -Provision of ancillary service	

Considering all the information provided, two remuneration methods for the ancillary service market are proposed for the developed second business model. The first proposed remuneration method combines pay-as-bid and regulated prices. In this structure, to encourage providers to submit competitive bids, which can lead to lower prices for ancillary service products, pay-as-bid price settlement is used in areas where competition is likely to be high; there are many providers. A regulated price is proposed in sub-markets with fewer providers, and competition is infeasible. The second method proposes that the use of the distribution system tariff charged from consumers by distribution system operators should not be billed to consumers who help mitigate voltage issues by providing reactive power. In addition, compensation for the lost opportunity costs of the active power generation that they lose for reactive power compensation. Since the first proposed remuneration mechanism is the auction-based-payment method and analyzing this bidding process requires excessive information, including specifying the quantity of the product and each provider's bidding price, the second mechanism is analyzed with a case study.

5 Case Study

The preceding sections of this work have presented the developed non-isolated microgrid business models and have suggested schemes for supporting the grid through reactive power compensation from microgrids in the case of Brazil. This chapter focuses on simulating an existing microgrid system with a test feeder in OpenDSS.

5.1 Barigui Park Microgrid

The Barigui Park microgrid is a pilot project executed under the ANEEL PD-02866-0511/2019 research and development project, where self-generation with PV and BESS can meet the energy demand when the distribution grid is insufficient. The project was implemented at the Curitiba Municipal Institute of Public Administration, as shown in Figure 5.1 [88].



Figure 5.1: Curitiba Municipal Institute of Public Administration ([89])

Barigui Park is located in southern Brazil, more precisely in Curitiba, the capital of Paraná state. The park's exact location can be identified using geographic coordinates 25.427003° S and 49.307953° W.

There is typically more daylight during summer, and the weather is usually less cloudy than in other seasons. Thus, solar radiation is higher in summer. Conversely, daylight is less in winter; the weather is often more rainy and cloudy than in other seasons, resulting in less solar radiation. Based on this information and the National Institute of Meteorology data [90], the highest irradiation for Curitiba occurs in January and the lowest in July. Figure 5.2 illustrates the weather-related data for both January and July.

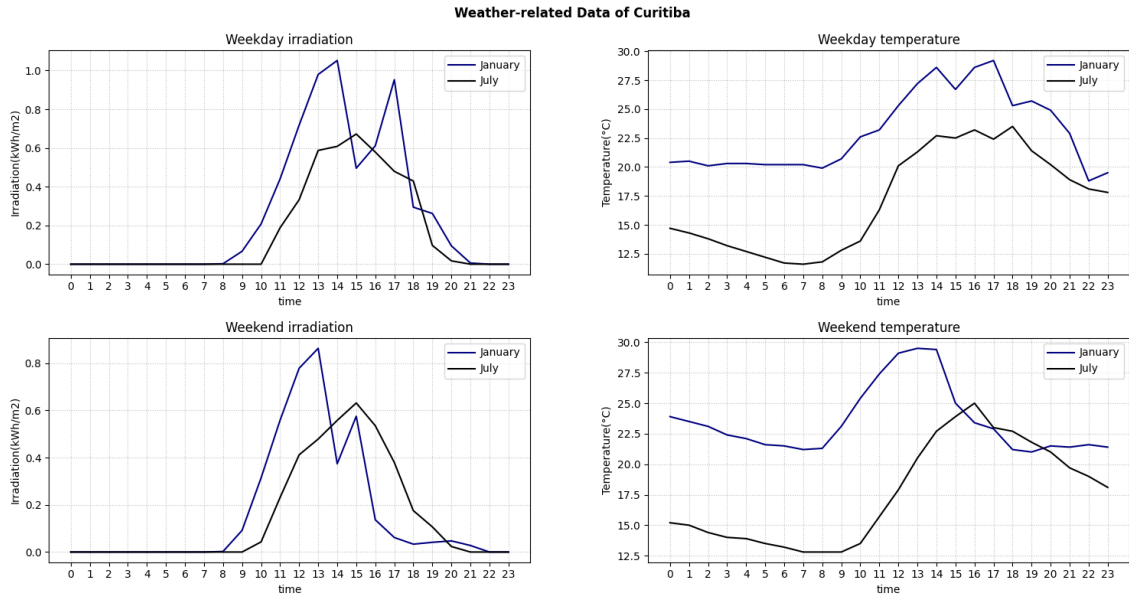


Figure 5.2: Weather-related data for Curitiba on a weekday and weekend (own illustration based on [90])

As mentioned in the previous chapters, there are two different electricity prices for Group A consumers on weekdays: peak and off-peak. From this perspective, the weekday and weekend load profiles are shown in Figure 5.3.

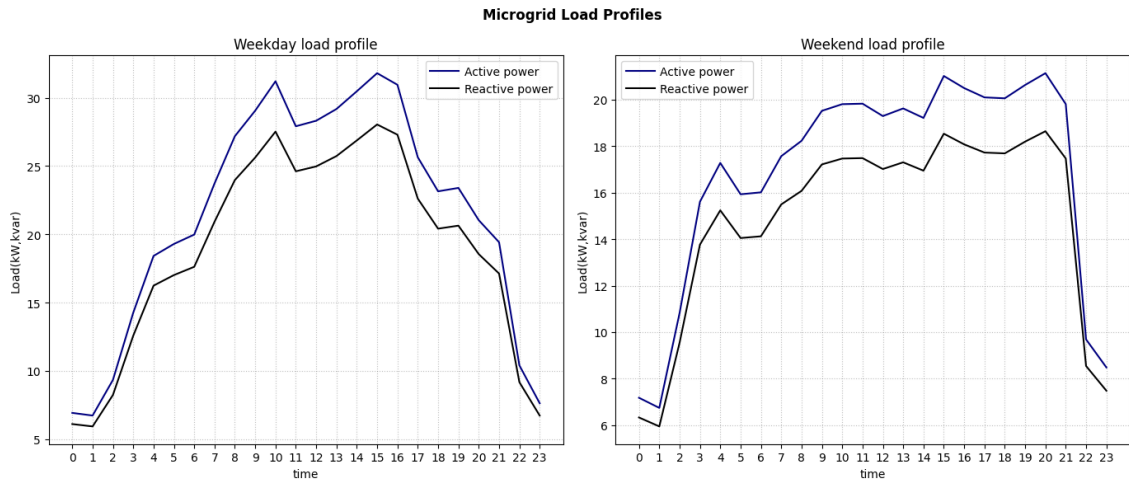


Figure 5.3: Microgrid load profiles on a weekday and weekend (own illustration based on [91])

The microgrid consists of a PV system with a capacity of 32.64 kWp, including 96 PV panels of 340W each, a battery energy storage system composed of three units with a total capacity of 28.8 kWh and an input/output nominal power of 8.7 kW, and an electric vehicle charging station [92]. The simplified representation of the microgrid is illustrated in Figure 5.4.

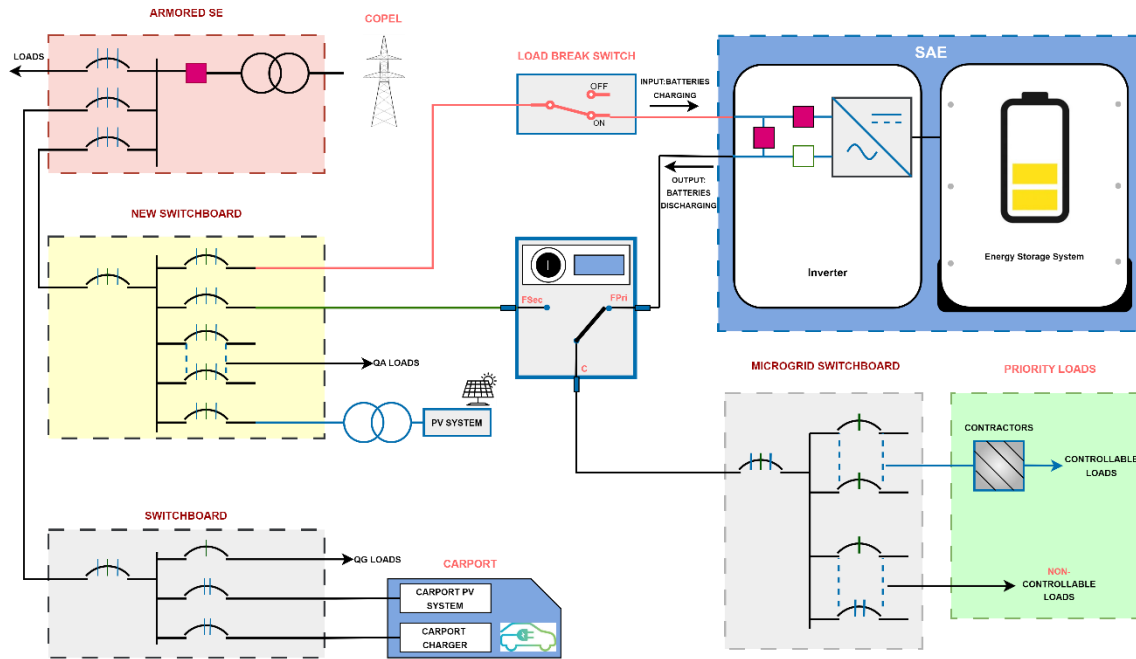


Figure 5.4: Simplified representation of Barigui Park
(own illustration based on [93])

5.2 Simulation

Simulation tools are widely used to analyze and enhance the performance of distribution grids. One of these simulation tools, OpenDSS, has been formed by the Electric Power Research Institute. OpenDSS offers various test systems, such as the IEEE 13-node test feeder, and allows users to create their test systems. Besides, OpenDSS has different simulation modes, including snapshot and time-series, among others [94]. The data sets required for the simulation are obtained by averaging the July and January weather-related data for weekdays and weekends. For both business models, the islanded operation of the microgrid during the weekday peak hours strategy is applied. However, it should be noted that the microgrid cannot supply all the loads during islanded operation. Therefore, 40% of the loads are categorized as critical and must always be supplied. Figure 5.5 presents the data set used in the simulation.

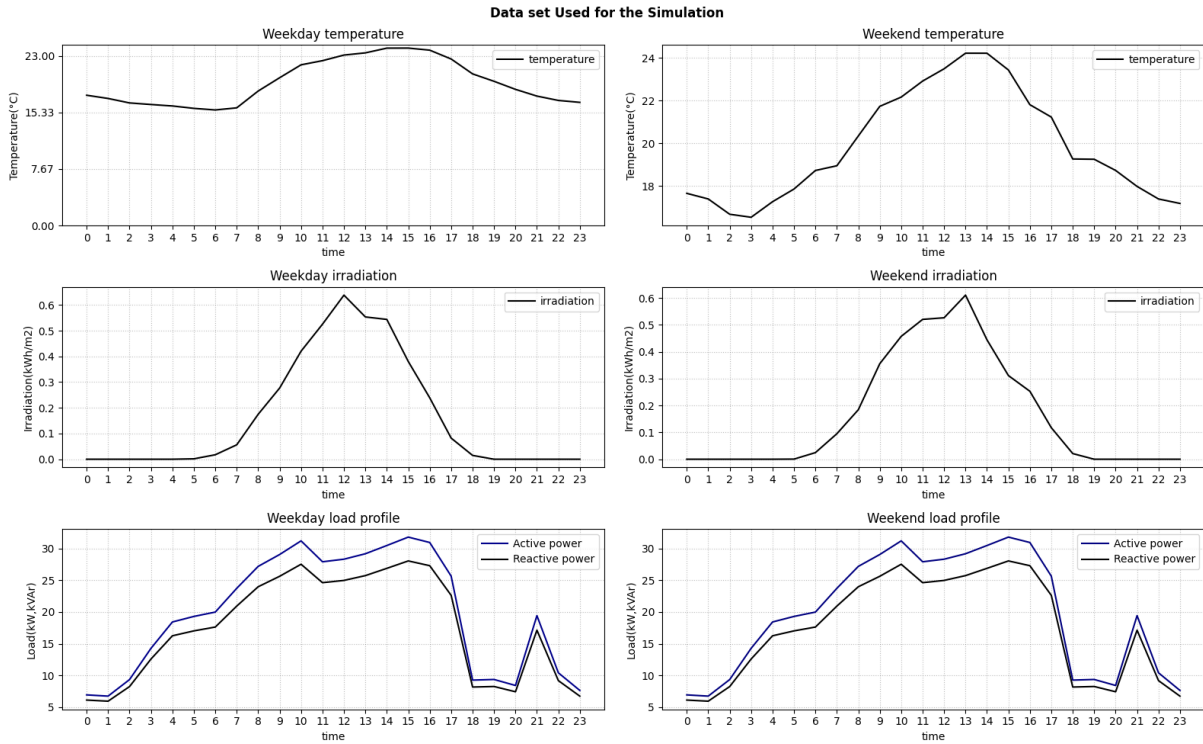


Figure 5.5: Data set used in the simulation (based on [90, 91])

As seen in the microgrid one-line diagram (Figure 5.4), the microgrid has a total of 3 bus. Considering the complexity of the real distribution grid simulation, the microgrid is considered as a single bus and simulated in OpenDSS with a modified IEEE 13-node test feeder as shown in Figure 5.6.

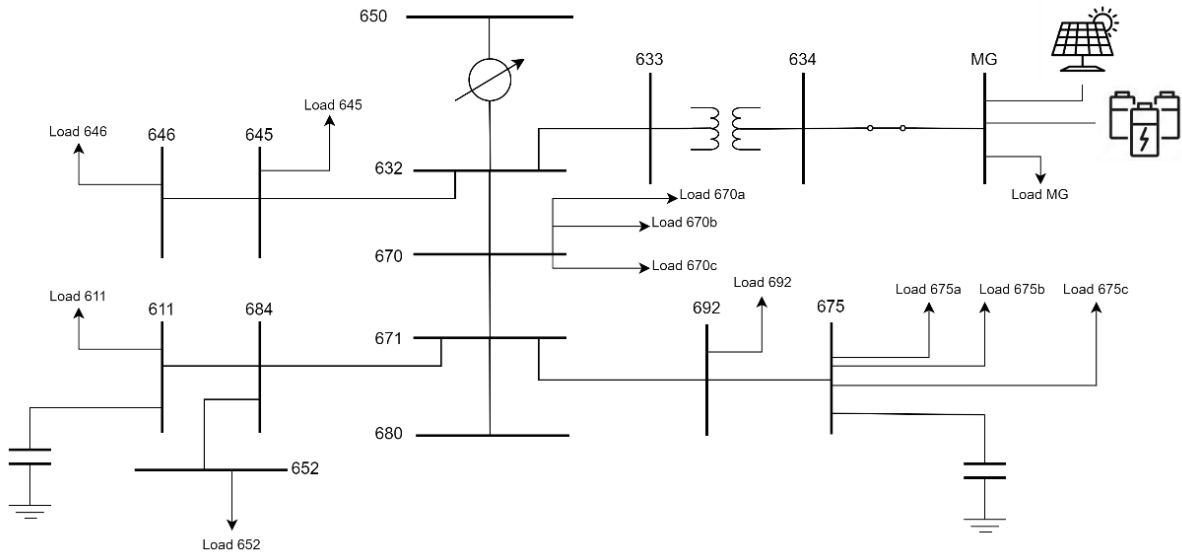


Figure 5.6: Modified IEEE 13-node test feeder

An additional MG bus and line with a switch have been incorporated into the 634 bus of the test distribution grid. The PV system, BESS, and microgrid load are connected to this bus. Except for load 634, the remaining loads in the test feeder are linked to their respective buses.

5.2.1 Developed business model by considering regulations' simulation

In this scenario, the PV feeds in the grid in case the generated energy is not consumed by microgrid loads. The battery does not discharge in grid-connected mode to supply the critical loads in islanded mode. During peak tariff hours, between 18:00 and 21:00 on weekdays, the microgrid disconnects from the grid, and the battery inverter is responsible for the frequency and voltage regulation of the system. In other words, while the microgrid is in islanded mode, the BESS inverter will operate in grid-forming mode. The battery's state of charge (SOC) is assumed to be 20% in the initial state. An energy meter is installed in the bus MG to analyze the behaviour during the simulation period. Furthermore, a monitor is connected to the relevant DER for analyzing the DERs' behaviour.

The weekday daily mode simulation is carried out in three phases. In the first stage, the microgrid is coupled to the grid, and the simulation is run for 18 hours. In this phase, battery and PV inverters are set to the grid-following mode. Then, the microgrid is separated from the grid by a switch, and the battery inverter mode is changed to grid-forming mode. In the 21st hour, the microgrid is reconnected to the grid, and the inverter is set to the grid-following mode parallel to peak tariff time. The battery that supplies the microgrid during the peak hours is charged for the next islanding operation. Figure 5.7 shows the microgrid node's voltage profile on a weekday.

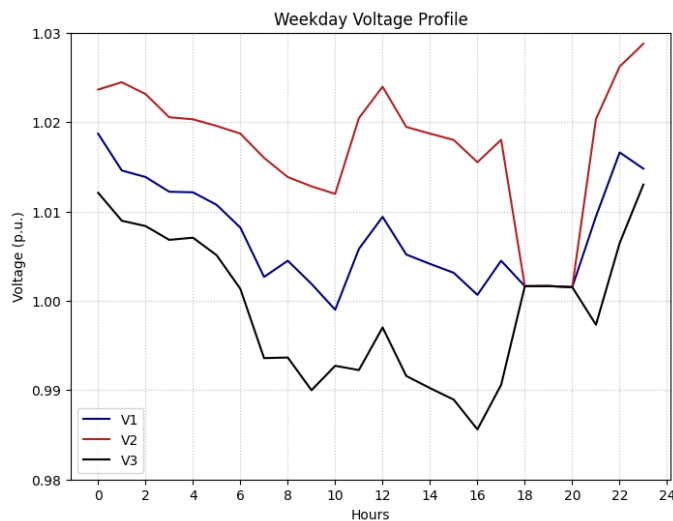


Figure 5.7: Weekday voltage profile of microgrid node

As observed in Figure 5.7, voltage values at the microgrid node are within the predetermined limit, 0.92-1.05 p.u., including 11:00 and 16:00, when the load peaks. The PV generates between 08:00 and 16:00, with a maximum production of 30 kWh in the simulation's 13th hour, as shown in Figure 5.8.

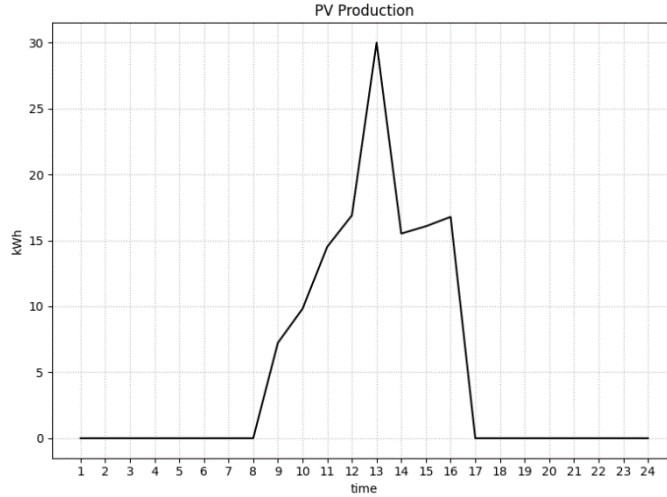


Figure 5.8: PV production on the weekday

As stated before, the PV inverter is set to the grid-following mode; PV does not inject or absorb any reactive power; also PV inverter is on only during generation. When the PV inverter is on, negligible reactive power values are monitored, as shown in Figure 5.9 below. In the figure, negative values indicate power flow out of the PV system, while positives indicate power flow to the system.

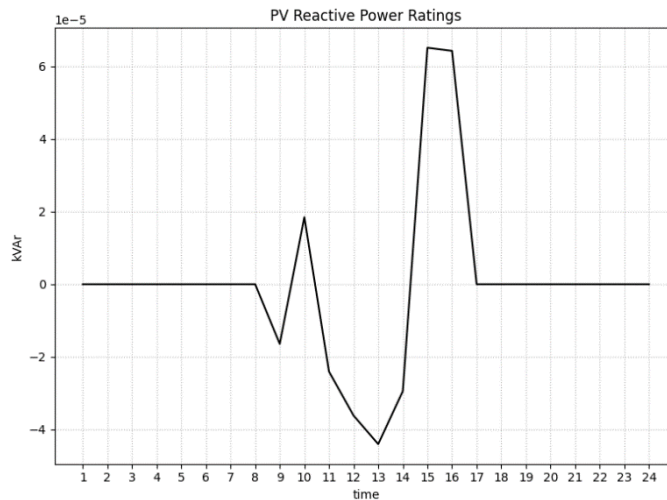


Figure 5.9: PV system reactive power values on the weekday

In the battery stored energy graph Figure 5.10, at the initial state, the energy stored in the battery is 5.76 kWh. The battery is charged for the first four hours and reaches 100% at the end

of the fourth hour. The battery idles (state=0, kWh=28.8 kWh) until the microgrid switches to island operation, 18:00. In the battery states graph, -1 indicates that the battery is charging, while +1 indicates that the battery is discharging. As observed in the Output kW graph, the battery supplies the loads while the microgrid is in islanding operation. The battery output power is non-zero between 18:00-21:00. At 21:00, the stored energy in the battery is 2.88 kWh. The battery starts charging after the microgrid is reconnected to the main grid. In the 24th hour, the stored energy is 17.88 kWh.

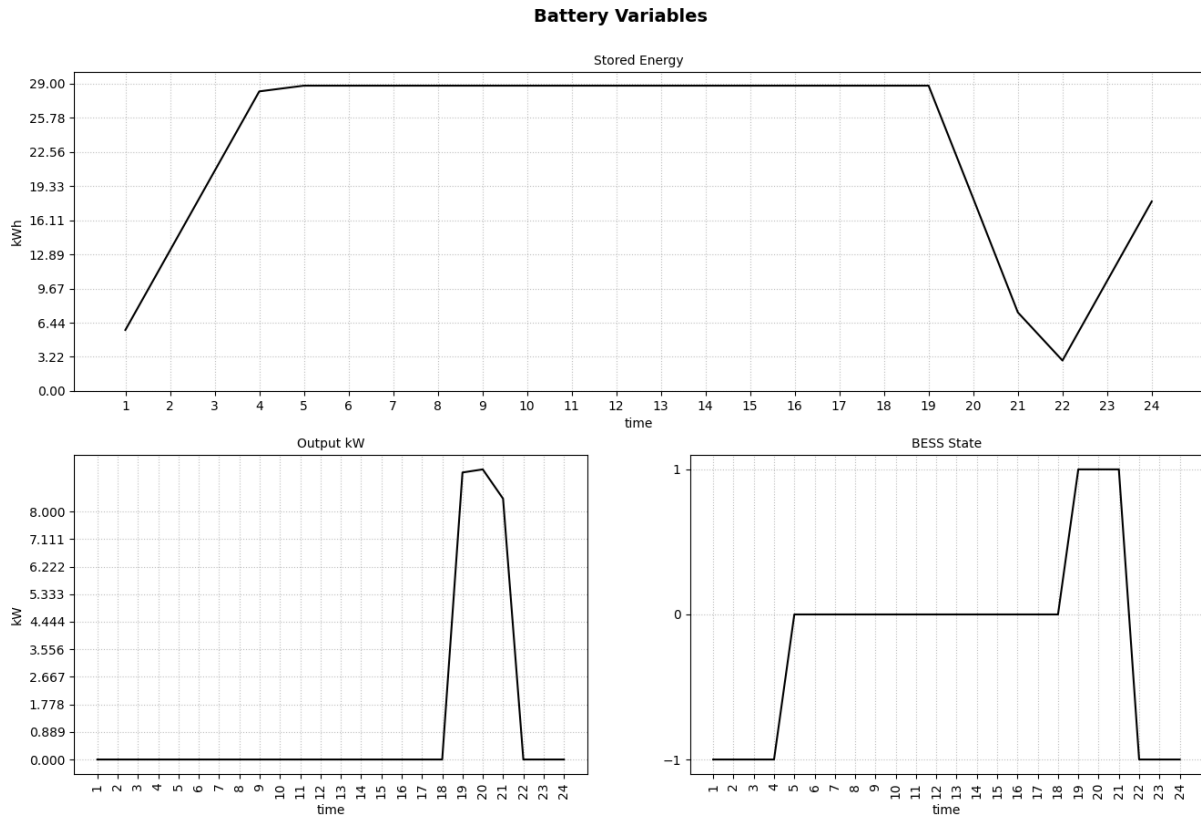


Figure 5.10: Stored energy, output kW, and states of the BESS on the weekday

Negative values in the PCC energy flow graph in Figure 5.11 indicate that the microgrid absorbs energy from the grid, while positive values indicate that energy flow from the microgrid to the main grid. In line with the load profile, battery stored energy graph and PV generation graph, it is seen that energy is supplied from the grid in the first four hours to meet the load demand and charge the battery. Between 08:00-16:00, the PV generation from the grid could not supply the load and the remaining energy is absorbed from the grid. In the 13th hour of the simulation, PV generation is more than the load demand, so extra energy is supplied into the grid, and the energy flow is positive with 1.581 kWh. Also, as seen in the graph, during the peak tariff hours, 18:00-21:00, the microgrid switches to island operation, and no energy flow occurs. When the microgrid is reconnected to the grid, the grid charges the battery and supplies

the loads.

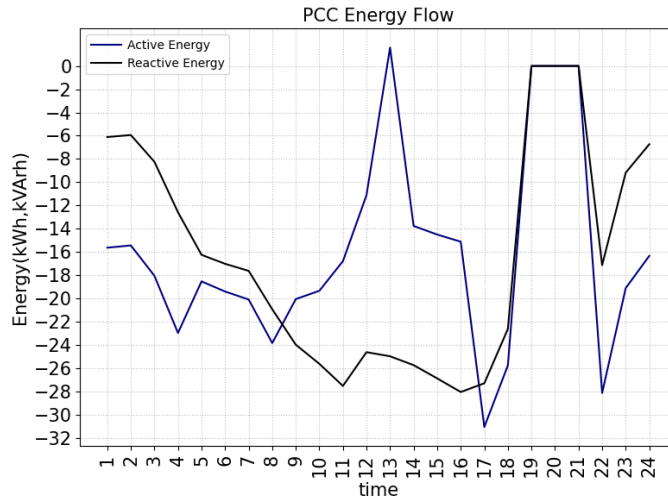


Figure 5.11: PCC energy flow on the weekday

As seen in the graph “Stored Energy” in Figure 5.10, by the end of the first-day battery is not fully charged; SOC is 62%. This value is considered for the rest of the weekday and weekend simulations.

On the other hand, since there is no different electricity tariff on weekends, the microgrid is connected to the main grid. The BESS stays in idling mode on weekends, with SOC 100%. The weekend daily mode simulation is carried out in one phase for 48 hours, and the SOC is set to 62% in the initial state.

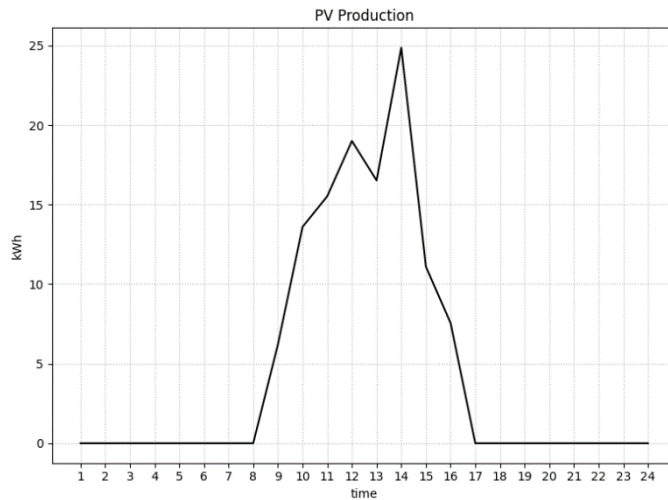


Figure 5.12: PV production at the weekend

As seen in “PV production” graph in Figure 5.12, PV generates between 08:00-16:00, with a maximum production of 25 kWh between 13:00-14:00. In the PV reactive power ratings graph (Figure 5.13), negative values indicate power flow from grid to the system. In contrast, positive

values indicate power flow to the system. As stated, the PV inverter is set to the grid following mode; PV does not inject or absorb any reactive power. When the PV inverter fed into the grid, negligible reactive power values are monitored, as seen in below Figure 5.13.

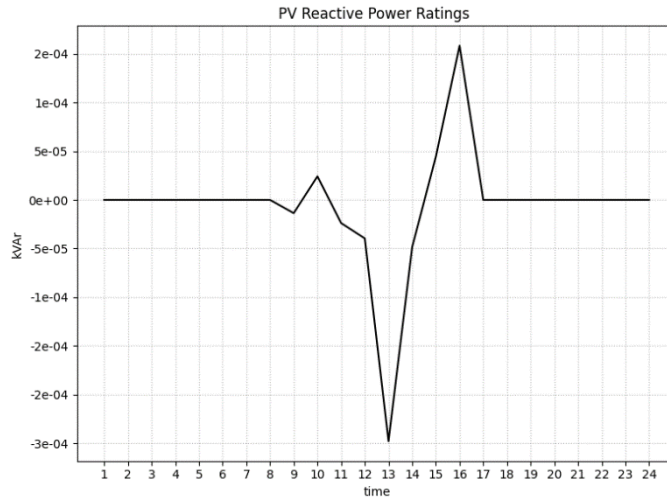


Figure 5.13: Reactive power values of the PV system on the weekend

In the graph of battery states in Figure 5.14, -1 indicates that the battery is charging, while +1 indicates that the battery is discharging. As seen in “stored energy” graph, in the initial state, the stored energy is 17.88 kWh. The battery is charged for the first two hours and reaches 100% at the end of the second hour.

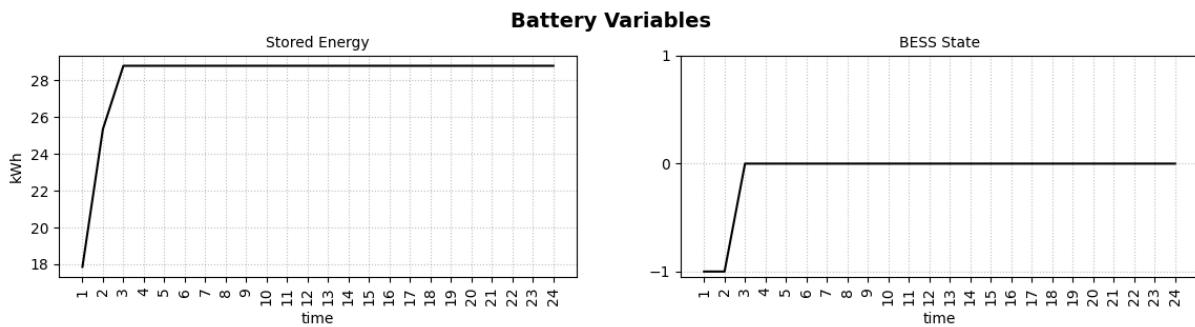


Figure 5.14: Stored energy, output kW, and states of the BESS on the weekend

Figure 5.15 shows the PCC energy flow; negative values indicate that the microgrid absorbs energy from the grid. In contrast, positive values indicate energy flows from the microgrid to the main grid.

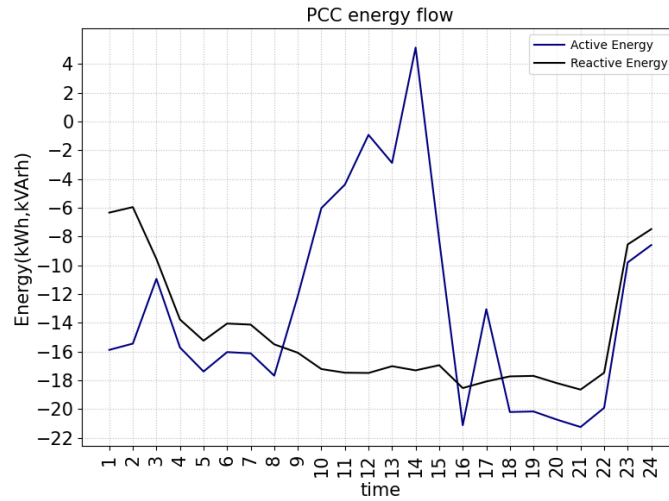


Figure 5.15: PCC energy flow on the weekend

In line with the load profile, battery stored energy graph and PV generation graph, it is seen that supplied energy from the grid in the first four hours is for the loads and charging the battery. Between 08:00-16:00, the PV generation from the grid could not supply the load, and the remaining energy is absorbed from the grid. In the 14th hour of the simulation, PV generation is more than the demand, so excess energy is injected to the grid, and the energy flow is 5.149 kWh.

The weekly result is obtained after three simulations are done for Monday, Tuesday to Friday, and the weekend as seen in Table 5.1 (See Appendix A.1). It should be stated that negative values represent the energy flow from the grid to the microgrid.

Table 5.1: Energy flow results of the microgrid simulation (First BM)

	Active Energy (kWh)	Reactive Energy (kVArh)
Monday	-383.355	-394.958
Tuesday-Friday	-366.166	-394.957
Weekend	-601.523	-712.654

The weekly result is multiplied four times to get the monthly result. The amount of energy consumed by the microgrid from the grid per month is calculated as 9,798.165 kWh. Considering the simulation result and the previously mentioned electricity prices (Table 3.2), the monthly electricity bill of the microgrid is calculated as BRL 4,878.51.

5.2.2 Developed business model by not considering regulations' simulation

In this scenario, PV provides reactive power service to the grid with volt-var control in addition to feeding the grid. The volt-var function curve that the controller follows is shown in Figure 5.16.

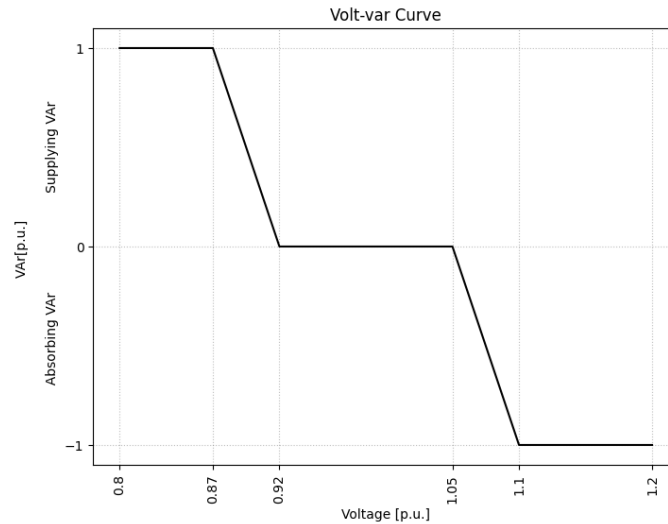


Figure 5.16: Volt-VAr curve for the simulation

The battery does not discharge when the microgrid is connected to the grid to supply the critical loads in islanded mode. During peak tariff hours, between 18:00 and 21:00 on weekdays, the microgrid disconnects from the grid, and the battery inverter is responsible for the frequency and voltage regulation of the microgrid. In other words, while the microgrid is in islanded mode, the BESS inverter will operate in grid-forming mode. The battery's SOC is assumed to be 20% in the initial state. On the other hand, since there is no different electricity tariff on weekends, the microgrid is always connected to the main grid. The BESS stays in idling mode on weekends, with SOC 100%. An energy meter is installed in the "bus MG" to analyze the behaviour during the simulation period. Furthermore, a monitor is connected to the relevant DER for analyzing the DER's behaviour.

The daily mode simulation is carried out in three phases. In the first phase, the microgrid is connected to the grid, and the simulation is run for 18 hours. In this phase, the battery is set to grid-following mode, whereas the PV inverter controller is set to volt-var mode. Moreover, in this mode, the inverter can exchange the reactive power independently of PV generation.

Then, at 18:00, the microgrid is disconnected from the grid with a switch, the battery inverter mode is changed to grid-forming, and the PV inverter controller is disabled. At the 21st hour

of the simulation, in parallel with the peak tariff time, the operation mode of the microgrid is changed to the grid-connected, the battery inverter is set to grid-following mode, and the PV inverter controller is enabled. The battery that supplies the microgrid during the peak hours is charged for the next islanding operation. Since the PV production is the same, it is not shown for this simulation.

There is no significant change in the reactive and active energy flow values that can be shown in the graph; the controller requests are described in Table 5.1.

Table 5.2: The Volt-var mode controller request to PV System

Hour	Requested PV System Output kVAr	Hour	Requested PV System Output kVAr
1	0.2	13	6.01E-05
2	0.006	14	5.11E-05
3	0.018	15	4.09E-05
4	0.0072	16	3.68E-05
5	0.00216	17	3.31E-05
6	8.64E-04	18	2.98E-05
7	4.32E-04	19	Disabled
8	2.59E-04	20	Disabled
9	1.68E-04	21	Disabled
10	1.18E-04	22	2.68E-05
11	9.43E-05	23	2.42E-05
12	7.08E-05	24	2.17E-05

The voltage profile graph Figure 5.7 shows that the PV inverter absorbs negligible reactive power since the microgrid node voltage is within the predefined limit.

The BESS and energy flow behaviour is the same as in the first simulation (See Chapter 5.2.1); therefore, it is not described here again.

The monthly result is obtained as done for the simulation of the first business model implementation. Alternatively, in this model, there is no use of distribution system tariff on the customers providing service to the grid, and lost opportunity costs are compensated, as mentioned in Chapter 4. The amount of energy consumed by the microgrid from the grid per month is calculated as 9,798.174 kWh, as seen in Table 5.3 (See Appendix A.2).

Table 5.3: Energy flow results of the microgrid simulation (Second BM)

	Active Energy (kWh)	Reactive Energy (kVArh)
Monday	-383.3560975	-395.249
Tuesday-Friday	-366.1672573	-395.266
Weekend	-601.5199438	-712.93

Considering the simulation result and the previously mentioned electricity prices (Table 3.2), the monthly electricity bill of the microgrid is calculated as BRL 3,095.25.

5.2.3 Sensitivity analysis

After analyzing the two different business models and the proposed remuneration mechanism applied to the microgrid, it is observed that the microgrid benefits BRL 1,783.26 through the remuneration mechanism. However, the remuneration mechanism should not be considered an appropriate approach for a microgrid of this size due to the absence of voltage issues. The microgrid’s profit source is the TUSD tariff, which is not paid even though the microgrid does not supply reactive power to the grid. In order to analyze proposed business models more accurately, the size of the microgrid is increased, and the mitigation effect of voltage problems by the microgrid is studied.

Figure 5.17 presents the voltage profile at the connected node when the size of the microgrid is increased by five times.

Hereinafter, the scaled-up microgrid is expressed with the help of numerical values. For instance, if the microgrid is expanded by a factor of five, it is stated as “5xmicrogrid”.

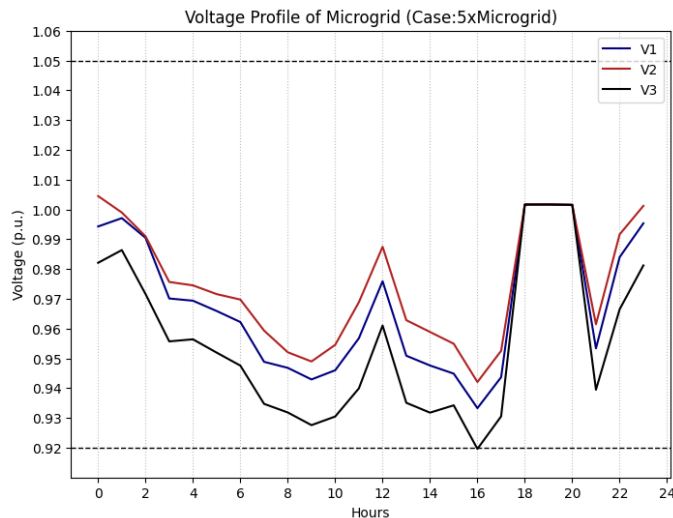


Figure 5.17: Voltage profile of microgrid node (Case:5xmicrogrid)

As seen in the figure above, the 5xmicrogrid voltage has not exceeded the limit throughout the day. However, it is observed that the node voltage decreases compared to the microgrid voltage (See Figure 5.7).

For further analysis, the size of the microgrid is expanded to ten times its original size. The voltage profiles of the 10xmicrogrid with the implementation of both business models are given in Figure 5.18. The left column of the figure illustrates the simulation results of the weekdays

by implementing both business models, showing the voltage profile without Volt-VAR during the weekday, the voltage profile with Volt-VAR control during the weekday, and the reactive power output of the PV inverter during the weekday, respectively. Moreover, the voltage profiles obtained by adapting both business models during the weekend, as well as the PV inverter reactive power output, are illustrated in the right column of the figure.

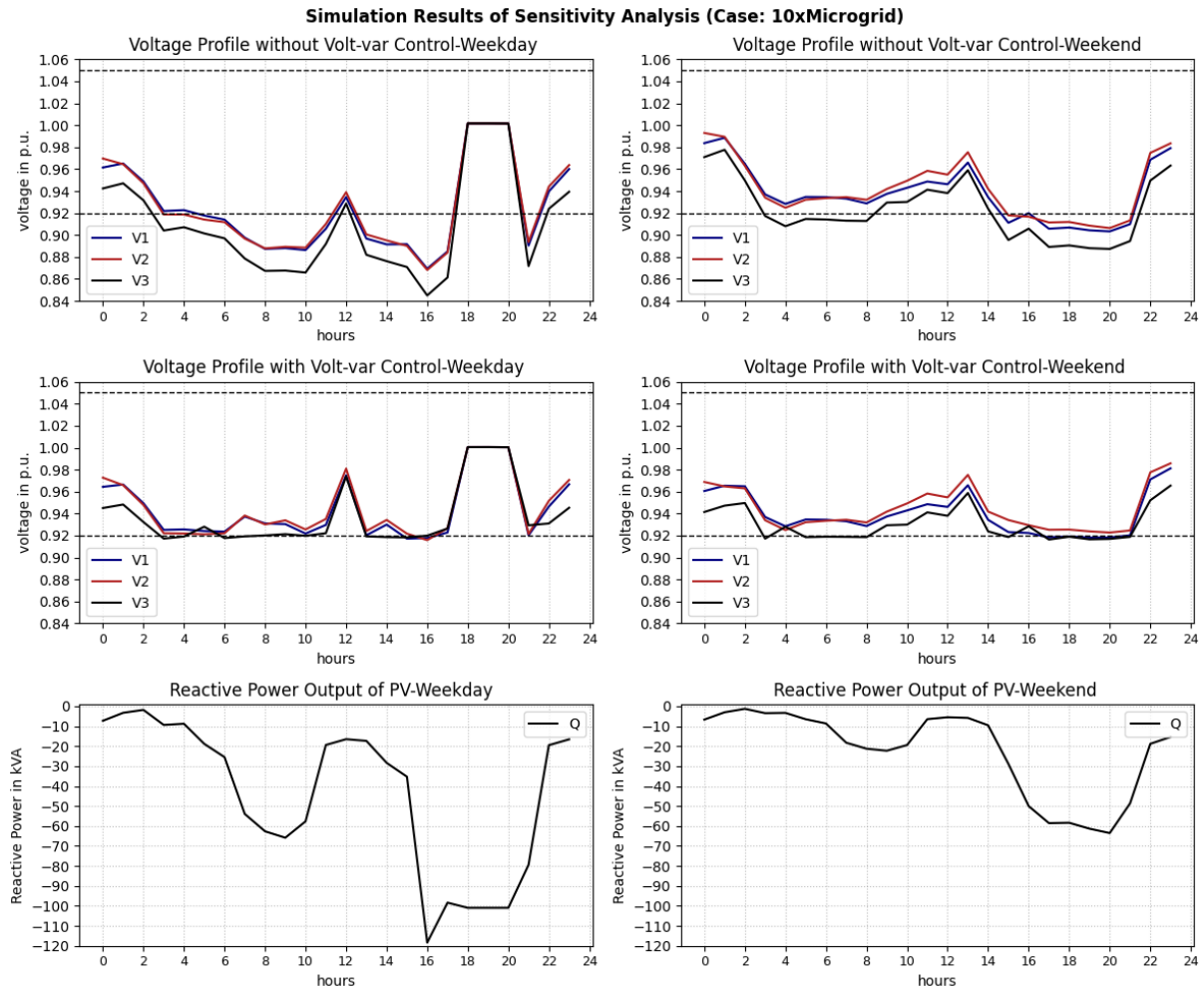


Figure 5.18: Simulation results of sensitivity analysis (case: 10xmicrogrid)

When the first business model is applied, the voltage of the microgrid node exceeds the predetermined limit simultaneously throughout the weekday. From the “Voltage Profile without Volt-VAR Control-Weekday” graph, the effect of PV generation on the voltage rise is observed at 13:00. The voltage is within the predefined limit when PV production is at its maximum. Moreover, the graph shows that the voltage profile decreases its minimum value at 16:00 since the load is at its peak (for the load profile of the microgrid, See Figure 5.3).

On the other hand, the innovative business model implementation results in the “Voltage Profile with Volt-VAR control-Weekday” graph show that the voltage rises to the desired level

through the Volt-VAR control. When the voltage level drops below 0.92 p.u., the PV inverter injects reactive power to increase the voltage. Moreover, as the minimum voltage is observed at 16:00, the PV inverter delivers the highest power output during this period, which can be observed from the “Reactive Power Output of PV-Weekday” graph.

Besides, comparing weekday and weekend profiles, the reactive power injection is relatively small since there are fewer voltage fluctuations at the weekend.

The 10xmicrogrid simulation shows that the voltage at the node to which the microgrid is connected goes far beyond the predefined limits. The microgrid is scaled up to a value ranging from five to ten to evaluate a more detailed analysis. The simulation results of the 7xmicrogrid for the weekday and the weekend can be seen in Figure 5.19.

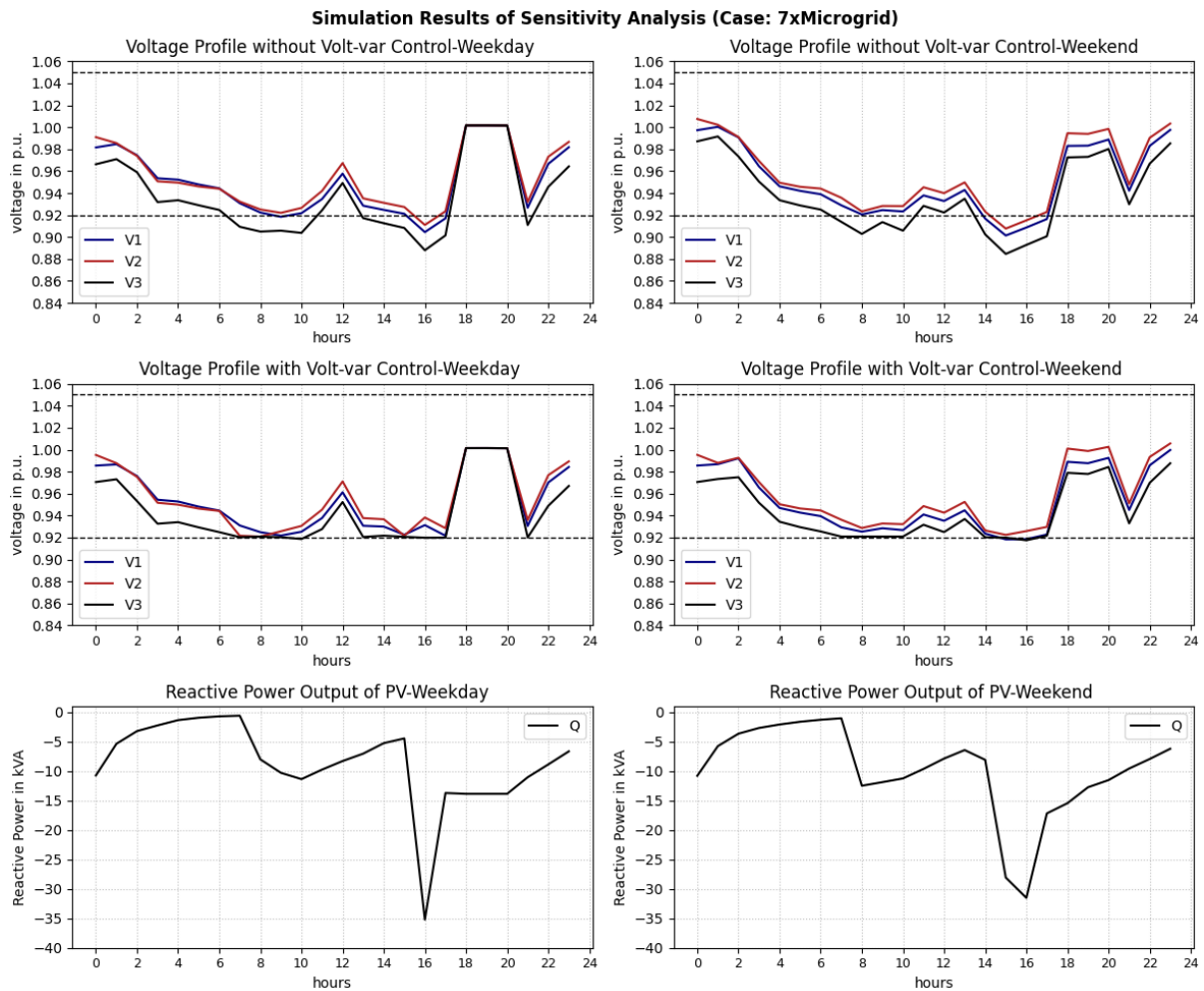


Figure 5.19: Simulation results of sensitivity analysis (case: 7xmicrogrid)

The left column of the figure illustrates the simulation results of the weekdays by implementing both business models, showing the voltage profile without Volt-VAR during the weekday, the voltage profile with Volt-VAR control during the weekday, and the reactive power

output of the PV inverter during the weekday, respectively. Moreover, the voltage profiles obtained by adapting both business models during the weekend, as well as the reactive power output of the PV inverter, can be seen from the right column of the figure.

It can be seen in “Voltage Profile without Volt-VAr Control-Weekday” in Figure 5.19 that when the first business model is applied, the voltage profile drops below the predetermined limit simultaneously throughout the weekday. Similar to the 10xmicrogrid analysis, the effect of PV generation on the voltage rise can be observed at 13:00. The voltage is within the predefined limit when PV production is at its maximum. Moreover, the figure shows that the voltage profile decreases its minimum value at 16:00 since the load is at its peak (for the load profile of the microgrid, See Figure 5.3). Since the load capacity is less than the previous sensitivity analysis, the voltage level is better, although it is outside the predefined limit. Likewise, since the generation capacity is less, the voltage level is lower than the previous analysis, even if it is in the time interval when the generation is highest.

The second business model implementation results in the “Voltage Profile with Volt-VAr Control-Weekday” show that the voltage reaches the desired level through the reactive power injected by the PV inverter to the grid. When the voltage level drops below 0.92 p.u., the PV inverter injects reactive power to increase the voltage. Moreover, as the minimum voltage is observed at 16:00, the PV inverter delivers the highest power output during this period, which can be observed from the “Reactive Power Output of PV-Weekday” graph.

The “Voltage Profile without Volt-VAr control-Weekend” graph shows that the voltage is minimum from 14:00 to 17:00. Besides, at 09:00, the V_3 value on the weekend is lower than on the weekday. In parallel, the reactive power injection is 2.342 kVAr higher for that hour on weekdays. Figure 5.20 below shows the developed business cases’ PCC energy flow results from the weekday and the weekend simulation. The figure’s left column depicts the effects of the Volt-VAr by illustrating the results of both implemented business models on the weekday, while the right column illustrates the same parameters for the weekend.

The positive impact of the volt-var control can be observed by comparing the weekday simulation graphs, as less reactive energy is absorbed from the grid with the volt-var control. For example, in the simulation with the first business model, whose result is shown in “Weekday Simulation without Volt-VAr control”, 40 kVArh is absorbed from the grid in the first hour of the weekday. On the other hand, this value decreases to 30 kVArh due to the Volt-VAr control in the second business model’s simulation, as illustrated with “Weekday Simulation with Volt-VAr control”.

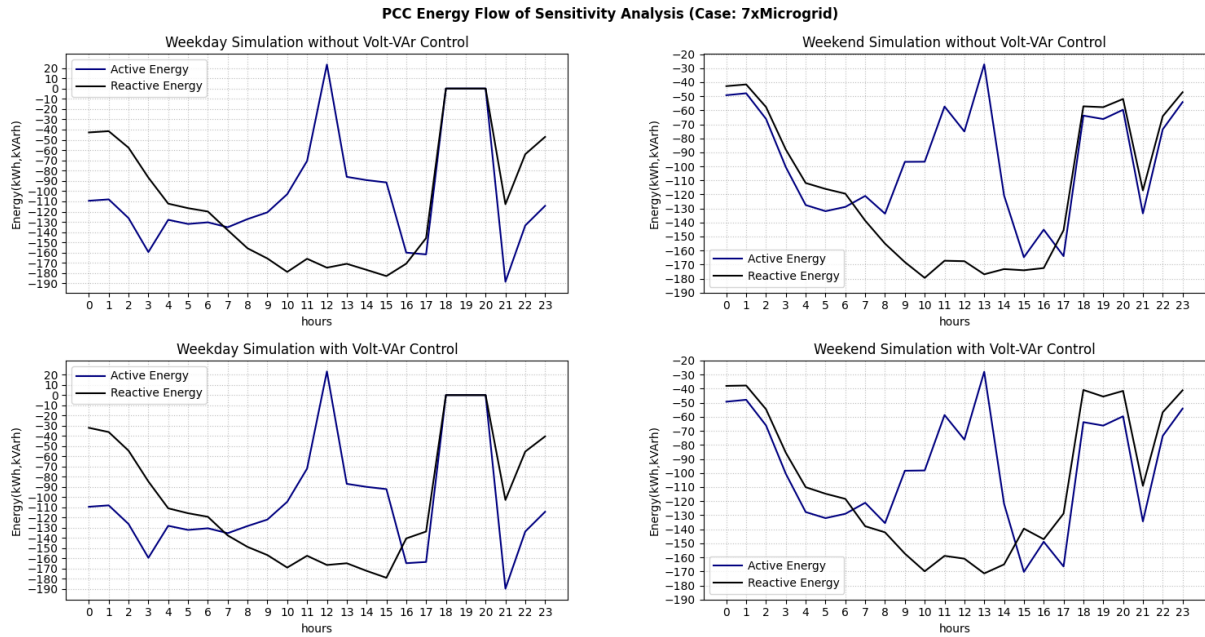


Figure 5.20: PCC energy flow of sensitivity analysis (Case: 7xmicrogrid)

In the simulation without control illustrated by “Weekday Simulation without Volt-VAr control”, 170 kVArh was absorbed from the grid, and this caused the voltage to drop. This value is 140 kVArh in the simulation with control, as shown in “Weekday Simulation with Volt-VAr control”.

As previously discussed, the voltage level drops the most between 14:00-17:00. Figure 5.20 above clearly shows the reactive power compensation for this purpose by comparing the absorbed energy values of both weekend simulation graphs. Absorbed reactive energy values for the weekend are 174 kVArh in the first business model simulation, while in the second model, it is 139 kVArh.

The weekly result is obtained after three simulations on Monday, Tuesday to Friday, and the weekend for both business cases, as seen in Table 5.4 (See Appendix B). The negative values represent the energy flow from the grid to the microgrid.

Table 5.4: Energy flow results of the sensitivity analysis (Case: 7xmicrogrid)

		Active Energy (kWh)	Reactive Energy (kVArh)
Monday	First BM	-2451.698	-2627.277
	Second BM	-2467.671	-2477.917
Tuesday-Friday	First BM	-2330.478	-2626.484
	Second BM	-2347.757	-2464.771
Weekend	First BM	-4731.810	-5583.115
	Second BM	-4777.247	-5135.724

By comparing the absorbed active energy by the microgrid for both BM implementations, it is seen that the microgrid consumes 15.973kWh, 17.279kWh and 45.437kWh more energy on Monday, Tuesday-Friday and weekend, respectively, in the simulation where the second business model is implemented. On the other hand, in the simulation where the first business model is adopted, the microgrid consumes 149.360 kVArh, 161.713 kVArh and 447.391 kVArh more reactive energy.

Considering the simulation results and previously mentioned electricity prices (Table 3.2), the monthly electricity bill of the microgrid calculated by implementing the first business model is BRL 32,872.20. Additionally, the monthly electricity bill of the microgrid by implementing the second business model is calculated as BRL 20,979.95. The implication is that if the microgrid provides a service to control the grid's voltage, the profit of the microgrid is BRL 11,892.25. This profit consists of two components. Firstly, since the microgrid provides ancillary services to the grid, it is charged only the energy tariff. The TUSD is not paid for the 66,543.783 kWh that the microgrid consumes per month, and the microgrid has made a profit of BRL 12,110.97. Secondly, for the reactive energy provision, 1243.60 kVArh, BRL 164.931 is compensated by the DSO, which is paid by the microgrid absorbing 522.1 kWh more energy from the grid.

6 Conclusion and Future Work

Increasing the penetration of distributed energy resources has led to the development of the idea of local production and local consumption and, accordingly, to the emergence of the microgrid concept. However, this situation brings additional problems, especially to distribution grids. For Brazil, the problem in the grids is mainly voltage issues and the diminishing of traditional power plants, which traditionally regulate voltage, requires finding alternative solutions. According to studied literature, it was found that in most countries, distributed energy resources connected to the low voltage level do not receive any remuneration even if they provide ancillary services to the grid. It is reviewed that ancillary service provision is mandatory for distributed energy resources and all generators connected to the grid in Brazil, where this thesis is focused.

This thesis aims to develop business models for non-isolated microgrids connected to low-voltage distribution systems considering IEC TS 62898-1:2017 BUC-B; and analyze the implemented business models in the microgrid.

In this respect, this thesis started with a comprehensive technical background. It has been demonstrated that microgrids, which have various technical, economic and environmental benefits, can also technically contribute ancillary services to the main grid, namely reactive power support, which is the focus of this thesis. After analyzing the Brazilian regulations related to distributed generation and microgrids as well as the electricity market structure, the lack of ancillary services market in the Brazilian electricity market has been observed. For Barigui Park in Curitiba, two business models have been developed with and without considering the country's regulations. Consequently, two remuneration mechanisms have been suggested for the innovative business model where regulations are not considered. The developed business models and the remuneration mechanism that does not require excessive data have been simulated in OpenDSS with a modified IEEE 13-node test feeder. The absence of any voltage issues in the distribution grid caused by the size of the microgrid leads to a sensitivity analysis. In the sensitivity analysis, the size of the microgrid is increased until the voltage issue occurs, and the contribution of the reactive power support remuneration mechanism proposed with the innovative business model applied to the microgrid is evaluated.

The sensitivity analysis simulation concluded that the microgrid's size should be increased by a factor of seven to for feasible implementation of the innovative business model. The reactive power provision capability of the microgrid is observed by comparing the two implemented business models. It has been found that the voltage drop problem in the grid has

been solved by reactive power injection with the PV inverter of the microgrid. Accordingly, it is observed that the most considerable profit in the proposed remuneration mechanism of the microgrid is the TUSD tariff, which is charged by DSO.

Although the thesis presents reasonable outcomes for the developed business models, several additional studies could be done to improve and further analyze the work. Firstly, the aggregation and virtual power plant concepts can be considered while performing the study, and developing the business models. Also, this study only evaluates reactive power support with a PV inverter; other inverter-based distributed energy resources, including BESS technology, can also be included in this analysis. In addition, the simulation could give more realistic results with real distribution grid models. Therefore, the microgrid where the developed business models are implemented can be simulated with the modelled real distribution grid instead of a test feeder. Finally, the feasibility of the proposed remuneration mechanism, pay-as-bid and regulated price combination, which was not analyzed in this thesis, can be assessed if the required data are available.

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Appendix A: Simulation Results of Microgrid

Appendix A.1: Without Volt-var control simulation results

Hour	Monday		Tuesday		Wednesday		Thursday		Friday		Saturday		Sunday	
	kWh	kVArh	kWh	kVArh	kWh	kVArh	kWh	kVArh	kWh	kVArh	kWh	kVArh	kWh	kVArh
1	-15.629	-6.111	-15.629	-6.111	-15.629	-6.111	-15.629	-6.111	-15.629	-6.111	-15.877	-6.330	-7.283	-6.330
2	-15.434	-5.939	-15.434	-5.939	-15.434	-5.939	-15.434	-5.939	-15.434	-5.939	-15.442	-5.946	-6.847	-5.946
3	-18.043	-8.240	-9.449	-8.240	-9.449	-8.240	-9.449	-8.240	-9.449	-8.240	-10.937	-9.552	-10.937	-9.552
4	-22.964	-12.579	-14.369	-12.579	-14.369	-12.579	-14.369	-12.579	-14.369	-12.579	-15.713	-13.764	-15.713	-13.764
5	-18.526	-16.245	-18.525	-16.244	-18.525	-16.244	-18.525	-16.244	-18.525	-16.244	-17.382	-15.237	-17.382	-15.237
6	-19.399	-17.015	-19.399	-17.016	-19.399	-17.016	-19.399	-17.016	-19.399	-17.016	-16.033	-14.047	-16.033	-14.047
7	-20.087	-17.622	-20.087	-17.622	-20.087	-17.622	-20.087	-17.622	-20.087	-17.622	-16.117	-14.120	-16.117	-14.120
8	-23.830	-20.923	-23.830	-20.923	-23.830	-20.923	-23.830	-20.923	-23.830	-20.923	-17.672	-15.492	-17.672	-15.492
9	-20.050	-23.972	-20.050	-23.972	-20.050	-23.972	-20.050	-23.972	-20.050	-23.972	-12.131	-16.076	-12.131	-16.076
10	-19.337	-25.620	-19.337	-25.620	-19.337	-25.620	-19.337	-25.620	-19.337	-25.620	-6.017	-17.212	-6.017	-17.212
11	-16.787	-27.518	-16.787	-27.518	-16.787	-27.518	-16.787	-27.518	-16.787	-27.518	-4.379	-17.465	-4.379	-17.465
12	-11.113	-24.613	-11.113	-24.613	-11.113	-24.613	-11.113	-24.613	-11.113	-24.613	-0.921	-17.484	-0.921	-17.484
13	1.581	-24.970	1.581	-24.970	1.581	-24.970	1.581	-24.970	1.581	-24.970	-2.873	-17.014	-2.873	-17.014
14	-13.758	-25.728	-13.758	-25.728	-13.758	-25.728	-13.758	-25.728	-13.758	-25.728	5.149	-17.303	5.149	-17.303
15	-14.499	-26.871	-14.499	-26.871	-14.499	-26.871	-14.499	-26.871	-14.499	-26.871	-8.216	-16.943	-8.216	-16.943
16	-15.114	-28.041	-15.114	-28.041	-15.114	-28.041	-15.114	-28.041	-15.114	-28.041	-21.120	-18.533	-21.120	-18.533
17	-31.051	-27.291	-31.051	-27.291	-31.051	-27.291	-31.051	-27.291	-31.051	-27.291	-13.046	-18.076	-13.046	-18.076
18	-25.751	-22.617	-25.751	-22.617	-25.751	-22.617	-25.751	-22.617	-25.751	-22.617	-20.200	-17.722	-20.200	-17.722
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-20.161	-17.687	-20.161	-17.687
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-20.734	-18.193	-20.734	-18.193
21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-21.242	-18.641	-21.242	-18.641
22	-28.123	-17.129	-28.123	-17.129	-28.123	-17.129	-28.123	-17.129	-28.123	-17.129	-19.912	-17.468	-19.912	-17.468
23	-19.108	-9.179	-19.108	-9.179	-19.108	-9.179	-19.108	-9.179	-19.108	-9.179	-9.793	-8.544	-9.793	-8.544
24	-16.334	-6.732	-16.334	-6.732	-16.334	-6.732	-16.334	-6.732	-16.334	-6.732	-8.587	-7.480	-8.587	-7.480

Appendix A.2: With Volt-var control simulation results

Hour	Monday		Tuesday		Wednesday		Thursday		Friday		Saturday		Sunday	
	kWh	kVArh	kWh	kVArh	kWh	kVArh	kWh	kVArh	kWh	kVArh	kWh	kVArh	kWh	kVArh
1	-15.629	-6.311	-15.629	-6.311	-15.629	-6.311	-15.629	-6.311	-15.629	-6.311	-15.877	-6.530	-7.283	-6.330
2	-15.434	-5.999	-15.434	-5.999	-15.434	-5.999	-15.434	-5.999	-15.434	-5.999	-15.442	-6.006	-6.847	-5.946
3	-18.043	-8.258	-9.449	-8.261	-9.449	-8.261	-9.449	-8.261	-9.449	-8.261	-10.936	-9.567	-10.936	-9.552
4	-22.964	-12.587	-14.369	-12.589	-14.369	-12.589	-14.369	-12.589	-14.369	-12.589	-15.713	-13.769	-15.713	-13.764
5	-18.526	-16.247	-18.526	-16.250	-18.526	-16.250	-18.526	-16.250	-18.526	-16.250	-17.383	-15.239	-17.383	-15.237
6	-19.400	-17.017	-19.400	-17.019	-19.400	-17.019	-19.400	-17.019	-19.400	-17.019	-16.033	-14.047	-16.033	-14.047
7	-20.087	-17.623	-20.087	-17.624	-20.087	-17.624	-20.087	-17.624	-20.087	-17.624	-16.117	-14.121	-16.117	-14.121
8	-23.830	-20.924	-23.830	-20.925	-23.830	-20.925	-23.830	-20.925	-23.830	-20.925	-17.672	-15.492	-17.672	-15.492
9	-20.050	-23.972	-20.050	-23.973	-20.050	-23.973	-20.050	-23.973	-20.050	-23.973	-12.131	-16.076	-12.131	-16.076
10	-19.337	-25.620	-19.337	-25.621	-19.337	-25.621	-19.337	-25.621	-19.337	-25.621	-6.017	-17.212	-6.017	-17.212
11	-16.787	-27.518	-16.787	-27.519	-16.787	-27.519	-16.787	-27.519	-16.787	-27.519	-4.379	-17.465	-4.379	-17.465
12	-11.113	-24.613	-11.113	-24.614	-11.113	-24.614	-11.113	-24.614	-11.113	-24.614	-0.921	-17.484	-0.921	-17.484
13	1.581	-24.970	1.581	-24.970	1.581	-24.970	1.581	-24.970	1.581	-24.970	-2.873	-17.013	-2.873	-17.013
14	-13.758	-25.728	-13.758	-25.728	-13.758	-25.728	-13.758	-25.728	-13.758	-25.728	5.149	-17.303	5.149	-17.303
15	-14.499	-26.871	-14.499	-26.872	-14.499	-26.872	-14.499	-26.872	-14.499	-26.872	-8.216	-16.943	-8.216	-16.943
16	-15.114	-28.042	-15.114	-28.042	-15.114	-28.042	-15.114	-28.042	-15.114	-28.042	-21.121	-18.533	-21.121	-18.533
17	-31.051	-27.291	-31.051	-27.291	-31.051	-27.291	-31.051	-27.291	-31.051	-27.291	-13.045	-18.075	-13.045	-18.075
18	-25.751	-22.617	-25.751	-22.617	-25.751	-22.617	-25.751	-22.617	-25.751	-22.617	-20.200	-17.722	-20.200	-17.722
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-20.161	-17.687	-20.161	-17.687
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-20.733	-18.192	-20.733	-18.192
21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-21.242	-18.640	-21.242	-18.640
22	-28.123	-17.129	-28.123	-17.129	-28.123	-17.129	-28.123	-17.129	-28.123	-17.129	-19.912	-17.467	-19.912	-17.467
23	-19.108	-9.179	-19.108	-9.179	-19.108	-9.179	-19.108	-9.179	-19.108	-9.179	-9.793	-8.544	-9.793	-8.544
24	-16.334	-6.732	-16.334	-6.732	-16.334	-6.732	-16.334	-6.732	-16.334	-6.732	-8.587	-7.480	-8.587	-7.480

Appendix B: Simulation Results for Sensitivity Analysis(Case: 7xMicrogrid)

Appendix B.1: Without Volt-var control simulation results

Hour	Monday		Tuesday		Wednesday		Thursday		Friday		Saturday		Sunday	
	kWh	kVArh	kWh	kVArh	kWh	kVArh	kWh	kVArh	kWh	kVArh	kWh	kVArh	kWh	kVArh
1	-109.408	-42.781	-109.408	-42.781	-109.408	-42.781	-109.408	-42.781	-109.408	-42.781	-109.408	-42.781	-49.248	-42.781
2	-108.043	-41.577	-108.043	-41.577	-108.043	-41.577	-108.043	-41.577	-108.043	-41.577	-108.043	-41.577	-47.882	-41.576
3	-126.298	-57.677	-66.139	-57.678	-66.139	-57.678	-66.139	-57.678	-66.139	-57.678	-66.139	-57.678	-66.139	-57.678
4	-159.385	-86.856	-100.584	-88.055	-100.584	-88.055	-100.584	-88.055	-100.584	-88.055	-100.584	-88.055	-100.584	-88.055
5	-127.986	-112.221	-127.574	-111.858	-127.574	-111.858	-127.574	-111.858	-127.574	-111.858	-127.574	-111.858	-127.574	-111.858
6	-132.027	-116.618	-131.451	-116.110	-131.451	-116.110	-131.451	-116.110	-131.451	-116.110	-131.451	-116.110	-131.940	-116.073
7	-130.427	-119.896	-129.835	-119.373	-129.835	-119.373	-129.835	-119.373	-129.835	-119.373	-129.835	-119.373	-128.871	-119.449
8	-135.224	-138.049	-134.544	-137.450	-134.544	-137.450	-134.544	-137.450	-134.544	-137.450	-134.544	-137.450	-121.064	-138.693
9	-127.248	-155.760	-127.248	-155.760	-127.248	-155.760	-127.248	-155.760	-127.248	-155.760	-127.248	-155.760	-133.712	-155.086
10	-120.677	-165.673	-120.677	-165.673	-120.677	-165.673	-120.677	-165.673	-120.677	-165.673	-120.677	-165.673	-96.763	-168.260
11	-102.989	-178.754	-102.989	-178.754	-102.989	-178.754	-102.989	-178.754	-102.989	-178.754	-102.989	-178.754	-96.672	-179.474
12	-70.593	-165.944	-70.593	-165.944	-70.593	-165.944	-70.593	-165.944	-70.593	-165.944	-70.593	-165.944	-57.347	-167.274
13	23.372	-174.624	23.372	-174.624	23.372	-174.624	23.372	-174.624	23.372	-174.624	23.372	-174.624	-75.123	-167.599
14	-86.082	-170.850	-86.082	-170.850	-86.082	-170.850	-86.082	-170.850	-86.082	-170.850	-86.082	-170.850	-27.261	-176.946
15	-89.284	-176.762	-89.284	-176.762	-89.284	-176.762	-89.284	-176.762	-89.284	-176.762	-89.284	-176.762	-120.677	-173.228
16	-91.549	-182.810	-91.549	-182.810	-91.549	-182.810	-91.549	-182.810	-91.549	-182.810	-91.549	-182.810	-164.774	-174.064
17	-159.952	-170.709	-159.952	-170.709	-159.952	-170.709	-159.952	-170.709	-159.952	-170.709	-159.952	-170.709	-145.113	-172.494
18	-161.702	-145.786	-161.702	-145.786	-161.702	-145.786	-161.702	-145.786	-161.702	-145.786	-161.702	-145.786	-163.964	-145.554
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-63.814	-57.175
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-66.256	-57.782
21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-59.643	-51.950
22	-188.351	-112.770	-188.351	-112.770	-188.351	-112.770	-188.351	-112.770	-188.351	-112.770	-188.351	-112.770	-133.546	-117.126
23	-133.503	-64.030	-133.503	-64.030	-133.503	-64.030	-133.503	-64.030	-133.503	-64.030	-133.503	-64.030	-73.597	-64.255
24	-114.343	-47.129	-114.343	-47.129	-114.343	-47.129	-114.343	-47.129	-114.343	-47.129	-114.343	-47.129	-54.178	-47.128

B.2: With Volt-var control simulation results

Hour	Monday		Tuesday		Wednesday		Thursday		Friday		Saturday		Sunday	
	kWh	kVArh	kWh	kVArh	kWh	kVArh	kWh	kVArh	kWh	kVArh	kWh	kVArh	kWh	kVArh
1	-109.408	-32.044	-109.408	-32.044	-109.408	-32.044	-109.408	-32.044	-109.408	-32.044	-109.408	-31.952	-49.248	-37.992
2	-108.043	-36.209	-108.043	-36.209	-108.043	-36.209	-108.043	-36.209	-108.043	-36.209	-108.043	-35.621	-47.882	-37.745
3	-126.300	-54.456	-66.139	-54.457	-66.139	-54.457	-66.139	-54.457	-66.139	-54.457	-66.139	-53.806	-66.139	-54.613
4	-159.432	-84.644	-100.584	-85.800	-100.584	-85.800	-100.584	-85.800	-100.584	-85.800	-100.584	-85.151	-100.584	-85.603
5	-128.073	-110.945	-127.755	-110.214	-127.755	-110.214	-127.755	-110.214	-127.755	-110.214	-127.822	-109.608	-127.771	-110.070
6	-132.125	-115.759	-131.591	-114.882	-131.591	-114.882	-131.591	-114.882	-131.591	-114.882	-132.145	-114.280	-132.093	-114.737
7	-130.503	-119.253	-129.957	-118.332	-129.957	-118.332	-129.957	-118.332	-129.957	-118.332	-129.040	-118.019	-128.997	-118.384
8	-135.296	-137.517	-134.661	-136.587	-134.661	-136.587	-134.661	-136.587	-134.661	-136.587	-121.210	-137.575	-121.173	-137.860
9	-128.285	-148.755	-128.761	-145.522	-128.761	-145.522	-128.761	-145.522	-128.761	-145.522	-135.644	-142.174	-135.639	-142.204
10	-121.963	-156.761	-122.268	-154.767	-122.268	-154.767	-122.268	-154.767	-122.268	-154.767	-98.365	-157.316	-98.361	-157.341
11	-104.528	-169.008	-104.703	-167.889	-104.703	-167.889	-104.703	-167.889	-104.703	-167.889	-98.165	-169.891	-98.163	-169.906
12	-72.003	-157.441	-72.072	-157.026	-72.072	-157.026	-72.072	-157.026	-72.072	-157.026	-58.734	-158.926	-58.732	-158.938
13	23.182	-166.472	23.178	-166.605	23.178	-166.605	23.178	-166.605	23.178	-166.605	-76.214	-160.932	-76.213	-160.942
14	-86.942	-164.761	-86.878	-165.194	-86.878	-165.194	-86.878	-165.194	-86.878	-165.194	-27.949	-171.428	-27.949	-171.436
15	-89.942	-172.239	-89.850	-172.841	-89.850	-172.841	-89.850	-172.841	-89.850	-172.841	-121.821	-165.035	-121.820	-165.039
16	-92.131	-179.002	-92.020	-179.703	-92.020	-179.703	-92.020	-179.703	-92.020	-179.703	-170.336	-139.575	-170.336	-139.576
17	-164.715	-140.447	-164.757	-140.185	-164.757	-140.185	-164.757	-140.185	-164.757	-140.185	-148.902	-147.103	-148.902	-147.103
18	-163.511	-133.688	-163.627	-132.918	-163.627	-132.918	-163.627	-132.918	-163.627	-132.918	-166.487	-128.854	-166.487	-128.854
19	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-63.800	-40.899	-63.800	-40.899
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-66.251	-45.591	-66.251	-45.591
21	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-59.638	-41.580	-59.638	-41.580
22	-189.663	-102.738	-189.833	-101.432	-189.833	-101.432	-189.833	-101.432	-189.833	-101.432	-134.416	-109.088	-134.416	-109.088
23	-133.674	-55.310	-133.708	-53.562	-133.708	-53.562	-133.708	-53.562	-133.708	-53.562	-73.597	-56.772	-73.597	-56.772
24	-114.317	-40.467	-114.318	-38.602	-114.318	-38.602	-114.318	-38.602	-114.318	-38.602	-54.171	-41.138	-54.171	-41.138