Microgrid Energy Market

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Electricity generation using distributed renewable energy systems is becoming increasingly common due to the significant increase in energy demand and the high operation of conventional power systems with fossil fuels. Microgrids are rapidly becoming attractive because they assist in reducing the load congestion on the traditional power system, have a less environmental impact, intensify the power generation capacity, are easy to install, offer localized generation to the consumers, and are highly efficient with increased reliability.

microgrid | energy management system | local energy market | market mechanisms | energy trading | transactive energy system

1. Introduction

The microgrid can be defined as a network consisting of different elements (distributed energy resources, energy storage systems, and loads) at a local scale either connected to the grid "grid-connected mode" or isolated "islanded-mode". In a grid-connected mode, power exchanges between the microgrid and the utility grid and vice-versa [1]. The power mismatch problem in grid-connected microgrids can be solved by controlling the generation or by varying the demand using load control. In the islanded mode, the microgrid is not connected to the primary grid, and the consumption is served from standalone distributed energy resources within the microgrid. The power mismatch in the islanded microgrid is solved using a proper control scheme to schedule the loads and distribute energy resources, including the energy storage systems [2]. The control actions in the microgrid are centrally evaluated at the microgrid central controller (MGCC) for solving the economic optimization problem aimed at minimizing the trade-off between the internal production resources and the power exchanged with the utility grid. To achieve this objective, the microgrid with the grid utility is formulated by mathematical equations [3].

A microgrid structure is divided into three types: AC microgrid, DC microgrid, and AC/DC (hybrid) microgrid [4]. In recent years, research has continuously been conducted on various microgrid features, particularly the reliability and quality of electrical power [5]. The microgrid management system's modern architecture is investigated, consisting of renewable energy resources, centralized/decentralized control, and protection strategies in both AC/DC microgrid systems. As expected, the microgrid is also associated with its share of drawbacks and technical complexities in the operation modes. The operation modes in the microgrid and its problems are investigated from different aspects, and some review literature on the classification and analysis of microgrid architecture have been published, including the impact of grid integration in microgrids with distributed energy resources, protection schemes, power quality, and stability of the microgrid, for example, ref. [3] defines the economical, reliable, and secure operation of microgrids operating either on the grid-connected mode or islanded mode. Authors of [6] present the operating modes and the different control techniques in AC microgrids. In [7], a detailed review has been carried out on the DC microgrid, architecture, topology, protection standards, protection issues and challenges, protective devices, and various protection solutions in terms of fault detection, location, and classification. The authors of [8] introduce different aspects of microgrid management, including control and energy management, different constraints, communication technologies, types of distributed energy resources and load, mathematical modelling, problem solvers, microgrid networks, and programming, including uncertainty and modelling. In [9][10], the protection challenges for both DC and AC microgrids, the different protection methods for DC and AC microgrids, their features and challenges, the protection equipment, standards, and future scope for improvement are discussed. In [11], the authors present a comprehensive methodology for microgrid stability classification based on the parameters of the microgrid, as well as characteristics investigation, which considers the microgrid operation mode, types of disturbance, and time frame. In [12], the authors summarize the optimization framework for microgrid operation, which contains the optimization objective for the microgrid operation, decision variables and constraints, along with systematically reviewing the optimization algorithms for microgrid operations, which are the most commonly used. The authors of [13] provide a comprehensive review of microgrid cybersecurity, while ref. [14] provides a review concerned about cyber-attacks on microgrids. In particular, communication protocols, standards, and vulnerabilities highlight the most recent cybersecurity technologies applied in microgrids.

Choosing the proper components in the microgrid architecture is a critical challenge since it significantly impacts the system's reliability and the project's economic viability. The microgrid components are selected based on the existing and planned distributed generators, loads, the space to place the energy storage devices, the existing communications, and the difficulty of placing new electrical lines [15]. Based on the above review papers, the most common architecture of microgrids consists of different distributed energy resources, loads, communication technologies, operation control, and market control, as illustrated in **Figure 1**. The function of each component has been explained in the following sections.

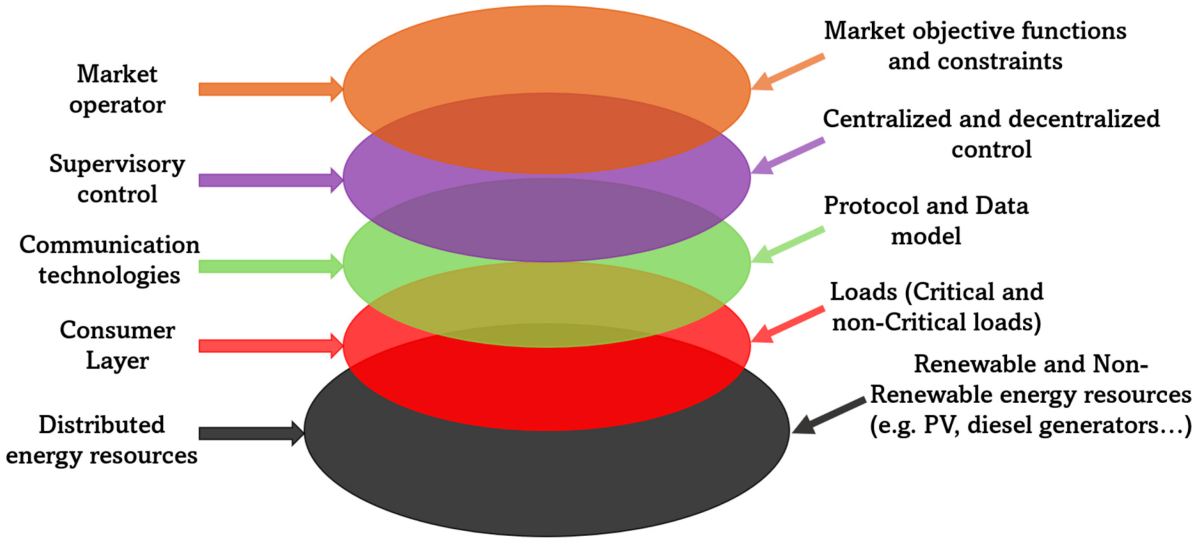

Figure 1. Microgrid architecture model.

2. Microgrid Components

Micrograms can have diverse components and architecture, which the internal stakeholder structure and the microgrid ownership can predominantly design. Moreover, operational ownership is generally decided based on the ownership of physical components such as distributed generators, energy storage systems, and power electronic converters, and each component brings about the control, protection, and management action connected either in autonomous or grid-tied mode through the plug and play (PP) mechanism [16]. The microgrid ownership can be the distribution system operator (DSO), end consumer, independent power producer (IPP), or energy supplier [17].

2.1. Distributed Energy Resources

Distributed energy resources (DERs) are energy resources that are typically located at the user's sites, where the energy is used to meet the consumer's needs. The DERs consist of small modular power sources and storage technologies. Generally, DERs provide electrical power at a low-cost production and high reliability and security with less environmental impact. The power sources can be renewable sources, such as solar cells and wind turbines, or non-renewable resources such as fuel cells, diesel generators, and combined heat and power (CHP) units. According to [17], a microgrid should have one or more controllable DERs units to enhance the flexibility and reliability of the power system. Moreover, it has been found that multiple smaller DGs are better at automatic load following, thereby improving energy security. Renewable energy sources are intermittent and fluctuate in their output due to the uncertainty and volatility of weather conditions [18]. Therefore, an extensive storage system must be installed to cover these resources' intermittence. The energy storage devices such as batteries, flywheels, energy capacitors, compressed air, and ultra-capacitors must be included in microgrid operation, especially in islanded mode, to ensure uninterrupted power supply during disturbances and drastic load changes, and to minimize the peak load and avoid the reliability problems. Usually, energy storage system is used to supply energy to the load during demand by storing energy and producing electricity [16]. Electric vehicles (EVs) are considered an alternative option to store power at night when the operation cost of electricity generation is low. These storage options provide more stability and allow the DERs to continuously meet the loads' needs.

Several multidisciplinary studies cover the wide variety of distributed energy resources deployed in microgrids, including renewable and non-renewable resources, and energy storage technologies. **Table 1** summarizes various studies integrating distributed energy resources and energy storage systems with microgrids.

Table 1. Summary of different distributed energy resources applied in the microgrids.

	PV	Wind Turbine	Battery Energy Storage	Fuel Cell	Micro-Turbine	Hydro-Power	Diesel Generator	CHP
[19]	x	x	x					
[20]	x	x	x	x	x			
[21]		x	x				x	

	PV	Wind Turbine	Battery Energy Storage	Fuel Cell	Micro-Turbine	Hydro-Power	Diesel Generator	CHP
[22]	x		x	x				
[23][24]	x						x	x
[25]	x		x				x	x
[26]			x				x	
[27]	x	x	x					x
[28]	x	x		x				x
[29][30]	x						x	x
[31]	x	x					x	
[32]	x	x	x				x	
[33]	x	x	x					x
[34]	x					x		
[35]	x	x	x	x	x		x	
[36]	x		x		x			x
[37]	x	x			x			x

2.2. Loads

The loads are appliances or equipment that consume electrical energy connected to the microgrid, such as homes, offices, industries, and many other places. These loads require electricity at different points in the day depending on usage profiles, activities of customers, and weather conditions [38]. Loads play a vital role in the optimum power system operation to achieve the DR program in order to schedule energy in the microgrid and modify the load pattern. Statistical metrics are usually used to construct the pattern of use. Ideally, the loads connected to the microgrid must be controllable with more flexibility when these are used to provide more reliability in matching demand and the power dispatch from the DERs [39]. Depending on their specific properties, controllable loads can either be shifted, curtailed, or completely disconnected. Since the microgrid supplies different types of consumers, including residential, commercial, and industrial, the classification of loads is essential to achieve the expected operating strategy and provide power balance or voltage control services [40].

The loads in a microgrid can be classified into critical and non-critical loads. Critical loads such as medical equipment and the fire department need high power quality and reliability, contrary to the non-critical loads such as residences and industry, which require a lower service quality [41]. The controllable loads can be reduced or shed during the critical time and for which the demand can be scheduled among a set of pre-defined operations at different time points. The MGCC sends the signal to controllable loads units for achieving a step change in electricity consumption, which can be based on a pricing signal, activities, and disturbance in the power supply [42]. **Figure 2** illustrates the block diagram of critical and non-critical loads connected with MGCC.

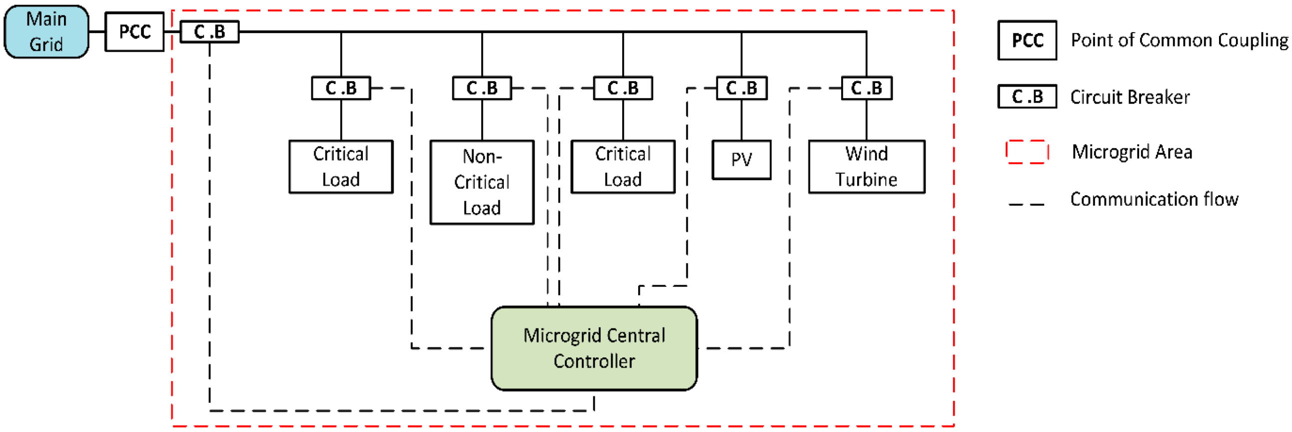

Figure 2. Block diagram of critical and non-critical loads connected with MGCC.

2.3. Communication Technologies

Microgrid systems require an efficient data communication system for fast, continuous, and effective operation. The communication technologies allow the optimum local operation and efficient information exchange between the microgrid components and the grid utility. Moreover, the communication technology system provides the market platform and connects the prosumers to the local energy market and energy transactions. The communication technology system of the market operates under a set of market allocation rules, payment rules, and a clearly defined bidding format. Wide area networks (WAN), field area networks (FAN), local area networks (LAN), and neighborhood area networks (NAN) are the most used communication network for data exchange in the microgrid [43]. The communication technologies in the microgrid system are selected based on cost-efficiency, transmittable range, security features, bandwidth, power quality, and the number of repetitions. In the literature, communication technologies have been classified into two categories: wired technologies and wireless technologies. Wired technologies have been widely used for their better performance than wireless technologies regarding reliability, robustness, security, and bandwidth properties. However, this technology costs high, and its implementation is complicated [44]. There are several wired technologies applied in microgrids, for example, the serial communication RS-232/422/485, bus-based technologies (e.g., Modbus, Profibus, CANBus), Ethernet (IEEE 802.3 technology and Ethernet port), and power line communication (e.g., DLC, PLC, BPLC) [2].

On the other hand, wireless technologies are often used to improve accessibility to services, including clean energy, at an affordable cost for small remote communities and difficult geographic circumstances. The most popular wireless technologies used in microgrids IEEE 802.11, Wi-Fi (WLANs), family standards IEEE 802.15 (wireless personal area network, WPANs), and IEEE 802.15.4 standard (low-rate wireless personal area network, LR-WPAN) [2].

2.4. Supervisory Control

A robust controller is recommended for optimal control of a microgrid's voltage and frequency for ensuring microgrid operation with high stability, reliability, and many economic goals [16]. The purpose of supervisory control in the microgrid is to ensure each system's optimized and coordinated operation during grid-connected and islanded modes while guaranteeing minimal operation costs, performing essential tasks such as controlling the power quality, and optimizing system operation through an enhanced system's intelligence level. Several supervisory control techniques have been reported in the literature and broadly classified into centralized control, decentralized control, and distributed control [45]. Centralized control highly promotes microgrid control. In centralized control, each microgrid is connected to the grid utility and the other microgrids through a centralized control center to manage the operation of different distributed energy units in the microgrid system. Generally, centralized control is used for small-scale microgrids, not large-scale microgrids. This type of control has many features, such as flexibility, lesser complexity, stability, reliability, and suitability to provide a set point to a local controller (LC) [45].

The decentralized control strategy uses local measurements of each microgrid system and decides the actions at the component level. The decentralized control strategy uses local measurements of each microgrid system and decides the actions at the component level with a plug-and-play possibility [38]. The decentralized control technique can enhance active and reactive power sharing without a communication network in DERs units. The decentralized control is usually employed in the high-rated microgrid with large-scale components, whereas the centralized control structure would be sluggish [46].

In the distributed control approach, the local units are operated using various centralized controllers or central agents, and each central agent uses data from other neighboring agents and information from local microgrids and LCs [47]. All the devices in the distributed control work together to reach a collective decision based on the set goals, and then each control center decides the power flow to the load based on the power generation of the same microgrid and power availability from other microgrids. Compared with centralized control, distributed control has many advantages as the operation of the whole system doesn't fail for the failure of a single device and also gives a better stability performance, and only limited information can be shared between each pair of nodes [45].

2.5. Market Operator

The operators (participants) and the utility have different goals in grid-connected mode. The market operators in the microgrid will strive for market clearing and serve the customers by the optimal tariff operation, meaning the minimization of operating energy and capital costs over the lifetime of the microgrid. In contrast, the utility is more concerned about the microgrid's reliability, voltage stability and power quality, and rightfully so, as it is becoming increasingly important with the increased integration of distributed generation and inverter-based loads [5]. The market operator is the entity in charge of carrying out the tariff calculation and the market procedures according to the design of the market mechanism. The market operator can be deployed with a fixed price in a monopoly market. However, for an ideal competition environment, a broader policy must be considered [48].

The market operation proceeds in three stages: negotiation, clearing, and settlement. At the beginning of the negotiation stage, the microgrid units register with the market operator, indicating that they wish to participate in the market [49]. The market operator then updates the forecasts and broadcasts initial prices. The market participants and utility operators then negotiate through bids and asks. The market clears when the negotiations have reached a steady state. The spot value of the cleared bid/ask is binding, while all futures values are non-binding advisory set points. The settlement phase may occur immediately, following the operating interval or after some other specified period depending on the settlement rules [50].

3. Market Players

The integration of renewable energy resources in the power system has motivated the modern electricity markets that stem from a distributed market architecture where the microgrid community represents multiple microgrid agents upstream. Compared with the traditional market, the microgrid community and microgrid agents are both consumers and prosumers [51]. An exemplary architecture of the microgrid energy market for residential consumers and prosumers is represented in **Figure 3**. Generally, the following market players are considered in the modern microgrid energy market models:

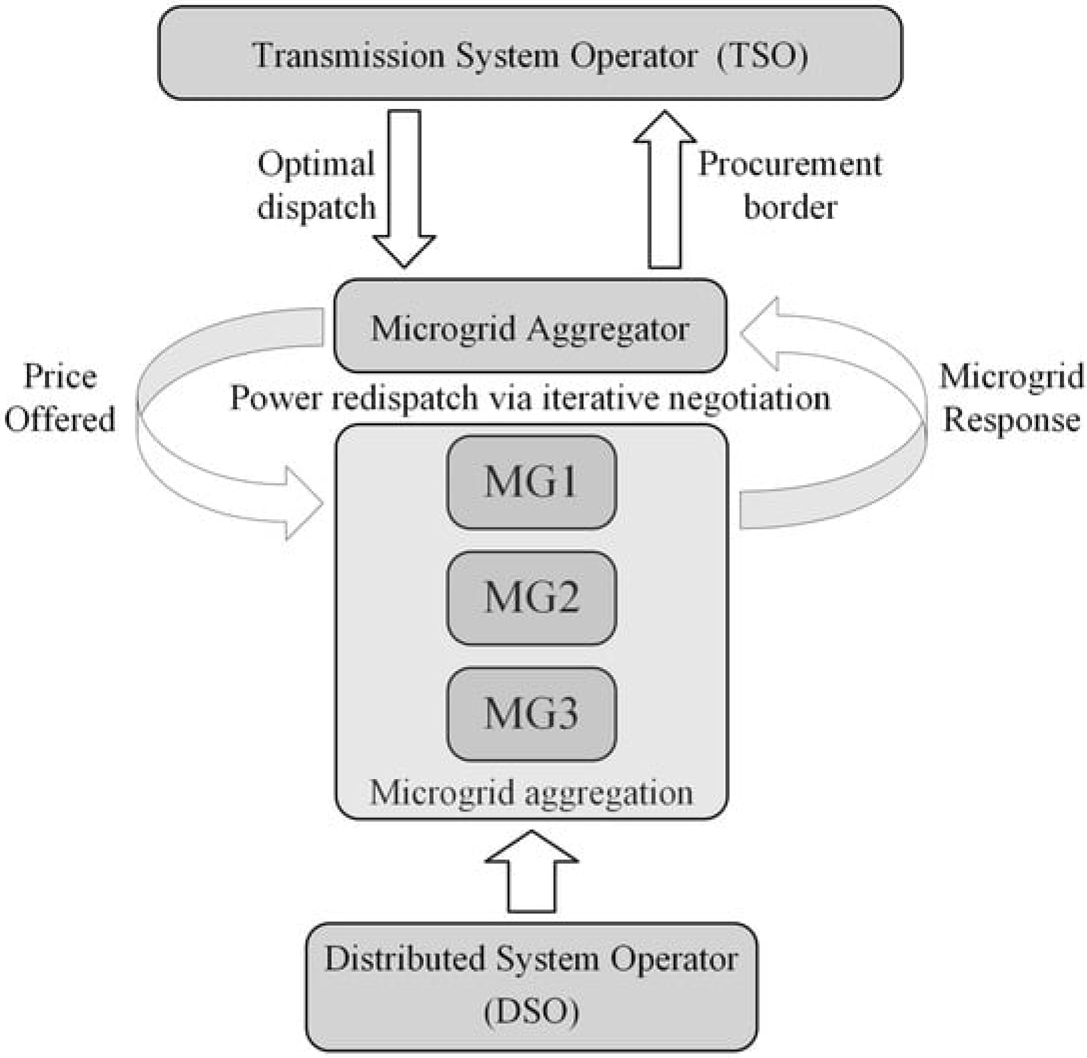

Figure 3. Example setup of microgrid market players.

The distribution system operator (DSO) is responsible for the operation and planning of the distribution grid utility, including DERs, as well as providing rules and mechanisms that properly value the benefits provided by DERs. The services of the traditional DSOs are to manage the local grid utility in case of forced and planned outages and ensure the grid utility operation and maintenance securely [52]. The modern DSO is an independent entity, without any acquiring biasing objectives, which are responsible for the operation and the planning of distribution systems as individual producers/consumers, ensuring balancing between supply and demand at the distribution level, and providing proper, fair compensation via some market mechanism [53].

The transmission system operator (TSO) is the entity responsible for controlling and operating the transmission grid. This includes monitoring and controlling the current grid topology and the voltage in all parts of the transmission grid. TSOs ensure the reliability of the transmission of power from DERs to DSOs by way of a high-voltage electrical grid. TSOs are responsible for operating the balancing market and providing grid access to the electricity market participant according to non-discriminatory and transparency in the market.

The aggregator is a novel architecture of energy service providers in the microgrid energy market that operates between a group of consumers and TSO, DERs, and electricity suppliers for the balancing energy market by undertaking balance responsibility [54]. Aggregators can enter the market and engage with consumers without the consent of energy suppliers to operate on behalf of a group of consumers producing their electricity by selling the excess electricity they produce. Aggregators can assess consumers' consumption profiles to provide offers that reflect their needs and lifestyle and increase their benefits [55].

4. Market Mechanism

The market operator implements the market mechanism for setting rules and market policies for the market participants' interaction and delivering an efficient energy trading experience. The market mechanism aims to provide payment rules and to lay out an efficient allocation of the energy exchange in the market and an employable approach for buying and selling [56]. The market mechanism involves different sub-markets with complementing functions to allocate resources and offer different trading opportunities where market participants maximize their revenue and minimize their energy costs [54]. The market mechanism can represent DERs and grid utility constraints at several locations and different time horizons consisting of a day-ahead (DA) spot market, an intraday (ID) market, a balancing (BA) market, and an imbalance settlement [57].

Given the market mechanism, the authors in [58] introduced a mechanism market concept of a microgrid aggregator to operate a small-scale microgrid in real-time for the day-ahead to balance the market bidding using a hierarchical market strategy. The risk-constrained mean-variance model and the event-driven mechanism constraints have been proposed to depress the effects of uncertainty in renewable energy sources and to reach the cleared quantity of the upper market. In [59], a novel market mechanism was developed to quantify the value of emergency energy transactions in renewable-based multi-microgrid systems. The proposed market mechanism integrates the pool emergency transactions and bilateral contracts to minimize the system risk in the face of different contingency events. In addition, an optimization approach was developed to optimize the bidding strategy of the microgrid in the market. In [60], a market mechanism based on multi-time interval electricity markets for microgrids is designed to use DERs and participants' storage. In addition, a novel bid structure for energy storage system participation has been proposed to allow the storage system units to communicate their cost to the market using energy-cycling functions that map prices to cycle depths. The market-clearing price is reduced using schedules and payments based on traditional energy prices for power supply and the cost of operation of the energy storage system in [61] designed an integrated dynamic market mechanism (DMM), which incorporates real-time market clearing and frequency regulation, allowing market players, including renewable energy resources and flexible consumers, to continuously negotiate electricity prices at the wholesale level while using the most recent information on the available power from the wind turbine and the quality of grid frequency. The authors of [62] introduced the spot market power mitigation clearing mechanism (MPMCM) to manage the limited potential market power execution, avoid overregulation, and maintain an actual market supply-demand situation. The proposed MPMCM consists of three processes: market power evaluation, bidding capacity division, and bidding capacity constraint. The MPMCM is formulated into bidding constraints set and adequately integrated into the local market clearing procedure. A bi-level objective function with equilibrium constraints market equilibrium model is proposed to formulate the MPMCM for market simulation. In [63], a double-sided auction market mechanism is presented for pricing the zero marginal cost renewable energy resource in the DERs. The proposed market mechanism has evolved into a set-and-forget bidding market for participants to integrate honesty as a key strategy. The authors of [64] present a market mechanism for smart charging stations for electric vehicles (EVs) that allocate the optimal charge and discharge status to provide power network stability and allow vehicles to express individual preferences regarding their charging rates. This mechanism considers network-specific constraints such as total voltage drop, network load, and phase unbalance for the participants who want to receive higher rates regardless of paying a higher price.

5. Pricing Mechanism

The substance objective for designing the market mechanism is to use value-based signals to incentivize market players to provide an efficient power supply for the demand by controlling the power dispatch of DERs, considering multiple constraints in generation supply capacity, transmission, flexibility, energy storage, and demand elasticity. The market mechanism implements the pricing mechanism for prices to be discovered and aims at efficiently allocating energy supply and demand. The pricing mechanism indicates that the price producers can charge for a specific commodity or consumers need to pay to obtain a particular service. The price signal is information conveyed to producers and prosumers where the prosumers can generate profits by pricing their energy by including the extra fees, such as taxes [65].

Different factors can change the price in the energy market, for example, the taxes and surcharges of the traditional energy, the power quantity of supply and demand, and the locations of the consumers and producers. Furthermore, the shortage in the local power supply leads to an increase in the market price, while the surplus of power reduces the market price. Pricing mechanisms can be classified based on price formation mechanism to single auction, double auction, uniform-price auction mechanism, and distributed optimization pricing mechanism [66]. **Table 2** shows the advantages and disadvantages of the auction pricing mechanism in the energy market.

Table 2. Summary of the typical auction price formation mechanism in the energy market.

Type	Definition	Advantages	Disadvantages	Ref	Contribution
Single Auction	The single auctions involve consumers submitting their bids to the market operator for clearing. In this type of auction, the market operator is defined as the aggregator.	-Flexible auction mechanism -Individual rationality	-One-sided auction. -Patronizing a neutral market.	[67]	Proposed a single auction to prevent users' cheating and enhance pricing methods. The authors used the smart meter for the data, collection, and communication with the energy provider's terminal to model the pattern for each customer. Then, the "Arrow-d'Aspremont-Gerard-Varet" mechanism is applied to guarantee the truthfulness of the user's payment.
				[68]	An economic load dispatch model was applied in a single-bid auction market to predict the market-learning price of electricity in the dynamic of the energy market.
				[69]	The single-sided reverse combinatorial auction was proposed to determine the winner's solution for the trading application. The combinatorial auction mechanism used can curtail the load in the microgrid.
Double Auction	Involves both buyers and sellers. Double auction refers to a transaction form with multiple sellers and multiple buyers	-Has a great advantage in terms of computation efficiency.	- The participating cost is included before the auction.	[70]	Provides decentralized trading based on a double auction for a mutual trust system and information

Type	Definition	Advantages	Disadvantages	Ref	Contribution
	where the buyers and sellers can communicate. Buyers and sellers can submit quoted prices at any time during the transaction cycle.	-Provide a fairer pricing mechanism.			transparency for each participant in the market.
				[71]	The proposed auction mechanism does not violate the constraints in the power system and does not require agents for information transfer.
				[72]	A novel winner-determination solution was introduced for combinatorial double auctions using evolutionary algorithms.
Uniform-price auction mechanism	Involves the price for all agents being equal to the price at the intersection. The uniform price auction mechanism is fair, in the sense that a buyer prosumer never pays more than other prosumers for buying the same quantity of energy.	-Truthfulness, and guaranteed approximation.	-The uncertainties in the award prices.	[73]	The proposed uniform-price auction mechanism was implemented in the two types of markets to determine a uniform trading price, maximize economic benefits, and efficient energy allocation.
				[74]	Prosumers and customers were designed as autonomous self-interested agents who can learn the best response policy to maximize their expected benefits in the microgrid market by adapting to the other agents using the uniform-price auction strategy.
Distributed Optimization Pricing mechanism	All participants in the energy market are received the market price from the market operator. Then agents respond to the market operator by declaring their	-Reduces supplier investment. -Achieve desirable properties.	-Difficulty managing the market with a large number of participants.	[75]	The authors proposed the alternating direction method of multiplier (ADMM) based distributed approach to determine the energy price in the power system. This strategy solves the energy

6. Energy Market Design

Type	Definition	Advantages	Disadvantages	Ref	Contribution
	supply/demand or offering flexibility.				pricing problem for the peer-to-peer (P2P) energy trading model by reducing the exchange of information among the agents participating in the energy market.

esources, or energy load and [65]. The efficiency se [76]. At the TSO level, the aggregator determines the power generation/load scheduling in different market time horizons for local participation, considering the technical constraints of the transmission network. The schedule is carried out to ensure that this particular dispatch is possible, given the network capacity [53]. The energy schedule should depend on the market design to cover the various stages of the market. Generally, the market design can include a day-ahead market, an intraday market, and a real-time market [77]. **Table 3** illustrates a comparison of the different market designs that have been proposed in the literature.

Table 3. Comparison of different market designs day-ahead, intraday, and real-time market.

Type	Definition	Pricing Mechanism	Ref	Contribution
Day-ahead market	The market operator opens the market bidding on the energy demand and supply until a certain period on the following day and the real market time. Market participants (prosumers and consumers) submit their bids/offers before that deadline which is typically 12:00 pm day-ahead. Typically, the real-time market makes up about 40–50% of the entire energy market capacity.	Pricing on the day-ahead markets is fixed.	[34]	Analyzed the cost operation of a microgrid consisting of a photovoltaic-hydro station on a day-ahead electricity market. The operation of solar and hydropower stations on the day-ahead market as separate power stations is utilized to schedule profit for the owner.
			[78]	Day-ahead strategy for combined cooling and power (CCP) microgrid was proposed for energy planning using the interval optimization model based on interval measurement. The proposed method reduced the operation cost by 3.152% and 3.115% compared to the conventional model.
			[79]	Presented day-ahead pricing electricity markets for the demand elasticities problem using stochastic matrix utility function. In the case of the study, the proposed model had less error of 10% compared to 73% of the traditional method.
			[80]	Introduce an auction-based day-ahead market framework based on a decentralized operating model for

Type	Definition	Pricing Mechanism	Ref	Contribution
				a multi-microgrid system with a private microgrid. The simulation results illustrate that the proposed framework promoted the economic performance of the microgrid by following the required constraints and providing suitable conditions.
Intra-day market	The intraday market is a short-term market and involves several auction sessions. It offers flexibility to reduce the need for more expensive resources with effective flexibility for real-time balance. Typically, the intraday market is used to make adjustments in the positions of participants as the delivery time approaches.	Prices on intraday markets deviate from trade to trade.	[81]	Studied the systematic electricity price formation of the Swedish intraday market for a large-scale wind power system. The study included the electricity market data for the period 2015–2018.
			[82]	Developed a multi-stage stochastic programming strategy for optimizing the bidding operation in intraday scheduling using a virtual power plant (VPP) on the Spanish spot electricity market.
			[83]	Design an optimal congestion scheduling model for the intraday market to evaluate the consumption of renewable energy sources with the aim to reduce congestion and operating cost.
Real-time market	The real-time market is associated with the dispatch of committed generating units due to remaining uncertainties between the gate closure of the day-ahead market and real-time delivery and sub-hourly variability. Generally, the real-time market represents 5–10% of the entire energy market capacity.	Pricing on real-time markets differs.	[84]	A balance responsible party-based reserve services mechanism with an auction-based pricing method was implemented in a real-time market to mitigate the supply from the uncertain resources and optimize the cost of the benefits.
			[85]	Proposed a novel online optimization framework based on the real-time market to maximize social welfare using an online consensus alternating the direction method of multipliers (OC-ADMM) approach.
			[86]	Developed a microgrid operator framework for real-time energy market participation under uncertain conditions. The microgrid operator bids in the real-time market are

In the aforementioned market's designs, energy is traded for delivery to consumers during a specific period. However, the power systems need to be balanced at each instant time. In this context, the TSO faces uncertainties

Type	Definition	Pricing Mechanism	Ref	Contribution
				modeled in the second stage of the proposed framework to represent the effect of the uncertainties of demand and generation from renewable energy sources on the market.

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