Chapter 1

Introduction

1.1 Background and motivation

In the traditional electricity system, the consumer interacted with the utility only as it was the single electricity provider in that vertically integrated system. The electricity power flow was uni-directional. The power generation was done at large facilities that were often located far away from the consumers. The local renewable generation was few or negligible. The whole system was under the control of the government to ensure a fair pricing mechanism and reliable operation. The distribution system operator (DSO) has only the responsibility of maintaining the electrical distribution network. There was no competition in the electricity market.

During the 1990s, in many countries, a deep transformation occurred in the electricity industry. This led to the restructuring of the electrical power system through the various Electricity Regulation Acts. The restructuring/ unbundling of the power system gave rise to several new entities and concepts. The entities such as power producers, consumers, system operators, and power exchange were born. Concepts such as energy trading, ancillary services, distributed generation, battery energy storage systems (BESS), and demand-side management also came up. The restructuring also gave a fillip to new research areas addressing the strategies of operations and strategies of players viz, generation, consumers and distribution companies (DISCOs) in response to the new scenario. The concept of network operators, and congestion management came up to address the problem of energy generation and supply. In recent, time there has been new research opening up due to the emergence of new and small power producers, which were essentially the consumers in the earlier scenario.

Also, with the growing concerns about climate change, increasing demand, and the rise

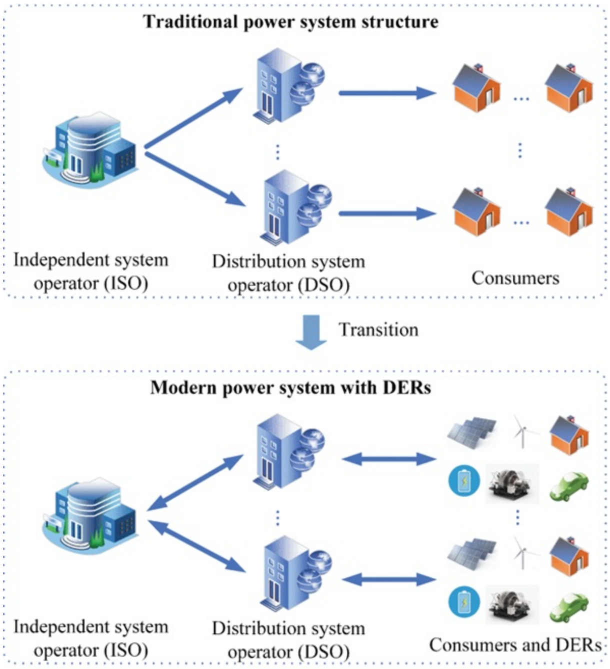

Figure 1.1: Power System Transition Diagram. [1]

of various distributed energy resources (DERs), it is very important to implement an effective energy management system to reduce carbon footprints and optimize energy consumption. The DERs such as wind turbines, rooftop solar panels, and energy storage systems, have given the capability of electricity generation to consumers by making them producers and thus are referred to as prosumers. This transition is further facilitated by the advent of smart grid technologies including advanced monitoring, control, and communication capabilities. These rapid developments have changed the operating condition, performance, and structure of the distribution system model. The electricity power flow has become bidirectional. All these factors led to the emergence of smart buildings, energy communities, and new roles of DSO.

The transition from traditional electricity systems to decentralized models is driven by the increasing penetration of renewable energy sources, advancements in digital technologies, and the need for more flexible and resilient energy systems. This shift is characterized by a move away from large, centralized power plants toward locally distributed generation, energy storage, and peer-to-peer (P2P) energy trading. The transition for the power system from conventional to modern can be seen from Figure 1.3.

Traditional electricity systems rely on large-scale generation from fossil fuel or nuclear power plants, with electricity transmitted over long distances to consumers via a centralized grid. In contrast, decentralized models integrate localized generation, such as solar photovoltaics

(PV) and wind turbines, enabling consumers (prosumers) to generate, store, and trade electricity within their communities. This transition reduces transmission losses, enhances grid reliability, and supports sustainable energy consumption. The followings are some of the case studies and quantitative data.

- Germany's Energiewende (Energy Transition) [4]: Germany's Energiewende policy is a leading example of large-scale decentralization. In 2020, renewable energy accounted for 50.5% of Germany's electricity generation, up from just 6% in 2000. Over 1.6 million small-scale renewable energy producers, including households and businesses, now contribute to decentralized electricity generation. The government has encouraged decentralized generation through feed-in tariffs (FiTs) and community energy cooperatives, where local communities collectively invest in and manage renewable energy projects. These efforts have led to a substantial reduction in carbon emissions and have demonstrated how decentralized models empower local energy consumers.

- Brooklyn Microgrid (USA) [5]: The Brooklyn Microgrid in New York is an example of a blockchain-based decentralized energy trading system. It allows residents with solar panels to sell excess energy directly to their neighbors through a peer-to-peer (P2P) marketplace. power outages. Smart contracts ensure transparent and secure energy transactions. This initiative highlights how digitalization, combined with decentralized energy generation, can create a self-sufficient local energy market.

- India's Decentralized Solar Expansion : India has witnessed rapid growth in decentralized energy models. Accordinf to [6] Over 10 GW of rooftop solar capacity has been installed as of 2023, contributing to local energy self-sufficiency. The Delhi P2P solar trading pilot project [7] allows consumers to trade solar power using blockchain technology, ensuring secure and efficient transactions. Decentralized solar mini-grids in rural areas have improved energy access for millions of people who were previously off-grid. India's approach demonstrates how decentralized energy models can enhance energy security, promote renewables, and support economic development.

The transition from traditional electricity systems to decentralized models is well underway, supported by technological advancements, policy incentives, and growing consumer participation. Case studies from Germany, the USA, and India, along with global trends, highlight how decentralized energy solutions improve grid resilience, empower local communities, and accelerate the shift toward a more sustainable energy future.

1.1.1 Emergence of Smart Buildings

By integrating advanced technology into the buildings, smart buildings have emerged. These technologies include demand-side management, automated systems, IOT-based technology for interacting with smart grids, and many more. These added features play a vital role in the energy management system for monitoring and optimizing energy usage. These smart buildings represent the consumers. Buildings with renewable energy sources (RESs) are also referred to as energy buildings.

1.1.1.1 Integration of battery energy storage

For mitigating the challenges associated with the fluctuating character of renewable energy sources, the flexible capacity of the network needs to be increased to enable a more sophisticated response to fluctuations in energy production [8]. The integration of the battery energy storage system is one such flexible capacity of the network. They can also be used to reduce the net electricity cost by saving energy in hours of low utility prices and utilizing the same during high utility prices. The BESS can be installed for an individual entity or a group of entities [9, 10]. In [9], the role of BESS is discussed by taking two cases: one with a centralized BESS and the other with an individual BESS. Compared to the individual BESS, the shared BESS is more profitable by incorporating idle resources and removing individual ownership [10].

1.1.1.2 Demand-side management

Modifying consumer demand patterns with the help of methods like financial incentives and/or Time-of-Use (TOU) pricing schemes is known as DSM [11]. The DSM, according to the U.S. Department of Energy [12] report, can be defined as *"Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized"*. It is an efficient tool to reduce the net energy cost of buildings. One example is shifting the load corresponding to the utility's prices [13]. However, this shift will result in an additional charge in the building's

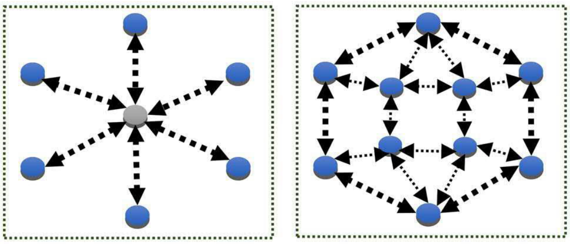

Figure 1.2: Pool based and Peer-to-peer based energy trading [2]

cost function due to the discomfort experienced by the consumers. A three-layer strategy is used in an active distribution network in [14] for load scheduling. The first layer deals with the demand response program, the second deals with the load scheduling of smart buildings and Electric vehicles, and the third deals with the microgrid problem. The IOT-enabled load is used in [15] for maintaining the network constraints during high-demand periods by shifting the load. Instead of using discomfort cost, [16] uses the satisfaction index for the modeling of flexible load in such a way that this index should be greater than a certain limit.

1.1.1.3 Local Electricity Market

A revolutionary approach to managing and distributing energy is through local energy markets which arise from trading excess renewable energy to the neighbouring buildings. This helps in reducing the net energy cost of the consumers. This type of sharing is called transactive energy sharing which is an economic and control mechanism for using the resources efficiently and economically. It can be of the following two types

1.1.1.3.1 Pool-based energy trading: In this type of energy trading, the producer and consumers contribute to and draw from a common energy pool. A central entity is present to manage and balance the energy management system. This central entity is responsible for the efficient distribution of energy. The risk of outrage or power imbalance is quite low in such types of trading. The effectiveness of pool-based energy trading depends on the integrity and capability of that central entity.

1.1.1.3.2 Peer-to-peer-based energy trading: In this type of energy trading the producer and consumer directly interact with each other without any centralized agent. They both have the flexibility to optimize their energy and price strategies. This approach uses digital platforms such as IOT or blockchain-based platforms to facilitate the transparent and secure energy trade.

One of the major challenges associated with these types of markets is their management with the increasing number of participants including the distribution of benefits efficiently and in a decentralized way among them.

The illustration showing the difference between pool and peer-to-peer energy trading is shown in Figure 1.2.

1.1.2 Energy Communities

The concept of energy communities arises from a combination of energy buildings, i.e., buildings with the capability of generating energy. Thus, these communities can also be referred to as virtual communities. The communities can be formed by grouping buildings based on their geographical locations, their location in the distribution system, or any other suitable criteria. For buildings of a certain community to interact with each other, the buildings need to have a different load pattern and sufficient renewable energy generation. This virtual community helps manage energy trade among a large number of buildings by reducing the number of energy transactions. Also, it helps in sharing BESS among its buildings and interacting with the DSO.

1.1.3 Distribution System Operator

Traditionally, the electricity distribution network was managed and operated by DSO for a stable and reliable operation. The responsibility of DSO was limited. In the modern power system, the roles of DSOs have extended. Apart from maintaining the grid parameters, it acts as a facilitator for integrating various distributed energy resources (DERs) and a market operator for clearing the energy market. It has also now become a key component in system planning & development and policy regulation & implementation. For enhancing the market participation of various DERs without any violation of network limit, the dynamic operating envelope [17] approach is used by DSO which solves the network problem and gives an acceptable range of network parameters at each point of the distribution system.

1.2 Literature survey

In the present distribution system, local energy trading is becoming increasingly popular. To minimise energy costs and meet the emission target, electricity generation and consumption

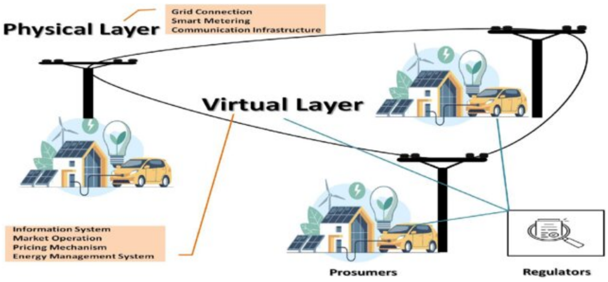

Figure 1.3: ELEMENTS OF P2P ENERGY TRADING [3]

must be coordinated to use resources efficiently. Many buildings are equipped with RESs and BESS facilities to reduce the energy demand from the utility grid, giving rise to the concept of (nearly) zero energy buildings (ZEBs) [18]. Several studies on optimised models of nearly ZEB solutions have been reported in the literature [19,20]. In the scope of the work discussed in this thesis, the existing literature can be categorized into the following identifiable categories.

1.2.1 Local energy trading: Pool based and Peer-to-Peer based

In recent years, the rapid development of various distributed energy resources has changed distribution networks' structure, operating conditions, and performance. The traditional distribution network with unidirectional power flow is transitioning towards a bidirectional power flow network. This has enabled the energy exchange in the distribution network, forming local energy markets. These energy markets are of two types pool-based (centralized) and peer-to-peer-based (distributed). In the former type, all the buildings negotiate and contract with a central entity that operates and manages the market. In contrast, in the latter type, buildings use bilateral contracts and energy trading among themselves. The main elements of P2P energy trading can be seen in Figure 1.1.

The idea of an energy community with an agent for P2P energy sharing was proposed in [21]. Profit-oriented and non-profit-oriented local trading centres (LTCs), used for managing the P2P energy trading, have been compared in [22]. However, the prosumers may have privacy concerns due to the involvement of middle or centralized agents. Ref. [23] proposes a decentralised optimization approach for P2P energy sharing. A two-stage optimization framework with a cooperative game has been developed in [24] for a community where the first stage deals with willingness of participation and calculation of power (if they decide to participate), and the second deals with the respective payments. For designing the P2P energy trading framework, the efficacy of Game Theory has been proved [25]. However, large-scale implementations of game theory, which means large numbers of players, would increase computational complexity, privacy concerns, and the need for a dedicated communications infrastructure. Also, in these works, the presumption is that the buildings are in close geographical proximity. In practice, the buildings can be located far from each other, leading to additional power loss. An equivalent amount of fee can be charged [26]. Furthermore, if the participants are geographically distant, then it is necessary to consider the distribution network constraint for viable P2P sharing.

In [27], an energy market is proposed having two levels, where one level is for intra-community trade, and the other is for energy exchange between the community controller and the utility. But in [27], no energy-storage is considered. A non-cooperative game among sellers for energy pricing and an evolutionary game among buyers for selecting the seller has been combined in a game theoretic model in [18]. The social welfare maximisation of problem for sellers and buyers has been used as an objective for optimization in [28] consisting of a model with pre-defined sellers and buyers for each time slot. A Stackelberg game is proposed in [29] with an upper level for pricing problems among sellers and a lower level for purchasing problems among buyers. The energy storage system like BESS and demand response was not considered in [29] which is not a realistic situation.

For preserving the participants' privacy, game theory-based P2P energy-sharing frameworks with a decentralized solution approach have been proposed in [30–32]. Real-time energy optimization at the building/community level is used to deal with the mismatch in generation and load due to the uncertainty of RES in [31, 32]. Ref. [33] introduces the concept of community as a combined set of buildings in terms of their load, generation, and storage to reduce the net energy cost of participating buildings and the community as a whole. By assembling various buildings together, a community can be formed that reduces the net energy cost of each building notably [33]. A community manager is used for inter and intra-community trade in [34]. The use of a middle agent, i.e., a community manager, is the main flaw in this work [34]. The local energy market based on a marginal pricing scheme in a community has been studied in [35] considering the virtual energy exchange on a local bus. The distribution network constraints are not considered in these works. The non-consideration of network constraints may lead to bus voltage and line loading limit violations, resulting in reduced power quality and increased power loss. Thus, to facilitate P2P trading, DSO has to make certain arrangements for load balancing and local resilience [36].

The major disadvantage of a centralised market includes loss of privacy, the burden due to extra communication, and large inter-dependency on each other. P2P energy trading among a large number of participants (buildings) leads to an increase in computational complexity, and consequently, the requirement for a robust communication infrastructure along with privacy concerns also increases. Further, the P2P energy-sharing model proposed in these works assumes the buildings to be geographically close, which, in practice, may not be the case.

1.2.2 Endogenous classification into seller and buyer

In [37], different roles of prosumers (buyer, seller, both or none) have been analysed using a coupling matrix-based energy-sharing mechanism. The nature of each consumer is assumed to be autonomous and heterogeneous in [38] for a realistic result. The model used in [38] consists of two phases. In the first phase, a dedicated mechanism for negotiating P2P energy trade is designed. The second phase is the settling phase, in which the transactions made in the first phase are cleared. The framework proposed in [39] consists of multiple energy storage providers and a middle agent that acts as a coordinator between the prosumers and storage providers. The middle-agent requirement is the main flaw in this framework. A pair-matching algorithm is used in [40] for matching the respective buyer and seller. In [41], a distributed P2P energy arbitrage model is proposed where the seller consumer shares the price information according to the energy demand of the buyer consumer.

Based on the available excess energy, these works [18, 27–29, 37–41], at the beginning itself, categorize the participants as a seller or a buyer. However, the BESS, flexible load shifting, and the strategies of other participants may encourage the participants to switch roles. Thus, the participants should have the autonomy in selecting their roles of either a buyer or seller or both or none.

1.2.3 Different pricing and incentive schemes for P2P trading

The economic benefits of P2P energy sharing motivates the prosumer for such energy trading. A dynamic pricing framework based on the supply and demand ratio (SDR) was proposed in [42]. This SDR method was modified with the help of a compensating factor for encouraging energy sharing in [43]. The ref. [44, 45] proposes a method for distributing the incentives based on the mid-market rate. The prosumers will need to share their power profile in these methods which is a concern for their privacy. Furthermore, in literature, Nash Bargaining is widely used for incentive distribution that disperses the benefits equally irrespective of their unequal contribution. In real life, this doesn't represents a practical scenario [46]. The authors [47] have examined hourly pricing mechanisms and incentive mechanisms and found that both mechanisms produce almost identical results. The main difference is in the execution time of both mechanisms. The incentive mechanism is comparatively faster.

1.2.4 Inclusion of network constraints to identify the feasibility of P2P transaction

Cooperative game-based peer-to-peer trading frameworks have been studied in [48–51]. A third-party agent, named P2P market coordinator (PMC), is assumed in [48–50] to maintain the conditions of the distribution network. Over-voltage caused by P2P trading has been prevented by specific reduction in power exported by prosumers. The impact of P2P trading on network losses has been investigated in ref [51]. Although the approaches proposed in refs [48–51] effectively deal with P2P trading and eliminate network over-voltage conditions. But [48–51] have some limitations such as consideration of a third-party agent as an intermediate between distribution network and prosumers, and no mechanism for under-voltage conditions and line loading limits. Also, the active participation of DGs has not been considered in these works. Different P2P market structures, communication infrastructure, and distribution network constraint handling techniques have been reviewed in ref [52]. Communication and computation complexity issues due to the extensive interaction of a large number of prosumers have been stated in [52]. Also, challenges regarding fair curtailment of prosumer export and a privacy issue (due to the assumption that PCM knows the sensitive data of the distribution network to the feasible settlement of P2P transaction) have also been indicated in [52].

The DSO ensures P2P energy trading by maintaining network constraints through reconfiguration [53]. A profit-based distribution network operator equipped with reactive power (Volt-VAR) control devices and on-load tap changing transformers, is considered a player with buyers and sellers in the energy market [54]. The network operational constraints are enforced in the cooperative game-based social welfare maximisation of DNO, buyers, and sellers. The optimisation model in [54] includes network constraints and parameters, which is impractical because this information is not shared by the DSO for security reasons.

However, this issue is addressed by replacing network constraints with a cost allocation function consisting of network charges in the P2P market problem [55, 56], but network usage prices for power trading are considered as a pre-fixed parameter. Having pre-fixed utilisation charges does not allow the DSO to have any adequate control over the level of violation caused by transacting entities, whereas a dynamic utilisation charge would allow the DSO to finetune the transaction on the network. In ref. [57], the violation of network constraints due to P2P trading is prevented using sensitivity analysis. In [58], the network parameters are maintained within their limits using an iterative algorithm. This algorithm considers the rescheduling of P2P trading after adding a penalty fee corresponding to the violation of network constraints. However, the network usage price is not considered in [57, 58].

A twofold framework is proposed in [59] for inter-area and intra-area (i.e. P2P) energy trading. Prosumers interact directly for intra-area energy trading. But for inter-area energy trading, DSO controls the scheduling of power and the respective payments. To account for the power loss and voltage regulation, the DSO determines the distributional locational marginal pricing (DLMP) through the optimal power flow (OPF) in [60] and [61] for the market operation. But [60] doesn't account for the energy storage system and uses a centralised approach that raises privacy concerns. The linear LinDistFlow model is proposed in [62] for analysing power flow and pricing in P2P energy trade. But this framework [62] neglects the uncertainties caused by the integration of renewable generation in such optimum scheduling. These uncertainties can create a discrepancy between local demand and supply, causing system instability, unreliability, and failure [63].

The network parameters, like voltages, power flow, power loss, etc., get affected by P2P energy trading. Bus voltage and line loading may violate their limit if the network constraints are not considered. This will result in increased power loss and reduced power quality. This is one of the important challenges faced in peer-to-peer energy trading [64].

1.3 Research gap

A comparison of the proposed work with the recent literature is shown in Table 1.1.

Based on a comprehensive literature review (section 1.2), several critical research gaps have been identified in the field of peer-to-peer (P2P) energy trading systems. This section outlines these gaps and their implications for future research directions.

Table 1.1: Comparison of the proposed work with the existing literature

	RES Uncertainty	Variable LMP	Variable NUC	Third-party Interference	Active participation of DGs	Consideration of network constraints	Pre-fixed status of prosumers as seller or buyer
[30]	×	×	×	×	×	×	×
[31]	✓	×	×	×	×	×	×
[32]	✓	×	×	×	×	×	×
[48]	×	×	×	✓	×	✓	✓
[49]	×	×	×	✓	×	✓	✓
[50]	×	×	×	✓	×	✓	✓
[51]	×	×	×	×	×	✓	✓
[53]	×	×	✓	×	×	✓	✓
[54]	×	×	×	×	×	✓	✓
[55]	×	×	×	×	×	✓	×
[56]	×	×	×	×	×	✓	✓
[57]	×	✓	×	×	×	✓	×
[58]	✓	×	×	×	×	✓	×
[34]	×	×	✓	✓	×	✓	✓
[59]	×	×	×	×	×	✓	✓
[60]	×	✓	×	×	×	✓	✓
[61]	×	✓	✓	×	×	✓	×
[62]	×	×	×	×	×	✓	×
Proposed Work	✓	✓	✓	×	✓	✓	×

- Scalability and Privacy Trade-offs: A significant challenge in existing P2P energy trading approaches is the trade-off between scalability and privacy preservation. As the number of participants in the system increases, the computational complexity grows substantially [65], leading to increased communication burden. This scalability issue often compromises the privacy of participants, highlighting the need for more efficient algorithms that can maintain privacy while handling large-scale systems.

- Geographical Considerations in Energy Sharing: Current P2P energy sharing models [11, 18, 66] often assume geographical proximity of participating buildings. However, this assumption may not hold in all scenarios. For geographically distant buildings, loss coefficients must be incorporated into the models to account for transmission losses. Future research should focus on developing more comprehensive models that can accurately represent energy sharing across varied geographical distances.

- Network Constraints and Technical Feasibility: The existing literature [27, 39] has not extensively explored the impact of network constraints on P2P energy transactions, potentially leading to technically infeasible solutions. Current approaches to address this issue include:

  - Pre-fixed network usage charges [55, 56], which provide inadequate control over energy transactions with respect to network constraints.
  - Explicit inclusion of constraints in problem formulations [54], which may lead to security issues due to the need for DSOs to share sensitive data with participants.
  - Involvement of third-party agents [34] , potentially compromising privacy.

  Future research should focus on developing methods that effectively incorporate network constraints while maintaining security and privacy.

- Dynamic Role Assignment: Many existing works [18, 27–29, 37] pre-classify participants into buyers and sellers. However, a more flexible approach is needed, allowing participants to autonomously switch roles based on market scenarios and other participants' strategies. This dynamic role assignment would better reflect real-world conditions and improve overall system efficiency.

- Fair Pricing Mechanisms: To encourage consumer participation in local energy trading, there is a need for suitable pricing mechanisms that distribute benefits fairly among participants without violating their privacy. Developing such mechanisms requires a delicate balance between economic incentives and privacy preservation.

- Renewable Energy Uncertainty: The intermittent nature of renewable energy generation poses a significant challenge to P2P energy-sharing frameworks. Future research should focus on developing robust models that can effectively handle uncertainties related to renewable energy generation, ensuring system stability and reliability.

- Integration of Dispatchable Distributed Generation: The simultaneous consideration of P2P trading and active participation of dispatchable Distributed Generation (DG) units has not been adequately addressed in existing literature. Further investigation is needed to understand the effects of active DG participation on P2P trading frameworks under various scenarios. This research could lead to more beneficial solutions that leverage the flexibility of dispatchable DG units within P2P energy trading systems.

In conclusion, addressing these research gaps will be crucial for the development of more robust, efficient, and widely applicable P2P energy trading systems.

1.4 Objectives and scope of the thesis

The main goal of this research is to develop a decentralized comprehensive P2P energy-sharing framework with BESS integration, meeting the uncertainties involved with renewable generation while securely maintaining the distribution network constraints. To accomplish this goal, the present work is further divided into the following sub-objectives.

- To design a decentralized P2P energy-sharing framework that integrates BESS and addresses uncertainties in renewable generation, ensuring the preservation of network constraints and enabling secure energy exchange among buildings. The framework also incorporates the concept of virtual communities (VCs), where buildings on the same bus are grouped to reduce the computational burden and communication complexity in large systems.

- To develop a game-theoretic-based algorithm for optimizing energy trading mechanisms (including B2B, B2C, and P2P transactions) within virtual communities. The algorithm aims to ensure fair pricing, privacy preservation, and efficient handling of network constraints. The concept of virtual communities is key here, as it helps aggregate energy exchanges within a bus, reducing the number of participants and simplifying transactions while maintaining the integrity of network operations.

- To implement a practical real-time and day-ahead energy trading system that incorporates dynamic pricing mechanisms, network usage charges, and cloud-based communication, facilitating secure data sharing with the Distribution System Operator (DSO) for effective coordination. The virtual communities concept is integral to this implementation, ensuring that energy exchanges are managed efficiently across multiple geographical locations while addressing privacy and scalability concerns.

These three objectives encapsulate the core design, development, and implementation aspects of the thesis, aligning with the broader research goal of creating an efficient and practical P2P energy trading framework.

1.5 Thesis Organization

Thesis is organized in the following manner to address the aforementioned objectives.

Chapter 2 presents the preliminary methodologies used in this work.

Chapter 3 discusses a decentralised and stochastic energy trading model to compare the daily incentive and hourly pricing mechanism using a cooperative game through Nash bargaining.

Chapter 4 presents a scalable and computationally efficient peer-to-peer energy management scheme based on a non-cooperative game theory.

Chapter 5 presents a framework enhancing network-constrained P2P energy sharing through virtual communities. It discusses a decentralised and stochastic energy trading model that uses a cooperative game through Nash bargaining while maintaining all the network constraints using the daily incentive method.

Chapter 6 presents a peer-to-peer energy trading framework with active participation of distributed generation. It discusses a decentralised and stochastic energy trading model that uses a cooperative game through KS bargaining while maintaining all the network constraints using the daily incentive method with DGs participating actively.

Chapter 7 presents a two-tier peer-to-peer energy trading framework with day-ahead and real-time energy scheduling. It discusses two decentralised and stochastic energy trading models that use a cooperative game through KS bargaining using the daily incentive method. One doesn't consider network constraints, and the other considers the network constraints with DGs participating actively in both day-ahead and real-time energy scheduling.

Chapter 8 summarizes the main findings from this research as well as possible improvements and future work that may follow the work presented in this thesis.

1.6 Summary

The revolutionizing of the electricity network into a more interactive and decentralized system results in both opportunities and challenges. The P2P energy trading offers a promising solution to the associated challenges. This thesis uses various game theoretic P2P energy trading models to provide insights into market dynamics, mechanism design, and equilibrium outcomes. The following chapters will investigate deeper into the strategic interaction of P2P energy trading to lay a basic foundation for a more sustainable energy future.