Software Requirement Specification Document for A Peer-to-Peer Energy Trading System

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Table 1: Document version history

Version	Date	Reason for Change
0.1.0	27-Nov-2023	SRS First version's specifications are defined.
0.2.0	28-Nov-2023	Added pre-written content to respective sections.
0.3.0	15-Dec-2023	Specified Functional Requirements and elaborated on machine learning models
1.0.0	14-Jan-2024	First major version

Abstract

Harnessing renewable energy is now within the reaches of the public. We live in a world where solar panels occupy many rooftops but despite all the great advantages of using renewable energy, there is one challenge that still holds back the transition to more renewable sources. Power units that use resources like solar and wind power respond to changes in demand very poorly. There is a solution to increase reliability and maximize the utilization of renewable energy by automatically trading generated energy between Prosumers on the same grid. A system installed on the smart meter of every prosumer connects to a peer-to-peer network of smart meters and automatic energy trading takes place among the meters with the goal of balancing the grid through an optimized series of trades, making profit for participants, minimizing the waste in generated energy, and fulfilling deficit with renewable energy rather than relying on fossil fuel backup.

Contents

1 Introduction

1.1 Purpose of this document

This Software Requirements Specification (SRS) document outlines the design and functionality of a peer-to-peer energy trading system aiming to optimize renewable energy utilization through automated energy trading among prosumers. It serves as a comprehensive guide for system development, detailing its components, communication mechanisms, and optimization algorithms.

1.2 Scope of this document

This document encompasses the required functionality and constraints of the energy trading system as well as the definition of the proposed system's boundaries in both real-life use on smart meters connected to a smart grid and within the proposed testing environment.

1.3 Business Context

The business motivation behind this project is to make use of the renewable energy generated by individuals to maximize the utilization of renewable energy while cutting down on using fossil fuel for energy generation. This project also makes value for the participating prosumers to sell the surplus they generate and make profit from it. Buyers will also benefit from the ability to buy renewable energy sold by prosumers at a lower price than the national grid.

2 Similar Systems

2.1 Academic

This section covers the academic contributions made in this field. An overview of the related works cited can be found in table 2.

Smart contracts in energy systems: A systematic review of fundamental approaches and implementations [1]

According to this paper, smart contracts can enable more efficient and transparent trading of energy, as well as facilitate the integration of renewable energy sources into the grid. Smart contracts can automate the exchange of energy between parties based on predefined conditions, such as the price of energy, the quantity of energy to be exchanged, and the time of delivery. This can reduce the need for intermediaries and manual intervention, which can lower transaction costs and increase the speed of transactions. Smart contracts can also enable more granular control over energy consumption and production, which can help to balance the grid and reduce the need for expensive infrastructure upgrades. Overall, the paper suggests that smart contracts have the potential to transform the energy sector by enabling more efficient and decentralized energy trading.

The paper explains that smart contracts are self-executing programs that run on a blockchain platform. They are designed to automate the exchange of assets, which is energy in our case, based on predefined conditions. In the context of energy trading, smart contracts can be used to automate the negotiation, execution, and settlement of energy transactions between parties. The smart contract can be programmed to include various conditions, such as the price of energy, the quantity of energy to be exchanged, and the time of delivery. Once these conditions are met, the smart contract automatically executes the transaction and transfers the energy from the seller to the buyer. The transaction is recorded on the blockchain, which provides a transparent and tamper-proof record of the transaction. Smart contracts can also be used to automate other functions, such as billing, settlement, and dispute resolution, which can further streamline the energy trading process. Overall, the paper suggests that smart contracts have the potential to transform the energy sector by enabling more efficient and decentralized energy trading.

A Stochastic Game Framework for Efficient Energy Management in Microgrid Networks [2]

In this paper, the proposed gamified stochastic framework optimizes energy usage in microgrid networks by turning the problems of demand scheduling, energy trading, and dynamic pricing into stochastic games. This involves scheduling the demands at the customer side, selling and buying power from neighboring microgrids depending on current and future needs, and allowing microgrids to decide the price of the transaction depending on their current configuration of demand and renewable energy. The proposed approach uses the Deep Q-learning algorithm with independent learners to solve this problem.

Microgrids can intelligently schedule customer demands by identifying flexible demands that can be satisfied during certain time periods throughout the day. They can then use this information to schedule the demands in a way that optimizes energy usage and minimizes waste. Microgrids can also trade energy with neighboring microgrids by selling power when there is a Surplus and buying power when there is a Deficit. This allows microgrids to balance their energy needs and reduce reliance on the central grid, which can be unreliable and inefficient. Additionally, microgrids can use dynamic pricing to negotiate prices with neighboring microgrids, allowing them to obtain the best possible price for the energy they are buying or selling. This paper offers an efficient solution for energy trading where it offers a decentralized system that does not depend on blockchain technology. It still works but it could be more vulnerable. However, this paper gives us an interesting view into how two grids would decide to trade energy which would help us build our smart contract.

Peer-to-peer energy trading in smart grid through blockchain: A double auction-based game theoretic approach [3]

In this paper, a group of researchers explain how they think an optimal peer-to-peer energy trading system would work. Their goal is to improve participants' profits and reduce the impacts on the grid in a double auction-based game theoretic peer-to-peer (P2P) energy trading system among prosumers. The proposed method benefits the participants while protecting their critical information for privacy. According to the researchers, the approach works as follows:

1. The role of a prosumer is determined by their energy generation and demand.
2. The auctioneer sets the price and the energy that is supplied to the market to meet demand.
3. Buyers adjust the amount of energy to buy according to varying electricity price to maximize benefit.
4. The auctioneer controls the game and the seller does not participate but finally makes profit.

The auctioneer in their proposed system is a coordinator that manages and coordinates the auction process. The auctioneer operates a double auction where both buyers and sellers bid and ask the auctioneer which then determines the prosumers who can participate in a trade based on the double auction. A list of buyers is compiled, sorted by the decreasing order of their reservation bid price, while a list of sellers is compiled, sorted in increasing order of their reservation ask price. The auctioneer generates the aggregate supply and demand curves using the sorted bids and asks and then determines the clearing price and the amount of energy for all participants. No participating party has access to the private information of others, such as the amount of energy to be sold or energy demand, despite the rules of the auction being known to all participants. The proposed auction policies consist of a winner-determination rule, a payment rule, and an energy allocation rule. The auction process is repeated until reaching the stop condition. A diagram of their system is shown in figure 1.

The end product of this research is a proposed peer-to-peer energy trading system that uses a blockchain to perform the algorithm for optimizing demand response and energy matching. The system is designed to balance supply and demand and achieve maximum social welfare for both buyers and sellers. The system is composed of end-users, decentralized applications (DAPPs), and a blockchain. End-users play the role of prosumers. The DAPPs were built on top of Hyperledger Fabric software development kit (SDK), which supports communication between the end-users and smart contracts. The blockchain implements a smart contract that acts as the coordinator in energy matching. The proposed system is expected to provide a more efficient and transparent way of trading energy in a smart grid. The system proposed in this paper creates a suitable platform for an energy market oriented towards profit rather than grid efficiency.

RefID	Proposed	Finding
[1]	Reviews of 178 papers on energy trading, smart contracts, and specifically the use of energy trading in the energy sector.	A cautious and iterative approach is necessary when developing an energy trading system to ensure that needs are met.
[2]	A framework for energy management in microgrid networks, which involves intelligently scheduling customer demands, trading energy with neighboring microgrids.	The proposed framework can help microgrids to balance their energy needs and reduce reliance on the central grid.
[3]	A secure decentralized energy trading system based on game theory and blockchain techniques that can optimize demand response and energy matching in a smart grid.	Simulation results demonstrate the effectiveness of the proposed approach in terms of social welfare, energy consumption, and peak-to-average ratio.
[4]	A Peer-to-Peer Electricity blockchain Trading (P2PEBT) System that uses smart contracts and a proof-of-benefit consensus protocol to achieve transparent and stable trading.	The P2PEBT system is able to optimize the 24-hour electricity flow by flattening the power consumption profile and reducing power consumption fluctuations.
[5]	A blockchain platform framework to satisfy prosumer requirements in peer-to-peer energy trading with a three-step P2P energy trading mechanism that adopts the double auction principle to enhance the vitality of the market.	The proposed method is able to reflect accurate market quotations and has obvious advantages in balancing the profits of players and facilitating the consumption of renewable energy.
[6]	A decentralized framework to manage the electrical consumption in a community of smart-buildings and local renewable energy sources (RES) using blockchain technology and smart-contracts.	The proposed algorithm fostered the local use of energy and, under special tariff structure, the peak grid demand could be reduced.
[7]	A new architecture that utilizes BlockChain technology to manage and control all energy transactions through a trustworthy agreement named Service Level Agreement (SLA).	The authors do not present any empirical findings or experimental results in this paper.

Table 2: An overview of the academic contributions in the field.

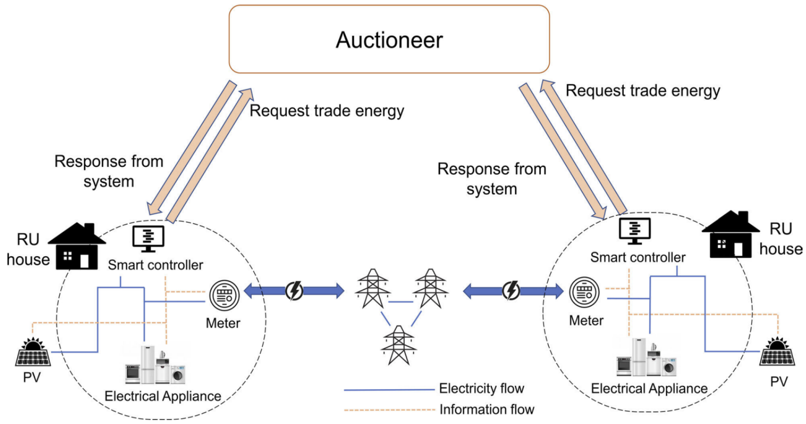

Figure 1: A diagram of the system proposed in [3]

2.2 Business Applications

Piclo Flex, owned by Piclo, is an independent marketplace for energy flexibility services, enabling system operators (such as National Grid ESO, UKPN and a growing number internationally) to source energy from flexible service providers during times of high demand or low supply. Their market is auction-based where the energy is sold to the highest bidder regardless of what the optimum transaction to balance the grid is. The system proposed in this document aims to optimally balance the grid to match demand with minimum generated waste while creating benefit for prosumers.

3 System Description

3.1 Problem Statement

3.1.1 Inefficient Load Matching for Renewable Energy Sources

The project addresses the challenge of inefficient load matching in renewable energy power units, where the uncontrollable nature of renewable resources leads to deficits and surpluses in energy generation. This inefficiency hampers the reliability and widespread adoption of renewable energy solutions.

3.1.2 Minimizing Wasted Energy in Decentralized Green Energy Systems

The project focuses on minimizing wasted energy in decentralized green energy systems, specifically in scenarios where individual households generate renewable energy. The aim is to create a solution, such as energy trading, that maximizes the usage of electricity generated by prosumers, allowing them to monetize surplus energy and enabling deficient prosumers to access cost-effective and environmentally friendly energy sources.

3.2 System Overview

The system consists of the components shown in figure 2.

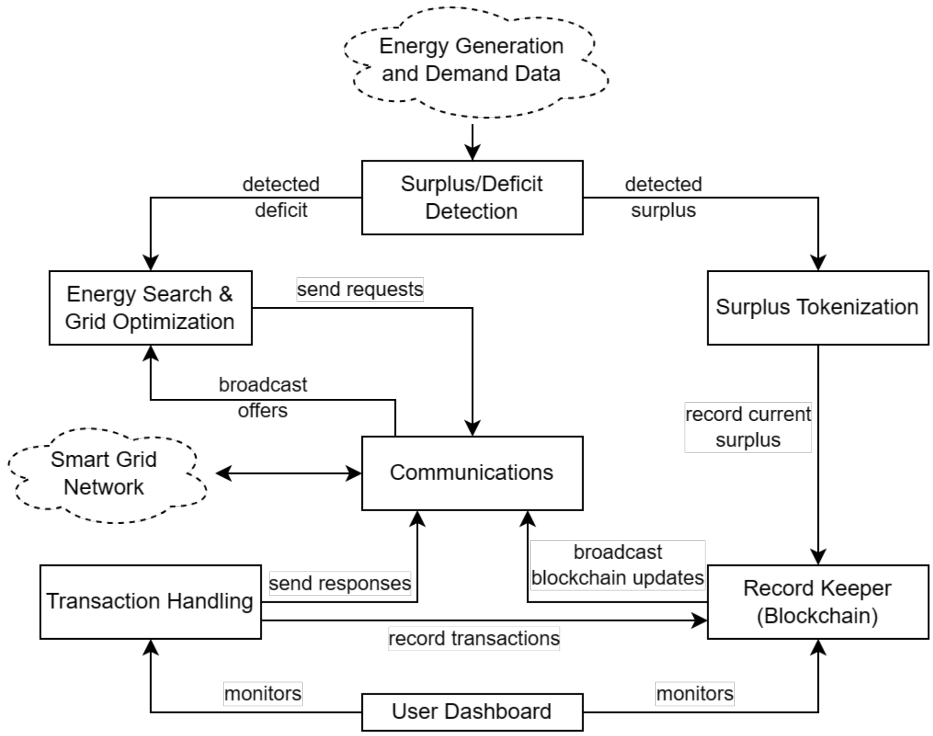

Figure 2: A diagram of the system components

3.2.1 Surplus/Deficit detection

The main attributes of a node will be power generation (the amount of power generated by the renewable energy source, measured in kilowatt hours), and need (the total amount of electricity the node requires). A surplus or deficit will be detected once the power generated by a node surpasses or is less than the node's need by some value. Once that occurs, a broadcast will be made to initialize a trade with another node.

3.2.2 Surplus Tokenization

Once a surplus of energy is detected within a node, the system will transform the available units of energy into a tradable token. This tokenization process involves converting the excess energy into a digital representation, referred to as an "energy token." Each token will represent a specific amount of excess energy, allowing for easy tracking, transfer, and trade of surplus energy units. The energy tokens will be stored and managed on a blockchain, ensuring a secure and transparent record of all transactions.

3.2.3 Record keeping (blockchain)

To ensure transparency, security, and immutability of transactions within the energy trading system, a blockchain technology will be employed. A public or permissioned blockchain will be utilized to record all transactions and token movements. Each transaction will be recorded as a block on the blockchain, containing information such as the addresses of the sender and receiver, the amount of energy tokens traded, timestamps, and any additional relevant data.

3.2.4 Communications

It is expected that all the meters that are expected to communicate with each other will be connected to a local network, when a new meter is connected, it will perform node discovery using adistributed hash table (DHT), over time building a local list of peers (storing node ID alongside some other information about some close peers, hashed). A simple representation of how the system communicates is shown in figure 3

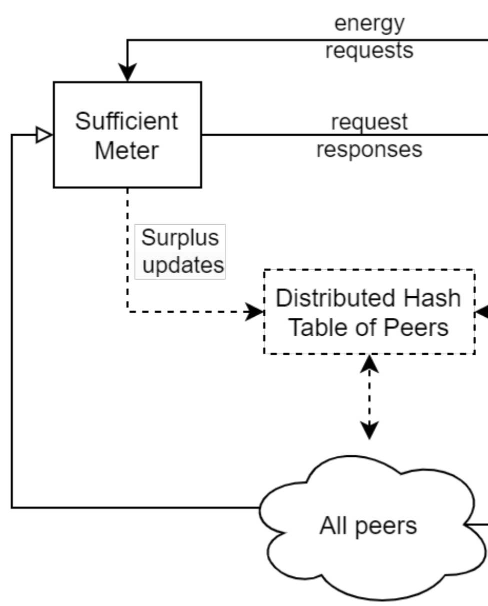

Figure 3: A diagram of how the system communications are built

When a meter wants to broadcast that it has surplus energy, the following steps are taken:

1. The id of the meter is hashed to find its record in the DHT.
2. The system updates the record of the meter with information about its offered surplus.

When a meter needs energy, the following steps are done:

1. The system queries the DHT multiple times in parallel with the hashed request parameters.
2. The system collects the meters with offers that match its queries.

3.2.5 Energy Search and Grid Optimization

After the meter collects all the responses for its parallel queries, it compares the information gathered about the offers in order to choose the optimum trade (or trades) that satisfy the needs of the Deficient user and brings the most balance to the grid.

An optimization algorithm needs to be used, feeding the algorithm the parameters for each peer, and using that to determine which meter to trade with. The optimization follows the constraints defined in table 3:

Constraint	Type	Description	Value Type
Surplus Availability	Hard	The chosen prosumer MUST have enough surplus to sell.	$x \in \{0,1\}$
Trade Surplus	Soft	The trade surplus should be as close to zero as possible.	$x \in [0,\infty]$
Transfer Efficiency	Soft	Better transfer efficiency to the grid is preferred.	$x \in [0,1]$
Transaction Duration	Soft	Shorter trade execution duration is preferred.	$x \in]0,\infty]$
Transaction Quality	Soft	Better transaction quality based on historical data is preferred.	$x \in [0,1]$
Market Participation	Soft	Sellers with little market participation should have a better chance.	$x \in Z^*$

Table 3: Constraints of the optimization problem

Surplus Availability: The amount of energy each meter has available to transfer, ideally, the entire amount of energy needed should be fulfilled from a single meter, failing that, the minimum number of meters should be used.

Trade Surplus: The amount of the surplus that is not needed by the deficient meter. Having a trade surplus keeps this surplus from being monetized during a trade. In order to maximize the utilization of the grid and minimize waste, the trade surplus should be as close to zero as possible.

Transfer Efficiency: Different factors affect the transfer efficiency between any two meters, such as proximity, the state of the electricity lines connecting the meters, and weather conditions. The selected meter should be able to transfer the energy with minimal loss in the amount transferred.

Trade Execution Duration: During a long trade, demand response for the deficient meter is at its worst in a case where the deficient meter no longer needs the trade while the trade currently in motion is not done yet. This results in unnecessary waste. So, for a system that aims to minimize waste in the first place, minimizing trade duration is important for keeping the grid efficient. Trade duration cannot be mathematically determined but based on historical data, a model can be created to estimate the trade duration for a given trade.

Transaction Quality: A metric that measures the quality of a transaction will be recorded for each transaction. The metric defines how well the transaction was executed based on how much of it was completed compared to the initial request. The accumulation of of these metrics are modeled to predict the quality of a transaction given certain transaction parameters. The dataset for training the transaction quality prediction model is constructed by incorporating potential attributes that capture various dimensions of energy transactions. These potential attributes are derived from different categories, encompassing aspects such as transaction details, environmental factors, technical specifications, location data, historical records, and market conditions. The dataset aims to represent the complexity of energy transactions comprehensively. One significant attribute considered in this dataset is the transaction duration, which reflects the time taken for each energy transaction to occur. Transaction duration is a key feature as it may correlate with the efficiency, reliability, and overall effectiveness of the energy exchange process. The labels for the dataset are generated through a scoring function. This function evaluates the overall quality of a transaction based on the combination of potential attributes, providing a numerical score. This score serves as the label for the machine learning model, allowing it to learn and predict the expected transaction quality based on the diverse contextual factors encapsulated in the dataset.

Market Participation: Market participation can be defined by the number of trades the prosumer historically participated in as a seller. Getting more users to participate in the market and trade energy helps introduce variety and availability in the market as well as more demand. This gives plenty of users more options for more accessible renewable energy and better grid efficiency. A good trade is one that gives the chance for more market participation.

Objective Function: The goal of the optimization problem is to maximize the objective function where the parameters for the objective function are:

- a is the surplus availability.
- s is the difference between the offered surplus and the requested energy.
- e is the transfer efficiency.
- t is the transaction duration.
- q is the transaction quality.
- p is the market participation.

Let $X = [a, s, e, t, q, p]$ C is the weights vector.

$$f(X) = C_1 X_1 \times \left(\sum_{i=2}^{n} C_i \times X_i \right) \tag{1}$$

A meta-heuristic algorithm is used to solve the optimization problem. The proposed algorithm is Genetic Algorithm (GA). The algorithm is chosen because it can be used to find the global optimum of a problem. The algorithm is also easy to implement and is easily modifiable.

3.2.6 Transaction Handling

Since energy is not stored in the meter, and it cannot be directly transferred from one meter to another, physically, a central “pool” of energy needs to be implemented, and any energy transfer will use that pool as a mediary between the two meters involved in a transaction, after the token is transferred from one meter to another, the meter needs to communicate with the central pool and use the tokens to get energy from it. Whenever surplus energy is generated, it is tokenized as a “cryptocurrency” of sorts, and that is what’s used in transactions. Once the optimal meter is selected, a request will be sent to that meter to initiate the transfer, if the meter is still available and it accepts the request, a transaction in the form of a smart contract will be created on the blockchain. The transaction will then be validated using the smart contract, checking that both parties have enough funds to complete the transaction, after which the transfer is initiated, and energy is transferred to the deficient meter, and payment is sent to the meter with surplus. After the transfer is successfully completed, a log of the transfer is stored on the blockchain as an immutable record of the transaction, and confirmation is sent to both parties.

3.2.7 Trading Process Overview

The system handles the trading process as follows:

1. Each smart meter waits to detect any surplus or deficit in its own supply.
   1.1. When surplus is detected:
      1.1.1. The system tokenizes the generated surplus.
      1.1.2. The system sets a price for the generated surplus depending on grid supply and demand.
      1.1.3. The system broadcasts the offering on the network and waits for peer requests.
      1.1.4. Once a request is received and approved:
         1.1.4.1. The system bills the request sender for the energy tokens.
         1.1.4.2. The energy tokens are transferred to the sender and is debited electricity to the grid.
   1.2. When deficit is detected:
      1.2.1. The system gathers all the offers made by other peers with surplus energy.
      1.2.2. If there are currently no offers:
         1.2.2.1. The system will fall back to the national grid to fulfill the demand.
      1.2.3. Else, the optimal offer is chosen according to what trade will balance the grid best.
      1.2.4. A request is sent to make the trade with the prosumer giving the optimal offer.
      1.2.5. If the request is approved, the trade is done as explained in 1.1.4 above.
      1.2.6. If the request is denied, the system sends a request to the next optimal peer.

A high-level diagram of the trading process can be found in figure 4

3.2.8 Testing Environment

A testing environment for the system will be built to validate the functionality of the system. The testing environment simulates day to day electricity generation and demand for each meter at an accelerated rate. The testing environment sends the simulated input to each meter and the system will then run within this environment to trade electricity. The testing environment will collect the output from the system and any data generated within the environment will be stored to be used for analysis and validation of the system. Figure 5 illustrates the structure of the testing environment.

3.3 System Scope

The system encompasses a peer-to-peer energy trading platform that optimizes renewable energy utilization. It facilitates trade between prosumers and consumers, allowing the monetization of surplus energy. Smart meters on renewable sources detect imbalances and tokenize excess energy.

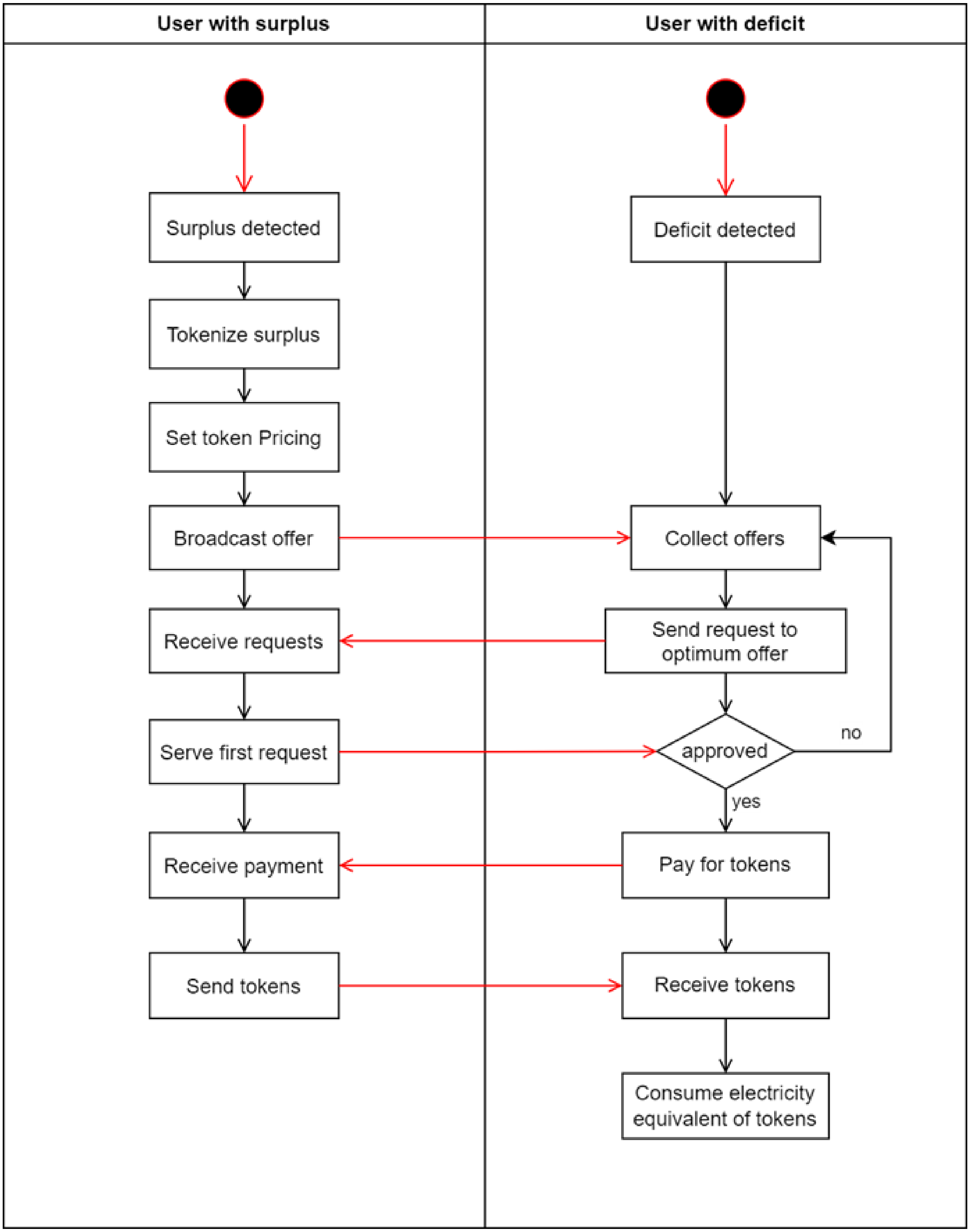

Figure 4: Activity Diagram of how the trading process works

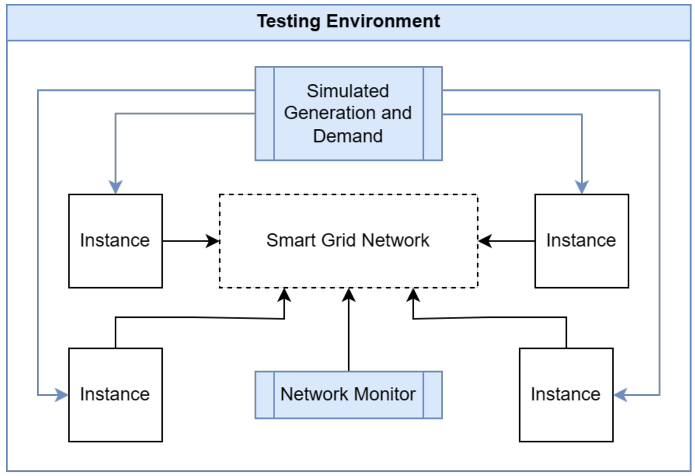

Figure 5: The structure of the system environment with running system instances

Trades are recorded transparently on the blockchain for security. The system employs a decentralized network with a distributed hash table (DHT) for efficient peer discovery. It ensures seamless communication, optimal grid balance, and efficient energy utilization, promoting sustainability and cost-effective energy solutions within a smart grid infrastructure.

3.4 System Context

The proposed system can be embedded on the smart meter or installed as Middleware between the meter and the smart grid. All meters with the same system will be connected to the existing smart grid. The system will be listening to inputs of energy generation from the renewable energy source of the unit and energy demand from the connected appliances. The system will also be gating the usage of the national grid where the system only allows it when demand cannot be met by the smart grid.

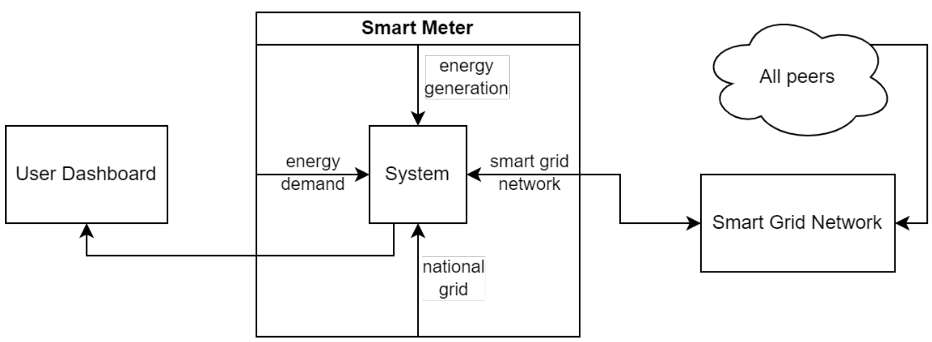

Figure 6: A diagram of the context where the system is running

3.5 Objectives

1. **Efficient Energy Utilization:** Optimize the use of renewable energy sources by facilitating peer-to-peer energy trading among prosumers.
2. **Reduction of Wasted Energy:** Minimize wasted energy by matching surplus energy with deficit nodes within the smart grid.
3. **Cost-effective and Sustainable Energy:** Enable prosumers to monetize surplus energy while providing consumers with access to cost-effective and sustainable energy sources.
4. **Transparent and Secure Transactions:** Ensure transparency and security in energy transactions by recording them on a blockchain, allowing participants to verify and validate each trade.
5. **Decentralized Energy Trading Platform:** Establish a decentralized network of smart meters connected to a smart grid, promoting a distributed and efficient energy trading platform.

3.6 User Characteristics

3.6.1 Prosumers

Prosumers generate renewable energy and trade surpluses. They need a user-friendly interface for energy monitoring and payment configuration.

3.6.2 Consumers

Consumers focus on cost-effective, sustainable energy solutions. They seek a simplified interface for exploring available energy trades.

3.6.3 System Administrators

Administrators oversee system operation, requiring technical expertise in blockchain and decentralized systems.

3.6.4 Blockchain Validators

Validators verify transactions, contributing to blockchain security and integrity.

3.6.5 Regulatory Authorities

Authorities enforce regulations, monitor compliance, and collaborate on legal and regulatory matters.

4 Functional Requirements

4.1 System Functions

Table 4 outlines the functional requirements (FR) for the Energy Trading System. Each requirement is identified by a unique FR-ID and is accompanied by a detailed description of the functionality it entails. Priorities, indicated numerically, guide the development team in focusing on crucial aspects during the implementation process.

ID	Description	Priority
FR-01	The system must detect surplus or deficit in a smart meter's energy supply.	1
FR-02	The system must tokenize surplus energy into tradable energy tokens.	1
FR-03	The system must record all transactions on the blockchain for transparency and security.	1
FR-04	Smart meters must communicate over a local network using a DHT for efficient peer discovery.	1
FR-05	The system must choose the optimum energy trade when deficit is detected.	1
FR-06	The system should implement a compatible and abstract interface so that it can be virtually tested in a simulated environment.	2
FR-07	The system should set a dynamic price for surplus energy based on grid supply and demand.	2
FR-08	The trading process must fallback to the national grid if no peer offers surplus energy.	2
FR-9	The system should initiate energy transfer using a smart contract after trade approval.	1
FR-10	The system must validate transactions using smart contracts to ensure both parties have sufficient funds.	1
FR-11	The system must log completed transactions on the blockchain as an immutable record.	2
FR-12	The optimization algorithm must consider factors like surplus availability, trade surplus, transfer efficiency, transaction duration, transaction quality, and market participation.	1
FR-13	The system must handle multiple parallel queries for energy trade optimization.	2
FR-14	The system should give the user controls over constraints of the automatic trading.	2
FR-15	The system should provide the user with easy access to the current grid state and the historic trading data.	1

Table 4: Functional Requirements of the system

4.2 Detailed Functional Specification

4.2.1 Functional Requirement FR-01

This functionality ensures that the system can accurately identify whether a smart meter is generating surplus energy or experiencing a deficit. Figure 7 explains how this process is triggered.

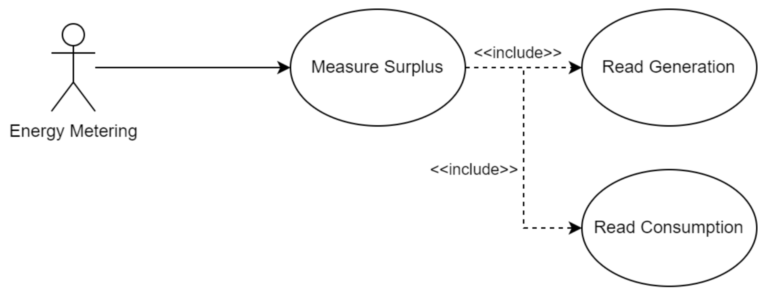

Figure 7: The use case of FR-01

Inputs:

- Energy generation data from the smart meter.
- Energy demand data from connected appliances.

Outputs:

- Detection of surplus or deficit status.
- Broadcast signal when a surplus is detected.

4.2.2 Functional Requirement FR-02

This requirement focuses on converting surplus energy generated by a smart meter into digital tokens. Tokenization facilitates seamless and secure trading of energy units, providing a standardized format for transactions within the system. Figure 8 explains how this process is triggered.

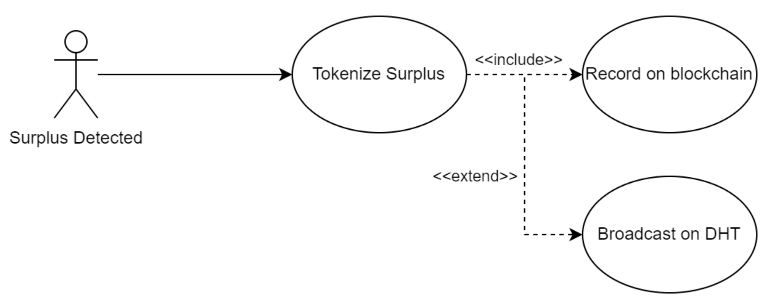

Figure 8: The use case of FR-02, FR-03, and FR-04

Inputs:

- Detected surplus energy amount.

Outputs:

- Tradable energy tokens representing the surplus.
- Price set for the surplus energy tokens.

4.2.3 Functional Requirement FR-03

To ensure transparency and security, all energy transactions, including token transfers and trades, must be recorded on the blockchain. This blockchain-based ledger serves as an immutable and auditable record of system activities. Figure 8 shows how this function serves the tokenization process.

Inputs:

- Details of the energy transaction (e.g., sender, receiver, amount).

Outputs:

- Transaction recorded as a block on the blockchain.

4.2.4 Functional Requirement FR-04

Efficient communication among smart meters is essential for successful peer discovery and trade initiation. Utilizing a DHT on the local network enhances the system's ability to discover and connect with nearby meters, facilitating the energy trading process. Figure 8 explains how tokenization triggers the broadcast.

Inputs:

- Smart meter identification and information.

Outputs:

- Updated records in the DHT containing information about the smart meters in the local network.

4.2.5 Functional Requirement FR-05

This function is at the heart of the operation, where the meters that detect deficit start looking for the best trades to fulfill its demand. Figure 9 shows how this use case fits within the use case defined in 8.

Inputs:

- Offers made by other peers with surplus energy.
- Current deficit in energy demand.

Outputs:

- Optimal offer selected based on trade parameters.

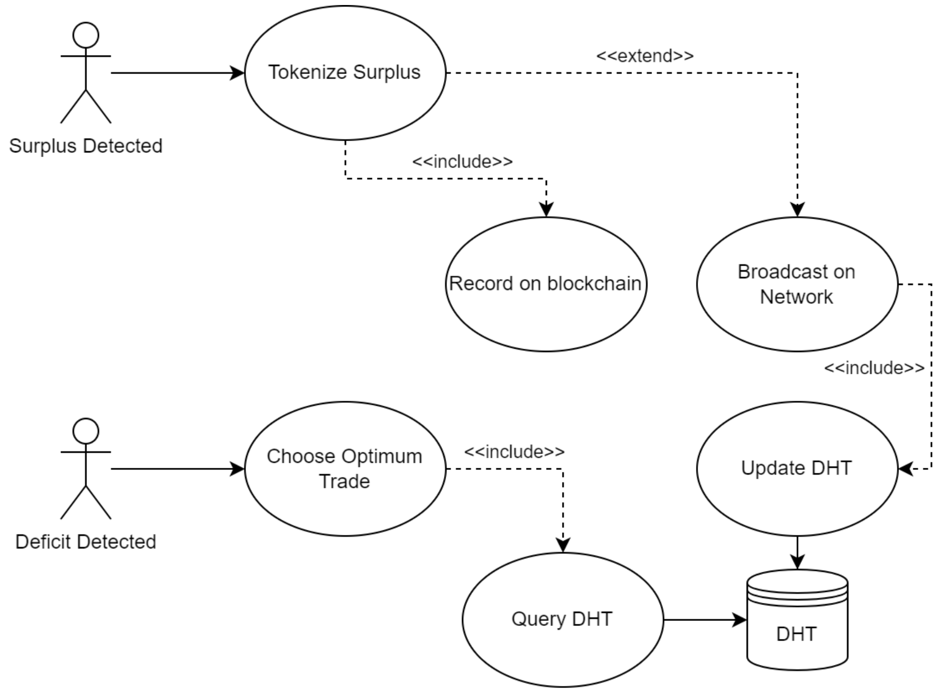

Figure 9: The use case of FR-05

5 Design Constraints

In this section, we identify and discuss various design constraints that may impact the development and implementation of the Peer-to-Peer Energy Trading System.

5.1 Standards Compliance

The system must adhere to the standard meter's expected behavior when it comes to inputs and outputs to ensure interoperability and compatibility with existing infrastructure.

5.2 Regulatory Compliance

The system must comply with relevant energy regulations and data privacy laws.

5.3 Environmental Considerations

The system should consider the environmental impact of energy trading activities. This includes promoting the use of renewable energy sources and minimizing the carbon footprint associated with energy transactions.

6 Non-functional Requirements

6.1 Security Requirements

Ensuring the security of the system is paramount. Constraints related to data encryption, secure communication protocols, and access control mechanisms must be implemented to protect sensitive information.

6.2 Usability Requirements

The user interface and overall user experience should meet usability standards.

6.3 Hardware Limitations

The system's functionality may be constrained by the capabilities of the hardware it runs on. The following hardware limitations should be considered during the development process:

- Processing Power: The system must be efficient with processing.
- Memory: Memory is limited on most embedded systems. This case is no different.
- Communication Interfaces: Compatibility with existing communication interfaces on smart meters is crucial for seamless integration.

7 Data Design

The system at its core is a peer-to-peer system. In this light, the system promotes a decentralized data design. As shown earlier in figure3, a DHT is used to keep track of participants on the network. Also, a blockchain is used to keep record of all the transactions and all the surplus token acquisitions. Figure 10, a simplified, data oriented version of figure 2, overviews how data is communicated between different parts of the system.

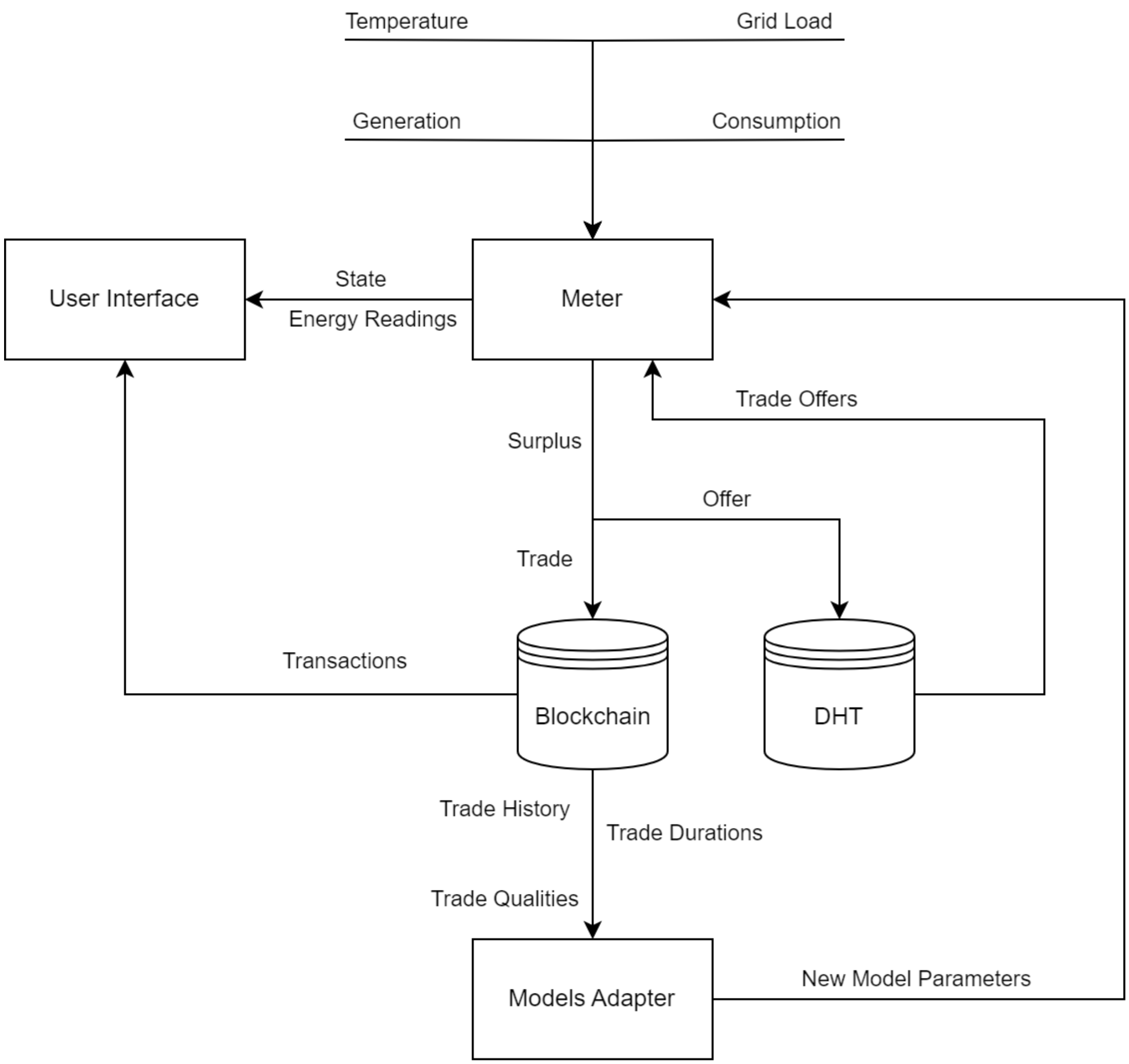

Figure 10: Data Design

8 Preliminary Object-Oriented Domain Analysis

In figure 11, a class diagram shows the relations between different classes of the system. Not all system components are covered by the class diagram due to a planned functional programming paradigm. However, the classes represented are classes that will be interacting with the user interface and given that most frameworks are object-oriented, these parts of the system were modeled in an object-oriented paradigm to fit in with the user interface.

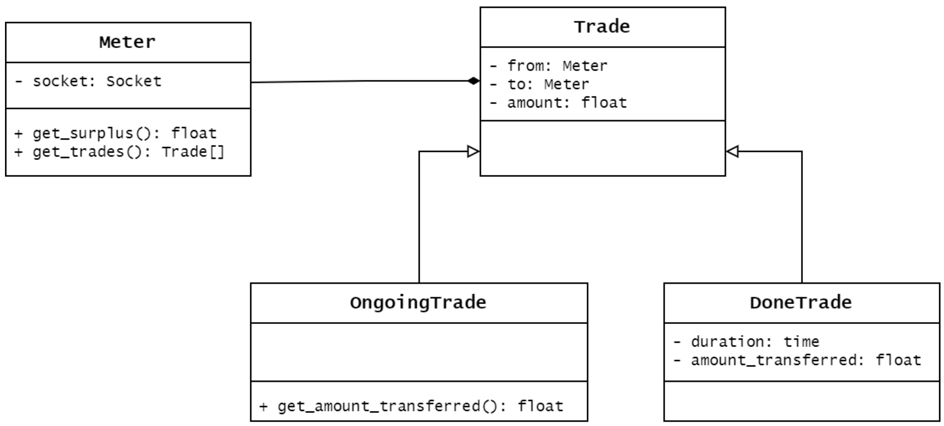

Figure 11: The class diagram

9 Operational Scenarios

9.1 Surplus/Deficit Detection Scenario

Scenario Description

When a node detects a surplus or deficit in energy generation and consumption, it initiates the energy trading process by broadcasting its status to nearby nodes.

Operational Steps

1. Measure power generation and energy needs of the node.
2. Determine surplus or deficit based on predefined thresholds.
3. Broadcast surplus or deficit status to neighboring nodes.

9.2 Surplus Tokenization Scenario

Scenario Description

Upon detecting a surplus, the system transforms excess energy into digital tokens for efficient tracking and trading.

Operational Steps

1. Convert excess energy into energy tokens.
2. Assign specific values to energy tokens.
3. Store energy tokens securely on the blockchain.

9.3 Record Keeping (Blockchain) Scenario

Scenario Description

To ensure transparency and security, all energy trading transactions are recorded on the blockchain.

Operational Steps

1. Record sender and receiver addresses.
2. Log the amount of energy tokens traded.
3. Include timestamps and relevant data in each block.

9.4 Communications Scenario

Scenario Description

Nodes communicate and share energy status using a Distributed Hash Table (DHT) for efficient peer discovery.

Operational Steps

1. Perform node discovery using DHT.
2. Update node records with surplus/deficit information.
3. Query DHT for potential energy trading partners.

9.5 Energy Search and Grid Optimization Scenario

Scenario Description

The system optimizes energy trades among nodes to minimize surplus, balancing the grid.

Operational Steps

1. Collect responses from parallel DHT queries.
2. Compare offers and parameters of potential trades.
3. Use optimization algorithm to select optimal trades.

10 Project Plan

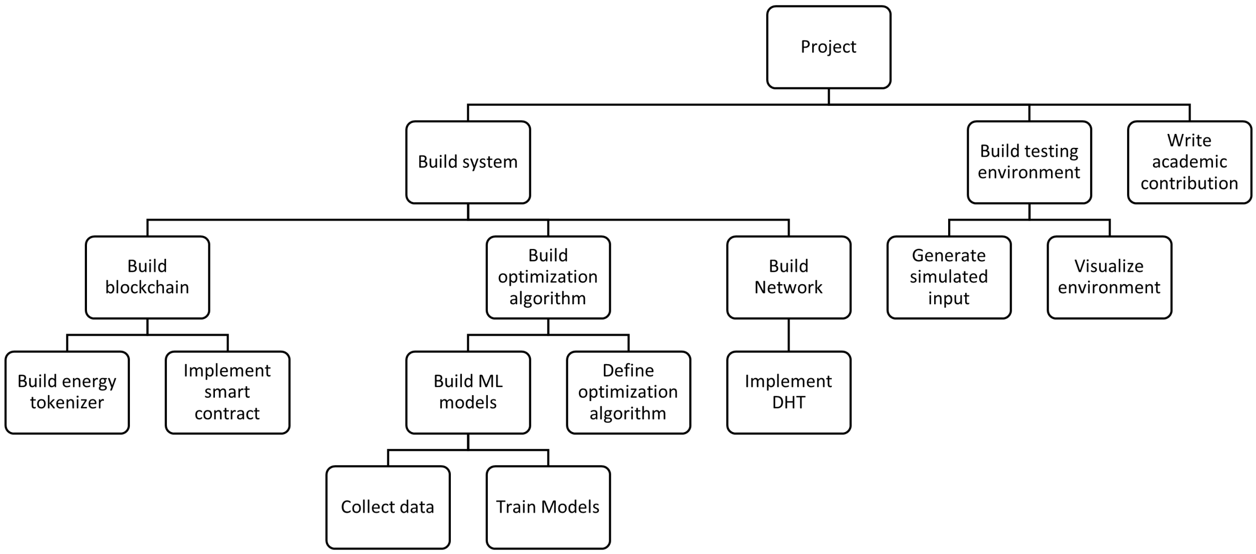

Figure 12: Work breakdown structure for the project

So far, implementation has covered the testing environment, the communications protocol, and the machine learning models that are responsible for predicting the parameters used for the optimization algorithm.

The next phase of the plan is writing a survey paper about the energy trading and grid optimization fields. This paper will cover the current state of the energy industry and how our proposed model plans to serve this industry. Additionally, the next phase includes implementing the optimization algorithm and the trading module.

11 Appendices

Figure 13: The repository link

11.1 Supportive Documents

As part of a movement for innovating landscape for a renewable-powered future, the International Renewable Energy Agency (IRENA) has proposed a framework for building energy trading systems and explains its implementation in various cases [8].

A dataset for grid loss [9].

A paper on grid loss patterns [10].

A paper on grid loss forecasting [11].

Glossary

blockchain A distributed ledger with growing lists of records (blocks) that are securely linked together via cryptographic hashes.. 5–7, 10, 11, 14, 24

DAPP decentralized application. 6

deficient Not having enough of a demanded material or quality. Someone with deficit. 12, 14

deficit The amount needed of something to meet demand. 5, 30

DHT distributed hash table. 11, 21, 24, 27

GA Genetic Algorithm. 13

IRENA Interational Renewable Energy Agency. 29

middleware a Software that acts as communication bridge between different software.. 17

prosumer An individual who consumes and produces value. 1, 4, 6–8, 13, 15

SDK software development kit. 6

surplus An excess in production or supply. 5, 11, 14

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