ENERGY TRADING USING BLOCKCHAIN

HANY ASHRAF MOHAMED ABDELLATIF

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ENERGY TRADING USING BLOCKCHAIN

HANY ASHRAF MOHAMED ABDELLATIF

A thesis submitted in fulfilment of the

requirements for the award of the degree of

Bachelor of Computer Science (Computer Network & Security)

School of Computing

Faculty of Engineering

Universiti Teknologi Malaysia

JUNE 2022

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DEDICATION

This thesis is dedicated to my father, who taught me that the best kind of knowledge to have is that which is learned for its own sake. It is also dedicated to my mother, who taught me that even the largest task can be accomplished if it is done one step at a time.

ACKNOWLEDGEMENT

In preparing this thesis, I was in contact with many people, researchers, academicians, and practitioners. They have contributed towards my understanding and thoughts.

My fellow student should also be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Unfortunately, it is not possible to list all of them in this limited space. I am grateful to all my family member.

ABSTRACT

As decentralized solutions provided by the blockchain technology are gaining a growing attention nowadays along with the rapidly growing usage of renewable energy sources, forming microgrids, which in turn leads to a growing need for allowing individuals to trade energy with each other in a Peer-to-Peer fashion, there is an increasing interest in utilizing the blockchain technology to create Peer-to-Peer energy trading solutions. However, most current Peer-to-Peer energy trading solutions mainly depend on blockchain auctions. Undoubtedly, significant development has been achieved in this direction, resulting in fairly transparent blockchain auction-based energy trading markets. Yet, what is missed in most current systems, is to take two steps further in two other directions which are providing traders with a blockchain mechanism to follow up the auctions that they have been involved in with further confirmations of the success or the failure of a trade to ensure the integrity of this entire trade, not just the integrity of the auction done for this trade, and embracing Web 2.0 module into the system, to improve the overall performance and UX delivered to end-users, and also to minimize the workload on the blockchain infrastructure when there’s no actual need for it (e.g., doing extensive reads from the blockchain). In this vein, this project is striving to build a blockchain-based energy trading web app with a unique architecture that involves Web 2.0 module for enhanced performance and UX, and sophisticated mechanism for maximizing the overall integrity in the system. Ultimately, the aim of this project came true by successfully achieving the four objectives of it which are developing and deploying an Ethereum smart contract as the backbone of the system and the module that orchestras the entire system using a unique mechanism, creating a Web 2.0 module that is centered around a NoSQL database and is synched with the Ethereum blockchain infrastructure, developing a web front-end that is able to communicate with the Web 3.0 blockchain module and the Web 2.0 module, and finally embedding a Web 3.0 authentication method using MetaMask cryptocurrency wallet. Notably, the developed mechanism to ensure the overall integrity of the proposed system can be generalized and used in other domains.

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LIST OF ABBREVIATIONS

|  |  |  |
| --- | --- | --- |
| ETH | - | Ether |
| EOA | - | External Owned Account |
| P2P | - | Peer-to-Peer |
| NoSQL | - | No Structured Query Language |
| DApp | - | Decentralized App |
| EVM | - | Ethereum Virtual Machine |
| Lo-Fi | - | Low Fidelity |
| UML | - | Unified Modelling Language |
| UI | - | User Interface |
| UX | - | User Experience |
| UAT | - | User Acceptance Testing |
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# INTRODUCTION

## Overview

Considering the rising of the promising decentralized solutions provided by the blockchain technology nowadays in addition to the rapidly growing usage of renewable energy sources (RESs), forming microgrids, which in turn leads to a growing need for allowing individuals to trade energy with each other in a Peer-to-Peer (P2P) fashion, there is an increasing interest in utilizing the blockchain technology to create P2P energy trading solutions (Wang et al, 2019; Esmat et al, 2021).

Most current P2P energy trading solutions mainly depend on blockchain auctions. And in fact, significant work has been done in this direction, resulting in very transparent blockchain auction-based energy trading markets. Yet, what is missed in most current systems, is to take two steps further in two other directions which are:

1. Providing traders with a blockchain mechanism to follow up the auctions that they have been involved in with further confirmations of the success or the failure of a trade to ensure the integrity of this trade in its entirety, not just the integrity of the auction done for this trade.
2. Including Web 2.0 module into the system, to enhance the overall performance and experience delivered to the end-users, and also to minimize the workload on the blockchain infrastructure when there’s no actual need for it (e.g., doing extensive reads from the blockchain).

Notably, as for the issue of ensuring the overall integrity of an energy trade, some current systems tackle this problem by establishing direct communication between hardware components (e.g., Smart Meters) and the blockchain infrastructure, instead of requiring users’ intervention for confirming the success or the failure of a trade.

In this context, this project comes with a new P2P blockchain energy trading solution that adopts some of the mechanisms that exist in current blockchain energy trading solutions (i.e., blockchain auctions), yet it also takes further steps toward enhancing the overall integrity of the system and delivering more efficient performance and experience to the end-users.

## Problem background

Although current blockchain energy trading systems involve a variety of sophisticated mechanisms for P2P energy trading, most of them lack considering the overall integrity of the energy trading process. In other words, most current solutions do not consider the question “How is it possible to ensure that an amount of energy is actually transferred from one party to the other once an auction ends?”. Furthermore, most existing solutions also are not sufficiently integrated systems for them being only focused on facilitating the action of trading energy once at a time, rather than being integrated and scalable systems that even if they are centered around facilitating energy trading for users, they also allow them to look at and search for details about trades that happened in the past which requires integrating Web 2.0 module, and not being limited to the Web 3.0 blockchain services.

The problem with ensuring the overall integrity of the entire energy trading process, not only the integrity of auction done, comes from a more general problem that is blockchain auctions suit digital goods more than physical goods (e.g., amount of energy), because even if the auction ended in a good shape, the actual transfer of an item or the ownership of that item would be done off-chain, thus, its integrity is not guaranteed as it is the case for the auction that happened on-chain.

Furthermore, the problem with not integrating Web 2.0 module to a blockchain-based energy trading web app is the unnecessary workload on the blockchain network only to execute extensive reads of large amounts of data from the logs stored on the blockchain infrastructure. On the other hand, with integrating a Web 2.0 module to the system, once it’s synced with the blockchain infrastructure properly, executing those extensive reads on the Web 2.0 module is not only reducing the unnecessary workload on the blockchain, but also is enhancing the overall performance of the system since performing pagination and filtering to the data requested is going to be achievable which in turn leads to a better Network I/O and improved user experience.

Here is a list of mechanisms that the proposed system uses to tackle the aforementioned issues:

1. Requiring traders to pay deposit upon them getting involved in a trade, either being a buyer (i.e., the one who creates a trade to get the cheapest possible selling price he can get for an amount of energy he needs) or a bidder (i.e., the one who bids to sell the buyer the needed amount of energy for a cheaper price), and allowing them to follow the auction up with some confirmations which in turn will determine how the collected deposits and selling price should be transferred. And if both traders fall into a conflict, an admin’s intervention will resolve it, giving the money to the one who really deserves it. Thus, users must not try to break the rules, otherwise, they will be wasting their money!
2. Integrating a Web 2.0 module that is centered around a NoSQL database which gets updated with all trades have been created on the blockchain infrastructure.

## Project aim

The aim of this project is to build a blockchain energy trading web app with a unique architecture that involves Web 2.0 module for enhanced performance and user experience, and sophisticated mechanism for maximizing the integrity in the blockchain-based energy trading system.

## Objectives

The objectives of this project are as follows:

1. Developing an Ethereum smart contract, using Solidity programming language, that includes all the logic for the energy trading system and deploying it to a local Ethereum blockchain. This smart contract is the heart of the system.
2. Creating a Web 2.0 module that consists of a NoSQL database and two JavaScript programs, one should be responsible for updating the NoSQL database with data from the Ethereum blockchain infrastructure, and the other should initiates a server that listens to upcoming requests and respond to it with the requested data from the NoSQL database.
3. Developing a web front-end for this system using React.js which should allow users to interact seamlessly with both the smart contract deployed to the local Ethereum network, and the Web 2.0 module.
4. Authentication should be using MetaMask which is a cryptocurrency wallet, as a Web 3.0 method instead of the traditional Web 2.0 methods (Choi et al, 2019).

## Scopes

The scopes of this project are as follows:

1. This project doesn’t involve any kind of work related to electrical engineering or Internet of Things (IoT) development, and the produced software shouldn’t need to connect to any external electrical component.
2. It’s assumed that all users’ decisions within the web app should only be motivated by information they acquire in a way that is beyond the scope of this project.
3. The blockchain infrastructure used in this project runs in a local environment.
4. The produced software should be hosted locally, not on a cloud or any other hosting service.

## Importance of the project

Since the ultimate goal of this project is to develop a blockchain-based energy trading system that can be used by individuals that are grouped together in electrical microgrids to exchange energy with each other, this project pushes forward toward migrating from conventional power supply systems to have more sophisticated decentralized small power supply systems (i.e., microgrids) which in turn pushes forward toward pursing more clean and renewable energy. In this vein, this project can be very useful for stand-alone systems in rural or green residential areas that are isolated from the main electrical grid.

Furthermore, the general architecture used in the project that embraces Web 2.0 solutions along with blockchain Web 3.0 solutions, makes the blockchain technology more desirable in domains that have not yet adopted it.

The developed mechanism to ensure the overall integrity of proposed system can actually be generalized and used in other domains and totally different businesses.

## Report organization

This report starts with Chapter 1, the current chapter, which provides an overview of the whole project covering the problem’s background, aim, objectives, scopes, and importance. Furthermore, it’s followed by five more chapters which are:

1. Chapter 2: In this chapter, current systems or the published research related to P2P energy trading using blockchain, the different technologies used to execute the project are literature-reviewed and discussed.
2. Chapter 3: In this chapter, the chosen methodology for this project is discussed covering, the various phases within it, the technologies used to develop the system, and system requirements.
3. Chapter 4: In this chapter, the requirements are analyzed and discussed coming up with both the functional and non-functional requirements of the proposed system. Furthermore, the design of the proposed system is discussed covering the overall architecture of the system, and some specifics on its main parts.
4. Chapter 5: In this chapter, the implementation of the proposed system is discussed, covering how the core components of the system were built to do their desired work efficiently. Moreover, the different kinds of testing that have been applied on the system are illustrated, showing how satisfying and robust the system is.
5. Chapter 6: In this chapter, the whole project is summarized and insights for future improvement are discussed.

# LITERATURE REVIEW

## Introduction

This chapter is a journey of reviewing, comparing, and analysing the current systems or the published research related to P2P energy trading using blockchain, the different technologies or techniques used to build the proposed system, and how all that reinforce the choices made in this project.

## Current systems/solutions analysis

In recent years, with the rising of decentralized solutions provided by blockchain technology in addition to the rapidly growing usage of renewable energy resources, forming microgrids, which in turn leads to a growing need for allowing individuals to trade energy with each other, there has been a lot of research and development done in this regard aiming to utilize the blockchain technology to create P2P energy trading solutions.

In this vein, blockchain auctions have been the most used trading mechanism in most researched or developed solutions, despite the crucial differences between them, for utilizing blockchain in P2P energy trading. Blockchain auctions have been used due to its ensured transparency and integrity that could solve the deficit of trust problem that is more likely to manifest itself in centralized systems.

Indeed, current solutions involve a variety of sophisticated blockchain auction mechanisms for P2P energy trading. However, most solutions lack considering the overall integrity of the energy trading process. In other words, current solutions do not consider the question “How is it possible to ensure that an amount of energy is actually transferred from one party to the other once an auction ends?”. Moreover, most solutions are only focused on facilitating the action of trading energy rather than developing a system that is centered around facilitating energy trading for users, yet it also allows them to look at and search for details about trades that have happened in the past.

Therefore, in this project, the proposed system is not limited to just develop another blockchain auctions platform for P2P energy trading, but it takes some steps further toward allowing the parties involved in an auction to follow it up with some required confirmations to ensure the integrity of the trade entirely. Furthermore, the proposed system considers integrating traditional centralized Web 2.0 modules to enhance the overall performance and efficiency of the system, especially, when it comes to enabling the users to see details about trades that have happened in the past.

## Comparison between existing systems

In addition to the systems that adopted the auction mechanism for P2P energy trading, there have been other P2P blockchain solutions for energy trading that used different trading mechanisms rather than auctions.

For example, according to Yang et al. (2019), The proposed solution was to create an energy trading market in which a pricing mechanism can regulate the trading price between traders, and a scoring criterion could impose the required behaviors. Also, according to Verma et al. (2018), for self-regulating their proposed P2P energy trading market, a blockchain-distributed consensus protocol was used.

And, as mentioned earlier, most solutions involved a form of auction mechanism to function. So, according to Saxena et al. (2019), the marketplace was implemented on a permissioned blockchain network (i.e., Hyperledger Fabric) on which bids were stored to an immutable ledger, and smart contract’s functions have been called to execute the Market Clearing Price (MCP) calculation and award service contracts to the winning bids.

Yet, none of the aforementioned solutions, proposed a blockchain-oriented mechanism for ensuring the entire integrity of a trade by allowing the involved parties to follow the auction up with required confirmations such as requiring the buyer to confirm that the needed amount of energy has been received successfully. Also, none of them integrated a traditional centralized module into their systems for enhanced experience and performance delivered to the end-user. However, notably some of those solutions consider direct communication between hardware components (e.g., Smart Meters) and the blockchain infrastructure for reinforcing the integrity of their systems.

Hence, here are the main differences in the proposed system for this project:

1. Requiring traders to pay deposit upon them getting involved in a trade, being a buyer (i.e., the one who created the trade to get the cheapest possible selling price he would get for an amount of energy he needs) or a bidder, and allowing them to follow the auction up with some confirmations which in turn will determine how the collected deposits and selling price should be transferred, instead of considering direct communication between hardware components and the blockchain infrastructure for reinforcing the integrity of the system, and guaranteeing users’ good behaviors. In other words, users must not try to break the rules, otherwise, they will be wasting their money!
2. Integrating a traditional centralized module into the system for enhanced experience and performance delivered to the end-user, mainly, Web 2.0 NoSQL database that stores all trades have been created on the blockchain infrastructure in order to allow users to check all the trades that happened in the past easily and efficiently.

Table . Comparing between several energy trading solutions

| System/Solution | blockchain technology | Auction Mechanism | Traders confirm trades’ integrity | Integrating Web 2.0 module |
| --- | --- | --- | --- | --- |
| (Yang et al., 2019) | Ethereum | × | × | × |
| (Saxena et al., 2019) | Hyperledger Fabric | √ | × | × |
| (Verma et al., 2018) | Hyperledger Fabric | × | × | × |
| Proposed system | Ethereum | √ | √ | √ |

Turning the focus onto general solutions for blockchain auctions, not necessary for energy trading, most these solutions aimed to implement first-price sealed-bid auction, also known as a blind auction (Galal & Youssef, 2018). Therefore, they had to deal with kinds of challenges such as encrypting the bids to ensure that bidders cannot see their competitors’ bids. Yet, for this project, there’s no need for such a complexity since the type of auction needed here is Dutch auction, an auction in which buyer declares what he needs for many sellers to bid by offering a cheaper selling price until the buyer is satisfied with one and ends the auction.

## Literature review on technologies used

Developing blockchain-based systems can be done easier by utilizing one of the blockchain technologies that have already been created to allow developers to build their own blockchain Decentralized Apps (DApps) simpler. One of the most famous blockchain technologies that is commonly used nowadays is Ethereum. And it is the chosen blockchain technology in this project.

Hence, in this section, Ethereum is being discussed and literature-reviewed in addition to the stack of tools used to ease the process of creating DApp on Ethereum such as Truffle Suite, Ganache, and MetaMask. Furthermore, as for the centralized Web 2.0 part of the system, MongoDB and Node.js also are literature-reviewed for them being the technologies used to build this module in the system.

### Ethereum

Ethereum is an open-source and globally decentralized computing infrastructure, often described as "The world computer", that runs programs called smart contracts. Ethereum uses a blockchain to synchronize and store the system’s state changes (Dannen, 2017). Moreover, Ethereum has its own cryptocurrency, called Ether, which is used to meter and constrain execution resource costs.

In essence, Ethereum enables developers to create DApps with high availability, transparency, and minimized censorship. Initially, Ethereum has been thought of as a general-purpose blockchain that could be programmed using smart contracts for numerous use cases. However, over a short span of time, the way Ethereum has been viewed changed to be a platform for creating DApps that represent a broader perspective than smart contracts.

Primarily, a DApp is the result of a smart contract connected to a web front-end interface, making it a web application that is powered by a decentralized and P2P infrastructure.

#### Smart contracts

Smart contracts are nothing but computer programs that run in the context of Ethereum Virtual Machine (EVM). Smart contracts are immutable so that once a smart contract is deployed to the Ethereum blockchain network, it’s no longer possible to modify or edit it, and the only way to modify it then is to stop using the deployed version and deploy a new modified version. In addition to being immutable, smart contracts are also deterministic. Therefore, everyone executes the same smart contract, must get the same outcome. Ethereum supports many programming languages for developing smart contracts such as LLL, Serpent, Solidity, Vyper, and Bamboo. In this context of this project, the chosen language is Solidity due to it being the most used language for developing Ethereum smart contracts, in addition to its similarity in syntax with the most famous programming languages such as C++, Java, and JavaScript.

#### MetaMask cryptocurrency wallet

In order for web users to interact with Ethereum smart contracts or commit transactions generally, a cryptocurrency wallet would be needed. A variety of wallets are available, yet the most used is MetaMask which serves as the primary user interface to Ethereum. Notably, MetaMask is supported, as an extension can be easily installed, by most browsers used nowadays such as Firefox, Microsoft Edge, and Brave. MetaMask wallet allows users to access to manage their keys and addresses, track their balances, and create and sign transactions. So, considering the need for and the characteristics of MetaMask, it is the chosen cryptocurrency wallet to be used throughout this project.

#### Truffle Suite

Due to the relatively difficult nature of developing and testing DApps, Truffle Suite can be used to help with that. Essentially, Truffle Suite is a development environment and testing framework for blockchains using the EVM.

Amongst the greatest tools provided by Truffle Suite are Truffle Boxes which are helpful boilerplates that can significantly reduce the amount of exhaustive work that would be needed to build up a DApp from scratch. Truffle Boxes usually include many helpful modules such as Solidity contracts and libraries, and web front-end views.

In this project, a Truffle Box, named react, is used for developing the desired DApp. The reason it’s used, as its name reveals, is because it comes with everything needed for writing, compiling, and deploying Ethereum smart contracts in addition to a boilerplate for a React web app that is initially configured, using Web3.js, to interact with those deployed Ethereum smart contracts seamlessly.

#### Ganache

In addition to Truffle Boxes, Truffle Suite provides a very handy tool that is commonly used for developing and testing DApps, which is Ganache. Ganache is used to run a local Ethereum blockchain which in turn eases the processes of developing, deploying, and testing DApps in a deterministic and safe environment.

### Web 2.0 module

As for the Web 2.0 part of the system, it’s centered around having a database that gets updated with some data from the Ethereum Blockchain and is used later to retrieve some or all this data on-demand.

First and foremost, as for the database, since the database required for this system doesn’t really need to handle complex schemas or run complex queries, a NoSQL database is sufficient and more efficient for this case. Thus, MongoDB is the chosen database for implementing this module of the project. MongoDB is open-source and one of the most used NoSQL databases nowadays (Chauhan, 2019). Moreover, it is widely supported by different development frameworks such as Node.js.

Furthermore, Node.js is used along with the MongoDB database because it supports Web3.js and Mongoose libraries which are needed to interact with the Web 3.0 side of the system and get the needed data from there, and connect to and update the MongoDB database with the received data from the Ethereum blockchain, respectively. In addition to that, Node.js is used to run a server, using Express.js, that is responsible for allowing the web front-end to request data from the MongoDB database.

## Chapter summary

In this chapter, current P2P blockchain energy trading solutions and systems have been reviewed, discussed, and compared with consideration to the proposed system, coming up with the key differences between those current systems and how the proposed system is supposed to be different from the current systems. Furthermore, the different technologies chosen to develop the different modules in the proposed system have been discussed and elaborated on.

# METHODOLOGY

## Introduction

In this chapter, the methodology of this project is illustrated covering the methodology choice and justification, the various phases within the chosen methodology, the technologies used to develop the system, and system requirements.

## Methodology choice and justification

The chosen methodology for this project is a custom approach inspired from the traditional Waterfall approach since not all the five common phases found in the traditional Waterfall model can be implemented in this project, yet most of them are still considered in the execution of it. The Waterfall model is a linear project management approach, in which the requirements are gathered at the first phase, and then a sequential plan is created to meet up with those requirements (McCormick, 2012). When there is a clear list of requirements that are not likely to be changed, the Waterfall model is the most suitable choice. Hence, as the requirements of this project are not expected to be modified, the Waterfall methodology is a decent choice.

## Phases within the chosen methodology

A traditional Waterfall model involves five phases which are, in order, Requirements Analysis, Designing, Implementation, Testing, and Maintenance, whereby each phase completely depends on the previous phase (Balaji & Murugaiyan, 2012). However, since the proposed system in this project is not deployed and maintained after being verified, the custom methodology of this project involves only four main phases which are, in order, Requirements analysis, Designing, Implementing, and Testing. Furthermore, each phase includes several tasks that may or may not be dependent on each other. Figure 3.1 visualizes and illustrates the chosen methodology.

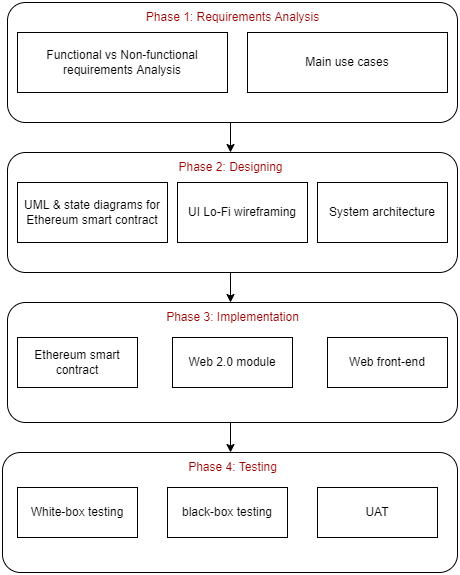


Figure . Project methodology

### Requirements analysis phase

In this first phase, all the requirements are analysed to ease the process of designing and developing the system later in the subsequent phases. In this project, requirements analysis is done by categorizing the requirements into functional or non-functional requirements whereby functional requirements define the system and its components, while non-functional requirements determine the preferred quality of services or modules in the system. For example, in this project, authenticating users using MetaMask wallets and allowing to them interact with the Ethereum smart contract to perform various energy trading actions are functional requirements, yet beautifying the user interfaces or considering enhanced network I/O performance are non-functional requirements.

In addition, main use cases are designed in accordance with the functional requirements, for further and deeper analysis that gives insights on what should be considered in the subsequent phases.

### Designing phase

This phase involves several tasks. First, designing the overall architecture of the entire system illustrating the basic components of the system, the main role for each component, and the relationships between those components or modules. Then, designing the internals of the system using proper tools. So, the Ethereum smart contract is modelled using Unified Modelling Language (UML) and state diagrams, while user interfaces have been using Lo-Fi wireframed.

### Implementation phase

In this phase, the modules that form the building blocks of the proposed system are implemented. In accordance with the system architecture designed during the Designing phase, there are 3 building blocks in the proposed system which are:

1. Ethereum smart contract which is programmed using the Solidity programming language.
2. Web 2.0 module which consists of a NoSQL database using MongoDB, a Listener/Synchronizer, using JavaScript programming language, that is only responsible for listening to the events emitted by the Ethereum smart contract whenever a trade is closed and synchronizing the MongoDB with the received data, and finally a server that is responsible for fetching data from the database and serves the web clients with these data on demand.
3. Web front-end, using ReactJS framework, that is responsible for enabling the users to communicate easily with both the Ethereum smart contract and MongoDB, whereby both form the back-end of the system.

### Testing phase

In this phase, the produced system from the previous phase is being tested using different techniques to validate its functionality and measure users’ satisfaction with it. Thus, three kinds of testing are implemented which are:

1. White-box testing
2. Black-box testing
3. User Acceptance Testing (UAT)

### Gantt charts

Figures 3.2 and 3.3 below show the Gantt charts for FYP1 and FYP2, respectively.

Graphical user interface

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Figure . FYP1 Gantt chart

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Figure . FYP2 Gantt chart

## Brief descriptions for technologies used

As discussed earlier in Chapter 2, several technologies are used to build the various modules or components in this project. In this section, those technologies are being briefly described along with the purpose of using them. Hence, Table 3.1 shows the technologies or tools used in this project along with brief descriptions and purposes of use.

Table . Brief descriptions and purposes of use for technologies used in this project

|  |  |  |
| --- | --- | --- |
| Technology/Tool | Description | Purpose |
| Ethereum | Ethereum is an open-source and globally decentralized blockchain-based computing infrastructure. | Enabling developers to create DApps with high availability, transparency, and minimized censorship. |
| MetaMask | A cryptocurrency wallet works as an extension on most used browsers nowadays | Enabling web users to interact with Ethereum smart contracts or commit transactions generally. Used for authentication too. |
| Truffle Suite | Truffle Suite is a development environment and testing framework for blockchains using the EVM. | Truffle Boxes are helpful boilerplates that can significantly reduce the amount of exhaustive work that would be needed to build up a new DApp from scratch. |
| Ganache GUI | Ganache is a high-end development tool used to run local blockchain Ethereum | Ganache is used to run an Ethereum blockchain locally. |
| MongoDB | Most famous NoSQL database nowadays. | The heart of the Web 2.0 module in the system. |

## System requirements analysis

There are software and hardware requirements must be met to build the proposed system seamlessly and efficiently.

### Software requirements

The software requirements are as follows:

1. Node.js and Node Package Manager (NPM)
2. Modern web browser that supports Web 3.0.
3. MongoDB Compass as a GUI for MongoDB.
4. Git & GitHub for versioning control and saving the code remotely on an online repository.
5. Visual Studio Code (VS code) as a text Editor for coding.

### Hardware requirements

As for the hardware requirements, a normal PC or laptop with at least 4Gb RAM would be sufficient to build up the proposed system in this project.

## Chapter summary

In this chapter, the methodology of the project has been discussed, including the justification for choosing a custom methodology inspired from the Waterfall model, the various phases within it and what is supposed to be done within each phase before moving forward toward the subsequent one, the technologies used to develop the system, and finally the software and hardware system requirements.

# REQUIREMENTS ANALYSIS AND DESIGN

## Introduction

In this chapter, the requirements are analysed and discussed coming up with both the functional and non-functional requirements of the proposed system. Furthermore, and based on the conducted analysis, the design of the proposed system is discussed covering the overall architecture of the system, and some specifics on its main parts.

## Requirements Analysis

All in all, the main requirement of the proposed system is to serve its ultimate objective, which is to be a web platform that allows normal users/traders, who are supposed to be linked together within a microgrid, to trade energy with each other through biddings, which should be managed by a smart contract on the Ethereum blockchain network. So, upon a successful log into the system, any user/trader should be able to create a new trade, being the buyer, in which he specifies the amount of energy he needs and the time restriction (i.e., how much time expected to receive the needed amount of energy) or bid over an existing trade, being the seller, by offering a cheaper selling price which he would sell the buyer the needed amount of energy for. Moreover, since conflicts between buyers and sellers may happen over whether a trade was successful or not, an admin portal is required to allow the admin of the system to resolve those conflicts.

Furthermore, the system should allow all users, including the admin, to see details about all trades that had happened in the past.

In this context, Table 4.1 below summarizes both the functional and non-functional requirements in this project.

Table . Functional vs non-functional requirements of the system

| Functional requirements | Non-functional requirements |
| --- | --- |
| Authentication: Users should be able to log into the system using cryptocurrency wallets (i.e., MetaMask accounts). | **Network I/O performance:** As the number of closed trades grows, the system should keep allowing users to see their details without any network I/O performance issues by paginating this data from the back-end. |
| Buying: As buyer, a user should be able to:   1. Start a new trade with his desired specifications. 2. Cancel his trade. 3. End bidding over his trade. 4. Confirm the success of his trade (i.e., the seller transferred the needed amount of energy within the specified amount of time). 5. Mark his trade as failed. | **User Interface/User Experience (UI/UX):** The system should provide all end-users with a good experience that enables them to interact much easier with it. |
| Selling: As seller, a user should be able to:   1. Place a bid on a running bidding. 2. Confirm the failure of a trade. 3. Raise a conflict over a trade. |
| Claiming money: Both buyers and sellers should be able to claim their deserved from any trade with consideration to the predefined rules (i.e., the other party in a trade didn’t take the action he was required to take within a specified amount of time). |
| Resolving conflicts: The admin should be able to resolve any conflict raised over any trade. |
| View closed trades: All users including the admin, should be able to see details about all trades that had happened in the past. |

### Main use cases

There are three main use cases/system’s flows the system is generally centered around which are:

1. Starting a new trade.
2. Bidding on a trade.
3. Resolving a conflict over a trade, if the logged in user is the admin.

Other than resolving conflicts, since it is very straightforward as all what the admin needs to do is just to decide, in one step, whether the trade was successful, engaging in a trade either by creating a new one or bidding on a running trade, would require having different flows which include many steps determined by the role of the user in a particular trade.

Figure 4.1 below show a flow chart that illustrate on how the system will flow from buyer's perspective.

Diagram

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Figure . The flow of the system from buyer’s perspective

Figure 4.2 below show a flow chart that illustrate on how the system will flow from seller's perspective.

Diagram

Description automatically generated

Figure . The flow of the system from seller’s perspective

## System architecture

Figure 4.3 below shows the overall architecture of the whole system including all its different components.

Diagram

Description automatically generated

Figure . System’s architecture

As shown in Figure 4.3, the system can be divided into three main parts which are:

1. The smart contract running on Ethereum blockchain network which is the heart of the entire system.
2. Web 2.0 back-end which consists of a database using MongoDB, a Listener/Synchronizer which is a JavaScript program that is only responsible for listening to the events emitted from the Ethereum smart contract whenever a trade is closed and synchronizing the MongoDB with the received data, and finally a server that is responsible for fetching data from the MongoDB database and serves the web clients with this data on demand.
3. Web front-end using ReactJS that connects the end-user with both the Ethereum smart contract using Remote Procedure Call (RPC) protocol, and the Web 2.0 back-end using normal HTTPS protocol.

Notably, the purpose of having Web 2.0 back-end is to store the data returned from events emitted from the Ethereum smart contract when any trade is closed. Hence, if any user wants to see some or even all closed trades that had happened in the past, the system won’t need to retrieve this data from the logged events on the Ethereum network, instead, the system will retrieve this data from the Web 2.0 back-end which can support paginating and filtering the data for better network I/O performance, and less overhead on the Ethereum network.

## Ethereum smart contract design

Figure 4.4 below shows the UML diagram that illustrates on the overall structure of the Solidity smart contract for this system which involves three elements:

1. The contract itself, named EnergyTrading
2. Struct, named Trade, that has a composition relationship with the contract since the contract holds an array of objects from type Trade.
3. Enumeration, named Status, that represents all the different statuses of a trade from the moment it’s created to the moment it’s emitted in an event indicating this trade is closed with a status of SUCCESSFUL, FAILED, or CANCELED.

Diagram

Description automatically generated

Figure . UML diagram for the Solidity smart contract

In addition to the UML diagram, Figure 4.5 below shows a state diagram that illustrates on how the status of a trade changes over time starting from being initially RUNNING all way till it ends with one of the ending statuses which are SUCCESSFUL, FAILED, or CANCELED.

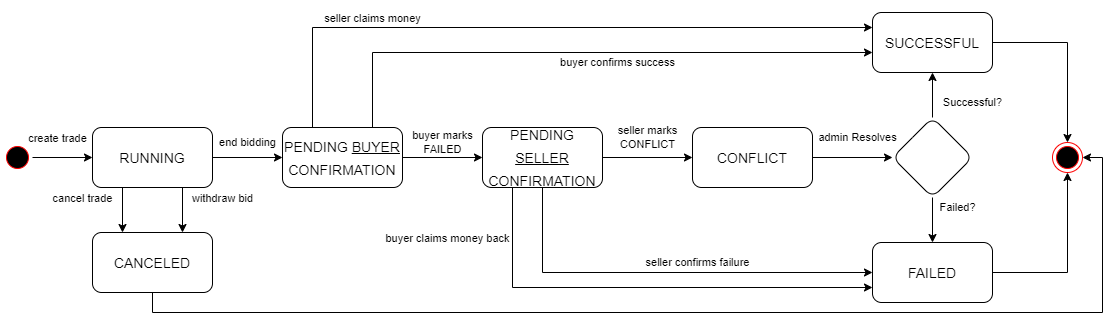


Figure . State diagram for how trade’s status changes over time by different users’ actions

## User interface design

In this section, the wireframing for the user interface of the proposed system is elaborated on, covering all the pages and what different users should be able to see upon different actions.

Figure 5.6 below shows the “Login” page design.

Graphical user interface, text, application

Description automatically generated

Figure . The “Login” page design

Figures 4.7 below shows the “Home” page which traders should be able to see once they are logged in. Figures 4.8 and 4.9 show the forms that pop up upon clicking the “Create New Trade” button or the “Bid” button associated with any running trade, respectively.

Graphical user interface

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Figure . The “Home” page design

Graphical user interface

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Figure . The “Create New Trade” popup form design

Graphical user interface

Description automatically generated

Figure . The “Place your bid” popup form design

Figures 4.10 and 4.11 below show the “My Opened Trades” page design that includes multiple opened trades with different statuses, and so with different buttons executing different actions. Yet, while Figure 4.10 shows these opened trades from buyer’s perspective, Figure 4.11 show them from seller’s perspective.

Notably, even if one user is normally supposed to be involved in one trade only at a time, the system allows one user to have multiple opened trades at a time, and this user can be the buyer in one trade and the seller in another, and all these opened trades should be listed in this “My Opened Trades” page.

Diagram

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Figure . The design of the “My Opened Trades” page from buyer’s perspective

A picture containing diagram

Description automatically generated

Figure . The design of the “My Opened Trades” page from seller’s perspective

Figures 4.12 and 4.13 below show the design of “Conflicts” page that the admin only should be directed to once logged into the system, and the popup “Resolve Conflict” dialogue box that should appear once the admin clicks the “Resolve Conflict” button associated with any conflict listed down in the “Conflicts” page, respectively.

Graphical user interface, application

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Figure ‎4.12 The “Conflicts” page design

Graphical user interface, application, Teams

Description automatically generated

Figure . The “Resolve Conflict” popup dialogue box

Graphical user interface, table

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Figure . The “View Closed Trades” page design

Figure 4.14 shows the design of the “View Closed Trades” page which should allow all the end-users of the system to see the details of the closed trades listed down in a table.

## Chapter summary

In this chapter, the requirements have been analysed coming up with both the functional and non-functional requirements of the proposed system. Moreover, the design of the proposed system has been discussed covering the overall architecture of the system, and the basic structure of the Solidity smart contract, and the web user interface of the system.

# RESULTS, TESTING AND DISCUSSION

## Introduction

In this chapter, the implementation of the proposed system is discussed, covering how the core components of the system are programmed to do their desired work efficiently. Moreover, the different kinds of testing that have been applied on the system are illustrated, showing how satisfying and robust the system is. And finally, a summary and discussion about the overall outcome of the implementation phase is provided.

## System Development

Considering the methodology and the design of the system that have been discussed earlier in Chapter 3 and Chapter 4, respectively, there are three building blocks that needed to be programmed in order to make the system function properly which are:

1. Ethereum smart contract using the Solidity programming language.
2. Web 2.0 infrastructure which consists of a database using MongoDB, a Listener/Synchronizer developed using JavaScript programming language that is only responsible for listening to the events emitted by the Ethereum smart contract whenever a trade is closed and synchronizing the MongoDB with the received data, and finally a server that is responsible for fetching data from the database and serves the web clients with these data on demand.
3. Web front-end, using ReactJS framework, that is responsible for enabling the users to communicate easily with both the Ethereum smart contract and MongoDB, which are the considered the building blocks of the back-end of the system.

In this context, the development of each of these three components is illustrated and discussed in the next few sections in the same order they are listed above. And due to the extreme importance of the Ethereum smart contract, being the heart of the system, a greater attention is given to it compared to the other components.

### The implementation of the Ethereum Smart contract

An Ethereum smart contract is basically a program that runs on the Ethereum blockchain. Essentially, it is a collection of code that involves data (i.e., contract’s state) and some functions which can show and manipulate the state/data. In addition to data and functions, Ethereum smart contracts written using Solidity programming language can also involve other beneficial elements such as Modifiers, Enums, Structs, and Events. Hence, the structure of the developed Ethereum smart contract, shown in Figure 5.1 below, and named EnergyTrading.sol, is simply a collection of those elements that work together serving the desired function of the smart contract.

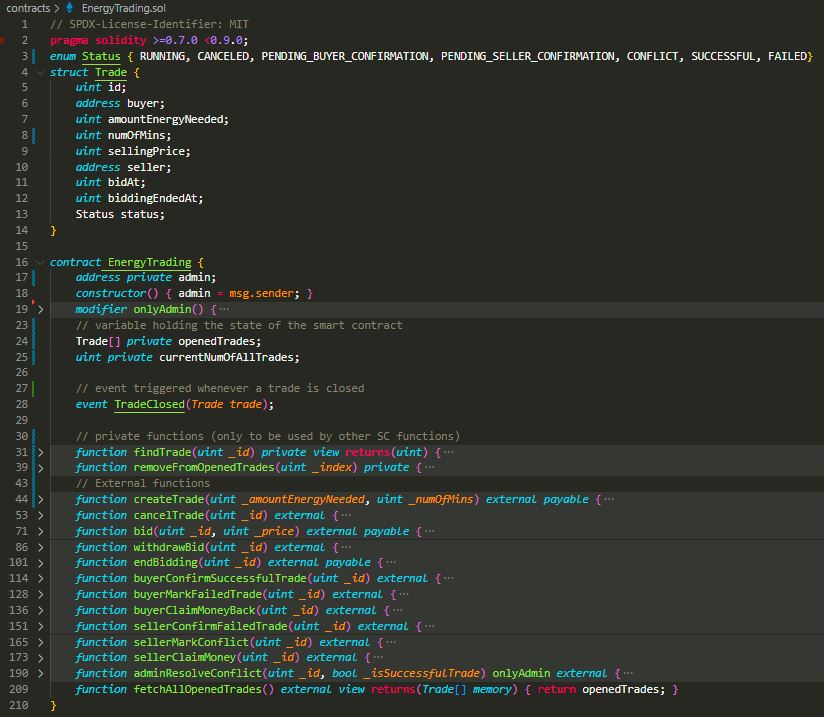


Figure . The structure of the Ethereum smart contract (the functions are collapsed using the used Text Editor, so their implementations are not shown)

#### Smart contract’s state

As shown in Figure 5.1, the contract has three variables that hold its state. The first one is named admin, of the address data type, and declared as private variable. This variable gets assigned with its value, which is the account address of the External Owned Account (EOA) that deploys this contract, only once on the deployment of this contract to the Ethereum blockchain network by the constructor function provided in the contract. The purpose of having this admin variable is to be later used to limit the access to one function, making invoking it permissible only to the admin using a modifier called onlyAdmin.

The second and most important variable is a private dynamic array, named openedTrades, of the Trade data type, which in turn is a custom data type created as Struct that involves a group of related variables of different data types (e.g., uint256, address, etc). But before proceeding with the purpose of the openedTrades array, a rock-solid understanding of the Struct called Trade is needed. So, basically Trade is a Struct that holds the data of each trade created by any user that aims to start a new bidding over an amount of energy he needs over a specific amount of time. Figure 5.2 below shows the code used to define the Trade Struct.

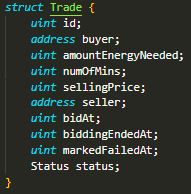


Figure . The code used to define the Trade Struct

For example, if a user called Omar needs an amount of 100-Watt to be transferred to him within maximum 10 minutes, upon him communicating with the contract through the web UI, the contract, using a function called createTrade() that is discussed later in this chapter, will create a new trade which stores these specifications in the specified attributes of the Trade Struct, which are the variables named amountEnergyNeeded and numOfMins respectively, and both are of the uint256 data type.

In this context, as shown in Figure 5.2, the last attribute in the Trade Struct is named status, and of the Status custom data type. This Status custom data type is basically an Enum that is used to indicate the status of every trade. Enums restrict a variable to have one of only a few predefined values, which makes it the most suitable programming solution in Solidity to manage trades’ different statuses. Figure 5.3 below shows the code used to define the Status Enum, and its 7 predefined values.

![Text

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eR9yNJIZSV5ALcNnkZ715+7F5Gc9WOTin2Dvf+t/8AgDaKKKYBRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFaF5pkkGl2upi5guIrp3Q+Vu3RuoUsrAqOcOOmR71n1v3EgsfA9taCa3kmvLt5njWVZWjjCJsOAT5bE7s9GIAB4GK5605RlBR6v8LfoaU4qTd+zMCiiiugzCiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooA/9k=)

Figure . The code used to define the Status Enum

Turning back to the purpose of the opendedTrades dynamic array, it is essentially used by the contract to hold all the opened trades which are trades have been created, and they are not closed yet by being either cancelled or confirmed as successful or failed trade.

The third variable is named currentNumOfAllTrades, of the uint256 data type, and declared as private. This variable is used to keep track of the number of all trades, no matter they are still opened or have already been closed, that are created in the contract starting from the moment that the contract is successfully deployed to the Ethereum blockchain network. The main purpose of this variable is to be used to give every new trade an auto incremented Id on its creation.

#### Smart contract’s functions

As shown in Figure 5.1, there are 15 functions that can be divided into 2 categories. The first category involves the private functions which are invoked only within the contract by other functions, but neither users with their EOAs nor other smart contracts would be able to invoke these functions.

The private functions are:

1. findTrade(uint \_id)
2. removeFromOpenedTrades(uint \_index)

As for findTrade(uint \_id) function, it is invoked by other functions in the contract to locate an opened trade using its ID, so the invoker would be able to know whether there is actually such a trade stored in openedTrades dynamic array, and if yes, what its index in the array is.

![Text

Description automatically 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Figure . The implementation of findTrade(uint \_id) function

Figure 5.4 shows the code written to implement findTrade(uint \_id) function. It simple takes one parameter of uint256 data type for the ID of the trade of interest and iterates over the openedTrades array comparing the given ID with the IDs of the current stored trades in the array. When a match is found the loop will break and the function will return the index number of the trade with the ID of interest. Otherwise, the returned value of will be a number that is certainly greater than the last index in the openedTrades array by 1. And since this function isn’t the state of the contract, the view keyword is used in defining the function.

As for removeFromOpenedTrades(uint \_index) function, it is invoked by other functions in the contract to remove a trade from the openedTrades array using its index. Figure 5.5 below shows the implementation of this function, which simply copies the trade located in the last index of the array to the index of the trade that should be removed, then it removes the trade located in the last index of the array.

![Text

Description automatically generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RDyRXhpZgAATU0AKgAAAAgABAE7AAIAAAANAAAISodpAAQAAAABAAAIWJydAAEAAAAaAAAQ0OocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAEhhbnkgTW9oYW1lZAAAAAWQAwACAAAAFAAAEKaQBAACAAAAFAAAELqSkQACAAAAAzQ2AACSkgACAAAAAzQ2AADqHAAHAAAIDAAACJoAAAAAHOoAAAAIAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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Figure . The implementation of removeFromOpenedTrades(uint \_index) function

The second category involves the external functions which are supposed to be invoked by the users of this contract. The external functions are:

1. function fetchAllOpenedTrades()
2. function createTrade(uint \_amountEnergyNeeded, uint \_numOfMins)
3. function cancelTrade(uint \_id)
4. function bid(uint \_id, uint \_price)
5. function withdrawBid(uint \_id)
6. function endBidding(uint \_id)
7. function buyerConfirmSuccessfulTrade(uint \_id)
8. function buyerMarkFailedTrade(uint \_id)
9. function buyerClaimMoneyBack(uint \_id)
10. function sellerConfirmFailedTrade(uint \_id)
11. function sellerMarkConflict(uint \_id)
12. function sellerClaimMoney(uint \_id)
13. function adminResolveConflict(uint \_id, bool \_isSuccessfulTrade)

As for fetchAllOpenedTrades(), it is the simplest function among all the external function. Since the dynamic array openedTrades is declared as private, this function is only responsible for letting the outside world view the stored trades in the openedTrades array. Figure 5.6 below shows the implementation of the fetchAllOpenedTrades() function. Notably, the view keyword is used in defining this function since it doesn’t change the state of the contract, instead, it just reveals or views the state to the outside world.



Figure . The implementation of fetchAllOpenedTrades() function

As for createTrade(uint \_amountEnergyNeeded, uint \_numOfMins), this function is responsible for creating a new trade and placing it in the openedTrades array. Figure 5.7 below shows the implementation of the createTrade() function.

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generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RDyRXhpZgAATU0AKgAAAAgABAE7AAIAAAANAAAISodpAAQAAAABAAAIWJydAAEAAAAaAAAQ0OocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAEhhbnkgTW9oYW1lZAAAAAWQAwACAAAAFAAAEKaQBAACAAAAFAAAELqSkQACAAAAAzk3AACSkgACAAAAAzk3AADqHAAHAAAIDAAACJoAAAAAHOoAAAAIAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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Figure . The implementation of the createTrade(uint \_amountEnergyNeeded, uint \_numOfMins) function

The payable keyword is used in defining the createTrade(uint \_amountEnergyNeeded, uint \_numOfMins) function, as the contract must receive an amount of 5 ETH paid by the user who is creating this trade as a deposit which proves user’s seriousness toward the trade, and part or all of it will be deducted if the creator of this trade misuses the system causing harm (i.e., not receiving deserved money, and paying unnecessary Ethereum Gas fees) for other users, and then the deducted amount will be transferred for those harmed users. As for the actual implementation of this function, first, it assures that an amount of 5 ETH has been received successfully before proceeding to next instructions, otherwise, the function will revert the transaction with an error message specifying the reason of the failure. Furthermore, the function creates a new instance of the Trade Struct, assigns its ID with an auto-incremented value based on the current number of all trades that have been created, assigns the buyer variable with the address of the sender of this transaction, assigns the two variables that hold information about the amount of energy needed and the number of minutes during which this amount of energy should be transferred, with the respective two arguments received by the function, assigns the status variable initially with the predefined value “RUNNING” which means bidding over this trade is still running so users who want to sell still can overbid each other over this trade by sending better offers (i.e., cheaper selling price) until the creator of this biding ends it, and finally, push the new created trade to the openedTrades array.

Moving forward to the 12 remaining functions, the way all these functions operate follows a similar pattern which can be divided into two parts. In the first part, the function tries to locate the targeted trade in the openedTrades array using the first parameter (i.e., uint \_id), then it performs some validations to test the validity of the transaction before proceeding with any changing in the contract’s state or transferring of ETH. These validations may vary from one function to another, yet they mostly impose common requirements. These requirements may include the existence of the targeted trade, the authoritativeness of the sender of the transaction to perform the action to be done, the permissibility of targeted trade’s status for the action the function does to take place, etc. On the other hand, the second part is unique for each function, and it may involve changing the contract’s state in a certain way, transferring ETH, or emitting TradeClosed event, all with respect to the targeted trade which has been located prior to that in the first part of the function.

In light of this understanding of how the 12 remaining functions work, only the implementation of the bid(uint \_id, uint \_price) function is discussed in detail to see how this understanding is applied in practice, but for the rest of those functions, just a brief elaboration on the implementation is provided since they all follow the same pattern.

Figure 5.8 below shows the implementation of the bid(uint \_id, uint \_price) function. In its first part, the function passes the value received in the \_id parameter as an argument to the findTrade(uint \_id) function to locate the targeted trade in the openedTrades array and know its index if the targeted trade really exists there. Then, using the received output from the findTrade(uint \_id) function, it checks that the targeted trade exists in the openedTrades array by assuring that the received output which represents the index of the targeted trade in the array is less than the length of the array since in case that the trade was not found, the received output would be a number exactly equals the length of the openedTrades array. Upon fulfilling the first requirement, the function fetches the targeted trade using its index from the openedTrades array and stores it in a variable named targetedTrade. Furthermore, first, the function checks that the sender’s address doesn’t equal the address stored in the buyer variable for this trade because no one should be allowed to bid a trade he is the who created it. Second, the function checks that the targeted trade’s status is “RUNNING” which means bidding over this trade is still running, otherwise, the bidding offers shouldn’t be allowed over this trade anymore. Third, the function checks that the value received in the \_price parameter is less than the current selling price (if any). And finally, the function checks that an amount of 5 ETH is sent in the transaction by the user who is bidding over this trade as a deposit which proves bidder’s seriousness toward the trade, being the seller, same as the deposit collected from the creator of this trade, being the buyer. Notably, the payable keywork is used in defining the function to handle receiving user’s deposit, same as the createTrade(uint \_amountEnergyNeeded, uint \_numOfMins) function, as discussed earlier.

In its second part, first, the function refunds the current winner of this bidding (if any) his deposit back for him being over bidden. Second, it changes the targeted trade’s selling price to the new offered price, seller address to the address of the transaction’s sender, and the bidAt variable to the timestamp of the current block using block.timestamp which is one of Solidity’s special variables. Considering the variable named bidAt, the purpose of having this variable is to allow the bidder to withdraw his bidding offer if the creator of the trade doesn’t end bidding over it within a certain amount of time from the time this bidding offer has been make.

A screenshot of a computer

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Figure . The implementation of the bid(uint \_id, uint \_price) function

Figure 5.9 below shows the implementation of the cancelTrade(uint \_id) function. This function is responsible for cancelling a trade using its ID. So, after locating the trade in the openedTrades array and checking the requirements, the function transfers to the creator of this trade (i.e., the buyer) either all his deposit if no bidding offer is placed on this trade, or only 50% of it as the bidder (i.e., the seller) should receive the other 50% plus his original deposit. Furthermore, the function changes the targeted trade’s status from “RUNNING” to “CANCELED”, emits a TradeClosed event, and removes this trade from the openedTrades array using the removeFromOpenedTrades(uint \_index) function.

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Figure . The implementation of the cancelTrade(uint \_id) function

Figure 5.10 shows the implementation of the withdrawBid(uint \_id) function. This function is responsible for allowing the bidder to withdraw his offer on a trade using trade’s ID if the creator of this trade doesn’t end bidding within one minute from the time the bidding offer has been placed, causing the trade to be cancelled and closed. In this context, after locating the targeted trade in the openedTrades array and checking the requirements, including checking the passing of the one minute period from the time the bidding offer has been placed using the Solidity’s special variable block.timestamp and the variable named bidAt within the targeted trade, the function transfers to the bidder his original deposit plus 50% of the deposit of the trade’s creator (i.e., 7.5 ETH), and to the other party only the remaining 50% of his deposit (i.e., 2.5 ETH). Furthermore, the function changes the targeted trade’s status from “RUNNING” to “CANCELED”, emits a TradeClosed event, and removes this trade from the openedTrades array using the removeFromOpenedTrades(uint \_index) function.

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Figure . The implementation of the withdrawBid(uint \_id) function

Figure 5.11 shows the implementation of the endBidding(uint \_id) function. This function is used by trade’s creator to end the running bidding over his trade using its ID. In this context, after locating the targeted trade in the openedTrades array and checking the requirements, including checking that the buyer has sent the agreed upon price within the transaction, the function stores the received value into the targeted trade’s sellingPrice variable, assigns this trade’s biddingEndedAt variable with the current timestamp, and changes the status of the trade from “RUNNING” to “PENDING\_BUYER\_CONFIRMATION”.

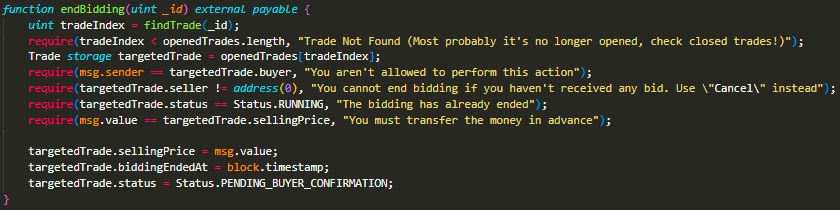


Figure . The implementation of the endBidding(uint \_id) function

Figure 5.12 shows the implementation of the buyerConfirmSuccessfulTrade(uint \_id) function. This function is used by the creator of a trade to close his trade, as a successful trade, using its ID. In this context, after locating the targeted trade in the openedTrades array and checking the requirements, the function transfers to the seller the stored value in the trade’s sellingPrice variable plus his original deposit, and to the other party (i.e., the buyer) all his deposit back without any deduction. Furthermore, the function changes the targeted trade’s status from “RUNNING” to “SUCCESSFUL”, emits a TradeClosed event, and removes this trade from the openedTrades array using the removeFromOpenedTrades(uint \_index) function.

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Description automatically 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Figure . The implementation of the buyerConfirmSuccessfulTrade(uint \_id) function

Figure 5.13 shows the implementation of the buyerMarkFailedTrade(uint \_id) function. This function is used by the creator of a trade to mark this trade as a failed one using its ID. Hence, after locating the targeted trade in the openedTrades array and checking the requirements, the function assigns the targeted trade’s markedFailedAt variable with the current timestamp and changes its status from “PENDING\_BUYER\_CONFIRMATION” to “PENDING\_SELLER\_CONFIRMATION”.

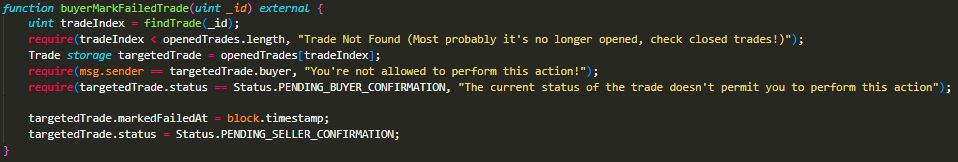


Figure . The implementation of the buyerMarkFailedTrade(uint \_id) function

Figure 5.14 shows the implementation of the buyerClaimMoneyBack(uint \_id) function. Using trade’s ID, this function is responsible for allowing the creator of this trade (i.e., the buyer) to claim his paid money, his deposit, and other party’s deposit, if the other party in this trade (i.e., the seller) neither confirms the failure of it nor marks its status as “CONFLICT” to seek admin’s intervention to resolve this conflict, within 3 minutes starting from the time when it was marked as failed trade by the buyer. So, after locating the targeted trade in the openedTrades array and checking the requirements, including checking the passing of the 3 minutes period, the function transfers to the buyer all his deserved money. Furthermore, the function changes the targeted trade’s status from “PENDING\_SELLER\_CONFIRMATION” to “FAILED”, emits a TradeClosed event, and removes this trade from the openedTrades array using the removeFromOpenedTrades(uint \_index) function.

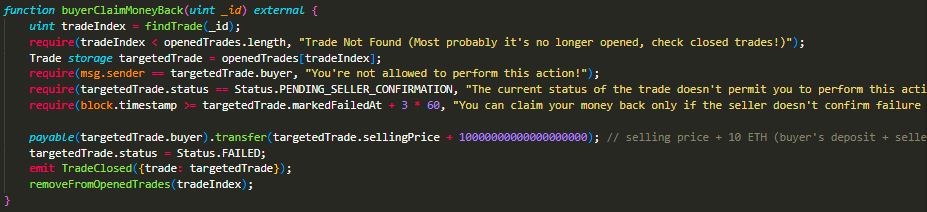


Figure . The implementation of buyerClaimMoneyBack(uint \_id) function

Figure 5.15 shows the implementation of the sellerConfirmFailedTrade(uint \_id) function. This function is used by the seller in a trade to confirm the failure of this trade, using its ID. So, after locating the targeted trade in the openedTrades array and checking the requirements, the function transfers to the seller only 50% of his deposit since the remaining 50% should be transferred to the buyer in addition to his original deposit and the agreed upon amount of ETH, as a selling price, which has been sent earlier by him to the contract when he ended bidding on this trade. Furthermore, the function changes the targeted trade’s status from “PENDING\_SELLER\_CONFIRMATION” to “FAILED”, emits a TradeClosed event, and removes this trade from the openedTrades array using the removeFromOpenedTrades(uint \_index) function.

![Text

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vge9Vrm4kurmSaaR5Hc5LOck/jVNLlT66/oaWj7O/W5FRRRUmYUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFAH/2Q==)

Figure . The implementation of the sellerConfirmFailedTrade(uint \_id) function

Figure 5.16 shows the implementation of the sellerMarkConflict(uint \_id) function. This function is used by the seller to change the status of a trade to be “CONFLICT”, using its ID. Hence, after locating the targeted trade in the openedTrades array and checking the requirements, the function changes this targeted trade’s status from “PENDING\_SELLER\_CONFIRMATION” to “CONFLICT”.

![Text

Description automatically 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Figure . The implementation of sellerMarkConflict(uint \_id) function

Figure 5.17 below shows the implementation of the sellerClaimMoney(uint \_id) function. This function is responsible for allowing the seller to claim his deserved money from a trade, using its ID if its creator (i.e., the buyer) doesn’t confirm its status within one minute after the number of minutes specified by him on creating this trade, starting from the time he ended bidding over this trade. For that to work, after locating the targeted trade in the openedTrades array and checking the requirements, including checking the time constraint, the function transfers to the seller his deserved money from this trade in addition to his original deposit and 50% of the other party’s deposit, and transfers to the other party (i.e., the buyer) only the remaining 50% of his deposit. Furthermore, the function changes the targeted trade’s status from “PENDING\_BUYER\_CONFIRMATION” to “SUCCESSFUL”, emits a TradeClosed event, and removes this trade from the openedTrades array using the removeFromOpenedTrades(uint \_index) function.

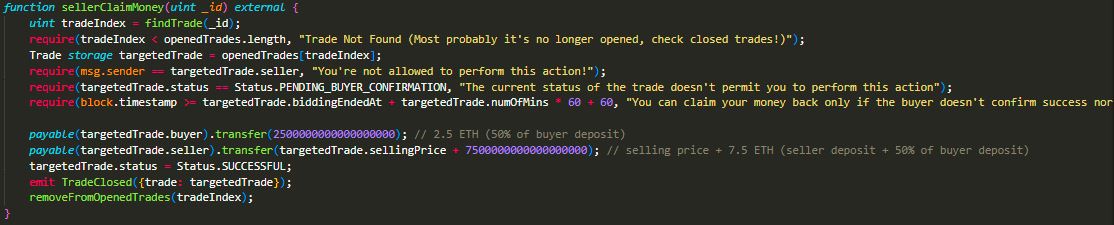


Figure . The implementation of the sellerClaimMoney(uint \_id) function

Figure 5.18 below shows the implementation of the adminResolveConflict(uint \_id, bool \_isSuccessfulTrade) function. This function is responsible for allowing the admin to resolve a conflict over a trade, using its ID and a parameter named \_isSuccessfulTrade of bool data type which indicates the admin’s decision on the targeted trade. So, after locating the targeted trade in the openedTrades array and checking the requirements, if \_isSuccessfulTrade equals True, meaning it was a successful trade, not failed as the buyer marked it earlier, the function transfers to the seller his deserved money from this trade in addition to his original deposit and 50% of the other party’s deposit, and transfers to the admin the remaining 50% of the buyer’s deposit. Otherwise, if \_isSuccessfulTrade equals False, meaning it was a failed trade despite the seller’s denial, the function transfers to the buyer his money back in addition to his original deposit and 50% of the other party’s deposit, and transfers to the admin the remaining 50% of the seller’s deposit. Furthermore, according to the admin’s decision, the function changes the targeted trade’s status from “CONFLICT” to either “SUCCESSFUL” or “FAILED”, emits a TradeClosed event, and removes this trade from the openedTrades array using the removeFromOpenedTrades(uint \_index) function. Notably, the onlyAdmin modifier is used in defining this function since the admin only is authorized to perform the action of resolving conflicts.

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Figure . The implementation of adminResolveConflict(uint \_id, bool \_isSuccessfulTrade) function

### The implementation of the Web 2.0 side

The main purpose of having a Web 2.0 part in the system working side by side with the Web 3.0 part, is to avoid fetching all TradeClosed events emitted from the contract just to let users view closed trades because, with the number of closed trades growing up, it’s going to be an unnecessary overhead done on the blockchain network, in addition to that and from UX/UI perspective, paginating this kind of data is very crucial in this kind of use cases due to the poor network I/O performance may be caused if all logged events get loaded from the blockchain network at once.

In this vein, a very simple Web 2.0 infrastructure has been developed to fulfil this purpose. This infrastructure consists of three elements:

1. A NoSQL database using MongoDB.
2. A JavaScript program responsible for listening to events of interest emitted from the smart contract and synchronizing the database with the data sent in those events.
3. A JavaScript program that is responsible for serving the Web clients with the data stored in the database (i.e., server using Express.js)

#### The implementation of the MongoDB database

Figure 5.19 shows a snapshot for the content of the MongoDB database. So, it basically shows that there is only one collection in the database named closed\_trades. And inside this collection, there are some documents each stores the data of a closed trade that has been emitted earlier from the smart contract using the TradeClosed event.

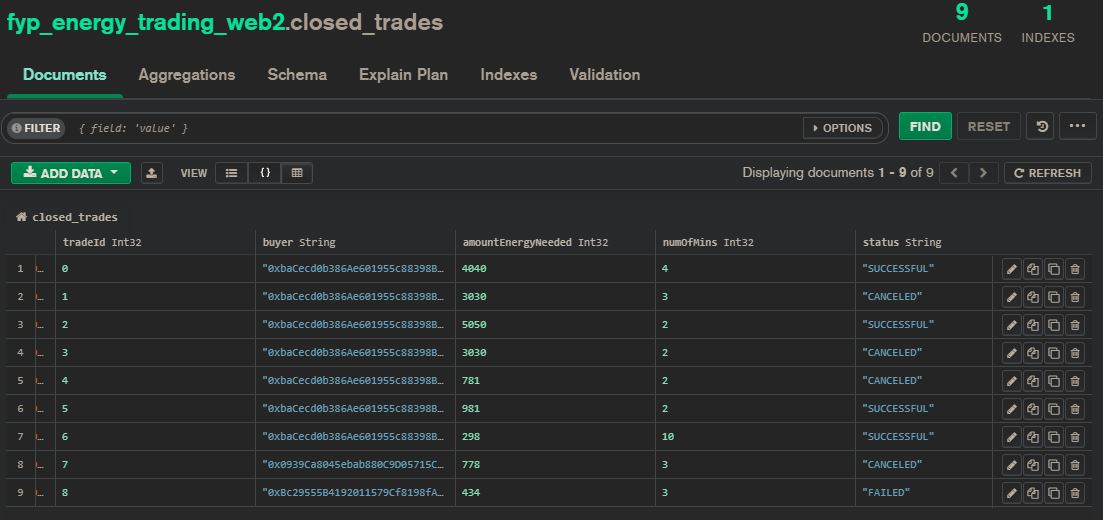


Figure . Snapshot for the MongoDB database

#### The implementation of the Listener/Synchronizer

Figure 5.20 below shows the full JavaScript source code written for the Listener/Synchronizer to work. The code could be divided into 3 parts. The first part is responsible for getting connected to the smart contract on the Ethereum blockchain network running locally on Ganache using Web3.js library and getting connected to the MongoDB database through a tool supported by JavaScript called mongoose. On the other hand, the second and the thirds parts are responsible for the synchronizing and listening missions.

Text

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Figure . The implementation of the Listener/Synchronizer program

Figure 5.21 below shows the full segment of code in the second part which basically queries the MongoDB database to get the biggest Block Number stored there. Then, it uses it to get all the past events emitted after this block up until the latest block so that the database gets synchronized with the untracked events which happened when the Listener program wasn’t working, before starting listening to the new events.

![Text

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generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RDyRXhpZgAATU0AKgAAAAgABAE7AAIAAAANAAAISodpAAQAAAABAAAIWJydAAEAAAAaAAAQ0OocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAEhhbnkgTW9oYW1lZAAAAAWQAwACAAAAFAAAEKaQBAACAAAAFAAAELqSkQACAAAAAzQwAACSkgACAAAAAzQwAADqHAAHAAAIDAAACJoAAAAAHOoAAAAIAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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Figure . Snapshot for the second part in the code of the Listener/Synchronizer program

Finally, the third part, shown in Figure 5.22, is responsible for listening to all new events emitted from the smart contract and synchronizing the MongoDB database with the data received in those events.

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Figure . Snapshot for the second part in the code of the Listener/Synchronizer program

#### Web 2.0 server

As for the server, it is the easiest part in system, not just in the context of the Web 2.0 side. As shown in Figure 5.23, it is a very simple JavaScript program that uses Mongoose, same as the Listener/Synchronizer program, yet it is using mongoose just to fetch the data stored in the collection named closed\_trades inside the MongoDB database. Furthermore, this program initiates a server using Express.js on port 5000 which responses to users’ requests with the data retrieved from the database.

![Text

Description automatically generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RDyRXhpZgAATU0AKgAAAAgABAE7AAIAAAANAAAISodpAAQAAAABAAAIWJydAAEAAAAaAAAQ0OocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAEhhbnkgTW9oYW1lZAAAAAWQAwACAAAAFAAAEKaQBAACAAAAFAAAELqSkQACAAAAAzQwAACSkgACAAAAAzQwAADqHAAHAAAIDAAACJoAAAAAHOoAAAAIAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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Figure . The implementation of the Web 2.0 server

### The implementation of the Web front-end using ReactJS

Considering the front-end, it is not easy nor feasible to cover every piece of code written as done earlier with the Ethereum smart contract and the Web 2.0 side due to the relatively large amount of code, and the big number of directories and files within this part compared to the other parts of the system. Therefore, only the basic structure and a few elaborations on some pieces within the front-end will be provided in this section.

Figure 5.24 shows the render function the ReactJS component named App which is the root component in the application meaning it is the first component to be rendered when any user opens the web application. The render function shows the user different output based on his status with the respect to the application. Essentially, the render function will show the user a centered loading circle indicating that the application is trying to connect to the Ethereum blockchain network running locally on Ganache using the user’s Ethereum account and through Web3.js library. If this connection fails, the render function will show the user a message pointing out this issue, otherwise, the function will check the status of the user to know whether he is logged in and show him, accordingly, the content on the website or the login page.

![Text

Description automatically generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RDyRXhpZgAATU0AKgAAAAgABAE7AAIAAAANAAAISodpAAQAAAABAAAIWJydAAEAAAAaAAAQ0OocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAEhhbnkgTW9oYW1lZAAAAAWQAwACAAAAFAAAEKaQBAACAAAAFAAAELqSkQACAAAAAzQ5AACSkgACAAAAAzQ5AADqHAAHAAAIDAAACJoAAAAAHOoAAAAIAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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8hPmIGBu4+bqeuaANCPQkk1G5tVmdjFc+Qu0DIGSN7DPTIH5/njHg1cfVruS4lnZovOl+9IsCBs+oIHB56jFUqQBT3+5H/ALv9TTKczZVAP4Rg/maYE1hHDNqEEV1u8qRwrFGCkAnGckGm3ds9neS28qlWjYqQw5p1jcJaX8NxLG0ixOH2K+3JHI5we9RSyGWZ5CMF2LY+tN2svn+n/BNPd9nbrf8AD+rDKKKKRmFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUHpRQelAEcPR/8Ae/pRRD0f/e/pRQBJW5br5mm28Ymtop/OXY800bBV2tk+qAcZznJxjkVh1aSwkeBZleLYWCMTIBsJBIzn2B/KgDobd7FLuVrg25IkjDjzYsSRhcMxIJHJBJVckkj61ypxuO3pnirn9lXO6YDyz5MYlY+YvKkZBAzk8VSpdQ6BXR6JJv8AB/iCG5eT7MiQyIqnO2XfhTg8c9CeuPWucqYXdytm1otxKLZn3tCHOwt03Femfesa1N1IqK7p/c0y4S5XchooorcgKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKD0ooPSgCOHo/wDvf0ooh6P/AL39KKAJK0otSt1tIbae2mniSQOyPcccA5C/L8oJPPXp+NZtaC2MH9mx3bvIB5gR1Tax5BPQH5enfrnI6UATLqtoLy5ne1uH8+IxAfaFG0EY7R4xjGBgYxWTWqNMt/7RktWllBVA+7YP3Xy5bfz2PB/yKpQf8etz/uqP/Hh/n/OQ4q7InLlV/NfjZFeiirUNhNPAZY8YycAg8498Y/OpOmjQqV5clJXZVoq2bB1ZA0kYDgspycFQM56dKDp0nH7yMlhlBk/OMZyOP54oujo/s/FfyeXTyt991bvdW3KlFXk04faViluIge4UkkcZ9KpuoVyFYOP7y5wfzovrYzrYStQipVFbVrdbrfQbRWgNLcxYVgZQ5DAZIUYz6dfpmhNN2LMbhh+7xgB9uc9+R/SlzI6llOLurx079rJt/cl+m5n0VbfT5UiEhZdpBPRh0Ge4FM8hRFKHz5iKrghuMHHGMe9O+tjnlgq8fjVv+Gv+RXoqzd2yW4j2Sq+9AxAB7/h0rS0nw/8A2lol/emVkeAHyEAyJSql3H4KPzIqJ1IwV5HNiIPDT5Km/wB+/oYlFdE3g28WRl+22RERYTMHfEJCb/m+X+6CeM9Kx9QsX068Nu8kcvyI6yRE7XVlDAjIB6EdQKUK0Ju0WYQqQn8LuVaKKK1NAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAoPSig9KAI4ej/739KKIej/739KKAJKuQ6rd24jEDRp5TB1xCnJAwCePmxk9c1Trp9Oijk022MiKxWdQCwzgeW5/mAfwoEY66zdoZdv2cCbG9fssWGx0424qCA5tbr12qf8Ax4f59PboR0ccMf8AwkEsflrseGMsu0YYmEk5H15rnLfm3u89ogR/32tVT+L5P8mZ1vh+a/NFepFndYTENpQknBUHH4npUdFSdEZyg7xdiyL6bdmQh8AgAqOMjHp09qQ31wc5cex2jI4xxxx+FV6KVkdH17FWt7SXfd/10JftEv2jz937zOd2KYzF2LHAJ9AAPyFNooMJVakk1KTd3f59/XzLJv7k9XHuNi88Y545/GojO5V1yAJMbgFABx0qOiiyNJ4rET+Obfq310f4aFlr+4Y5Z1PJP3F54xzxzxSG9mJckoTJ94mNTn9Paq9FFi3jcU96kvvfp+WhJJPJKiq5BCDA+UZx9etbuk6hd29jAtv4lttPSN2YWzpMeTwSwWJlbOB1JrnqKipTU1Z/p+pyVW6rvUd/XX8zuJNaSTUprj+29JELxyKkHkTbQzx7Nzf6P85H+0D6d65TVpXn1F5JLyG9YhR50CMiEAAABSq4AAAxgDiqVFZ0sPCk7x9On+RlTpRp/CFFFFdBqFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFB6UUHpQBHD0f8A3v6UUQ9H/wB7+lFAH//Z)

Figure . The render function in the App component in the ReactJS web application

Using the Web3.js library to connect the front-end ReactJS application with the smart contract deployed and running on the Ethereum network is the primary task the application does. In this context, Figure 5.25 below shows the code used to import this library and how it is used.

![Text

Description automatically generated](data:image/jpeg;base64,/9j/4AAQSkZJRgABAQEAYABgAAD/4RDyRXhpZgAATU0AKgAAAAgABAE7AAIAAAANAAAISodpAAQAAAABAAAIWJydAAEAAAAaAAAQ0OocAAcAAAgMAAAAPgAAAAAc6gAAAAgAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAEhhbnkgTW9oYW1lZAAAAAWQAwACAAAAFAAAEKaQBAACAAAAFAAAELqSkQACAAAAAzY4AACSkgACAAAAAzY4AADqHAAHAAAIDAAACJoAAAAAHOoAAAAIAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAAA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/0YXYe1RnBhK7t5GAVAHXIGKFUhK1nuUmm7IzKKKK0GFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAUUUUAFFFFABRRRQAVYspEiulke5nttvKywLucH2+Zf51XooA6KLXrQTyyMJoizoXdIlc3KhcMsgJAG48nryec4BrAkZXldkTYrMSFBztHpTKKQBUkEnk3EcmM7GDY9cVHRTWhUZOElKO6NA3yCdX8yR0QlwvlKmW98dfepBcwSx3Eju6b2jbaMbsjOcc/rWXRSsepHNa6b5ldO+jvu4uO977Pa9jS/tGJ5EmdGV49+EUDa2737dfSq1xc+Y0flllCxLG3OM4/pVaikklsZVsyxNeDhN77/cl+SS+RYvZYp7hpYi/z8kMoGP15pbeWFYZI5zIAzK37sDnGeDn61WoqlpsYvFTdd12ld3v21TT++7NJtRRl+RmiZWcg+UrZDHPUnjrURvy8dskzSSKjZlVjkOM59eeKpUUkrHTPNcVO95bq3W3Tpe32UttVuaTX1uflUOEKupIjVcbsYwB16Ui3dsLxJf3oSOMIo2gk8EetZ1FFk/6/ruV/a2IcuZpbp/da3XyRaEsBtGgZpABJvVggOeMYIzx+tP0d0TXLF5XWNFuYyzscBRuGST2qlRScbpruebXqOvBRkrWVvl/wP8Ahz0fU9csdPmEwuLcxT/aU8i3hinaMy4LSkedIrZIUbSVyM4Fc2dctbnULxdRubmW1nshaRyxWcUTRgMjj90rBcArj73Q1zlFctPCQgtXqc0aSjqt/wDg3/r/ADO00fxdpmlWNpa+TdSeTuV5vLUEqsjSRYG7jljnnj1NR3Hi6CYwyxyywgm38+1TT4QGERXjzgd5+7kAj26Vx9FH1OlzOXVkPD03Jye7Oovtd0+eRY7S81GFHvpb6S68hfNR2AChVEnbHJ3A+3FaWlXuna14guLm/wBUvNOsodLaC4vUuY4bi6bacFkJJk3HClV3HGMnvXC0VpChGG3Z/iaRpqMlJf1rcKKKK6DQKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigAooooAKKKKACiiigD/2Q==)

Figure . The code for importing and connecting Web3.js in the ReactJS web application

Since the main purpose of the web interface is to let users interact with the smart contract on the Ethereum blockchain network easily, the most important pieces of code in the ReactJS front-end are those responsible for calling the smart contract’s functions such as fetchAllOpenedTrades() and createTrade(uint \_amountEnergyNeeded, uint \_numOfMins). Figure 5.26 shows some of the functions on the front-end that, inside their implementations, are calling smart contract’s functions.

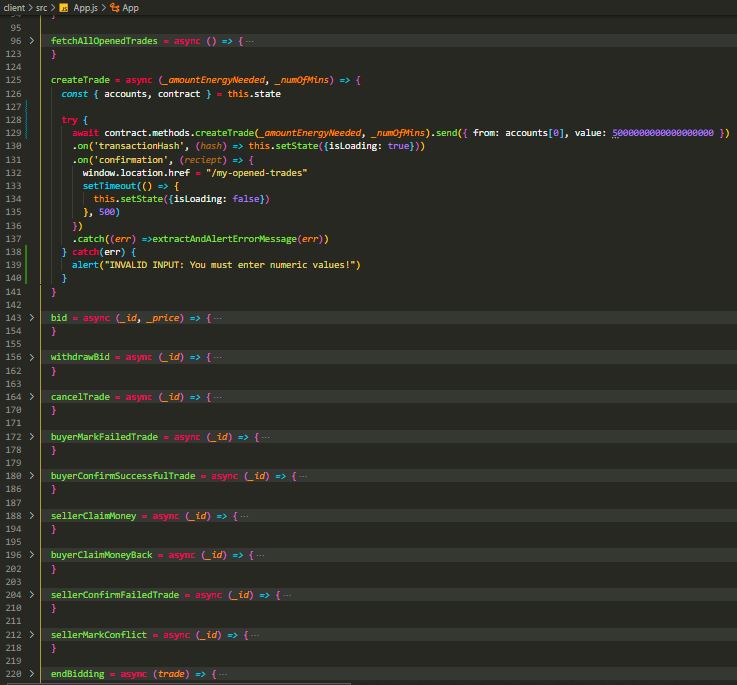


Figure . Some functions on the front-end mapped to the smart contract’s functions

## Essential interfaces showing the produced system in action

In this section, all the essential interfaces that the different users of the system should see throughout their experience within the produced system are shown with some elaborations (if any).

Figure 5.27 below shows the interface that the system will show upon failing to connect the front-end to the Ethereum blockchain network, otherwise, the interface will be as shown in Figure 5.28 if the user isn’t already logged, yet if he is already logged in, he will be redirected straightaway to the “Home” page as shown in Figure 2.29 or Figure 2.30 depending on whether there are running biddings.

Graphical user interface, text, application

Description automatically generated

Figure . Snapshot for “Failed to connect to Web3” page

Graphical user interface, text, application

Description automatically generated

Figure . Snapshot for “Login using MetaMask” page

Graphical user interface, text, application

Description automatically generated

Figure . Snapshot for the “Home” page (When no running biddings)

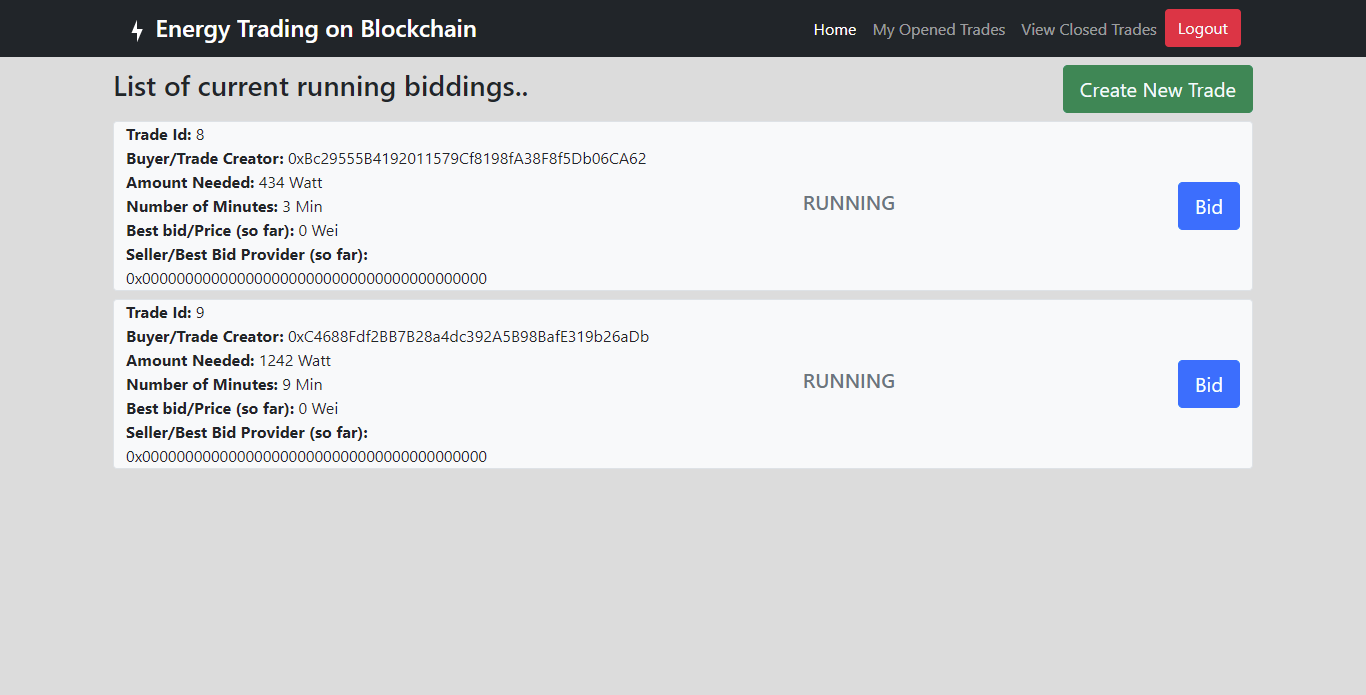


Figure . Snapshot for the “Home” interface (Some running trades exist)

Figures 5.31 and 5.32 below show the popping up forms when users click on the “Create New Trade” button, or the “Bid” button associated with any of the running biddings showed in the list, respectively.

Graphical user interface, application

Description automatically generated

Figure . Snapshot for the “Create New Trade” form

Graphical user interface, application, Teams

Description automatically generated

Figure . Snapshot for the “Place your bid” form

Figures 5.33 and 5.34 below show the “My Opened Trades” page which here includes one opened trade only with status of “RUNNING” from the buyer’s perspective and the seller’s perspective, respectively. As shown in Figure 5.33, the buyer (i.e., the creator of the trade) has two options which are either to cancel the trade or end the bidding running over it, meanwhile as shown in Figure 5.34, the seller (i.e., the bidder) has one option which is withdrawing his bid if the trade’s creator didn’t end bidding over it within one minute from the time the bid has been placed, if the one minute period hasn't passed yet, the “Withdraw” button will be disabled.

Graphical user interface, text, application, website

Description automatically generated

Figure . Snapshot for the “My Opened Trades” page with one trade only its status is “RUNNING” (Buyer’s perspective)

Graphical user interface, text, application, website

Description automatically generated

Figure . Snapshot for the “My Opened Trades” page with one trade only its status is “RUNNING” (Seller’s perspective)

Figures 5.35 and 5.36 below show the “My Opened Trades” page which here includes one opened trade only with status of “PENDING BUYER CONFIRMATION” from the buyer’s perspective and the seller’s perspective, respectively. As shown in Figure 5.35, the buyer has two options which are either to confirm the success of the trade or mark it as a failed trade, meanwhile as shown in Figure 5.36, the seller has one option which is claiming his deserved money if the buyer didn’t confirm the status of the trade within the number of minutes specified earlier by him on creatin the trade starting from the time bidding ended, if the specified period hasn't passed yet, the “Claim Money” button will be disabled.

Graphical user interface, text, application

Description automatically generated

Figure . Snapshot for the “My Opened Trades” page with one trade only its status is “PENDING BUYER CONFIRMATION” (Buyer’s perspective)

Graphical user interface, text, application

Description automatically generated

Figure . Snapshot for the “My Opened Trades” page with one trade only its status is “PENDING BUYER CONFIRMATION” (Seller’s perspective)

Figures 5.37 and 5.38 below show the “My Opened Trades” page which here includes one opened trade only with status of “PENDING SELLER CONFIRMATION” from the buyer’s perspective and the seller’s perspective, respectively. As shown in Figure 5.37, the buyer has one option which is claiming his money back if the seller didn’t confirm the status of the trade, either by confirming its failure or marking it as a conflict, within 3 minutes starting from the time he marked the trade as “FAILED”, if this 3-minute period hasn't passed yet, the “Claim Money Back” button will be disabled. Meanwhile, as shown in Figure 5.38, the seller has two options which are either to confirm the failure of the trade, or mark it as a conflict to be resolved by the admin.

Graphical user interface, text, application, website

Description automatically generated

Figure . Snapshot for the “My Opened Trades” page with one trade only its status is “PENDING SELLER CONFIRMATION” (Buyer’s perspective)

Graphical user interface, text, application

Description automatically generated

Figure . Snapshot for the “My Opened Trades” page with one trade only its status is “PENDING SELLER CONFIRMATION” (Seller’s perspective)

Figure 5.39 below shows the “My Opened Trades” page which here includes one opened trade with status of “CONFLICT” from the perspective of both the buyer and the seller.

Graphical user interface, text, application

Description automatically generated

Figure . Snapshot for the “My Opened Trades” page with one trade only its status is “CONFLICT”

Considering when the logged in user is the admin, Figure 5.40 below shows the “Conflicts” page which here includes one conflict. Furthermore, Figure 5.41 below shows the dialogue box popping up when the admin clicks on the “Resolve Conflict” button, which is responsible for allowing the admin to give his decision on a particular conflict.

Graphical user interface, text

Description automatically generated

Figure . Snapshot for the “Conflicts” page (Logged in user is the admin)

Graphical user interface, text, website

Description automatically generated

Figure . Snapshot for the “Resolve Conflict” dialogue box ((Logged in user is the admin)

Figures 5.42 and 5.43 below show a snapshot for the “View Closed Trades” page which lists down the closed trades fetched from the MongoDB database, placed in the Web 2.0 part of the system, into a paginated table.

Graphical user interface, application, Word

Description automatically generated

Figure . Snapshot for the “View Closed Trades” page (Page No. 1)

Graphical user interface, application, Word

Description automatically generated

Figure . Snapshot for the “View Closed Trades” page (Page No. 2)

## Testing

In this section, the testing performed on the system to validate it and measure user satisfaction with it, is covered. In this context, three kinds of testing have been implemented which are:

1. White-box testing
2. Black-box testing
3. User Acceptance Testing (UAT)

### Black-Box Testing

Black box testing involves testing the system with no prior knowledge of its internal workings. It’s conducting by providing an input, and observing the output generated by the system under test. Table 5.1 below shows the results of the Black-box testing performed on the system.

Table . Black-box testing results

| Test Case | Input | Output |
| --- | --- | --- |
| User logs in using MetaMask | 1. Connect MetaMask non-Admin account to the website.  2. Click on the “Login using MetaMask” button. | 1. New session on the browser for this account is created.  2. Redirected successfully to the “Home” page. |
| 1. Connect MetaMask admin account to the website.  2. Click on the “Login using MetaMask” button. | 1. New session on the browser for this account is created.  2. Redirected successfully to the “Conflicts” page. |
| User logs out | Click on the “Logout” button. | Redirected successfully to the “Login” page. |
| User navigates through the web application using the navigation bar | Click on any item in the navigation bar menu. | Redirected successfully to the selected page. |
| Buyer creates a new trade | 1. Click on the “Create New Trade” button.  2. Insert integer values in the “Create New Trade” form fields.  3. Submit the form  4. Confirm the transaction using MetaMask. | 1. A MetaMask notification message confirming the success of the transaction, is sent.  2. Redirected successfully to the “My Opened Trades” page which shows the new created trade. |
| 1. Click on the “Create New Trade” button.  2. Insert non-integer values in the “Create New Trade” form fields.  3. Submit the form. | An alert showing the message: “INVALID INPUT: You must enter integer values!”. |
| Seller bids on a trade | 1. Click on the “Bid” button associated with any running trade.  2. Insert integer value in the “Place your bid” form field.  3. Submit the form  4. Confirm the transaction using MetaMask. | 1. A MetaMask notification message confirming the success of the transaction, is sent.  2. Redirected successfully to the “My Opened Trades” page. |
| 1. Click on the “Bid” button associated with any running trade.  2. Insert integer value, that is higher than or equal the current selling price, in the “Place your bid” form field.  3. Submit the form  4. Confirm the transaction using MetaMask. | An alert showing the message: “ERROR: There is already a lower or equal bid!”. |
| 1. Click on the “Bid” button associated with any running trade.  2. Insert a non-integer value in the “Place your bid” form field.  3. Submit the form | An alert showing the message: “INVALID INPUT: You must enter integer value!”. |
| Buyer cancels a trade | 1. Click on the “Cancel” button associated with the targeted trade listed in the “My Opened Trades” page.  2. Confirm the transaction using MetaMask. | 1. A MetaMask notification message confirming the success of the transaction, is sent.  2. The buyer’s account receives the deposit back (5 ETH).  3. “My Opened Trades” page is reloaded, and this cancelled trade is no longer listed down. |
| Buyer ends bidding on a trade | 1. Click on the “End Bidding” button associated with the targeted trade listed in the “My Opened Trades” page.  2. Confirm the transaction using MetaMask. | 1. A MetaMask notification message confirming the success of the transaction, is sent.  2. The selling price is transferred from the buyer’s account to the smart contract.  3. “My Opened Trades” page is reloaded showing the status of this trade as “PENDING BUYER CONFIRMATION”. |
| Buyer confirms the success of a trade | 1. Click on the “Successful” button associated with the targeted trade listed in the “My Opened Trades” page.  2. Confirm the transaction using MetaMask. | 1. A MetaMask notification message confirming the success of the transaction, is sent.  2. The buyer’s account receives the deposit back (5 ETH).  3. “My Opened Trades” page is reloaded, and the targeted trade is no longer listed down. |
| Buyer marks a trade as “FAILED” | 1. Click on the “Failed” button associated with the targeted trade listed in the “My Opened Trades” page.  2. Confirm the transaction using MetaMask. | 1. A MetaMask notification message confirming the success of the transaction, is sent.  2. “My Opened Trades” page is reloaded showing the status of this trade as “PENDING SELLER CONFIRMATION”. |
| Seller claims his deserved money | 1. Click on the “Claim Money” button associated with the targeted trade listed in the “My Opened Trades” page.  2. Confirm the transaction using MetaMask. | 1. A MetaMask notification message confirming the success of the transaction, is sent.  2. The seller’s account receives the deserved money.  3. “My Opened Trades” page is reloaded, and the targeted trade is no longer listed down. |
| Seller confirms the failure of a trade | 1. Click on the “Confirm Failure” button associated with the targeted trade listed in the “My Opened Trades” page.  2. Confirm the transaction using MetaMask. | 1. A MetaMask notification message confirming the success of the transaction, is sent.  2. The seller’s account receives 50% of the deposit back (2.5 ETH).  3. “My Opened Trades” page is reloaded, and the targeted trade is no longer listed down. |
| Seller marks a trade as “CONFLICT” | 1. Click on the “Mark Conflict” button associated with the targeted trade listed in the “My Opened Trades” page.  2. Confirm the transaction using MetaMask. | 1. A MetaMask notification message confirming the success of the transaction, is sent.  2. “My Opened Trades” page is reloaded showing the status of this trade as “CONFLICT”. |
| Buyer claims his money back | 1. Click on the “Claim Money Back” button associated with the targeted trade listed in the “My Opened Trades” page.  2. Confirm the transaction using MetaMask. | 1. A MetaMask notification message confirming the success of the transaction, is sent.  2. The buyer’s account receives all the deserved money.  3. “My Opened Trades” page is reloaded, and the targeted trade is no longer listed down. |
| Admin resolves a conflict over a trade | 1. Click on the “Resolve Conflict” button associated with the targeted trade listed down in the “Conflicts” page.  2. As the “Resolve Conflict” dialogue box appears, click on either “Successful” or “Failed”.  3. Confirm the transaction using MetaMask. | 1. A MetaMask notification message confirming the success of the transaction, is sent.  2. Admin’s account receives 2.5 ETH (50% of one party’s deposit).  3. “Conflicts” page is reloaded, and the resolved conflict is no longer listed down. |

### White-Box Testing

White-box testing tests the internal coding and infrastructure of the system focusing on checking predefined inputs against expected and desired outputs. Table 5.2 below shows the results of the White-box testing performed on the system.

Table . White-box testing results

| Test Case | Input | Expected Output | Output |
| --- | --- | --- | --- |
| User logs in using MetaMask | 1. Connect MetaMask non-Admin account to the website.  2. Click on the “Login using MetaMask” button. | 1. New session on the browser for this account should be created.  2. non-Admin user should be redirected to the “Home” page. | 1. New session on the browser for this account is created.  2. Redirected successfully to the “Home” page. |
| 1. Connect MetaMask admin account to the website.  2. Click on the “Login using MetaMask” button. | 1. New session on the browser for this account should be created.  2. Admin user should be redirected to the “Conflicts” page. | 1. New session on the browser for this account is created.  2. Redirected successfully to the “Conflicts” page. |
| User logs out | 1. Click on the “Logout” button. | 1. User’s session on the browser for this account should be destroyed.  2. non-Admin user should be redirected to the “Login” page. | 1. New session on the browser for this account is destroyed.  2. Redirected successfully to the “Login” page. |
| User navigates through the web application using the navigation bar | 1. Click on any item in the navigation bar menu. | User should be redirected to the selected page. | Redirected to the selected page. |
| Non-Admin user tries to manipulate the path in the URL bar to get access to a protected route | 1. Change the path in the URL bar to be “/conflicts” instead of just “/”. | 1. User shouldn’t be allowed to see the content of the “Conflicts” page, instead, user should see a short message saying “Unauthorized”. | 1. A message saying “Unauthorized” is shown instead of the content of the “Conflicts” page. |
| Buyer creates a new trade | 1. Click on the “Create New Trade” button.  2. Insert integer values in the “Create New Trade” form fields.  3. Submit the form  4. Confirm the transaction using MetaMask. | 1. MetaMask should send a notification that confirms the success of the transaction.  2. A new trade should be added to the openedTrades array in the smart contract.  3. The user should be redirected to the “My Opened Trades” page and be able to see his new trade. | 1. MetaMask notification message confirming the success of the transaction is sent.  2. A new trade gets added to the openedTrades array in the smart contract.  3. Redirected successfully to the “My Opened Trades” page which shows the new created trade. |
| 1. Click on the “Create New Trade” button.  2. Insert non-integer values in the “Create New Trade” form fields.  3. Submit the form. | An alert showing the message: “INVALID INPUT: You must enter integer values!” should appear. | An alert showing the message: “INVALID INPUT: You must enter integer values!” successfully appears. |
| Seller bids on a trade | 1. Click on the “Bid” button associated with any running trade.  2. Insert integer value in the “Place your bid” form field.  3. Submit the form  4. Confirm the transaction using MetaMask. | 1. MetaMask should send a notification that confirms the success of the transaction.  2. The state of the targeted trade in the smart contract should be updated with the new bid.  3. The user should be redirected to the “My Opened Trades” page and be able to see the trade he has just placed his bidding offer on. | 1. MetaMask notification message confirming the success of the transaction is sent.  2. The state of the targeted trade in the smart contract gets updated with the new bid.  3. Redirected successfully to the “My Opened Trades” page. |
| 1. Click on the “Bid” button associated with any running trade.  2. Insert integer value, that is higher than or equal the current selling price, in the “Place your bid” form field.  3. Submit the form  4. Confirm the transaction using MetaMask. | 1. Transaction should be reverted by the smart contract.  2. An alert showing the message: “ERROR: There is already a lower or equal bid!” should appear. | 1. Transaction is reverted by the smart contract.  2. An alert showing the message: “ERROR: There is already a lower or equal bid!” successfully appears. |
| 1. Click on the “Bid” button associated with any running trade.  2. Insert non-integer value in the “Place your bid” form field.  3. Submit the form  4. Confirm the transaction using MetaMask. | An alert showing the message: “INVALID INPUT: You must enter integer value!” should appear. | An alert showing the message: “INVALID INPUT: You must enter integer value!” successfully appears. |
| Buyer cancels a trade | 1. Click on the “Cancel” button associated with the targeted trade listed in the “My Opened Trades” page.  2. Confirm the transaction using MetaMask. | 1. MetaMask should send a notification that confirms the success of the transaction.  2. Both the buyer and the seller (if a bid exists) accounts should receive their money according to the predefined rules.  3. The status of the targeted trade in the smart contract should be changed to “CANCELED”.  4. The Web 2.0 listener should update the MongoDB database with this closed trade.  5. “My Opened Trades” page should be reloaded, and this cancelled trade should no longer be listed down. | 1. MetaMask notification message confirming the success of the transaction is sent.  2. Both the buyer and the seller (if a bid exists) accounts receive their money according to the predefined rules.  3. The status of the targeted trade in the smart contract is changed to “CANCELED”.  4. The Web 2.0 listener updates the MongoDB database with this closed trade.  5. “My Opened Trades” page is reloaded, and this cancelled trade is no longer listed down. |
| Buyer ends bidding on a trade | 1. Click on the “End Bidding” button associated with the targeted trade listed in the “My Opened Trades” page.  2. Confirm the transaction using MetaMask. | 1. MetaMask should send a notification that confirms the success of the transaction.  2. The status of the targeted trade in the smart contract should be changed to “PENDING\_BUYER CONFIRMATION”.  3. “My Opened Trades” page should be reloaded showing the status of this trade as “PENDING BUYER CONFIRMATION”. | 1. MetaMask notification message confirming the success of the transaction is sent.  2. The status of the targeted trade in the smart contract is changed to “PENDING\_BUYER CONFIRMATION”.  3. “My Opened Trades” page is reloaded showing the status of this trade as “PENDING BUYER CONFIRMATION”. |
| Buyer confirms the success of a trade | 1. Click on the “Successful” button associated with the targeted trade listed in the “My Opened Trades” page.  2. Confirm the transaction using MetaMask. | 1. MetaMask should send a notification that confirms the success of the transaction.  2. Both the buyer and the seller accounts should receive money according to the predefined rules.  3. The status of the targeted trade in the smart contract should be changed to “SUCCESSFUL”.  4. The Web 2.0 listener should update the MongoDB database with this closed trade.  5. “My Opened Trades” page should be reloaded, and the targeted trade should no longer be listed down. | 1. MetaMask notification message confirming the success of the transaction is sent.  2. Both the buyer and the seller accounts receive money according to the predefined rules.  3. The status of the targeted trade in the smart contract is changed to “SUCCESSFUL”.  4. The Web 2.0 listener should update the MongoDB database with this closed trade.  5. “My Opened Trades” page is reloaded, and the targeted trade is no longer listed down. |
| Buyer marks a trade as “FAILED” | 1. Click on the “Failed” button associated with the targeted trade listed in the “My Opened Trades” page.  2. Confirm the transaction using MetaMask. | 1. MetaMask should send a notification that confirms the success of the transaction.  2. The status of the targeted trade in the smart contract should be changed to “PENDING\_SELLER CONFIRMATION”.  3. “My Opened Trades” page should be reloaded showing the status of this trade as “PENDING SELLER CONFIRMATION”. | 1. MetaMask notification message confirming the success of the transaction is sent.  2. The status of the targeted trade in the smart contract is changed to “PENDING\_SELLER CONFIRMATION”.  3. “My Opened Trades” page is reloaded showing the status of this trade as “PENDING SELLER CONFIRMATION”. |
| Seller claims his deserved money | 1. Click on the “Claim Money” button associated with the targeted trade listed in the “My Opened Trades” page.  2. Confirm the transaction using MetaMask. | 1. MetaMask should send a notification that confirms the success of the transaction.  2. Both the seller and the buyer accounts should receive money according to the predefined rules.  3. The status of the targeted trade in the smart contract should be changed to “SUCCESSFUL”.  4. The Web 2.0 listener should update the MongoDB database with this closed trade.  5. “My Opened Trades” page should be reloaded, and the targeted trade should no longer be listed down. | 1. MetaMask notification message confirming the success of the transaction is sent.  2. Both the seller and the buyer accounts receive money according to the predefined rules.  3. The status of the targeted trade in the smart contract is changed to “SUCCESSFUL”.  4. The Web 2.0 listener updates the MongoDB database with this closed trade.  5. “My Opened Trades” page is reloaded, and the targeted trade is no longer listed down. |
| Seller confirms the failure of a trade | 1. Click on the “Confirm Failure” button associated with the targeted trade listed in the “My Opened Trades” page.  2. Confirm the transaction using MetaMask. | 1. MetaMask should send a notification that confirms the success of the transaction.  2. Both the buyer and the seller accounts should receive money according to the predefined rules.  3. The status of the targeted trade in the smart contract should be changed to “FAILED”.  4. The Web 2.0 listener should update the MongoDB database with this closed trade.  5. “My Opened Trades” page should be reloaded, and the targeted trade should no longer be listed down. | 1. A MetaMask notification message confirming the success of the transaction, is sent.  2. Both the buyer and the seller accounts receive money according to the predefined rules.  3. The status of the targeted trade in the smart contract is changed to “FAILED”.  4. The Web 2.0 listener should update the MongoDB database with this closed trade.  5. “My Opened Trades” page is reloaded, and the targeted trade is no longer listed down. |

### User Acceptance Testing (UAT)

UAT is defined as testing the system by the end-user to determine whether it is acceptable not. This is the final testing performed once the White-box and Black-box tests are completed. For conducted UAT on the produced system, a survey has been used to collect end-users’ feedback on the system. The survey was designed to measure users’ level of satisfaction with the functionality and the UX/UI of the system, and to get their suggestions for improving.

Figure 5.44 shows the bar chart that illustrates users’ level of satisfaction with the system’s functionality. The bar chart shows clearly that most responses received strongly agree that the system is performing its functionality perfectly.

A picture containing graphical user interface

Description automatically generated

Figure . Bar chart showing users’ level of satisfaction with the system’s functionality

On the other hand, Figure 5.45 below shows the bar chart that illustrates users’ level of satisfaction with the system’s UX/UI. The bar chart shows clearly that most responses received strongly agree that the UX/UI of the system is very satisfying. However, users’ level of dissatisfaction with the UX/UI isn't trivial as it’s with their level of dissatisfaction of the system’s functionality.

Chart

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Figure . Bar chart showing users’ level of satisfaction with the system’s UX/UI

Furthermore, as shown in Figure 5.46, there have been three suggestions received which generally were suggesting improving the UI of the web application.

Graphical user interface, text, application

Description automatically generated

Figure . Respondents’ suggestions for improving the system.

## Chapter summary

In this chapter, the implementation of the project has been discussed in detail, covering the development of each and every part in the system, the various UIs can be found within the produced system, and the different kinds of testing conducted on the system.

# CONCLUSION

## Introduction

In accordance with the aim of this project which is building a blockchain energy trading web app with a unique architecture that involves Web 2.0 module for enhanced performance and user experience, and sophisticated mechanism for maximizing the integrity in the blockchain-based energy trading system, the ultimate goal of the project has been broken down into four objectives which, briefly, were developing an Ethereum smart contract, creating Web 2.0 module, developing a web front-end, and authenticating users using MetaMask cryptocurrency wallets, each with respect to its supposed role in the proposed system.

## Achievement of project objectives

Considering the four objectives of this project, all the objectives have been fully and successfully achieved.

First, as for the Ethereum smart contract, being the backbone of the proposed system, it has been developed successfully introducing a unique mechanism that involves taking deposits from users and enforcing a chain of confirmations to ensure the overall integrity of the proposed blockchain-based energy trading system. Subsequently, the contract has been deployed to a local Ethereum blockchain powered by Ganache.

Second, the Web 2.0 module, which is included in the proposed system for an improved user experience and minimized workload on the Ethereum blockchain, has been successfully created using a MongoDB database and two JavaScript programs, one as a Listener to the smart contract’s events and a Synchronizer to the MongoDB database with the received data in those events, while the other as a server that is an interface between web users and the MongoDB database.

Third, the web front-end has been developed successfully using React.js, serving as an interface between end-users and the entire system.

Fourth, instead of the traditional Web 2.0 authentication methods, a modern Web 3.0 method for authenticating users has been implemented successfully using MetaMask wallets.

Overall, with all these objectives been achieved successfully, the proposed system has been built fully, and passed the subsequent various tests in a satisfying shape.

## Suggestions for future improvement

Considering possible improvements in the future, a few points would help which are:

1. The module developed to listen to the Ethereum smart contract’s events was found to skip some events from time to time. Hence, a scheduled task can be implemented to check for missed events on a daily basis.
2. One admin resolving conflicts may undermine the integrity of the system. Thus, a new technique for resolving conflicts would fix that.
3. Instead of enforcing a unified fixed deposit, dynamic deposits set by bidders while submitting their bids, abided by defined rules, would make the system more desirable.
4. Cloud services such as Amazon Web Services (AWS) can help with deploying the system due to the Ethereum blockchain solutions some cloud services providers offer nowadays.

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Appendix FYP1 & FYP2 Gantt charts

FYP1 Gantt chart:

Graphical user interface

Description automatically generated with medium confidence

FYP2 Gantt chart:

Graphical user interface

Description automatically generated with medium confidence

Appendix Source code for the Ethereum smart contract

// SPDX-License-Identifier: MIT

pragma solidity >=0.7.0 <0.9.0;

*enum* Status { RUNNING, CANCELED, PENDING\_BUYER\_CONFIRMATION, PENDING\_SELLER\_CONFIRMATION, CONFLICT, SUCCESSFUL, FAILED }

*struct* Trade {

*uint* id;

*address* buyer;

*uint* amountEnergyNeeded;

*uint* numOfMins;

*uint* sellingPrice;

*address* seller;

*uint* bidAt;

*uint* biddingEndedAt;

*uint* markedFailedAt;

    Status status;

}

*contract* EnergyTrading {

*address* *private* admin;

*constructor*() { admin = msg.sender; }

*modifier* onlyAdmin() {

        require(msg.sender == admin, "Only admin is allowed to perform this action!");

        \_;}

    // variable holding the state of the smart contract

    Trade[] *private* openedTrades;

*uint* *private* currentNumOfAllTrades;

    // event triggered whenever a trade is closed

*event* TradeClosed(*Trade* *trade*);

    // private functions (only to be used by other SC functions)

*function* findTrade(*uint* *\_id*) *private* *view* returns(*uint*) {

*uint* i = 0;

        for (; i < openedTrades.length; i++) {

            if (openedTrades[i].id == \_id) {

                break;

            }

        }

        return i;

    }

*function* removeFromOpenedTrades(*uint* *\_index*) *private* {

        openedTrades[\_index] = openedTrades[openedTrades.length - 1];

        openedTrades.pop();

    }

    // External functions

*function* fetchAllOpenedTrades() *external* *view* returns(*Trade*[] *memory*) { return openedTrades; }

*function* createTrade(*uint* *\_amountEnergyNeeded*, *uint* *\_numOfMins*) *external* *payable* {

        require(msg.value == 5000000000000000000, "You must send a value of 5 ETH as deposit!");

        Trade *memory* newTrade;

        newTrade.id = currentNumOfAllTrades++;

        newTrade.buyer = msg.sender;

        newTrade.amountEnergyNeeded = \_amountEnergyNeeded;

        newTrade.numOfMins = \_numOfMins;

        newTrade.status = Status.RUNNING;

        openedTrades.push(newTrade);

    }

*function* cancelTrade(*uint* *\_id*) *external* {

*uint* tradeIndex = findTrade(\_id);

        require(tradeIndex < openedTrades.length, "Trade Not Found (Most probably it's no longer opened, check closed trades!)");

        Trade *storage* targetedTrade = openedTrades[tradeIndex];

        require(msg.sender == targetedTrade.buyer, "You aren't allowed to perform this action");

        require(targetedTrade.status == Status.RUNNING, "The bidding has already ended");

        if (targetedTrade.seller != *address*(0)) {

*payable*(targetedTrade.seller).transfer(7500000000000000000); // 7.5 ETH

*payable*(targetedTrade.buyer).transfer(2500000000000000000); // 2.5 ETH

        } else {

*payable*(targetedTrade.buyer).transfer(5000000000000000000); // 5 ETH

        }

        targetedTrade.status = Status.CANCELED;

        emit TradeClosed({trade: targetedTrade});

        removeFromOpenedTrades(tradeIndex);

    }

*function* bid(*uint* *\_id*, *uint* *\_price*) *external* *payable* {

*uint* tradeIndex = findTrade(\_id);

        require(tradeIndex < openedTrades.length, "Trade Not Found (Most probably it's no longer opened, check closed trades!)");

        Trade *storage* targetedTrade = openedTrades[tradeIndex];

        require(msg.sender != targetedTrade.buyer, "You can't bid on a trade you have created!!");

        require(targetedTrade.status == Status.RUNNING, "The bidding has already ended");

        require(targetedTrade.sellingPrice == 0 || targetedTrade.sellingPrice > \_price, "There is already a lower or equal bid!");

        require(msg.value == 5000000000000000000, "You must send a value of 5 ETH as deposit!");

        if (targetedTrade.seller != *address*(0)) {

*payable*(targetedTrade.seller).transfer(5000000000000000000); // 5 ETH (deposit)

        }

        targetedTrade.sellingPrice = \_price;

        targetedTrade.seller = msg.sender;

        targetedTrade.bidAt = block.timestamp;

    }

*function* withdrawBid(*uint* *\_id*) *external* {

*uint* tradeIndex = findTrade(\_id);

        require(tradeIndex < openedTrades.length, "Trade Not Found (Most probably it's no longer opened, check closed trades!)");

        Trade *storage* targetedTrade = openedTrades[tradeIndex];

        require(msg.sender == targetedTrade.seller, "You aren't allowed to perform this action");

        require(targetedTrade.status == Status.RUNNING, "The bidding has already ended");

        require(block.timestamp >= targetedTrade.bidAt + 60, "You can withdraw your bid ONLY if the creator of this trade doesn't end bidding within 1 minute from the time you successfully placed your bid");

*payable*(targetedTrade.seller).transfer(7500000000000000000); // 7.5 ETH

*payable*(targetedTrade.buyer).transfer(2500000000000000000); // 2.5 ETH

        targetedTrade.status = Status.CANCELED;

        emit TradeClosed({trade: targetedTrade});

        removeFromOpenedTrades(tradeIndex);

    }

*function* endBidding(*uint* *\_id*) *external* *payable* {

*uint* tradeIndex = findTrade(\_id);

        require(tradeIndex < openedTrades.length, "Trade Not Found (Most probably it's no longer opened, check closed trades!)");

        Trade *storage* targetedTrade = openedTrades[tradeIndex];

        require(msg.sender == targetedTrade.buyer, "You aren't allowed to perform this action");

        require(targetedTrade.seller != *address*(0), "You cannot end bidding if you haven't received any bid. Use \"Cancel\" instead");

        require(targetedTrade.status == Status.RUNNING, "The bidding has already ended");

        require(msg.value == targetedTrade.sellingPrice, "You must transfer the money in advance");

        targetedTrade.sellingPrice = msg.value;

        targetedTrade.biddingEndedAt = block.timestamp;

        targetedTrade.status = Status.PENDING\_BUYER\_CONFIRMATION;

        /\*\* We may emit an event here, if we want to notify an IoT component that is listening to this kind of event to act accordingly (Start tranfering energy!) \*/

    }

*function* buyerConfirmSuccessfulTrade(*uint* *\_id*) *external* {

*uint* tradeIndex = findTrade(\_id);

        require(tradeIndex < openedTrades.length, "Trade Not Found (Most probably it's no longer opened, check closed trades!)");

        Trade *storage* targetedTrade = openedTrades[tradeIndex];

        require(msg.sender == targetedTrade.buyer, "You're not allowed to perform this action!");

        require(targetedTrade.status == Status.PENDING\_BUYER\_CONFIRMATION, "The current status of the trade doesn't permit you to perform this action");

*payable*(targetedTrade.seller).transfer(targetedTrade.sellingPrice + 5000000000000000000); // selling price + 5 ETH (deposit)

*payable*(targetedTrade.buyer).transfer(5000000000000000000); // 5 ETH (deposit)

        targetedTrade.status = Status.SUCCESSFUL;

        emit TradeClosed({trade: targetedTrade});

        removeFromOpenedTrades(tradeIndex);

    }

*function* buyerMarkFailedTrade(*uint* *\_id*) *external* {

*uint* tradeIndex = findTrade(\_id);

        require(tradeIndex < openedTrades.length, "Trade Not Found (Most probably it's no longer opened, check closed trades!)");

        Trade *storage* targetedTrade = openedTrades[tradeIndex];

        require(msg.sender == targetedTrade.buyer, "You're not allowed to perform this action!");

        require(targetedTrade.status == Status.PENDING\_BUYER\_CONFIRMATION, "The current status of the trade doesn't permit you to perform this action");

        targetedTrade.markedFailedAt = block.timestamp;

        targetedTrade.status = Status.PENDING\_SELLER\_CONFIRMATION;

    }

*function* buyerClaimMoneyBack(*uint* *\_id*) *external* {

*uint* tradeIndex = findTrade(\_id);

        require(tradeIndex < openedTrades.length, "Trade Not Found (Most probably it's no longer opened, check closed trades!)");

        Trade *storage* targetedTrade = openedTrades[tradeIndex];

        require(msg.sender == targetedTrade.buyer, "You're not allowed to perform this action!");

        require(targetedTrade.status == Status.PENDING\_SELLER\_CONFIRMATION, "The current status of the trade doesn't permit you to perform this action");

        require(block.timestamp >= targetedTrade.markedFailedAt + 3 \* 60, "You can claim your money back only if the seller doesn't confirm failure nor request admin's intervention within 3 minutes from the time this trade was marked as Failed by you");

*payable*(targetedTrade.buyer).transfer(targetedTrade.sellingPrice + 10000000000000000000); // selling price + 10 ETH (buyer's deposit + seller's deposit)

        targetedTrade.status = Status.FAILED;

        emit TradeClosed({trade: targetedTrade});

        removeFromOpenedTrades(tradeIndex);

    }

*function* sellerConfirmFailedTrade(*uint* *\_id*) *external* {

*uint* tradeIndex = findTrade(\_id);

        require(tradeIndex < openedTrades.length, "Trade Not Found (Most probably it's no longer opened, check closed trades!)");

        Trade *storage* targetedTrade = openedTrades[tradeIndex];

        require(msg.sender == targetedTrade.seller, "You're not allowed to perform this action!");

        require(targetedTrade.status == Status.PENDING\_SELLER\_CONFIRMATION, "The current status of the trade doesn't permit you to perform this action");

*payable*(targetedTrade.seller).transfer(2500000000000000000); // 2.5 ETH (50% of seller deposit)

*payable*(targetedTrade.buyer).transfer(targetedTrade.sellingPrice + 7500000000000000000); // refund + 7.5 ETH (buyer deposit + 50% of seller deposit)

        targetedTrade.status = Status.FAILED;

        emit TradeClosed({trade: targetedTrade});

        removeFromOpenedTrades(tradeIndex);

    }

*function* sellerMarkConflict(*uint* *\_id*) *external* {

*uint* tradeIndex = findTrade(\_id);

        require(tradeIndex < openedTrades.length, "Trade Not Found (Most probably it's no longer opened, check closed trades!)");

        Trade *storage* targetedTrade = openedTrades[tradeIndex];

        require(msg.sender == targetedTrade.seller, "You're not allowed to perform this action!");

        require(targetedTrade.status == Status.PENDING\_SELLER\_CONFIRMATION, "The current status of the trade doesn't permit you to perform this action");

        targetedTrade.status = Status.CONFLICT;

    }

*function* sellerClaimMoney(*uint* *\_id*) *external* {

*uint* tradeIndex = findTrade(\_id);

        require(tradeIndex < openedTrades.length, "Trade Not Found (Most probably it's no longer opened, check closed trades!)");

        Trade *storage* targetedTrade = openedTrades[tradeIndex];

        require(msg.sender == targetedTrade.seller, "You're not allowed to perform this action!");

        require(targetedTrade.status == Status.PENDING\_BUYER\_CONFIRMATION, "The current status of the trade doesn't permit you to perform this action");

        require(block.timestamp >= targetedTrade.biddingEndedAt + targetedTrade.numOfMins \* 60 + 60, "You can claim your money back only if the buyer doesn't confirm success nor mark the trade as a failed one within one minute after the number of minutes specified in the trade starting from the time he ended the bidding");

*payable*(targetedTrade.buyer).transfer(2500000000000000000); // 2.5 ETH (50% of buyer deposit)

*payable*(targetedTrade.seller).transfer(targetedTrade.sellingPrice + 7500000000000000000); // selling price + 7.5 ETH (seller deposit + 50% of buyer deposit)

        targetedTrade.status = Status.SUCCESSFUL;

        emit TradeClosed({trade: targetedTrade});

        removeFromOpenedTrades(tradeIndex);

    }

*function* adminResolveConflict(*uint* *\_id*, *bool* *\_isSuccessfulTrade*) onlyAdmin *external* {

*uint* tradeIndex = findTrade(\_id);

        require(tradeIndex < openedTrades.length, "Trade Not Found (Most probably it's no longer opened, check closed trades!)");

        Trade *storage* targetedTrade = openedTrades[tradeIndex];

        require(targetedTrade.status == Status.CONFLICT, "The current status of the trade doesn't permit you to perform this action");

        if (\_isSuccessfulTrade) {

*payable*(admin).transfer(2500000000000000000); // 2.5 ETH (50% of buyer deposit)

*payable*(targetedTrade.seller).transfer(targetedTrade.sellingPrice + 7500000000000000000); // selling price + 7.5 ETH (seller deposit + 50% of buyer deposit)

            targetedTrade.status = Status.SUCCESSFUL;

        } else {

*payable*(admin).transfer(2500000000000000000); // 2.5 ETH (50% of seller deposit)

*payable*(targetedTrade.buyer).transfer(targetedTrade.sellingPrice + 7500000000000000000); // refund + 7.5 ETH (buyer deposit + 50% of seller deposit)

            targetedTrade.status = Status.FAILED;

        }

        emit TradeClosed({trade: targetedTrade});

        removeFromOpenedTrades(tradeIndex);

    }

}

Appendix Source code for the Listener/Synchronizer in Web 2.0 module

*const* mongoose = require('mongoose')

*const* Web3 = require('web3')

*const* EnerygTradingContract = require('../client/src/contracts/EnergyTrading.json')

*const* Status = {

    '1': 'CANCELED',

    '5': 'SUCCESSFUL',

    '6': 'FAILED'

}

*const* main = async () *=>* {

    try {

        // initialize web3 and connecting to the smaty contract

*const* web3 = new Web3('ws://127.0.0.1:7545')

        // Get the contract instance.

*const* networkId = await web3.eth.net.getId()

*const* deployedNetwork = EnerygTradingContract.networks[networkId]

*const* contract = new web3.eth.Contract(

            EnerygTradingContract.abi,

            deployedNetwork && deployedNetwork.address,

        )

        // Connect to the mongodb & create model

        await mongoose.connect('mongodb://localhost/fyp\_energy\_trading\_web2')

*const* ClosedTrade = mongoose.model('ClosedTrade', new mongoose.Schema({}, { strict: false }), 'closed\_trades')

        // sync between the DB and blockchain by updating the DB with the events that have been emitted when the listener was shut down

*const* data = await ClosedTrade.findOne().sort('-blockNumber').select({blockNumber:1,\_id:0})

*const* biggestBlockNumber = data === null || data['blockNumber'] === undefined ? -1 : data['blockNumber']

        contract.getPastEvents('TradeClosed', {fromBlock: biggestBlockNumber + 1, toBlock: 'latest'})

            .then((*events*) *=>* {

                events.forEach(async (*event*) *=>* {

*const* closedTrade = new ClosedTrade({

                        tradeId: parseInt(event['returnValues']['trade']['id']),

                        buyer: event['returnValues']['trade']['buyer'],

                        amountEnergyNeeded: parseInt(event['returnValues']['trade']['amountEnergyNeeded']),

                        numOfMins: parseInt(event['returnValues']['trade']['numOfMins']),

                        status: Status[event['returnValues']['trade']['status']],

                        blockNumber: parseInt(event['blockNumber'])

                    })

                    if (event['returnValues']['trade']['seller'] !== '0x0000000000000000000000000000000000000000') {

                        closedTrade.set('seller', event['returnValues']['trade']['seller'])

                        closedTrade.set('sellingPrice', parseInt(event['returnValues']['trade']['sellingPrice']))

                        closedTrade.set("bidAt", new Date(parseInt(event['returnValues']['trade']['bidAt']) \* 1000))

                    }

                    if (parseInt(event['returnValues']['trade']['biddingEndedAt']) !== 0) {

                        closedTrade.set("biddingEndedAt", new Date(parseInt(event['returnValues']['trade']['biddingEndedAt']) \* 1000) )

                    }

*const* res = await closedTrade.save()

                    console.log(res)

                })

            })

            .catch(*err* *=>* console.log(err))

        // start listening to the new events emitted in the BC and update the DB with it

        web3.eth.getBlockNumber().then((*latestBlockNumber*) *=>* {

            contract.events.TradeClosed({fromBlock: latestBlockNumber + 1})

                .on('data', async (*event*) *=>* {

*const* closedTrade = new ClosedTrade({

                        tradeId: parseInt(event['returnValues']['trade']['id']),

                        buyer: event['returnValues']['trade']['buyer'],

                        amountEnergyNeeded: parseInt(event['returnValues']['trade']['amountEnergyNeeded']),

                        numOfMins: parseInt(event['returnValues']['trade']['numOfMins']),

                        status: Status[event['returnValues']['trade']['status']],

                        blockNumber: parseInt(event['blockNumber'])

                    })

                    if (event['returnValues']['trade']['seller'] !== '0x0000000000000000000000000000000000000000') {

                        closedTrade.set('seller', event['returnValues']['trade']['seller'])

                        closedTrade.set('sellingPrice', parseInt(event['returnValues']['trade']['sellingPrice']))

                        closedTrade.set("bidAt", new Date(parseInt(event['returnValues']['trade']['bidAt']) \* 1000))

                    }

                    if (parseInt(event['returnValues']['trade']['biddingEndedAt']) !== 0) {

                        closedTrade.set("biddingEndedAt", new Date(parseInt(event['returnValues']['trade']['biddingEndedAt']) \* 1000) )

                    }

*const* res = await closedTrade.save()

                    console.log(res)

                })

                .on('error', *err* *=>* console.log(err))

        })

    } catch (err) {

        console.error(err);

    }

}

// run the main function

main()

Appendix Source code for the server in Web 2.0 module

*const* mongoose = require('mongoose')

// Connect to the mongodb

mongoose.connect('mongodb://localhost/fyp\_energy\_trading\_web2').then(() *=>* {

*const* ClosedTrade = mongoose.model('ClosedTrade', new mongoose.Schema({}, { strict: false }), 'closed\_trades')

*const* express = require('express')

*const* cors = require('cors')

*const* app = express()

    app.use(cors())

*const* port = 5000

    app.get('/', async (*req*, *res*) *=>* {

*res*.send(await ClosedTrade.find().sort({\_id:-1}))

    })

    app.listen(port, () *=>* {

      console.log(`Example app listening on port ${port}`)

    })

})

Appendix UAT survey

Graphical user interface, text, application, email

Description automatically generated

Appendix User manual

The steps to get started with using the blockchain-based energy trading system are very few and straightforward which are as follows:

1. Install MetaMask plugin on your preferred web browser that provides it.
2. Once MetaMask is installed, make sure to choose the correct Ethereum network.
3. Open the web app.
4. Your browser is supposed to fire up MetaMask to ask you if you want to connect your Ethereum account to this website. So, confirm.
5. As your Ethereum account is connected to the web app, you show see the “Login” page with button in the centre that asks you to “Login using MetaMask”, so click on it.
6. Here you are!! Now you should be redirected to either the “Home” or the “Conflicts” page, depending on whether you’re a normal user or the admin, respectively.