Department of Mechanical and Aerospace Engineering

# Electricity Trading Among Microgrids

Author: Pisokas Konstantinos

Supervisor: Professor Joe Clarke

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# Copyright Declaration



Signed: Pisokas Konstantinos Date: Tuesday 21st August 2018

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# Abstract

The increasing energy demands make it necessary to develop renewable energy resources to meet the growth requirements energy demand, mitigation of environmental pollutants and the achievement of social and economic benefits to sustainable development. The integration of such kinds of distributed energy sources into the existing utility network facilitates the creation of micro-grids.

The idea of micro-grid is based on the fact that it is a self-sustaining system consisting of distributed energy resources that during a network failure can operate autonomously in an island way. A micro-grid can be defined as a low voltage distribution system to which small modular generation systems are to be connected. On the micro-grid, the appropriate use of these distributed energy resources with a reliable and intelligent way is essential for the viability of the process.

Therefore, a need has been identified to create a software model to simulate a future negotiating scenario while exploring the factors affecting trade and identifying the conditions that make it trade sustainable. This dissertation presents a detailed analysis of parameters of energy trading, which are related with the viability of this process and summarises the findings of the simulations. In this dissertation, the algorithm of MGET-SIM software was customized to depict the electricity trading among micro-grids. The bidding scenario has evolved to prioritize micro-grids with a higher adoption of renewable energy sources. In the context of this work, there have been assumptions about the connection of micro-grids through the national network, the central control system and the electricity prices. After the algorithm has been formulated ,so as to ascertain the impact of the various factors on a trade negotiation, several simulations have been made.

The results of these simulations illustrate in detail the effects of each factor on the energy trade, in order to prove the viability of a micro-grids network. Also, the economic impact of these changes on energy trade is presented.

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CHP : Combined Heat & Power (CHP) systems

MGET-SIM : Micro-grid Energy trading Simulator

# Chapter One: Micro-grid Energy Trading

## 1.1 Introduction

The management of the electric power is characterized as the most enormous and complex of the energy system community. While the demand of energy is increasing annually, at the same time the conventional energy resources is exhausted, we must use alternative options of energy resources. Fossil fuels based power generation has been accused several times that causing harmful emissions threatening our environment, so our goal must be to develop low-carbon electricity generation technologies to meet future power requirements. The next decade, problems as environmental pollution and changing climate conditions had been characterized as alarming and we have to cope with them with the introduction of micro-grid which is developed to generate electricity with less harmful emissions for the environment and as low as possible transmission losses (Kaur, et al. 2014).

The development of a new concept of the energy system  which is commonly referred as smart grid has as target to face the increasing effects of distributed generation and active distributed networks, the changes in nomarlities, improving meanwhile the reliability of the power system and clean energy support.

According to this respect, micro-grid can be considered as one of the most promising concepts (Chaoucahci, et al. 2013).

In our time, the energy market is in a broader turnaround with its opening to new players, such as concentrators and the participation of Renewable Energy Sources, by implementing specific pricing policies instead of outdated policies such as Feed-In-Tariff (FIT) (Vergados, et al. 2017).

## 1.2 Microgrid explained

A micro-grid can be defined as a low voltage distribution system to which small modular generation systems are to be connected. It consists of small generation systems and electrical loads through allow voltage distribution network (Kaur, et al. 2014).

The function of micro-grids could allow us to install a small renewable energy sources to fulfil the load demand. A micro-grid can be installed in a village, a small town or even in a block of flats.

Renewable energy resources like photovoltaic systems, wind turbines, micro turbines using CHP systems, fuel cells and batteries with storage facilities etc. could be integrated in each micro-grid. The interconnected distributed generators, loads and intermediate storage units are able to co-operate with each other to be collectively treated by the utility grid as a controllable load or generator on an applicable power solution for the applicable deficiency fossil fuel (Kaur, et al. 2014).

A micro-grid can be described as an active distribution network which have the ability to deliver the integrated power. Usually, a micro-grid consists of a low-voltage network composed of loads, renewable energy sources, and DG units operating as a controllable load connected to the main grid. In addition, a micro-grid could be characterized as complex operational network who's function depending on several stochastic parameters (Gonzalez de Durana and Barambones, 2018).

As a result, the implementation of concepts included micro-grid requires the establishment of energy manager aiming at a reliable control of the microgrid to achieve the best operational cost and to mitigate the environmental impact (Chaoucahci, et al. 2013).

The simplest form of a micro-grid is a small scale power network which can generate the appropriate amount of electricity to meet its own needs in local scale, or operating as part of a wider grid (Karling, 2014).

The last decade, the electrical energy continues to rise significantly in global climax. The UK presents lower difference between expected power supply and peak demand each year raising concerns of power failure (Lokeshgupta, et al. 2017).

However, the adoption of low carbon movement depicts that the use of fossil fuels cannot be the answer. The renewable energy resources is non dispatchable way of energy production and are not easily integrated in the grid, as the traditional sources of power as coal, gas or nuclear which can be placed wherever it is necessary.

The UK and especially Scotland has developed an energy plan based on renewable energy production. The Scottish Energy Strategy is determined with a specific energy policy, defining the source of the energy and its way of use either for heat, transport and electricity (Scottish Government, 2017). The 'all-energy' goal of 50% of Scotland's heat, transport and electricity consumption to be supplied from renewable energy resources until 2030, depicts the focused approach of this subject (Scottish Government, 2018).

In recent years, Scotland has made significantly steps away  away from traditional models of centralised energy provision and passive consumption. The development of innovative local energy systems have been realised in a wide range from Scottish companies and communities. More precisely, the autonomous energy production using renewable energy systems generation has created innovative technology systems and models in the region.

In 2015,  the equivalent of 17,8 % of Scotland’s total energy consumption was generated by renewable, up from 15.2% in 2014  with the growth of onshore wind and large-scale hydro played to had a significant role.

Furthermore, according to recent reports the Scottish government targets on a 30% renewable ‘all-energy’ target by 2030, which clearly illustrates the direction of governmental policies (Scottish Government, 2018).

The UK based ‘Customer-Led Network Revolution’  has as a purpose to provide knowledge and experience to deploy the existed network management and demand response technologies at distribution level in the UK market with the degree of vertical separation (Customer- Led Network Revolution, 2015).

As an alternative way is presented the implementation of micro-grid energy systems, with which trading could be viable.

In our days, it is known that the Renewable Energy sources should cope with the challenge to provide energy to thousands of homes from a small number of locations. Nevertheless, they are able to supply the network with an amount of energy with a ‘passive’ way having the most of the times  the lower carbon emissions. Solar panels on roof which generate electricity during the day, small scale wind power generators and heat pumps could represent a non-intrusive and non-disruptive solution.

With the UK government bringing specific policies, there is also a business motivation to make money from small-scale production.

Another problem with the existing grid is its form. The national grid is a regulated monopoly where the amount and the price is determined strictly (Zia, et al. 2018). Instead of the existed trading conditions, micro-generation cultivate a different prospect of the market. The creation of a functional micro-grid energy trading system could encourage the shift of the energy market which will be investigated further in this project.

The transformation of the consumers to 'prosumers' with the development of energy monitoring and managing technology is one another reason for the emergence of micro-grids .

A substantial component of each micro-grid is the smart meter. Smart meters has the ability to inform in real-time feedback the user about the energy use and cost, providing at the same time the energy businesses with accurate date related to energy demand.(Tan, et al. 2013).

In the existing network, this will inform the users to adopt theirs charging profil. It will allow the supply businesses to know exactly the system needs in goal or gas to meet demand, shaping the prices and resource management. Users can configure their energy consumption profile by varying usage parameters when demand and values are high or when green electricity is more abundant.

Monitoring the energy imports and production , the management of energy storage on micro-grid , the control of the demand by disabling or reducing the production of certain household or professional appliances (such as lighting or air conditioning) consist some of the great abilities which could be provided in a micro-grid by a smart meter (Bullich-Massagué, et al. 2018).

In addition, this project with offered abilities of smart metering and multi-cloud management would allow us to exchange energy as an economic element, trade (Maity and Rao 2010).

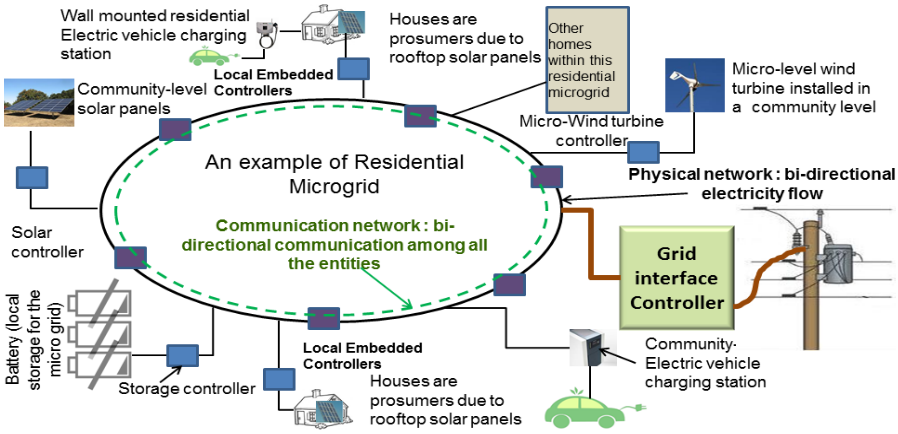



Figure.1 – An example of Residential Micro-grid [Picture Courtesy: http://aicps.eng.uci.edu/research/CPES/]

## 1.3 Market Energy Trading

Electricity has been characterized as a basic commodity in everyday life. In nowadays market form, the utilities are responsible to generate, transmit and distribute power to consumers. The regulation of the electricity industry is based on the belief that economies make the power generation business a natural monopoly. The traditional electric power industry has been subjected to restrictions (Prabavathi and Gnanadass, 2014).

The rest ruction of the market is consisted of the introduction of new more competitive form energy markets and electricity services with simultaneous open access to the grid.

The purpose of reforming is to introduce qualitative services and economical prices for the customers. Furthermore, this process comprises changes on companies corporation, privatization and dissociation (Lai, et al. 2018).

The existing market between retailers, users and distribution companies is the retail marketplace. The electricity markets has three broad categories perfect competition, oligopoly and monopoly (Prabavathi and Gnanadass, 2014).

The electricity market is a competitive market which is characterized by the limited number of power generators, power plants, transmission constraints and losses. This form of the market allow the companies to increase their profits bidding at higher prices than their marginal production cost. This is called as a strategic bidding problem (Lai, et al. 2018).

## 1.4 Power trading market

Electricity trading is determined by an activity in which transactions were transacted between different participants or indirectly via an exchange (Prabavathi and Gnanadass, 2014).

The main purpose of the market restriction is to reduce the cost in favour of the consumers. The introduction of competition between energy producers and debtors could achieve the implementation of more efficient and cheaper technologies. Different purchase models have been proposed in many countries. Generally, they can be categorized into two types, in bilateral markets and in mediation markets.

In bilateral markets, sellers and buyers trade directly. In the mediation markets, there is a mediator between buyers and sellers. The most important type of mediation market is a market for traders (Customer- Led Network Revolution, 2015).

The market participants in a competitive electricity market are the customers and suppliers. In the energy market, all competitors either generators or buyers obliges to bid for energy purchases and sales. Subsequently, the total hourly supply and demand data should be evaluated to determine the market price and the appropriate supply and demand schedules.

### 1.4.1 Market model at present

In the electricity market, the micro-grid is designed to be a price recipient. The main idea is based on the trading of the energy when we have a surplus, the micro grid will sell its power to the main network. Otherwise, in the case of deficit when the local generation is not enough to cover its local load, the micro grid will need to buy electricity from the main grid. Each day, every micro-grid has to submit its hourly bids the day before the purchase several hours before physical delivery. In the case of a micro-grid you can not follow the scheduled action for the next day, a penalty will be applied to the bid deviation. After the collection of all offer bids the market operator calculates the market price.

A significant deviation may be caused between planned power delivery and real-time power delivery due to various system uncertainties, resulting in an optimal hourly bidding strategy for the micro-grid being a difficult task (Nguyen and Le, 2014). Additionally, the pool model is one of the main market competition structures which is used in the power market. The pool is also a mediated market which also generates start-up costs, no load costs and ancillary services (Zia, et al. 2018).

In a pool market, electricity sellers and buyers submit theirs offers to a central market for buying or selling energy. The bids in a pool market are very complex and usually includes cost structure and several technical constraints. Each offer should be submitted by participants in specific time period and as much as closer to the market clearing price. Otherwise, if the offer which is submitted is too high, the process might end up without selling some energy (Bullich-Massagué, et al. 2018).

The intersection of the two curves determines the market value of the liquidation. This point is called a point of equilibrium and the market is defined as cleared (Zia,et al. 2018).

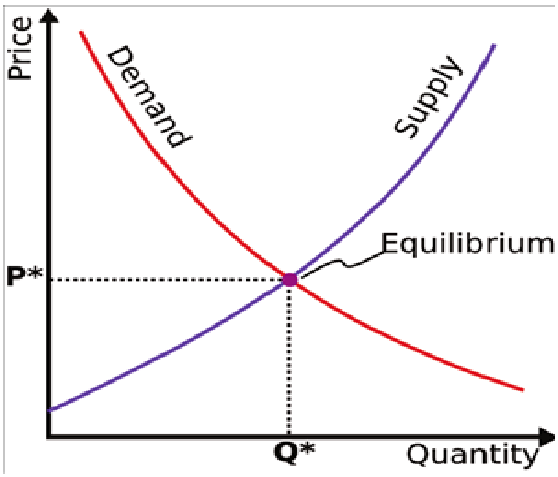



Figure.2 – The equilibrium point of micro-grid supply- demand curve.

Bidding strategies should be developed based on the market structure, auction rules and bidding protocols. A number of different strategic bidding models have been proposed by many researchers.

In general, accordance with the recent researches the suppliers seek to mark up their bids above marginal costs (Bullich-Massagué, et al. 2018).

The electricity market offers the ability the power can be traded either via exchange or bilaterally. A bilateral contract is a flexible type of market in which participants can agree to the terms and conditions of trade agreements without take under consideration the system operator. This could be achieved with the long term contracts with the traders which will include the transfer prices among them.

A challenging problem of bilateral electricity market is the bidding process . For that reason several methods have been developed to deal with this task.

### 1.4.2 Market model in future

#### 1.4.2.1 Energy Internet

The next generation of energy trade will not be entirely limited to electricity but will incorporate various energy sources. The resulting new power system is known as Energy Internet..The Energy Internet is characterized as the Internet of Energy Networks in which all forms of energy sources are integrated into an open contact form, similar to the current Internet form. In addition, a key feature of Energy Internet is expected to be a flexible energy design, two-way power flow, power conversion and routing features that are not currently available in existing smart grid systems (Abdella and Shuaib, 2018).

#### 1.4.2.2 SDN (Software Defined Networking)

Existing networking systems are currently operating with decentralized control and static configurations.

However, this future type of networking will allow centralized control and dynamic configuration of the network and its devices. This type could also achieve the functionality of the network by distinguishing the process of network promotion from the decision making process. The control level is a part of a central software control. By using this centralized control, multiple network devices can be managed from a single point and the dynamic configuration of the existing network through open application programming interfaces (Abdella and Shuaib, 2018).

#### 1.4.2.3 Blockchain

Blockchain is a growing technology that helps secure payment transactions in distributed energy trading. This technology allows the exchange, verification and storage of information in a publicly distributed manner using the communication network between users. Blockchain restricts information falsification and provides the ability to track history and user anonymization without the need for third-party trust. In addition, Blockchain allows electronic contracts between distributed energy consumers and consumers in the form of smart contracts. These features make Blockchain technology suitable for servicing the distributed distributed exchange market (Abdella and Shuaib, 2018).

## 1.5 Micro-grid Energy Trading Research

Micro-grid commercial energy trading could bring significant benefits to improving the economic viability and balance of energy supply to consumers. The energy trading already exists at macroeconomic level among international transmission operators and international system operators, this illustrates that it would be beneficial for small scale community to develop an energy trading mechanism.
The energy marketing of microsystems has two different framework of function the Peer to Peer and the Intermediary / Centralized (Zhang, et al. 2018).

The electricity generation of distributed energy systems is not stable for that reason is difficult to predict. The surplus electricity can limit it and store it with energy storage devices. Furthermore, the ‘prosumers’ could export it back to the grid or sell it to other energy consumers (Zia, et al. 2018).

The Peer-to-Peer (P2P) energy trading is the direct energy trading among consumers and ‘prosumers’. It consists a significant part of the sharing economy  using a local electricity distribution system.

Producers, consumers and customers are involved in peer-to-peer marketing. They can buy or sell energy directly between them without mediation from conventional energy suppliers. Each micro-grid will report its surplus or deficit to the group and one of the other networks will sell or lend energy to this network. As result micro-grids and each grid share a minimal amount of information remaining more independent.

Generating energy from distributed energy resources typically requires a communication infrastructure that shares information with each other and optimizes their local operation. Therefore, an efficient data communication system is required for continuous, fast, reliable and accurate information transfer between sensors without disturbances and disconnections. These data communication systems could have a high investment cost depending on the appropriate number of repeaters to achieve high-quality transmission in a geographical area. Therefore, it is vital to reduce installation costs while maintaining reliable operation by selecting the appropriate data communication technology for short and long distance applications. Effective communication between the various micro-grid components could be achieved by the use of wired and wireless communication technologies. The data rate, coverage area, service quality, reliability, delay and power consumption define the communication system  (Bullich-Massagué, et al. 2018).

Furthermore, many researchers have highlighted difficulties in power flow. Although power flow problems are generally too complex to calculate an optimal solution with the use of a centralised system of energy trading can help on coordination of voltage. For that reason, suboptimal management solutions are usually be adopted and even they might have high precision, is difficult to eliminate the losses (Gregoratti & Matamous, 2015).

Many iterative algorithms are suggested which examines energy requirements and cost until an agreement is achieved between micro-grids about the exchangeable amount of energy at the energy price.

As far as the literature conclusions are concerned, the idea that the micro-trade energy trade, if established, will be a positive thing, is generally agreed. However, there are different approaches to coming to this implementation. The collective trading it seems to be the most efficient way to start a viable energy trading. With privacy concerns and the scalability issues that exist in these peer-to-peer approaches, peer marketing is not recognized as the primary solution. However, it has been shown that after a significant number of iterations, the economic viability of peer and collective bargaining are converging (Gregoratti & Matamous, 2015).

Both the economic as well as the technical challenges of micro-grid energy trading logistically are needed to be addressed.

One suggestion might be to have a type of stock market. The micro-grids with the using of smart meters could monitor the energy prices to evaluate when to sell or buy energy. The complexity of the stock market makes it difficult to implement as they are disadvantaged. Because the real stock market has a large input from the end user and automation requires complex and costly systems it is proposed to adopt some variants.

Using predefined energy prices is the cheapest and simpler way to implement an economic energy trading model. Thus, microsystems may pay above or below the actual market value of the energy they trade.

The economical viability of micro-grids could be achieved if the pre-negotiated price covers the level of cost included generation costs, storage costs, and cost of transfer, maintenance, etc. (Luo,et al. 2014).

The field of micro-grid energy trading is a field of further research in the future years and of course there is much opportunity for improvement of all techniques.

The objectives of this thesis can now be defined. The objective of the market is to realize an optimal distribution of the power system resources in that way so each of the participants can earn the maximal profit (Lai, et al. 2018).

## 1.6 Objectives

The micro-grid energy trading which is described above, with a few exceptions which have been developed the recent years, does not exist. Therefore there is not the ability to examine in real conditions the micro-grid trading theory.

After the detailed investigation of the theoretical trading mechanisms and the basic economic viability of micro-grid energy trading there are two options to examine the micro-grid trading process the mathematical or computational modelling.

The objective of this project is determined after taking under consideration the lack of software available which could simulate the complexity of energy trading with all those degrees of freedom and excessive variability of the networks. Therefore, the objective of this project is to develop software that it can simulate and investigate the real world trading environment as possible.

The simulation of a real world scenario would be the purpose of this software. It can be simulate a single low voltage network with a group of micro grids which are able to trade.

The software will be able to explore the factors that make the trade sustainable, such as the variability of micro-grid , the number and size of micro-grids.

The investigation of policies that might affect trade such as a day-night price plan should be evaluated by the software. Furthermore, this software should be able to evaluate factors as equipment failure or renewable intermittence which can effect the energy trading.

The users of this software could also gain results related to the economic effectiveness of trading. As well as they could evaluate the energy savings or wastage both for the national grid and the micro-grid pool.

To summarise, the objectives of this project are.

- To develop a software model for a micro-grid energy trading.
- To investigate what factors could affect energy trading positively and negatively.
- To investigate in what extent each of those factor could effect the trading process.
- To identify the  specific circumstances under which it could be implemented a viable micro grid energy trading framework.
- To make conclusions about the viability of micro grid energy trading.

## 1.7 Method

The method which is used  for this project is a computational modelling. The code is for a micro-grid energy trading software package called MGET-SIM and was originally developed by Sheik Muhammed Ali in 2009 in conjunction with his paper on micro-grid energy trading (Ali, 2009).
The capabilities of the software and its operation will be described in next chapter.

MGET-SIM software is written in C and the source code will be customized and assess the possible impacts of agents on micro-grid trading. A total demand for and generation of electricity is generated on a micro-grid within 24 hours. The actual data used was originally created for the purposes of my group project "Integration of Electric Vehicles with Existing Distributed Energy Resources in Findhorn Ecovillage" at the University of Strathclyde.  The data set could be replaced by any actual data set of each micro-grid. The program creates the required number of data for the supply and demand of micro grids and simulates the electricity trade among them.

All parameters of interest could be exported to a text file, which is used for further analysis and to outline the useful conclusions. The program simulates energy trading for 24 hours based on user inputs and exports the relevant data to a text file for analysis. The success in a trading is characterized as ideal when will use as much as possible of the  energy contributed to the pool.

Therefore, the energy trading is pursuing the minimum waste of energy and the relieve of load in the national grid.

## 1.8 Scope & Assumptions

Many issues related to the marketing of micro-grid energy will not be explored during this project. All assumptions made during the simulation are all within the probability fields.

Firstly, it is assumed that the delivery network for electricity trading is the national grid. Although, the grid was not built to accept multi directional power flow, it could be adapted with various controls and protections making needless the extremely expensive choice of creation of a new power networks.

The use of the national network will ensure security of supply when a micro grid can not meet demand and facilitates the extraction of surplus energy.

The development in smart metering, cloud computing and Internet of Things allow us to assume that a smart grid can be created at device level, at micro grid level and at central control level.

The aim of this project is to define the viability of the micro grid of energy distribution from a technical and economic point of view. The privacy issues do not fall within the scope of the project. The central control will be able to synchronize the timing of all micro grid devices and data within the team contributors.

This is defined as the only way to ensure fair negotiation between micro grids at any given time. Power providers use timing synchronization as an established practice that could be technically easy to implement.

Factors such as transmission losses that will affect the results are difficult to simulate accurately.

The simulation of transmission losses due to the distance does not fall within the scope of this project.

The simulations which is undertaken in this project have as a goal to present some of the factors impact this project. This project is trying to reflect the essence of the impact that these factors will have on the sustainability of each micro-grid.

The cost of micro-grid energy trading must be less than that of importing from the national grid. It is assumed within the software that the energy trade prices, both at micro-grid and national grid level, are constant for at least 24 hours. There is a plan for different charges in day and night time despite this option the economic side of the simulation is not dynamic. This means that the energy price will be constant during bidding process among micro-grids and does not adapt to demand.

This simplification has a major advantage if the supply among the contributors is not limited, the larger microsystems could exploit the system. They could buy energy when it was cheap to store it and then when the demand was high to release it with great economic benefit. In that way, the larger micro grids will affect the viability of smaller micro grids which will can not afford this financial strategy, reducing the viability of the whole system.

Furthermore, it is not within the scope of this project to create this framework for a bidding and response process, which requires time and cost.

The software selects a randomized micro-grid based on certain criteria that we determine each time and evaluates if trade is feasible to address any gaps in the micro grid. This process is repeated until the pool is depleted or all the requirements for it are met the time step.

# Chapter Two: Software Development

In the first chapter the subject and objectives of this project were defined. Additionally, the need for software development has been identified and justified.

This chapter will explain in detail the process of changing the software code to achieve the desired results..

## 2.1 MGET-SIM Introduction

The develop of this code was based on MGET-SIM code (Ali, 2009), which had as purpose to simulate micro-grid energy trading. The software was created so that each user can examine the viability of each micro-grid depending on specific parameters . Also, the software has the ability to simulate both electricity and heat trading, however is crucial to be defined the relevant parameters which might define the result in each case.
The source code  is available for download at esru.strath.ac.uk/ along with a readme file. The software which was developed by  Sheikh Muhammad Ali allowed the investigation of the following factors (Ali, 2009):

- Effects of the number of micro-grids in a system
- Effects of variability in micro-grid sizes (capacities and demands)
- Effects of equipment failure being possible
- Effects of renewable energy intermittence
- Effects of separate price plans for peak/off-peak timings

The code and readme will be provided at the end of this paper. The program is designed to be easy to implement. Firstly, the user is asked to provide a text file called ‘Supply and Demand Findhorn’.txt which includes 48 tab-separated numbers, for the pairs of generation and demand data of an actual micro-grid. The software gives us the ability to input each parameter one by one, how the variability effects the trading ? How the size effects the trading? etc.
As soon as the software gathers all the required information, it creates the micro-grid with the corresponding attributes based on the original database provided by ‘Supply

and Demand Findhorn'.txt. The simulation then begins by recording any deficits and any surplus energy which usually added to the pool  in each micro grid. Immediately after analysing all the elements of surplus and deficits, the negotiation begins.

The program based on the proposed scenario selected a micro grid in deficit for trade which it has renewable energy resources adoption. This selection process is the best way to ensure the feasibility of trading process. The bidding process which will be defined has as purpose to assure the sustainability of the micro grid energy trading. The micro grid will be able to fulfilled his demand for the pool, in the case when the deficit can be met by the energy in the pool. In other case, if the deficit of the micro grid cannot be met, the energy must be imported from the national grid.

The energy of the pool cannot be used to meet the majority of its deficit. This is not possible for a grid to sustain the energy fairness between them.

Once all the deficits are satisfied, the pool is reset to 0 kWh and the process is repeated for the next step. After 24 time steps as defined, a text file is output to the program folder for further analysis.

## 2.2 The articulation of the Software

### 2.2.1 Demand and Supply Curve

Input data can affect the effects of simulations many times. If the bulk of the data is in surplus or the corresponding deficit, the reliability of the transaction may be affected (Li, et al. 2018). The sensitivity of the results is given and is inextricably linked to their complexity To ensure the quality of input and results, data from the group project database will be used by Strathclyde University and its data used in the industry and the academic world.

Initially, the software created random datasets by multiplying the numbers in the seed file by variables that depend on the user-selected volatility. In order to investigate the effect of diversity, the shape of each demand and supply curve in the seed records must be maintained within the software. For each micro-grid created, 24 production and demand values are generated by multiplying the seed data by a single number for maintaining the volatility of the bidding curve, adding or subtracting a percentage of this price.

### 2.2.2 Storage abilities

The fluctuation and the intermittence resulted from unstable micro grids and non-linear loads will determine the considerable significance of the storage in the function of a micro grid. Energy storage technology constitutes a solution to the above issue.

The storage is characterized as an important part of any micro grid system and would be important in each trading scenario (Tan, et al. 2013).

In collective storage, the energy storage of the pool is controlled by the centralised system and it is paid for and maintained by the contributors of the system. The storage premises could be in a location or could be a part of micro grid system. In this way, a reduction of energy wasted might be achieved at the end of each step.

In individual micro grid storage, the storage of each participant is controlled individually by him.

A private reserve of energy could be maintained leading to smaller contribution in the pool but also to smaller requirement from the pool.

Micro grids with larger capacities of storage could use this ability to exploit the market. In the case of energy deficit, a large storage owner could release this energy in the market making significant profit. However, this is a clearly business move and it is not compatible with the rules and the function of a sharing energy community like a micro-grid (Zamora and Srivastava, 2010).

This project includes the centralised storage only. The simulation cannot be influenced whether or not each micro-grid has or not a private storage. The main issue which must be defined is if a grid is a pool contributor or a pool dependant during each time step.

### 2.2.3 Demand Management importance

Already, it has been proven that electricity demand fluctuates dramatically during some short time frames. The adjustment of supply takes place with the use of a power system to increasing/decreasing the generation or adding/curtailing additional resources (e.g., renewable resources and energy storage) to meet the demand. The idea of demand side management has been emerged by two significant reasons. Firstly, due to severe climate change the reduction of dioxide emission is more urgent than ever. In this way, the use of renewable and more friendly energy resources could help us. Secondly, the additional cost and the yield system instability which is provoked by the use of standby generators, it may consist the reason for a power shortage during the peak period (Li, et al. 2018).

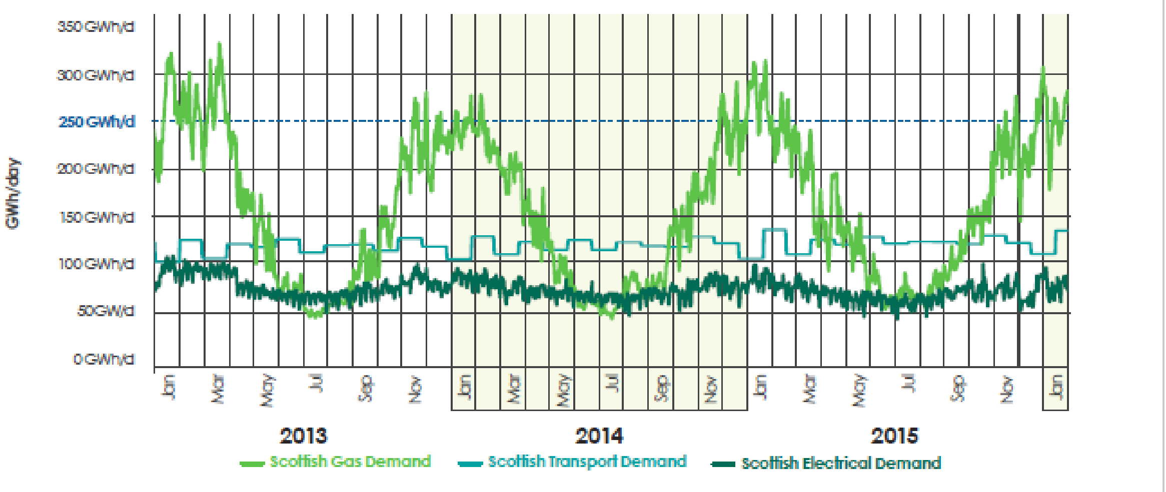



Figure.3 – Yearly pattern of Energy consumption in Scotland (Scottish Government, 2018).

This figure gives an example of the yearly electricity consumption in Scotland. Apparently, there are peak periods (i.e.,Winter) and off-peak periods (i.e., Summer). The highest consumption on the year is 100 GW/d, while the is 47 GW/d.

One of the major problems with demand-supply matching with renewable resources is the non-dispatchable nature of technologies such as wind or solar power. In the case, when the demand is high, the production for the reserve gas turbines power are activated or the output of fossil fuel power stations are increased until supply matches this demand (MacKay, 2009).

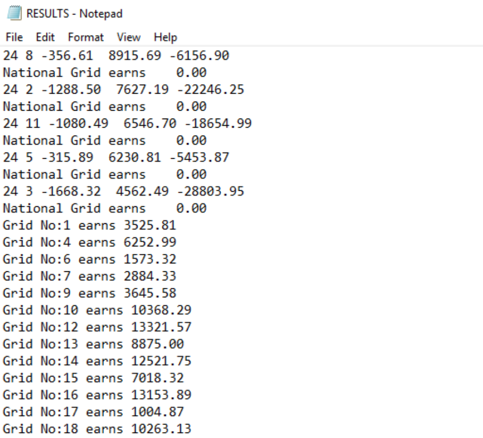
The non-dispatchable function of renewable energy, it is not permit us to correct the energy balance. If the energy demand exceeds the energy supply, the import from a foreign source, the use of storage reserves or the construction of larger capacity generators are the solutions to sustain the balance. The function framework for all these options are too expensive and the function results are likely inferior to dispatchable fossil fuel generation. Generally, the demand side management improves load profile shape, maximizes the over all infrastructure utilization and also minimizes the over all system cost with the help of controllable loads. Furthermore, the smart pricing tool helps reduce the cost for individual consumers further of its utility (Gonzalez de Durana and Barambones, 2018).

Additionally, incentives based on demand side management encourage the participation of consumers. The active consumers could cause the more efficient utilization of the existing infrastructure making the system operation more stable. The introduction of critical peak pricing and low price for off peak periods is one of the smart pricing methods which is used more.  In a micro grid trading system, the demand side management  holds a significant role in electricity market bidding strategies to improve the profit. Recent years, more and more complex communication network structures is used by demand side management to forecast load demand and its prices (Lokeshgupta, et al. 2017)

## 2.3 How MGET-SIM  Works

The software requires from the user is to supply data for a seed generation and demand data. In our case this data is supplied by Supply and Demand profile of Findhorn ecovillage in Northern Scotland.  However, a file are now required ‘Supply and Demand Findhorn’.txt.

The software requested user information and reads the input of the keyboard and allows the user to record all of his options in a file called " Results.txt ".



```
RESULTS - Notepad
File  Edit  Format  View  Help
24 8 -356.61  8915.69 -6156.90
National Grid earns    0.00
24 2 -1288.50  7627.19 -22246.25
National Grid earns    0.00
24 11 -1080.49  6546.70 -18654.99
National Grid earns    0.00
24 5 -315.89  6230.81 -5453.87
National Grid earns    0.00
24 3 -1668.32  4562.49 -28803.95
National Grid earns    0.00
Grid No:1 earns 3525.81
Grid No:4 earns 6252.99
Grid No:6 earns 1573.32
Grid No:7 earns 2884.33
Grid No:9 earns 3645.58
Grid No:10 earns 10368.29
Grid No:12 earns 13321.57
Grid No:13 earns 8875.00
Grid No:14 earns 12521.75
Grid No:15 earns 7018.32
Grid No:16 earns 13153.89
Grid No:17 earns 1004.87
Grid No:18 earns 10263.13
```

Figure.4 – Example of a results file.

The program calculates the amount of energy that is to be exported or imported according the provided generation and demand data. If a micro grid has surplus, its surplus amount is added into a common electricity pool for all micro grids . In the next step, the program selects one of the micro grids which has renewable intermittence according the proposed bidding scenario and with electricity demand. Its demand is fulfilled from the micro grids surplus electricity pool. In the case, when the pool can not satisfy the amount of demand, then it will be met from the national grid public electricity supply.

Information about  the amount of energy trading carried out per hour, the amount of energy which left in the pool at the end of trading, the amount of energy demand satisfied by the pool and the costs  are now available.

## 2.4 Decisive measures

The success of the software function must be examined on a technical energy and economic basis. The software outputs are used to measure the success of micro-grid energy trading simulation.

### 2.4.1 Measures for Success

#### 2.4.1.1 Derived from Literature

The success factors ,which are necessary, for the existence of a fully functional and commercially viable micro-grid are described by a significant part of researchers. These success factors can be summarized as:

- Stable, reliable, and cost-effective power sources like CHP,  hydro power, wind local primary energy, should be a part of the micro-grid. Especially, in the case when there is a need for stable  to supply stable energy during times of outage this type of power sources are crucial.
- Larger capacity allow micro-grids to meet power demands and maintain power quality more effectively in island mode.
- The use of storage devices could maximize peak shaving and facilitate the transition between grid-connected and island mode.
- Effective energy quality and energy management systems that aim at optimizing consumption and maintaining the quality of electricity during island operation.
- A supportive regulatory and market framework is critical in order to allow micro-grid power back into the grid facilitating trading with the main network and between participants.

- Stakeholder involvement in decision-making to develop trust and cohesiveness among consumers and other stakeholders. This relationship is very important if the micro-grid is to be connected to the grid.
- Micro-grid operator training to maintain the normal operation of micro-grids, and particularly during unforeseen events, like faults and natural disasters (Lokeshgupta, et al. 2017).

#### 2.4.1.2 Derived from Simulations

Energy wasted

Energy wasted of the pool (%) = (Energy available on the pool/ Energy added to the pool) x 100%

This equation could measure what factors increase the amount of energy which is consumed by the micro-grids with deficit. The smaller the energy consumption of micro-grids, the more revenue is for all the parties involved. .The waste of every kind of energy is a problem in the energy market. In addition, energy produced by environmentally damaging methods such as fossil fuels and rare fossil fuels should not be wasted.

Total import from the grid

Energy import from the national grid(%) = (Total import from the national grid/ Total Energy Consumed) x 100%.

The basic idea of the micro-grids is to manage a part of the ever increasing energy demand in the existing networks. This solution has so far been presented as more economical, since it does not require a huge amount of money to be invested in the construction of new power plants. Moreover, the ability to implement in remote areas with renewable energy sources or not these systems is viable and should therefore be studied further.

## 2.5 Validation of the software

The software validation is necessary to check if the simulation program is suitable for the aim designed. The purpose of the program is to explore the effects of the proposed bidding scenario in the energy trading. As the new bidding scenario has been adopted by the existing code, the software is necessary to be validated to could be trusted for simulating electricity trading.

The analytical approach is chosen to validate the purpose of the software. The small number of similar software on the market makes the comparison between them quite difficult. In addition, the results of the software, although based on actual supply and demand figures, are difficult to compare because there is no existing similar energy trading test. The codification will be simplified and checked with the analytical approach to see if it is controlling its purpose.

Simplification of the software that produces a series of numbers at each stage is required.

The main idea that should be ratified is that instead of randomly choosing the software is modified to first select micro-grids with renewable energy resources adoption, which have an energy deficit.

### 2.5.1 Simple simulation validation

Initially, a simple simulation model is defined to see if the simulation calculations match the results of our calculations. The demand and supply profiles used are from Findhorn ecovillage a profile with different generation types as CHP, storage batteries, wind turbines and solar panels, These profiles and their sources will be examined in detail in the next chapter. The cost of micro-grid energy trade is 9p/kWh, and the cost of national grid energy is 12p/kWh with no day-night price plan.

| Time | Microgrid 1 | | |
|---|---|---|---|
| Hour | AC Load (kW) | AC required(kW) | Deficit/Surplus (kW) |
| 1 | 180.2852 | 163.2231 | 17.0621 |
| 2 | 148.4388 | 168.4840 | -20.0452 |
| 3 | 160.8955 | 158.3092 | 2.5863 |
| 4 | 133.1077 | 146.7754 | -13.6677 |
| 5 | 121.3159 | 133.9435 | -12.6276 |
| 6 | 124.5802 | 137.5758 | -12.9956 |
| 7 | 134.6577 | 148.6109 | -13.9532 |
| 8 | 124.6979 | 137.9715 | -13.2736 |
| 9 | 150.4052 | 144.2394 | 6.1658 |
| 10 | 151.1669 | 166.9892 | -15.8223 |
| 11 | 184.7813 | 207.4341 | -22.6528 |
| 12 | 160.4581 | 177.0663 | -16.6082 |
| 13 | 162.4719 | 179.1940 | -16.7221 |
| 14 | 177.1189 | 195.5760 | -18.4571 |
| 15 | 183.3263 | 169.2349 | 14.0914 |
| 16 | 198.5980 | 192.5082 | 6.0898 |
| 17 | 171.7441 | 201.9287 | -30.1846 |
| 18 | 212.3044 | 245.2712 | -32.9668 |
| 19 | 214.2085 | 203.9126 | 10.2959 |
| 20 | 165.6505 | 194.1830 | -28.5325 |
| 21 | 149.9604 | 187.3587 | -37.3983 |
| 22 | 157.6427 | 186.5882 | -28.9455 |
| 23 | 152.1420 | 168.9643 | -16.8223 |
| 24 | 140.9664 | 137.1600 | 3.8064 |

Table.1 – Simple validation hourly generation/demand values of Findhorn ecovillage

To complete the test, the pool size should be identified per hour in both cases, as shown below in Table 2.

| Time | Microgrid 1 | | |
|---|---|---|---|
| Hour | Pool size (kW) | Software pool size (kWh) | Differences (kWh) |
| 1 | 17.06 | 17.01 | 0.0489 |
| 2 | -20.05 | -21.03 | 0.9848 |
| 3 | 2.59 | 2.59 | -0.0011 |
| 4 | -13.67 | -13.67 | 0.0066 |
| 5 | -12.63 | -12.63 | 0.0045 |
| 6 | -13.00 | -13.00 | 0.0000 |
| 7 | -13.95 | -13.95 | 0.0000 |
| 8 | -13.27 | -13.27 | -0.0004 |
| 9 | 6.17 | 6.17 | -0.0085 |
| 10 | -15.82 | -15.83 | 0.0098 |
| 11 | -22.65 | -22.67 | 0.0215 |
| 12 | -16.61 | -16.61 | 0.0000 |
| 13 | -16.72 | -16.72 | 0.0000 |
| 14 | -18.46 | -18.46 | 0.0005 |
| 15 | 14.09 | 14.10 | -0.0099 |
| 16 | 6.09 | 6.09 | -0.0001 |
| 17 | -30.18 | -30.19 | 0.0086 |
| 18 | -32.97 | -32.97 | 0.0000 |
| 19 | 10.30 | 10.30 | 0.0000 |
| 20 | -28.53 | -28.53 | 0.0000 |
| 21 | -37.40 | -37.40 | 0.0000 |
| 22 | -28.95 | -28.95 | 0.0000 |
| 23 | -16.82 | -16.82 | 0.0011 |
| 24 | 3.81 | 3.81 | -0.0036 |

Table.2 – Simple validation of pool size

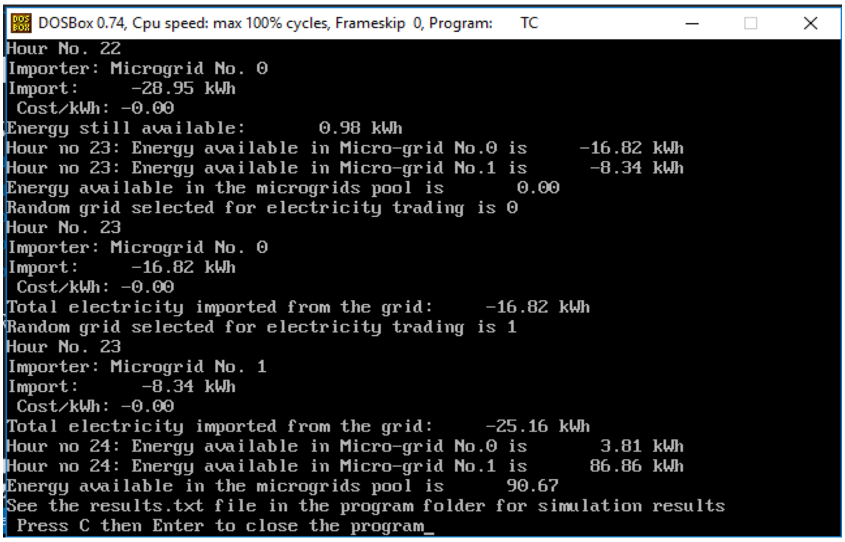



Figure.5 – Simple software validation

The simple function of calculating the size of the pool is proven to be correct as a match with a small deviation of the results is identified each hour of operation. For the purpose of validation, the procedure is checked in detail at 1 and 2 hours. The validation process will accept the selection of the software grid and check the results of the trade.

At hour 1, Micro-grid  adds 17.02 kWh to the pool. At hour 2, we have a -20.04kWh deficit. At hour 3  we have  a 3.58 kWh surplus. The first grid selected for trading is micro-grid 1. The -20.04 kWh deficit is satisfied by the 20.60 kWh pool, leaving 0.56 kWh leftover in the pool. The cost of this trade is: 9 p/kWh x 20.04 kWh= 180.36 p.

The next hour 4, the energy deficit 13.67kWh deficit cannot be met by remaining energy in the pool so a national grid import will be necessary. Import costs are calculated as:

12 p/kWh x 13.11 kWh = 157.32 p.

The national grid earns all of this amount. Now that trading is complete, it is known that 20.04 kWh

is used at 100%,therefore micro-grid earns: 100% x 20.04kWh x 9p/kWh = 180.36 p.

As can be seen from the software screenshot of result file below in figure 6, the simulator has calculated this outcome correctly also.

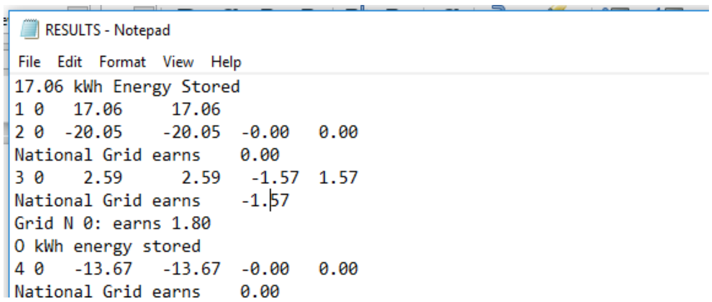

RESULTS - Notepad
File Edit Format View Help
```
17.06 kWh Energy Stored
1 0    17.06      17.06
2 0   -20.05     -20.05  -0.00   0.00
National Grid earns     0.00
3 0     2.59       2.59   -1.57  1.57
National Grid earns     -1.57
Grid N 0: earns 1.80
0 kWh energy stored
4 0    -13.67    -13.67  -0.00   0.00
National Grid earns     0.00
```

Figure.6 – Simply case validation outcomes

### 2.5.2 Extreme Case Validation

In addition, the functionality of the software could be evaluated by simulating specific scenarios. In this validation, the following could be investigated.

a) The case where the trade is expected to be unviable, when the majority of the micro-grids are in deficit.

b) The case where the trade is expected to be viable, when the majority of the micro-grids are in surplus.

#### Case A

First in case a, the Supply and Demand Findhorn.txt to be analysed including the majority of micro-grids with deficit. Thirty medium-volatility small networks will be created. The case will be dealt with renewable intermittence and equipment failures, without taking into account a different day and night tariff, as well as demand management. The prices of 12 pence / kWh for the national energy efficiency of the grid and 9 pence / kWh for the energy of the micro-grid remain constant.

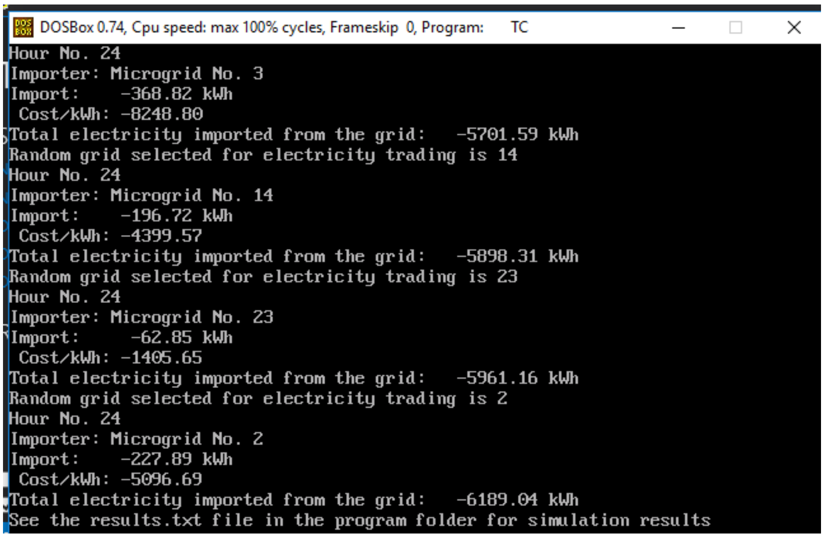



Figure.7 – Extreme case software validation

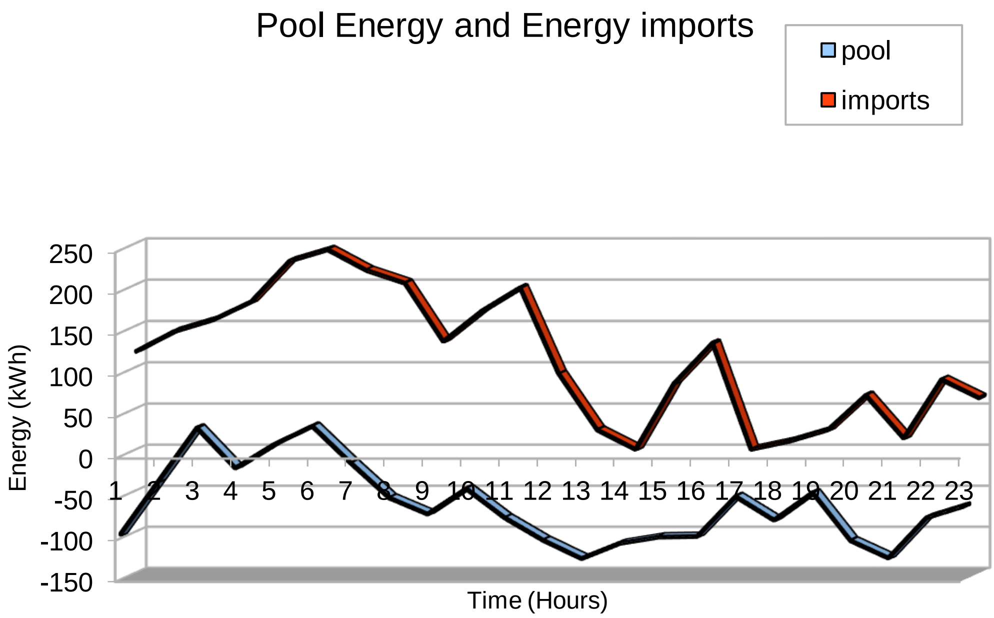



Figure.8 – Comparison of pool energy available and energy imports

According to the input data as shown in figure 8 for micro-grid 23 the simulation proves unsustainable. The size of the pool is always less than the amount of energy required. As a result, imports to the electricity grid remain at a high level. Total demand plays a crucial role in the pool configuration. However, as expected, when the available energy in the pool is satisfactory, national grid imports is eliminated.

<u>Case B</u>

Secondly in case b, the Supply and Demand Findhorn.txt  to be analysed including the majority of micro-grids with surplus. Thirty medium-volatility small networks will be created. The case will be dealt with renewable intermittence and equipment failures, without taking into account a different day and night tariff, as well as demand management. The prices of 12 pence / kWh for the national energy efficiency of the grid and 9 pence / kWh for the energy of the micro-grid remain constant.

RESULTS - Notepad

File Edit Format View Help

```
24 8  155.36    381.22
24 9 -134.60
24 10   46.52    427.73
24 11   -2.62
24 12  -47.49
24 13   20.93    448.66
24 14   44.70    493.36
24 15   39.80    -0.91
24 16   94.69    588.06
24 17  157.82    745.88
24 18 -134.97
24 19  160.54    906.42
24 20 -205.90
24 21  188.90   1095.33
24 22   97.57   1192.90
24 23  -19.07
24 24   90.95   1283.85
24 25   76.91   1360.75
24 26  -81.88
24 27  130.47   1491.23
24 28   55.65   1546.87
24 29    5.28   1552.15
24 30   -4.33 24 6  -44.07  1508.08 -544.96
National Grid earns    0.00
```

Figure.9 – Extreme case validation outcomes

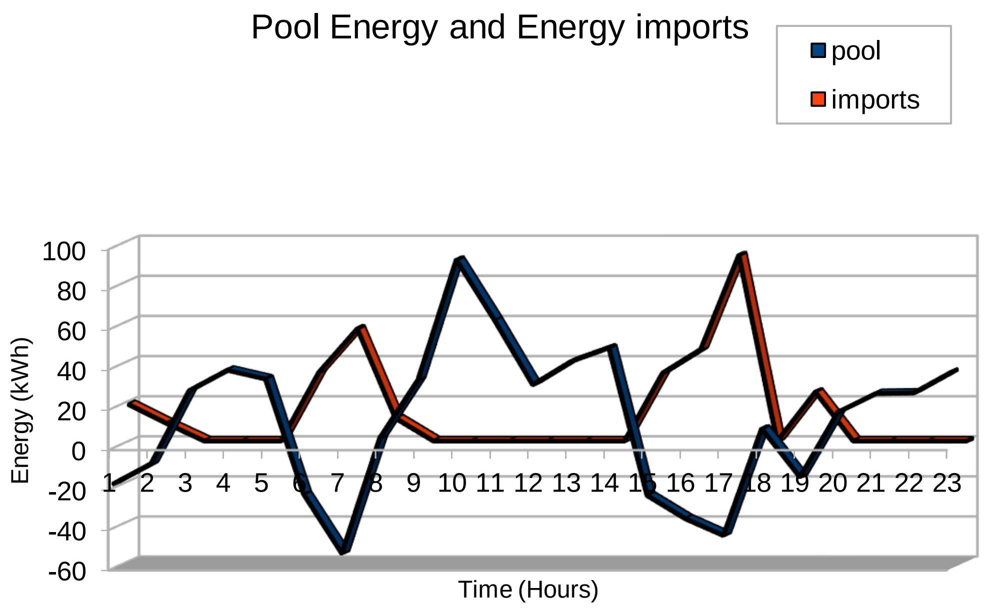



Figure.10 – Comparison of pool energy available and energy imports

Once again, the validity of the software for the micro-grid 23 is confirmed by figure 10. A significant amount of energy was produced by the 30 micro-grids, therefore is depicted the need for the national grid to import energy only at the peak hours. An amount of energy in the pool is wasted with the stored energy that was never used.

### 2.5.3 Comparison of results between MGET-SIM and new configuration of MGET-SIM

The final validation of the data will be accomplished by comparing the results of the initial MGET-SIM, available on the university page, with the algorithm that has undergone changes. The final case proposed by Sheik Muhammed Ali ,which created the program, he characterized as the ideal circumstance for micro-grid trading. This final case scenario will be simulated again and investigate any differences between the results.

| Input | Final Case |
|---|---|
| Number of microgrids | 101 |
| Variability | High |
| Equipment failure | Yes |
| Renewable Intermittence | Yes |
| Peak/Off Peak Rates | No |
| National grid imports | 10 |
| Microgrid trade price | 7 |

Table.3 – 'Final Case' (Ali, 2009) for comparison

The data in Supply and Demand Findhorn.txt is the same as in the previous sections for the purpose of this validation.

| | MGET-SIM Initial | MGET-SIM New |
|---|---|---|
| Microgrid imports | 41% | 45.46% |
| Energy wasted | 51.16% | 53.33% |

Table.4 – Comparison of results

The results did not show complete identification. In the case of national grid entry, results can be considered to be within the error limits. In addition, variations in inputs of the micro-networks play a role in modulating the results, and since MGET-SIM seed data is not available on the Internet, it is impossible to reproduce accurately.

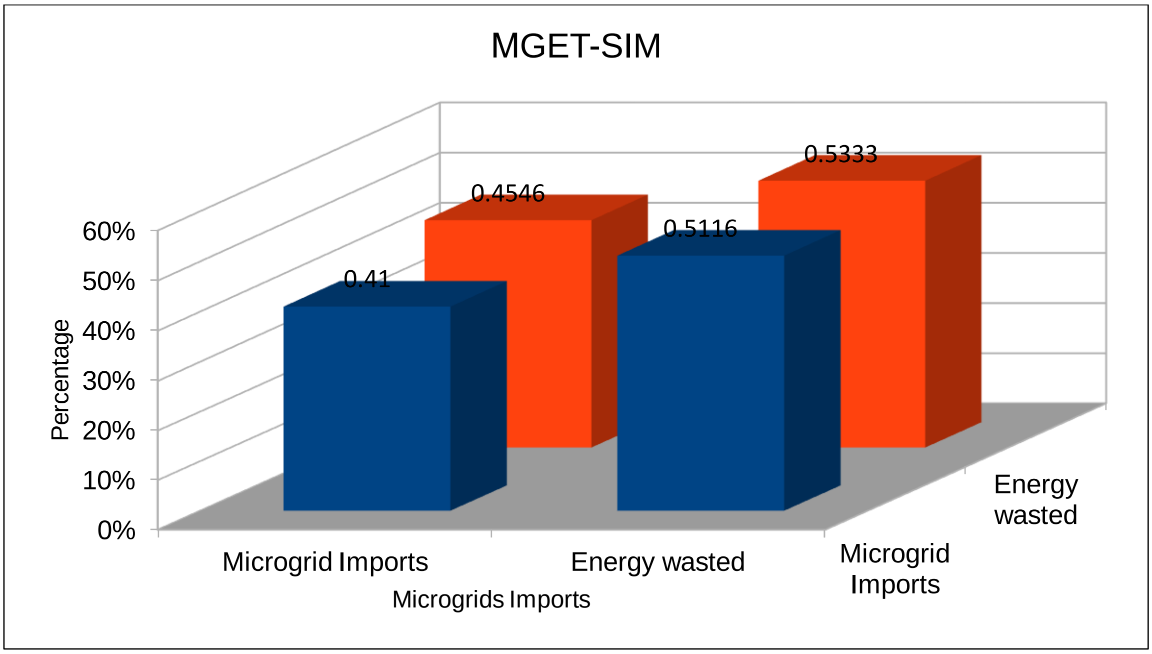



Figure.11 – Comparison of validation results

Despite the variation in the results of MGET-SIM, the validity of the changes can be confirmed. The above differences may be due either to the unavailable seed data or to changes in the code. Significant changes in functionality when creating virtual grids and additional features may make the findings of the research that has been carried out no longer taken as a rule. The investigation of all factors available to the user during the simulations is the subject of this project.

# Chapter Three: Micro-grid Energy Trade Investigation

In the first chapter the objectives of the project have been defined, while examining the conditions in the field of micro grid energy. Subsequently, in the second chapter has been described and developed the software. In this chapter we will examine and analyse the simulations performed during the project. The results will be analysed in detail in each simulation. However, the general conclusions of the project will be made in the fourth chapter.

For these simulations, the national electricity price in the grid is set at 12p / kWh, which is around the electricity price in the United Kingdom according to the 2018 National Grid Report (2018).

The value of micro-grids network energy for these simulations is more difficult to determine, as there is no real trade in energy micro-grids. The price should be lower than the national network import price but higher than the national pricing of the network. For this project, the micro-grids energy value is set at 9 p / kWh.

The software has six different variables that can be inputted into the programme. The new software has been developed to choose in the bidding process first the micro-grids which could be affected by non-dispachable energy resources. Energy prices, the profiles for the input files, day-night pricing, and equipment failure at the start can set to anything the user likes.

The simulation of these variables can result in a variety of combinations. However, this reference is not feasible to explore one by one these combinations, the majority of which may have marginal differences between them.

After investigating the effects of each factor on the trade, the most realistic case will be simulated and the findings will be presented.

The purpose of this project was not just to simulate the electricity trade between microcells, but also to identify their potential impact on micro-grid energy trading and the possible benefits of creating such a system.

## 3.1 Number of Microgrids

The impact of the number of micro-grids will have a major impact on the sustainability of micro-grid energy trade. If trading is viable with only a few available micro-grids, it could develop in the near future. The implementation could help in the further evolution of the distributed and embedded generation. However, in a different case if trade is viable only with many micro-grids then its adoption should be judged further. Since the ability of micro-grid to produce can reach a certain point.

| Variable | Case 1 | Case 2 | Case 3 |
|---|---|---|---|
| Number of microgrids | 20 | 60 | 100 |
| Variability | High | High | High |
| Equipment failure | No | No | No |
| Renewable intermittence | No | No | No |
| Peak/Off peak rates | No | No | No |
| National network electricity price (pence/kWh) | 12 | 12 | 12 |
| Microgrids electricity price (pence/kWh) | 9 | 9 | 9 |

Table.5 – Software set up to investigate the effect of number of micro-grids

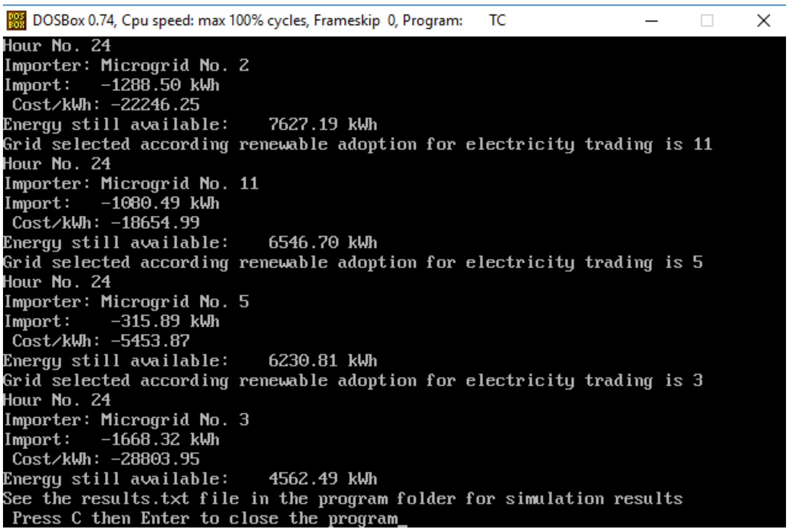



Figure.12 – Software frame from Case 1

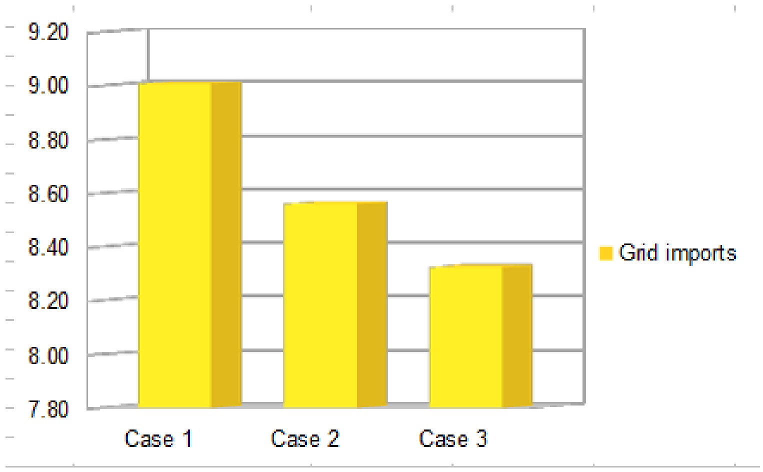



Figure. 13 – Effect of number of micro-grids on grid imports


Figure. 14 – Effect of number of micro-grids on energy wasted

As illustrated in figures 13 and 14, trading conditions improve with more micro-grids. In each step of time, as the number of microsystems increases, the waste of energy is reduced, as other micro-grids need energy.

As the number of microsystems contributing to the system increases, the load of the national network decreases. It is also interesting to note the economic aspect of the adoption of more microsystems on the market. The probability of increasing the profits of trading as the number of micro-grids increases is to be explored. In the case of more micro-grids that need energy, less energy is wasted at the end of every step of the time.

Among the cases of 20 to 80 micro-grids there is a significant 15.34% decrease in energy loss between 20 and 80 micro-grids. Furthermore, it is clearly depicted a decrease in grid imports among those cases. More precisely, a decrease of 0.69% is spotted among the case 1 of 20 micro-grids and case 3 of 80 micro-grids.

An immediate improvement occurs even in the case of negotiation between 80 micrograms in all measures. It is therefore necessary to further explore the viability of the application of these trading systems in the near future.

## 3.2 Variability

The size variability is expected to have a significant impact on both the energy wasted and the imports from the network.

| Variable | Case 1 | Case 2 | Case 3 |
|---|---|---|---|
| Number of microgrids | 20 | 20 | 20 |
| Variability | Low | Medium | High |
| Equipment failure | No | No | No |
| Renewable intermittence | No | No | No |
| Peak/Off peak rates | No | No | No |
| National network electricity price (pence/kWh) | 12 | 12 | 12 |
| Microgrids electricity price (pence/kWh) | 9 | 9 | 9 |

Table. 6 – Software set up to investigate the effect of variability of micro-grids

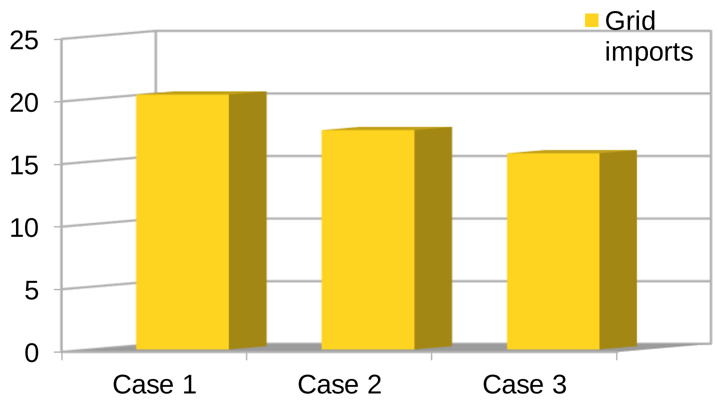



Figure. 15 – Effect of variability of micro-grids on grid imports

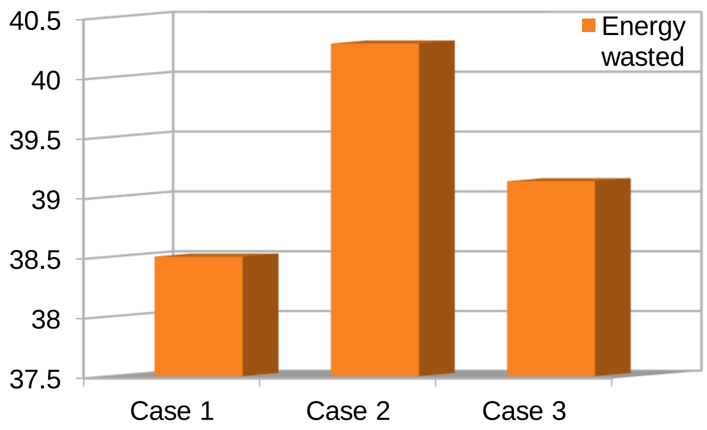



Figure. 16 – Effect of variability of micro-grids on energy wasted

The results of the simulation illustrate the impact of greater variation of sizes of micro-grids in the grid imports and in the energy wasted. A drop of 5% across the simulation cases is depicted in grid imports. The reduction of grid imports consists one of the primary objectives of the micro-grid generation concept. As larger grid is simulated, larger surpluses are fed into the pool this has as result more energy is wasted than with low variability. According our simulation a decrease of 2% is depicted in energy wasted among cases of low and medium variability, verifying the above. The new bidding process that gives priority to renewable users has influenced the simulation results in relation to previous surveys.

## 3.3 Equipment Failure

Equipment failure is expected to increase demand on the pool and national grid. The effects of this demand are investigated further.

| **Variable** | **Case 1** | **Case 2** |
|---|---|---|
| Number of microgrids | 50 | 50 |
| Variability | Medium | Medium |
| Equipment failure | Yes | No |
| Renewable intermittence | No | No |
| Peak/Off peak rates | No | No |
| National network electricity price (pence/kWh) | 12 | 12 |
| Microgrids electricity price (pence/kWh) | 9 | 9 |

Table. 7 – Software set up to investigate the effect of equipment failure of micro-grids

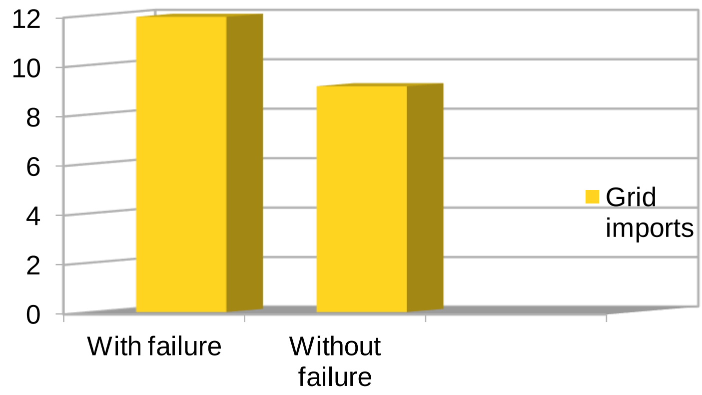



Figure. 17 – Effect of equipment failure of micro-grids on grid imports

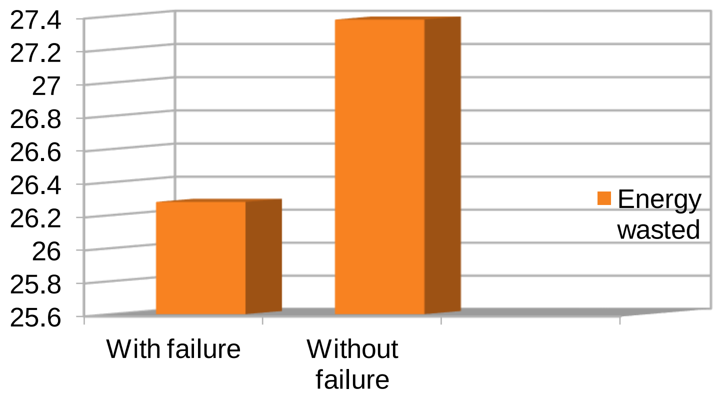



Figure. 18 – Effect of equipment failure of micro-grids on energy wasted

In the case of equipment failure, all the required energy for micro-grids should be met by the national grid or the pool. In that case, as expected the demand on the pool depicts an increase of 8%.

Moreover, according to simulation the national grid import actually remains relatively stable. As more energy used in the pool we have spotted less wasted at the end of each time step. This meaning that the trading framework which has been developed provides safety from equipment failure for each micro-grid.

## 3.4 Renewable Intermittence

This simulation investigates the effects of renewable unreliability during generation.

| **Variable** | **Case 1** | **Case 2** |
|---|---|---|
| Number of microgrids | 50 | 50 |
| Variability | Medium | Medium |
| Equipment failure | No | No |
| Renewable intermittence | Yes | No |
| Peak/Off peak rates | No | No |
| National network electricity price (pence/kWh) | 12 | 12 |
| Microgrids electricity price (pence/kWh) | 9 | 9 |

Table. 8 – Software set up to investigate the effect of renewable intermittence of micro-grids

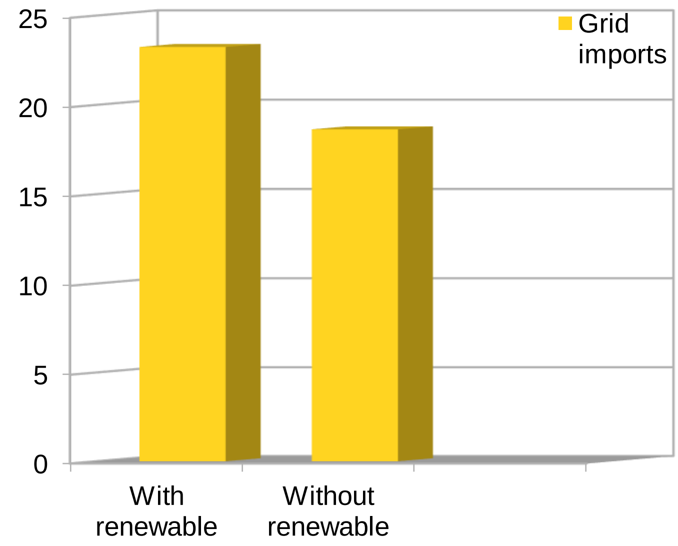



Figure. 19 – Effect of renewable intermittence of micro-grids on grid imports

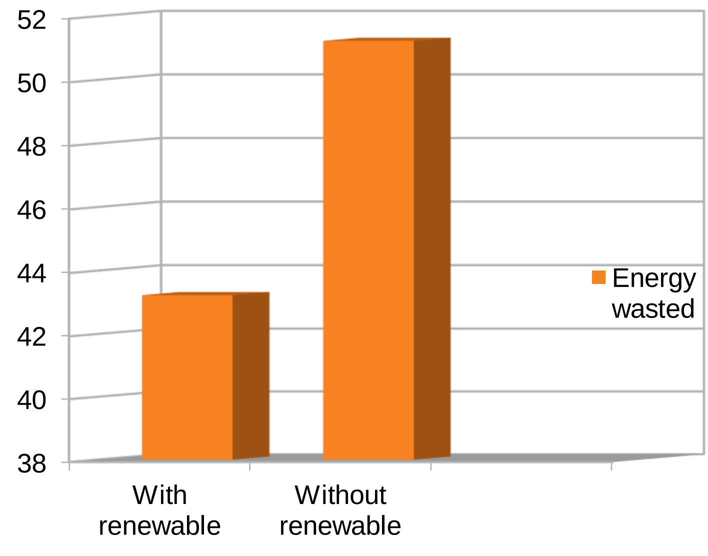


Figure. 20 – Effect of renewable intermittence of micro-grids on energy wasted

It can be seen a sharply fluctuation  on the network demand and the national network due to this scenario. The amount of the energy wasted is decreased by 9%  among the case with renewable intermittence and without renewable intermittence.

The effect of renewable intermittence is displayed to have the same behaviour with equipment failure but it seems to have greater impact. The likelihood and the prospect frequency of this case is significantly greater the totally equipment failure. So the impacts on the results  are more noticeable. Where the renewable intermittence is considered, a 5% increase in the national network import is shown. This is due to the fact that the tank has less energy to contribute generally and therefore less equipped to meet the requirements of inadequate micro-grids.

As the deficit is increased less energy is wasted from the pool. The renewable intermittency affects the micro-grid in a similar way to in the case of equipment failure.

## 3.5 Peak/Off-Peak Price Plans

The peak/off-peak price plans is implemented by government allowed the household to consume cheaper electricity in the early hours of demand when the national energy demand is low. Such plans on micro-grid energy trading could be significant in the energy micro-grid trading In the UK, the price plan consists of a 50% price reduction per kWh from the hours of 12am until 6am.

| **Variable** | **Case 1** | **Case 2** |
|---|---|---|
| Number of microgrids | 20 | 20 |
| Variability | Medium | Medium |
| Equipment failure | No | No |
| Renewable intermittence | No | No |
| Peak/Off peak rates | Yes | No |
| National network electricity price (pence/kWh) | 12 | 12 |
| Microgrids electricity price (pence/kWh) | 9 | 9 |

Table. 9 – Software set up to investigate the effect of peak/ off-peak plans of micro-grids

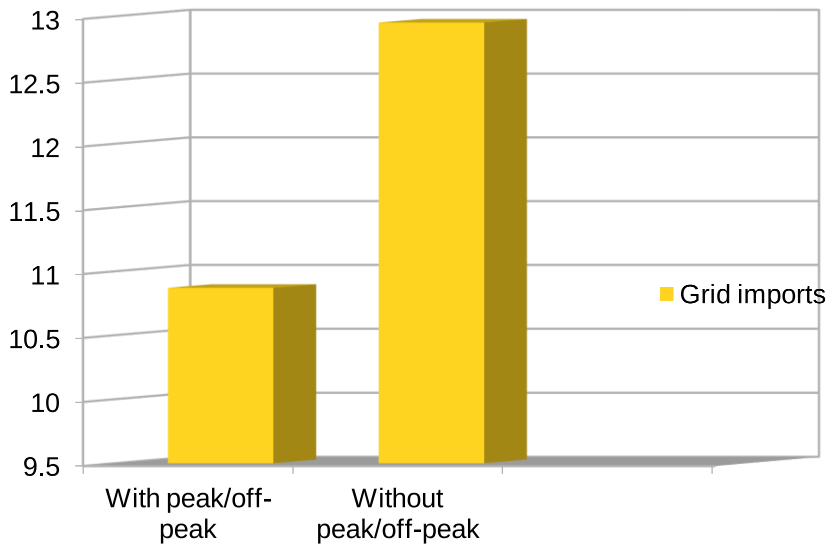



Figure. 21 – Effect of peak/off-peak plans of micro-grids on grids imports

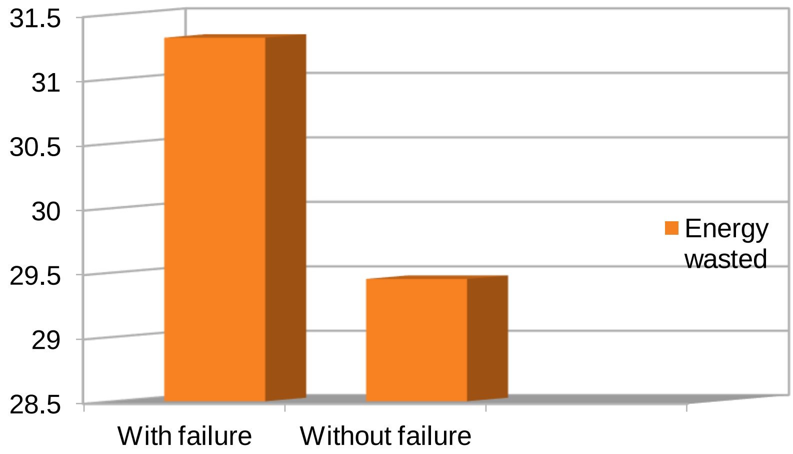



Figure. 22 – Effect of peak/off-peak plans of micro-grids on energy wasted

The introduction of the day night price plan reduces the grid imports and increase the energy wasted as expected. Therefore, according the figure the adoption of day night price plan could make micro-grid energy production more affordable. Each pool member would maintain their own storage and will be able to buy cheap electricity during the price plan times avoiding at the same time charges of peak demand.

## 3.6 Financial effects in Micro-grid in each parameters

The economic viability of the micro-grids constitutes the basis of the trade between them. It is clear that the economic impact that will be caused by the comparative parametrizations will determine the viability of the whole project of energy trading process.

According J A Clarke et Ali Monetary loss (Ml) is a parameter which is related only to the seed micro-grid and could define the difference between the amount paid for energy imports from the grid (if the micro-grid operated alone) and the amount paid within the trading scheme for pool imports giving a clear view of economic viability of trading process.

$$Ml = 1 - \left(\frac{ig - it}{ig}\right)$$

where ig the income generated when the micro-grid imports only from the national grid

it the income generated when the micro-grid trade with other micro-grids.

It should be noted that a negative MI could indicate an income for the micro-grid after paying for all imports.

3.6.1 Number of micro-grids

The effect on micro-grid earnings in different size of micro-grids in the energy trading will be investigated further.

| **Variable** | **Case 1** | **Case 2** | **Case 3** |
|---|---|---|---|
| Number of microgrids | 20 | 60 | 100 |
| Variability | High | High | High |
| Equipment failure | No | No | No |
| Renewable intermittence | No | No | No |
| Peak/Off peak rates | No | No | No |
| National network electricity price (pence/kWh) | 12 | 12 | 12 |
| Microgrids electricity price (pence/kWh) | 9 | 9 | 9 |

Table.10 – Software set up to investigate the monetary losses of micro-grids

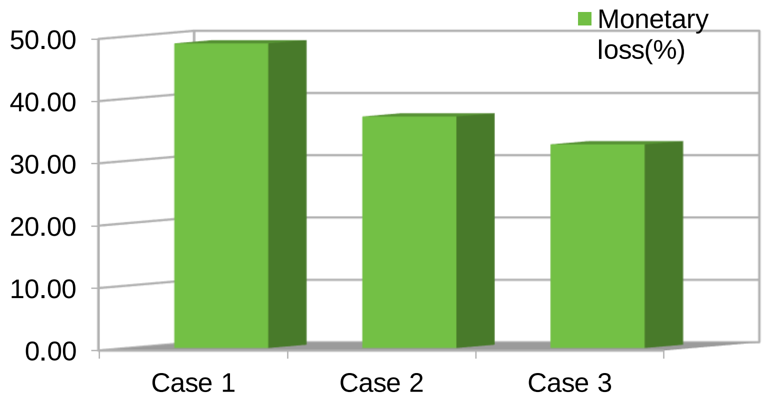



Figure.23 – Monetary losses due to different number of micro- grids

As clearly illustrated, the monetary loss of the microarray decreases sharply as the number of microbes increases. As a result, the financial viability of transactions is closely related to their size. The future implementation of these type of energy trading could be determined by their size. As a result, the creation of minimum size standards could help to achieve their economic viability.

### 3.6.2 Variability

The size variability is expected to have a significant impact on grid earnings and should be investigated further.

| Variable | Case 1 | Case 2 | Case 3 |
|---|---|---|---|
| Number of microgrids | 50 | 50 | 50 |
| Variability | Low | Medium | High |
| Equipment failure | No | No | No |
| Renewable intermittence | No | No | No |
| Peak/Off peak rates | No | No | No |
| National network electricity price (pence/kWh) | 12 | 12 | 12 |
| Microgrids electricity price (pence/kWh) | 9 | 9 | 9 |

Table.11 – Software set up to investigate the monetary losses of micro-grids

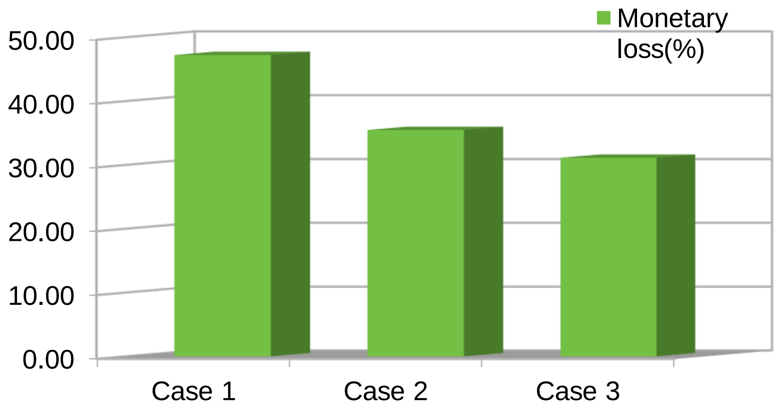



Figure. 24 – Monetary losses due to different variability of micro- grids

In high variability, which includes larger micro-grids available for trading, the earnings are depicted to be less than the medium variability case . In the case of low variability where smaller micro-grids occurs the trading the monetary losses are smaller. As larger  is a micro-grid, the more likely it contributes  larger share of the pool. Therefore,  a large capacity micro-grid available for trading could benefit in economic terms the trading.

### 3.6.3 Equipment Failure

The failure of equipment is expected to effect immediately the monetary losses of microgrids trading. A further investigation was realised.

| Variable | Case 1 | Case 2 |
|---|---|---|
| Number of microgrids | 50 | 50 |
| Variability | Medium | Medium |
| Equipment failure | Yes | No |
| Renewable intermittence | No | No |
| Peak/Off peak rates | No | No |
| National network electricity price (pence/kWh) | 12 | 12 |
| Microgrids electricity price (pence/kWh) | 9 | 9 |

Table.12 – Software set up to investigate the monetary losses of micro-grids

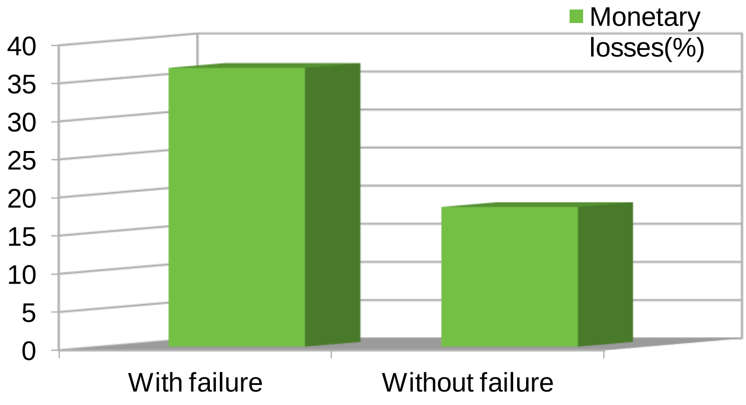



Figure. 25 – Monetary losses due to equipment failure of micro- grids

It is depicted that the economic loss of the grid in the case of consideration failure factor increased. This difference could be explained by the failure of the micro-grid to adjust in the new condition of the shared pool, when some of the micro-grids are not available. Furthermore, the continued increased demand for electricity has the effect of providing less power to the grid by increasing economic losses.

### 3.6.4 Renewable intermittence

The effect of renewable intermittence on micro-grid earnings in the energy trading will be investigated further.

| Variable | Case 1 | Case 2 |
|---|---|---|
| Number of microgrids | 50 | 50 |
| Variability | Medium | Medium |
| Equipment failure | No | No |
| Renewable intermittence | Yes | No |
| Peak/Off peak rates | No | No |
| National network electricity price (pence/kWh) | 12 | 12 |
| Microgrids electricity price (pence/kWh) | 9 | 9 |

Table.13 – Software set up to investigate the monetary losses of micro-grids

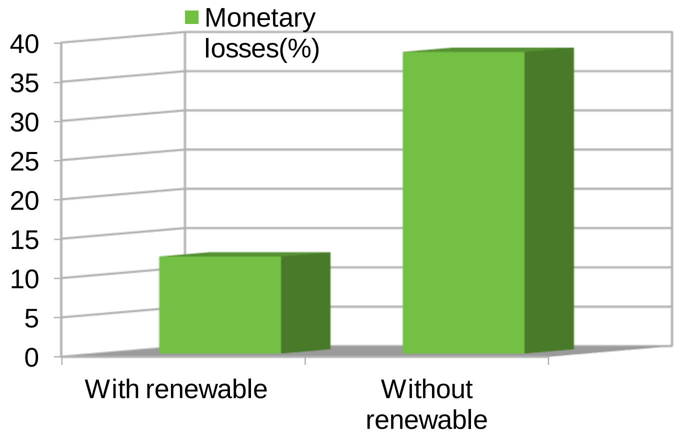



Figure. 26 – Monetary losses due to renewable intermittence of micro- grids

The renewable intermittence factor affects the micro-grid trading in economic aspect. A sharply decrease is depicted by the figure when the factor is taken under consideration. The type of this microgrid might help to increase shared electricity in the micro-grids electricity pool.

3.6.5 Peak/off-peak rates

The effect of such scheme on microgrid energy trading could be significant. For that reason, it will be investigated further.

| Variable | Case 1 | Case 2 |
|---|---|---|
| Number of microgrids | 50 | 50 |
| Variability | Medium | Medium |
| Equipment failure | No | No |
| Renewable intermittence | No | No |
| Peak/Off peak rates | Yes | No |
| National network electricity price (pence/kWh) | 12 | 12 |
| Microgrids electricity price (pence/kWh) | 9 | 9 |

Table.14 – Software set up to investigate the monetary losses of micro-grids

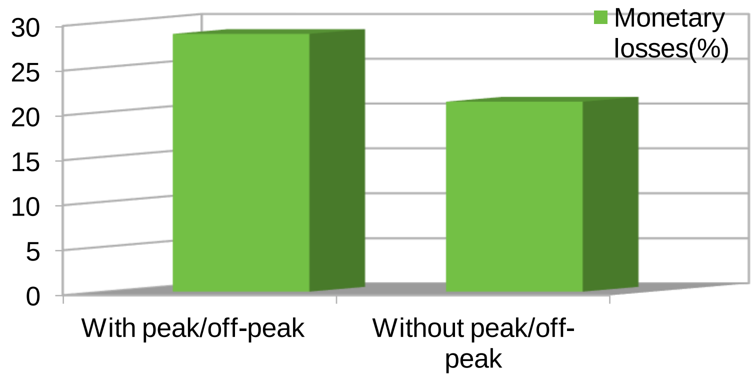



Figure. 27 – Monetary losses due to peak/off-peak plans of micro- grids

The scheme which is implemented in the UK concerns the hour between 12am to 6pm. Those hours are not characterized as rush hours especially in the weekdays. The energy surplus detected at specific times when demand is reduced makes available pool energy cheaper. Electricity sold through the pool at lower prices than normal. For this reason, this sharply reduction is shown according to the chart.

3.6.6 Final Case

After the careful examination of each factor and the economical effect of each of them in the micro-grid energy trading. We are now able to understand the effects of each one creating a realistic case to simulate the trading conditions. The complexity and the high variability of some factors makes the creation of a realistic case a difficult issue. However, based on simulations a final case which assure the economical viability of the trading, were formed.

| **Variable** | **Final Case** |
|---|---|
| Number of microgrids | 150 |
| Variability | High |
| Equipment failure | No |
| Renewable intermittence | Yes |
| Peak/Off peak rates | No |
| National network electricity price (pence/kWh) | 12 |
| Microgrids electricity price (pence/kWh) | 9 |

Table.15 – Software set up of the final case

| Best Case | | | |
|---|---|---|---|
| | Energy wasted | Energy imports | Monetary losses |
| Microgrid size biggest | 30.37 | 8.32 | 32.65 |
| Variability | 40.28 | 17.52 | 31.11 |
| Equipment failure factor | 18.65 | 11.94 | 18.29 |
| Renewable intermittence factor | 43.23 | 18.63 | 12.33 |
| Peak/Off-peak rates | 29.45 | 12.95 | 21.14 |
| Final Case | 25.29 | 14.49 | 8.65 |

Table.16 – Comparison of the results of best case in each parameter

A comparison of the best case to each factor is necessary to fulfil the purpose of this project. This will allow us to understand the impact of each factor in shaping the most viable financial solution.

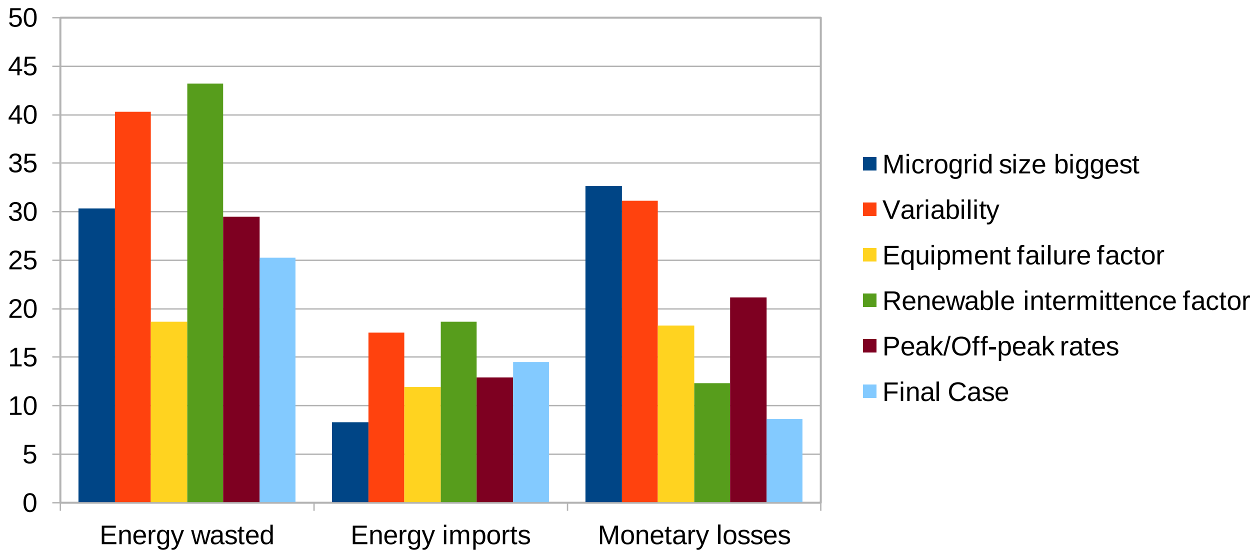



Figure. 28 – Final case results compared with all cases

The resulting final case presents the lowest economic losses as we have been targeting, however, energy losses and network imports are at the levels of the previous cases. More specifically, it was observed that the electricity lost in the latter case is around 25%, less than almost all the previous simulations. In addition, energy imports from the network range to 14.49%, which is high in relation to the average. However, the final case was adopted because the original objective of economic viability was fulfilled.

The simulation showed that with a real system of electricity distribution of microsystems, with differences in size, equipment failures, and a large number of micro-grids, the waste of electricity will be reduced and most of the electricity produced the micro-grid will be consumed by other microsystems. In addition, we can conclude from the results that the waste of electricity can be further reduced either by increasing the number of systems or by increasing the variability of their sizes.

Furthermore, it was also concluded that a normally occurring equipment failures and renewable intermittence factor could reduce significantly the monetary losses of the micro-grid trading. A peak/off peak price plans could also benefit a micro-grid under certain circumstances. To reform the hours of implementation when the generation is less than its own demand, in that way the micro-grid might buy electricity at cheaper prices.

In the next chapter we will proceed to export conclusions after taking into account all the information discussed above. In addition, it will be examined whether the original objectives have been met in order to clarify the general conclusions of this report.

# Chapter Four: Conclusions & Future Work

In this project, possible implementation abilities of micro-grid energy trading were discussed. Furthermore, several solutions were simulated to meet the criteria of a viable trading process. The energy trading between micro-grid ,which is defined as an active distribution network which have the ability to deliver the integrated power at community level, is identified .

Different cases were examined based on the complexity of parameters, having as a purpose to spot various aspects of the micro-grid trading system. During this project, MGET-SIM software was changed to simulate the trade of electricity between micro-grids through the national network. All results were presented and discussed in detail to obtain the appropriate conclusions.

To conclude, the purpose of the project is highlighted and all the simulations results are linked with the real trading scenario. Finally, the overall conclusions obtained from this project and some future work proposed are presented in detail.

## 4.1 Overall conclusions

The features of micro-grids as described in the introduction create the need to identify further the energy micro-grid trading among them. Especially, in our era where this type of trading appears to be a promising solution for the increased future energy demand. In addition, its properties such as increased security of supply, greater reliability of energy systems and reduction of environmental pollutants through the implementation of environmentally-friendly energy solutions are some of the important reasons for carrying out additional research.
Several simulations took place so as to investigate the effects of different factors on this new bidding model.
The priority given by the bidding model to systems that have used some renewable energy has played a key role in shaping the final results.
Furthermore, several assumptions have been made to overcome any difficulties of the originally developed MGET-SIM algorithm. The main conclusions drawn from these simulations were recorded as follows.

- In spite of the difficulties encountered in some simulations such as the high level of network imports in the event of equipment failure and high levels of energy wasted on the peak/off peak rates , it has been shown that electricity can be traded between micro-grids.

- As the number of micro-grids is increased the energy wasted and the national energy imports are. Having exactly the same reduction in monetary losses the viability of bigger micro-grids is being verified.

- Also, it has been demonstrated that low variability of micro-grids reduces the energy cost of the network. Nevertheless, monetary losses were recorded less when the variability was high. The level of imports in the different variables varied at the same levels.

- As far as the failure factor is concerned, without this, there is a low financial loss. However, high network imports are observed with a possible failure of equipment factor with a lower wasted energy at the same time, indicating that the network has been able to cope with such types of events.

- Taking into account the renewable intermittence factor, lower monetary losses and less energy wasted were observed. In addition, in the case of with renewable intermittence factor, higher network imports were identified. This is due to the fact that the tank has less energy to contribute generally and is therefore less equipped to meet the requirements of inadequate microbes.

- The implementation of peak/off peak rates benefits the energy imports. However, without peak/off peak rates scenario less monetary losses observed and less energy wasted also.

The final conclusion of this work is directly related to the possibility of using such a trading system in a profitable way in the future. Through the research carried out, the viability of the trading system becomes clear as well as its dynamic future implementation. Through the simulations, the complexity of such a commercial model with the risks involved is recognized.
The decongestion of the national network, as well as the reduction of harmful pollutants of existing networks through the use of this trading pattern, can not be questioned. In addition, the simultaneous potential for better tariffs in relation to those currently available is a stimulating factor for their further adoption.
Finally, the implementation of this bidding model and, in particular, the final case as outlined above gave us a clear picture of how energy trade is affected when it prioritises micro-grids with renewable energy systems.

The economic viability of the micro-grid trading scenario is confirmed. However, the energy wasted in such a system remains in slightly high levels, with energy imports from the national network remaining at tolerable levels.

## 4.2 Future work

The nature and the size of a subject such as energy trading among micro-grids was impossible to be covered in detail in this project. Complex trade transactions, variability of parameters and lack of time restricted our ability to make a more detailed research. Many opportunities for further developed were identified either for research purpose either for future adoption in the micro-grid trading algorithm.

As concerning the research, the bidding process could be developed further. More specifically, many researchers have linked offer to game theory that develops hundreds of parameters of varying systems. Even more, the control of large numbers of distributed energy resources together as a virtual power plant should be examined further, due to estimate their potential value for the whole power system. Especially, when individual 'prosumers' own these resources, it is a challenge to create a system which has the ability to direct control providing sufficient flexibility and functionality. Finally, the introduction of responses to demand should be examined in detail at the survey level. In this case, customers can plan to turn on and off some of their devices from the network administrator to allow for a better balance between demand and supply.

As far as future additions to the existing algorithm are concerned, a series of actions could be proposed.

Initially, future energy requirements increase the demand for individual energy storage for each fine tuning. Studies have been made by researchers and students at our university demonstrating the importance of energy storage in the energy market. However, due to the complexity of energy transactions, additional steps are needed to advance the algorithm so that it can calculate the energy balance at each step of the time in order to or not to proceed on an energy transaction.

In addition, it should be underlined that the storage capacity of a micro-network, with its particular features, should be proportional to its capacity to be viable in proportion to its size and according to the bidding process. In a different case, separate storage would not have a significant impact on the final results. Furthermore, the economic exploitation of the micro-grid should be further examined. As we already have mentioned that the economic viability of the system defines the success of the whole trading project. So, it is extremely important to manage correctly the excessive energy in the pool in the favour of local demand customers. This could be achieved with further changes in the prioritizing process of micro grids during the trading.
From the point of view of the accuracy of the results, a thorough development of all parameters is desirable. All factors taken into account such as size and variability could be enriched further into the code. Various additional options in parametrization of energy trading systems would have an impact on the resulting final picture of the commercial process, affecting the accuracy of the results.
Creating real micro-grids would help in particular to this improvement.
In conclusion, the assessment of the new trend in the energy market is crucial for the further development of this type of energy trading. In particular, the creation of a new enriched software that could calculate the intangible parameters would be critical. Scheduled maintenance, side demand management, a variety of storage options, smart contracts and the use of smart meters could be included by the editors of those software.

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Appendix 1

Initial MGET-SIM code

```
#include <stdio.h>
#include <stdlib.h>
#include <iostream.h>
#include <time.h>
void init_mm( );
int number_range( int from, int to );
int number_mm( void );
static int rgiState[2+55]; // for random number
int main(void)
{
FILE *fp; /* file pointer */
int
c,i,j,x,z,N,abc,vsz,effz,refz,dnpz,xyz,lmn,mno,opq,pqr,qrs,gsk,gh,gn
,traderand;
float
mg[1000][48],vs,ngsp,mgsp,eff,ref,dnp[24],trade[1000][24],exp,grid,c
ost,costg,ghi,jk
l,mnop,inc[1000][24];
if ((fp=fopen("mg1.txt", "r"))==NULL)
{
printf("Cannot open file.\n");
71
}
for (i = 0; i < 48; i++)
{
if (fscanf(fp, "%f", &mg[0][i]) != 1)
{
break;
}
}
fclose(fp);
x = i;
printf("Supply & Demand data in text file is found for %d hours\n",
(x/2));
for (i = 0; i < x; i++)
{
printf("mg[0][%d] = %6.2f\n", i, mg[0][i]);
}
// ask user how many dummy grids are required
printf ("what are the number of dummy micro-grids do you want to
simulate
electricity trading with?\n");
scanf ("%d", &N);
// ask user how much variability in size is required
```

```
printf ("what should be the variability in size of dummy micro-grids
from the given
micro-grid?\n Enter 1 for low, 2 for medium and 3 for high.\n");
scanf ("%d", &vsz);
while (vsz < 1)
72
{
printf ("Error: Please Enter a value in the given range. \n what
should be the
variability in size of dummy micro-grids from the given micro-
grid?\n Enter 1 for
low, 2 for medium and 3 for high.\n");
scanf ("%d", &vsz);
}
while (vsz > 3)
{
printf ("Error: Please Enter a value in the given range. \n what
should be the
variability in size of dummy micro-grids from the given micro-
grid?\n Enter 1 for
low, 2 for medium and 3 for high.\n");
scanf ("%d", &vsz);
}
// ask user if equipment failure possibility is to be considered
printf ("Do you want to consider the possibility of equipment
failure in microgrids?\
n Enter 1 for Yes, 2 for No.\n");
scanf ("%d", &effz);
while (effz < 1)
{
printf ("Error: Please Enter a value in the given range. \n Do you
want to
consider the possibility of equipment failure in micro-grids?\n
Enter 1 for Yes, 2 for
No.\n");
scanf ("%d", &effz);
}
73
while (effz > 2)
{
printf ("Error: Please Enter a value in the given range. \n Do you
want to
consider the possibility of equipment failure in micro-grids?\n
Enter 1 for Yes, 2 for
No.\n");
scanf ("%d", &effz);
}
// ask user if intermittence of renewable energy sources is to be
considered
printf ("Do you want to consider the intermittence of renewable
energy supplies in
micro-grids?\n Enter 1 for Yes, 2 for No.\n");
scanf ("%d", &refz);
while (refz < 1)
{
```

```
printf ("Error: Please Enter a value in the given range. \n Do you
want to
consider the intermittence of renewable energy supplies in micro-
grids?\n Enter 1 for
Yes, 2 for No.\n");
scanf ("%d", &refz);
}
while (refz > 2)
{
printf ("Error: Please Enter a value in the given range. \n Do you
want to
consider the intermittence of renewable energy supplies in micro-
grids?\n Enter 1 for
Yes, 2 for No.\n");
scanf ("%d", &refz);
74
}
// ask user the national grid electricity price
printf ("Please enter the national grid electricity price in
pence/kWh\n");
scanf ("%f", &ngsp);
while (ngsp < 0.001)
{
printf ("Error: Invalid Price entered \n Please enter the national
grid electricity
price in pence/kWh\n");
scanf ("%f", &ngsp);
}
// ask user the microgrid electricity price
printf ("Please enter the micro-grid electricity price in
pence/kWh\n");
scanf ("%f", &mgsp);
while (mgsp >= ngsp)
{
printf ("Error: Invalid Price entered \n Price must be less than
national grid
electricity price\n Please enter the micro-grid electricity price in
pence/kWh\n");
scanf ("%f", &mgsp);
}
// ask user ask user if the night money saver plan is to be
considered for electricity
price
printf ("Do you want to consider different electricity rates in day
& night?\n Enter 1
for Yes, 2 for No.\n");
scanf ("%d", &dnpz);
75
while (dnpz < 1)
{
printf ("Error: Please Enter a value in the given range. \n Do you
want to
consider different electricity rates in day & night?\n Enter 1 for
Yes, 2 for No.\n");
scanf ("%d", &dnpz);
}
```

```
while (dnpz > 2)
{
printf ("Error: Please Enter a value in the given range. \n Do you
want to
consider different electricity rates in day & night?\n Enter 1 for
Yes, 2 for No.\n");
scanf ("%d", &dnpz);
}
init_mm(); //seed the number generator
for (j=1; j<=N; j++)
for (i=0; i<48; i++)
{
if (vsz == 1)
{
abc = number_range( 0, 10 );
vs = (0.1*(5.0+abc));
}
if (vsz == 2)
76
{
abc = number_range( 0, 27 );
vs = (0.1*(3.0+abc));
}
if (vsz == 3)
{
abc = number_range( 0, 100 );
vs = (0.1*abc);
}
if (effz == 1)
{
lmn = number_range( 0, 1 );
mno = number_range( 0, 1 );
opq = number_range( 0, 1 );
pqr = number_range( 0, 1 );
qrs = number_range( 0, 1 );
eff = (lmn+mno+opq+pqr+qrs)/(lmn+mno+opq+pqr+qrs+0.000001);
}
if (effz == 2)
{
eff = 1.0;
}
if (refz == 1)
{
77
xyz = number_range( 7, 10 );
ref = (0.1*(xyz));
}
if (refz == 2)
{
ref = 1.0;
}
if (dnpz == 1)
{
if ((fp=fopen("dnp1.txt", "r"))==NULL)
{
printf("Cannot open the night package file.\n");
```

```
}
for (int dnlp = 1; dnlp <= 24; dnlp++)
{
if (fscanf(fp, "%f", &dnp[dnlp]) != 1)
{
break;
}
}
fclose(fp);
}
if (dnpz == 2)
{
78
if ((fp=fopen("dnp0.txt", "r"))==NULL)
{
printf("Cannot open the price package file.\n");
}
for (int dnlp = 1; dnlp <= 24; dnlp++)
{
if (fscanf(fp, "%f", &dnp[dnlp]) != 1)
{
break;
}
}
fclose(fp);
}
{
if (i%2!=0)
{
mg[j][i]= (mg[0][i]*vs);
}
else mg[j][i]= (mg[0][i]*vs*eff*ref);
printf ("mg[%d][%d] is %10.2f\n", j, i, mg[j][i]);
}
};
fp = fopen("results.txt", "w");
if (fp == NULL)
79
{
printf("\nError opening write.txt\n");
exit(1);
}
else;
for (gh=1; gh<=24; gh++)
{
exp = 0;
grid = 0;
mnop=0;
for (gn=0; gn<=N; gn++)
{
trade [gn][gh]= (mg[gn][(gh*2)-2])-(mg[gn][(gh*2)-1]);
printf ("Hour no %d: Energy available in Micro-grid No.%d is %10.2f
kWh\n", gh, gn, trade[gn][gh]);
fprintf(fp, "%d %d %7.2f ", gh, gn, trade[gn][gh]);
if ((trade[gn][gh])>0)
{
```

```
exp = exp + (trade[gn][gh]);
ghi = exp;
fprintf(fp, "%9.2f\n", exp);
}
if (gn == N)
{
80
printf ("Energy available in the microgrids pool is %10.2f\n", exp);
for (gsk=0; gsk<(10*N); gsk++)
{
traderand = number_range( 0, gn );
if ((trade[traderand][gh])<0)
{
printf ("Random grid selected for electricity trading is %d\n",
traderand);
if (((trade[traderand][gh])+exp)>0)
{
cost = (trade[traderand][gh])*dnp[gh]*mgsp*0.01;
printf ("Hour No. %d\nImporter: Microgrid No. %d\nImport:
%10.2f kWh\n Cost/kWh: %3.2f\n",
gh,traderand,(trade[traderand][gh]),cost);
fprintf (fp, "%d %d %7.2f", gh,traderand,(trade[traderand][gh]));
exp = exp + (trade[traderand][gh]);
printf ("Energy still available: %10.2f kWh\n",exp);
fprintf(fp, "%9.2f %6.2f\n", exp,cost);
(trade[traderand][gh])= 0;
}
if (((trade[traderand][gh])+exp)<0)
{
costg = (trade[traderand][gh])*dnp[gh]*ngsp*0.01;
printf ("Hour No. %d\nImporter: Microgrid No. %d\nImport:
%10.2f kWh\n Cost/kWh: %3.2f\n",
gh,traderand,(trade[traderand][gh]),costg);
81
fprintf (fp, "%d %d %7.2f", gh,traderand,(trade[traderand][gh]));
grid = grid + (trade[traderand][gh]);
fprintf(fp, "%9.2f %6.2f", grid,costg);
printf ("Total electricity imported from the grid: %10.2f
kWh\n",grid);
(trade[traderand][gh])= 0;
mnop=mnop+costg;
fprintf(fp, "%7.2f\n", mnop);
}
fprintf(fp, "National Grid earns %7.2f\n", mnop);
}
}
jkl=ghi-exp;
}
inc[i][gh]=0;
for (i=0;i<=N;i++)
{
if ((trade[i][gh])>0)
{
inc[i][gh]=((trade[i][gh])*dnp[gh]*mgsp*0.01*jkl)/ghi;
if (inc[i][gh]>0)
{
```

```
fprintf(fp, "Grid No:%d earns %6.2f\n", i,inc[i][gh]);
inc[i][gh]=0;
82
}
}
}
jkl=0;
}
};
fclose(fp);
printf ("See the results.txt file in the program folder for
simulation results\n Press C
then Enter to close the program");
scanf ("%d",&c);
return 0;
}
int number_mm( void ) //for random number generator (ref.16) //
{
int *piState;
int iState1;
int iState2;
int iRand;
piState = &rgiState[2];
iState1 = piState[-2];
iState2 = piState[-1];
iRand = ( piState[iState1] + piState[iState2] )
& ( ( 1 << 30 ) - 1 );
piState[iState1] = iRand;
83
if ( ++iState1 == 55 )
iState1 = 0;
if ( ++iState2 == 55 )
iState2 = 0;
piState[-2] = iState1;
piState[-1] = iState2;
return iRand >> 6;
}
/*
* Generate a random number.
*/
int number_range( int from, int to ) //for random number generator
{
int power;
int number;
if ( ( to = to - from + 1 ) <= 1 )
return from;
for ( power = 2; power < to; power <<= 1 )
;
while ( ( number = number_mm( ) & ( power - 1 ) ) >= to )
;
return from + number;
}
/*
84
* This is the Mitchell-Moore algorithm from Knuth Volume II.
*/
```

```
void init_mm( ) //for random number generator
{
int *piState;
int iState;
piState = &rgiState[2];
piState[-2] = 55 - 55;
piState[-1] = 55 - 24;
piState[0] = ( (int) time( NULL ) ) & ( ( 1 << 30 ) - 1 );
piState[1] = 1;
for ( iState = 2; iState < 55; iState++ )
{
piState[iState] = ( piState[iState-1] + piState[iState-2] )
& ( ( 1 << 30 ) - 1 );
}
return ; //end of code for random number generator
}
```

Appendix 2

New MGET-SIM code

```
#include <stdio.h>
#include <stdlib.h>
#include <iostream>
#include <time.h>
void init_mm( );
int number_range( int from, int to );
int number_mm( void );
static int rgiState[2+55]; // for random number
int main(void)
{
FILE *fp; /* file pointer */
int
c,i,j,x,z,N,abc,vsz,effz,refz,dnpz,xyz,lmn,mno,opq,pqr,qrs,gsk,gh,gn
,traderand;
float
mg[100][48],vs,ngsp,mgsp,eff,ref,dnp[24],trade[1000][24],exp,grid,co
st,costg,ghi,jkl,mnop,inc[1000][24];
if ((fp=fopen("Supply and Demand Findhorn.txt", "r"))==NULL)
{
printf("Cannot open file.\n");
//71
}
for (i = 0; i < 48; i++)
{
if (fscanf(fp, "%f", &mg[0][i]) != 1)
{
break;
}
}
fclose(fp);
x = i;
printf("Supply & Demand data in text file is found for %d hours\n",
(x/2));
for (i = 0; i < x; i++)
{
printf("mg[0][%d] = %6.2f\n", i, mg[0][i]);
}
```

```
// ask user how many dummy grids are required
printf ("what are the number of micro-grids do you want to simulate
electricity trading with?\n");
scanf ("%d", &N);
// ask user how much variability in size is required
printf ("what should be the variability in size of micro-grids from
the given micro-grid?\n Enter 1 for low, 2 for medium and 3 for
high.\n");
scanf ("%d", &vsz);
while (vsz < 1)
//72
{
printf ("Error: Please Enter a value in the given range. \n what
should be the variability in size of micro-grids from the given
micro-grid?\n Enter 1 for low, 2 for medium and 3 for high.\n");
scanf ("%d", &vsz);
}
while (vsz > 3)
{
printf ("Error: Please Enter a value in the given range. \n what
should be the variability in size of micro-grids from the given
micro-grid?\n Enter 1 for low, 2 for medium and 3 for high.\n");
scanf ("%d", &vsz);
}
// ask user if equipment failure possibility is to be considered
printf ("Do you want to consider the possibility of equipment
failure in microgrids?\
n Enter 1 for Yes, 2 for No.\n");
scanf ("%d", &effz);
while (effz < 1)
{
printf ("Error: Please Enter a value in the given range. \n Do you
want to consider the possibility of equipment failure in micro-
grids?\n Enter 1 for Yes, 2 for No.\n");
scanf ("%d", &effz);
}
//73
while (effz > 2)
{
printf ("Error: Please Enter a value in the given range. \n Do you
want to consider the possibility of equipment failure in micro-
grids?\n Enter 1 for Yes, 2 for o.\n");
scanf ("%d", &effz);
}
// ask user if intermittence of renewable energy sources is to be
considered
printf ("Do you want to consider the intermittence of renewable
energy supplies in micro-grids?\n Enter 1 for Yes, 2 for No.\n");
scanf ("%d", &refz);
while (refz < 1)
{
printf ("Error: Please Enter a value in the given range. \n Do you
want to consider the intermittence of renewable energy supplies in
micro-grids?\n Enter 1 for Yes, 2 for No.\n");
scanf ("%d", &refz);
}
```

```
while (refz > 2)
{
printf ("Error: Please Enter a value in the given range. \n Do you
want to consider the intermittence of renewable energy supplies in
micro-grids?\n Enter 1 for Yes, 2 for No.\n");
scanf ("%d", &refz);
//74
}
// ask user the national grid electricity price
printf ("Please enter the national grid electricity price in
pence/kWh\n");
scanf ("%f", &ngsp);
while (ngsp < 0.001)
{
printf ("Error: Invalid Price entered \n Please enter the national
grid electricity price in pence/kWh\n");
scanf ("%f", &ngsp);
}
// ask user the microgrid electricity price
printf ("Please enter the micro-grid electricity price in
pence/kWh\n");
scanf ("%f", &mgsp);
while (mgsp >= ngsp)
{
printf ("Error: Invalid Price entered \n Price must be less than
national grid electricity price\n Please enter the micro-grid
electricity price in pence/kWh\n");
scanf ("%f", &mgsp);
}
// ask user ask user if the night money saver plan is to be
considered for electricity price
printf ("Do you want to consider different electricity rates in day
& night?\n Enter 1 for Yes, 2 for No.\n");
scanf ("%d", &dnpz);
//75
while (dnpz < 1)
{
printf ("Error: Please Enter a value in the given range. \n Do you
want to consider different electricity rates in day & night?\n Enter
1 for Yes, 2 for No.\n");
scanf ("%d", &dnpz);
}
while (dnpz > 2)
{
printf ("Error: Please Enter a value in the given range. \n Do you
want to consider different electricity rates in day & night?\n Enter
1 for Yes, 2 for No.\n");
scanf ("%d", &dnpz);
}
init_mm(); //seed the number generator
for (j=1; j<=N; j++)
for (i=0; i<48; i++)
{
if (vsz == 1)
{
abc = number_range( 0, 10 );
```

```
vs = (0.1*(5.0+abc));
}
if (vsz == 2)
//76
{
abc = number_range( 0, 27 );
vs = (0.1*(3.0+abc));
}
if (vsz == 3)
{
abc = number_range( 0, 100 );
vs = (0.1*abc);
}
if (effz == 1)
{
lmn = number_range( 0, 1 );
mno = number_range( 0, 1 );
opq = number_range( 0, 1 );
pqr = number_range( 0, 1 );
qrs = number_range( 0, 1 );
eff = (lmn+mno+opq+pqr+qrs)/(lmn+mno+opq+pqr+qrs+0.000001);
}
if (effz == 2)
{
eff = 1.0;
}
if (refz == 1)
{
//77
xyz = number_range( 7, 10 );
ref = (0.1*(xyz));
}
if (refz == 2)
{
ref = 1.0;
}
if (dnpz == 1)
{
if ((fp=fopen("dnp1.txt", "r"))==NULL)
{
printf("Cannot open the night package file.\n");
}
for (int dnlp = 1; dnlp <= 24; dnlp++)
{
if (fscanf(fp, "%f", &dnp[dnlp]) != 1)
{
break;
}
}
fclose(fp);
}
if (dnpz == 2)
{
//78
if ((fp=fopen("dnp0.txt", "r"))==NULL)
{
```

```
printf("Cannot open the price package file.\n");
}
for (int dnlp = 1; dnlp <= 24; dnlp++)
{
if (fscanf(fp, "%f", &dnp[dnlp]) != 1)
{
break;
}
}
fclose(fp);
}
{
if (i%2!=0)
{
mg[j][i]= (mg[0][i]*vs);
}
else mg[j][i]= (mg[0][i]*vs*eff*ref);
printf ("mg[%d][%d] is %10.2f\n", j, i, mg[j][i]);
}
};
fp = fopen("results.txt", "w");
if (fp == NULL)
//79
{
printf("\nError opening write.txt\n");
exit(1);
}
else;
for (gh=1; gh<=24; gh++)
{
exp = 0;
grid = 0;
mnop=0;
for (gn=0; gn<=N; gn++)
{
trade [gn][gh]= (mg[gn][(gh*2)-2])-(mg[gn][(gh*2)-1]);
printf ("Hour no %d: Energy available in Micro-grid No.%d is %10.2f
kWh\n", gh, gn, trade[gn][gh]);
fprintf(fp, "%d %d %7.2f ", gh, gn, trade[gn][gh]);
if ((trade[gn][gh])>0)
{
exp = exp + (trade[gn][gh]);
ghi = exp;
fprintf(fp, "%9.2f\n", exp);
}
if (gn == N)
{
//80
printf ("Energy available in the microgrids pool is %10.2f\n", exp);
for (gsk=0; gsk<(10*N); gsk++)
{
traderand =(refz==2) + (number_range( 0, gn ));
if ((trade[traderand][gh])<0)
{
printf ("Grid selected according his renewable intermittence for
electricity trading is %d\n",
```

```
traderand);
if (((trade[traderand][gh])+exp)>0)
{
cost = (trade[traderand][gh])*dnp[gh]*mgsp*0.01;
printf ("Hour No. %d\nImporter: Microgrid No. %d\nImport: %10.2f
kWh\n Cost/kWh: %3.2f\n", gh,traderand,(trade[traderand][gh]),cost);
fprintf (fp, "%d %d %7.2f", gh,traderand,(trade[traderand][gh]));
exp = exp + (trade[traderand][gh]);
printf ("Energy still available: %10.2f kWh\n",exp);
fprintf(fp, "%9.2f %6.2f\n", exp,cost);
(trade[traderand][gh])= 0;
}
if (((trade[traderand][gh])+exp)<0)
{
costg = (trade[traderand][gh])*dnp[gh]*ngsp*0.01;
printf ("Hour No. %d\nImporter: Microgrid No. %d\nImport: %10.2f
kWh\n Cost/kWh: %3.2f\n", gh,traderand,(trade[traderand][gh]),costg);
//81
fprintf (fp, "%d %d %7.2f", gh,traderand,(trade[traderand][gh]));
grid = grid + (trade[traderand][gh]);
fprintf(fp, "%9.2f %6.2f", grid,costg);
printf ("Total electricity imported from the grid: %10.2f
kWh\n",grid);
(trade[traderand][gh])= 0;
mnop=mnop+costg;
fprintf(fp, "%7.2f\n", mnop);
}
fprintf(fp, "National Grid earns %7.2f\n", mnop);
}
}
jkl=ghi-exp;
}
inc[i][gh]=0;
for (i=0;i<=N;i++)
{
if ((trade[i][gh])>0)
{
inc[i][gh]=((trade[i][gh])*dnp[gh]*mgsp*0.01*jkl)/ghi;
if (inc[i][gh]>0)
{
fprintf(fp, "Grid No:%d earns %6.2f\n", i,inc[i][gh]);
inc[i][gh]=0;
//82
}
}
}
jkl=0;
}
};
fclose(fp);
printf ("See the Results.txt file in the program folder for
simulation results\n Press C then Enter to close the program");
scanf ("%d",&c);
return 0;
}
int number_mm( void ) //for random number generator (ref.16) //
```

```
{
int *piState;
int iState1;
int iState2;
int iRand;
piState = &rgiState[2];
iState1 = piState[-2];
iState2 = piState[-1];
iRand = ( piState[iState1] + piState[iState2] )
& ( ( 1 << 30 ) - 1 );
piState[iState1] = iRand;
//83
if ( ++iState1 == 55 )
iState1 = 0;
if ( ++iState2 == 55 )
iState2 = 0;
piState[-2] = iState1;
piState[-1] = iState2;
return iRand >> 6;
}
/*
* Generate a random number.
*/
int number_range( int from, int to ) //for random number generator
{
int power;
int number;
if ( ( to = to - from + 1 ) <= 1 )
return from;
for ( power = 2; power < to; power <<= 1 )
;
while ( ( number = number_mm( ) & ( power - 1 ) ) >= to )
;
return from + number;
}
/*
84
* This is the Mitchell-Moore algorithm from Knuth Volume II.
*/
void init_mm( ) //for random number generator
{
int *piState;
int iState;
piState = &rgiState[2];
piState[-2] = 55 - 55;
piState[-1] = 55 - 24;
piState[0] = ( (int) time( NULL ) ) & ( ( 1 << 30 ) - 1 );
piState[1] = 1;
for ( iState = 2; iState < 55; iState++ )
{
piState[iState] = ( piState[iState-1] + piState[iState-2] )
& ( ( 1 << 30 ) - 1 );
}
return ; //end of code for random number generator
}
```