Department of Mechanical Engineering

Electricity Trading Among Microgrids

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Copyright Declaration

Signed: Sheikh Muhammad Ali Date: 16-Sep-2009

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In the loving memory of my grandparents - Mr. & Mrs. Omar Khan

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Abstract

The latest energy policies to encounter the environmental damage, depletion of fossil fuel reserves and insecurity of supply have provided the reason to increase the share of renewable energy sources in energy generation. The importance of conventional energy sources still can not be neglected as they are more reliable than renewables and the technologies which are used to obtain energy from them are mature. One of the possibilities to have a reliable, economical and less harmful to the environment generation system is embedded generation which is a combination of renewable and conventional energy sources. A microgrid is a community level embedded generation system with local loads and micro-sources of energy. It can be operated in island mode or connected to the national grid. It was hypothesized that a microgrid can also be connected to the other microgrids through the national grid to trade energy and to improve the energy supply, reliability and efficiency. However, connecting microgrids to each other through the national grid has the question of tradability due to their stochastic sources such as renewables. A number of microgrids of different natures from each other which are likely to spread over the national grid would need a centralized control and dispatching system to trade electricity. This system should have the ability to deal with the stochastic natures of microgrids to ensure tradability. In this thesis, a computer program MGET-SIM was developed that can simulate the electricity trading among microgrids. Assumptions were made about microgrids' connection through the national grid, a centralized control & dispatching system and electricity prices. Several simulations were run after the development of the computer program to know the tradability and the effects of different factors on such a trading system. The results of these simulations show the extent of how much this system could be affected by various factors, and prove the tradability of electricity among microgrids. The technical & economical benefits of the system have also been presented.

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Chapter One : Introduction & Background

1.1 Energy & Environment

Energy usage and demand have consistently increased with economic growth. The conventional sources of energy have been meeting these energy demands for centuries. Issues like the depletion of ozone layer, global warming, oil prices, security of supply and the depletion of fossil reserves in earth have highlighted the need to increase the share of renewables in energy generation. Through energy generation from renewables, these issues could be dealt with. As an example, it can be seen in Brown's [1] work that carbon emissions, which are blamed to be the main source of global warming, could be reduced by a significant amount by using such sources of energy that are renewable. Brown [1] estimates that through restructuring in energy generation, 3,240 million tons, which is about 35%, of carbon emissions could be reduced. This could be done by replacing fossil fuels with renewables for electricity and heat, and reducing the use of oil and coal in the industry.

The latest energy policies are aiming to generate clean energy. The targets, that are expected to be achieved by the enforcement of these policies, are the reduction of emissions of hazardous gases that damage the environment, and an increase in the share of energy generated from renewable energy sources. These policies are now demanding, from the energy suppliers, to deviate from the present culture of energy generation, supply, and dispatching.

There are various solutions available for these new challenges to the energy suppliers. One of these solutions is to build centralized generation plants of renewable energy to produce energy in bulk at excellent economy of scale. Even now, there are wind farms, hydroelectricity schemes, solar power stations and other renewable schemes already generating bulks of energy economically. There are solar thermal power stations operating in Spain and USA, and the largest of these is the 354 Megawatt SEGS power plant in the Mojave Desert [2]. The world's largest geothermal power installation is 'The Geysers' in California, USA with a rated capacity of 750 Megawatt [3]. 'The Horse Hollow wind energy centre' in Texas, USA is the world's largest wind farm with 735.5 Megawatt capacity [4] and the London Array project off the Kent and Essex coasts in England, when fully completed, would become the largest wind farm with 1,000 Megawatt of generation capacity [5]. The world's largest hydro-electric plant is 'The Three Gorges' in China with 13,400 Megawatt capacity, which will increase to 22,500 Megawatt by 2011 [6].

The demand for increased share of renewables could also be met through decentralized distributed energy resources (DER). Renewable energy systems could be deployed at or near the location as per feasibility. It will not only help to increase the local area potential of renewables but also increase the security of supply and reduce the energy transmission losses. These decentralized distributed generation systems are similar to the earliest power systems when power systems were kept and run close to the loads. These power blocks closer to the loads lost their place with the arrival and success of larger power stations that could generate bulks of electricity economically, transform it to high voltages and transmit it to distances as long as one country to another through high voltage transmission lines. Goldstein et al [7] believe that DER technologies provide opportunities for greater local control of electricity delivery and consumption.

In reality, there are many problems associated with the use of renewables as energy source. The renewable sources do not offer the reliability and economic benefits of conventional fossil fuels. The technology is not mature enough to take place of fossils in energy generation. Different regions in the world do not have the same potential to generate energy from renewables. The reliability of renewable energy sources still needs to be enhanced through improved energy capture, conversion and storage techniques. Proper siting and energy prediction, in cases of wind and solar energy, are also vital. To be pragmatic, this all comes with a price, which is not yet reasonable enough to compete with the price at which fossil fuels are providing energy to the world. Apart from the technological development, there are other concerns with renewable energy sources like the barriers in policy and socio-economic deployment. A country, with huge oil and gas reserves which are already generating energy at very cheap rates, would find it hard to believe if its energy future is insecure. A country like this would not easily agree to spend billions of pounds to ensure the use of renewables as its prominent source of energy.

Another solution could be the use of Combined Heat & Power (CHP) systems. According to Greenpeace (UK) [8], the power stations in UK throw away the same amount of heat as is needed to provide hot water and heating for every building in the UK. On average, the large centralized power stations throw away, as waste heat, two thirds of the energy they generate [8]. A CHP system captures the waste heat which could be used to meet industrial or residential heating requirements. According to Breeze [9], such systems can operate with an energy efficiency of up to 90%. Though some CHP systems could be run on bio-fuels, most of them use fossils. However, a natural gas fired CHP system emits significantly less amount of hazardous greenhouse gases. Energy Information Administration in US Department of Energy [10] has published statistics of CO_2, N_2O and CH_4 emissions by fuel type which are presented in table.1.

The statistical data in table.1 [10] shows that gas fired CHP systems emit the least hazardous emissions in comparison to other main sources of energy.

Understanding the issues with both conventional and renewable energy systems, a possible solution can be a combination of conventional and renewable energy sources. In such a case, it will take the advantages of reliability and low-cost of conventional system, with the cleanliness and sustainability of renewables. The system improves even further if the conventional system is a gas fired CHP which is energy efficient and emits least hazardous emissions than other fossils.

Technology	CO_2 Emissions Factor (lbs/MWh)	N_2O Emissions Factor (lbs/MWh)	CH_4 Emissions Factor (lbs/MWh)
Coal - Pulverized	1,970	0.34	0.04
Nuclear/Other	0.00	0.00	0.00
Hydroelectric	0.00	0.00	0.00
Wood Waste Biomass Boiler	3,400	0.55	0.14
Municipal Solid Waste Boiler	3,747	0.55	0.02
Gas - Steam Turbine	968	0.00	0.05
Gas - Combustion Turbine	1,560	0.24	0.16
Gas- Combined Cycle	952	0.063	0.015
Oil - Steam Turbine	1,452	0.00	0.002
Oil - Combustion Turbine	2,150	0.276	0.021
Oil- Combined Cycle	1,330	0.268	0.013
Renewables	0.00	0.00	0.00

Sources: WAPA 1994; DOE 1991; NREL 1993; IPCC 1991.

Table.1 [ref.10]

1.2 Microgrids

The combined systems of fossil and renewable energy systems could be designed at a power plant level generating bulks of electricity or a community level as shown in figure.1. The intelligent approach could be to have a combination of conventional and renewable energy systems embedded in energy generation systems for communities like residential or commercial buildings, hospitals, blocks of houses, etc. A microgrid is a community level embedded generation system with local loads and micro-sources of energy. It can be operated in island mode or connected to the national grid. The generation system embedded within the local distribution system would increase the security of supply, utilization of local renewable energy potential, utilization of most of the heat generated by CHP system as the loads are near the source, and reduce the transmission losses and public infrastructure costs.

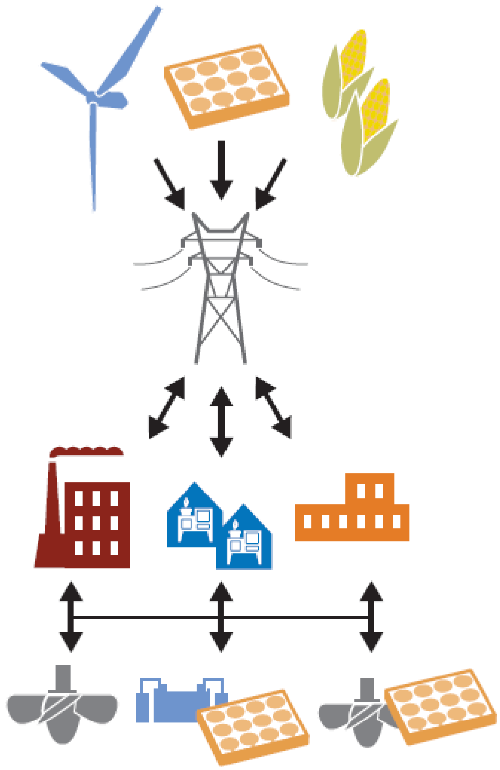

Figure.1 – Combined Power Systems [Picture Courtesy: www.dreamingnewmexico.org]

The importance of the system has been acknowledged by the UK government, as presented in a joint report by UK government and OFGEM [11], "*There are potential benefits in having a more decentralised energy supply. Electricity and heat can be generated locally from renewable sources, making valuable carbon savings. Losses incurred in transmitting centrally-generated electricity to the point of use can be significantly reduced. And even where fossil fuels are used, Combined Heat and Power (CHP) can, in the right setting, ensure that these fuels are used more efficiently by capturing and using the heat created as a by-product in the generation of electricity. A more community-based energy system would also lead to greater individual awareness of energy issues, driving a change in social attitudes and, in turn, more efficient use of our energy resources*".

Another major benefit of the system is based on the fact that the majority of renewable energy sources have relatively smaller power outputs, and so it is more economical to connect them at low voltages in the electricity distribution system. It makes renewable energy systems suitable to be part of a microgrid. This will increase the share of renewable energy sources into the energy markets through the low voltage distribution networks and help to utilize the local potential of renewables.

At present, there are no functional microgrids available. However, there are a few projects running like 'The Ashton Hayes Going Carbon Neutral Project' [12], which is the first project of its kind in England, where multiple renewable electricity generation sources are embedded in a microgrid in a village at Cheshire, so the village could become carbon neutral. Options like wind power, biomass and solar PV are being considered. There are some other projects [13] like Kythnos Island in Greece, Bornholm in Denmark, Manheim in Germany, Kozuf in Macedonia, etc. These projects shall not only help in a better understanding of the behaviour and control of real microgrids, but they would also provide useful real data sets which could be used to support the study of impacts of these microgrids on the national grid and energy tradability among these microgrids.

The novel concept has various issues associated with it. Conner [15] highlighted the issues of control and coordination among the generators distributed over the network, and proposed a novel dispatching management system, distributing the dispatching functions throughout the network. It traded successfully both in the simulation environment and the experimental test bed designed specifically for this purpose. However, some of the issues related to electricity trading among microgrids still remain unanswered.

It is now considered better to divide these issues into intra-microgrid and inter-microgrid issues to have a clear view.

1.2.1 Intra-microgrid Issues

The major source of problem is the connection of microgrids to the main grid. The supply of electricity must be equal to its demand. As the demand rises, the generators slow down and thus their frequency drops. This is more likely to happen when microgrids are connected to the main grid with continuously changing demand. The load frequency control sensors sense this change and increase the fuel supply to the generation system through governors, pro-act motors, etc. However, in case of renewable energy systems in the microgrid, where the fuel supply is controlled by the weather, they can not be controlled in the same way. But the problems could still be resolved by providing the additionally required power from the non-renewable energy system in the microgrid, thus maintaining the frequency back to normal. Another issue is the variation in voltage. The voltage drops due to various reasons like resistance, reactance, temperature, external pressure, etc. AVR (Automatic Voltage regulator) is used to detect and control the voltage so that the electricity is supplied to the end-user at desired voltage level. System protection is also vital in a microgrid. The protection system should have the capability to detect fault and isolate the fault area if required as quickly as possible, and maintain the stability of the system. When there is a fault in national grid, the protection system should isolate the microgrid so it could function normally. In case of islanding, the microgrid would drift out of the phase of the main grid. This issue could be resolved by locking the equipment with the timebase of global positioning system. Another issue in a microgrid is the intermittence of supply from its renewable energy systems. However, this energy lack could be compensated by increasing power output from the non-renewable partners of the microgrid power generation system. The solution to this problem could also be made possible by having more reserve capacity of renewables to tackle this problem, or by adding energy storage. Another issue is whether generating power in a microgrid is economically viable or not. A microgrid can not generate electricity as cheap as a traditional power plant that generates bulk of electricity. However, there are many options to obtain economic benefits. These options include utilizing waste heat energy using CHP system, adding energy storage, selling excess electricity to the main grid and through incentives offered by the government.

1.2.2 Inter-microgrid Issues

The microgrids could possibly be connected to each other through the national grid. However, there is the issue if electricity trading is possible among the microgrids. There are number of questions concerned with such tradability. First of all, there is need of a centralized control system that could allow fair trade of electricity on the basis of some defined laws. The system, as shown in figure.2, will take information from each of the microgrids and the national grid to take its action. However Jiayi et al [14] propose that a multi-agent system (MAS) with distributed control and autonomous operation could be better than a centralized system. This system should also be capable to deal with random nature of energy demand and supply from microgrids. The microgrids in the whole system may range from a few to thousands in number. Conner [15] states that, *"As the network is made bigger, it will become more complex, and the scope for error will increase too. As the system gets larger, the dynamics get harder and harder to model. It would be almost impossible to predict the transient performance, stability, response to faults, etc. of a network with hundreds of thousands of embedded generators"*. Also these microgrids would vary in their sizes, which may be from a few kilowatts to tens of megawatts or even more. It raises the question if all the microgrids' demands are going to be satisfied or not, and also, whether most of the energy generated by microgrids would be consumed or not. Also, these microgrids are assumed to be generating part of their energy from renewables which are intermittent sources. It raises the question how they would affect the system. It will also be necessary that the trading system must economically benefit each of the microgrids. Another important issue is to have an alternative of the centralized control system in a case when it breaks down to continue electricity trading without interruption.

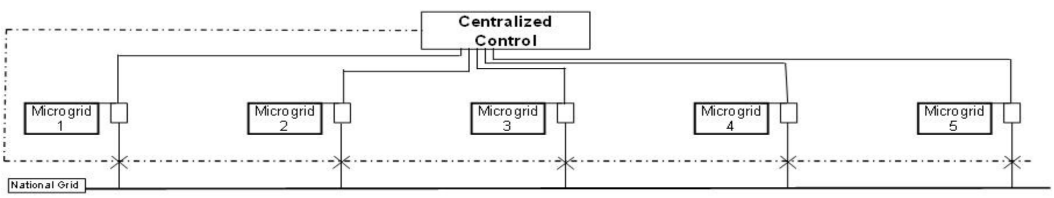

Figure.2 – Centralized Control for Microgrids

There has been identified a need to gain an insight into these issues in the inter-microgrid electricity trading. This could be done by simulating trading of electricity among microgrids. There is no simulator presently available that could simulate such a trading. So the subject of this thesis has been identified as to develop a new simulator MGET-SIM, Microgrid Electricity trading Simulator, a software having the capability to generate a large number of dummy microgrids with random natures and simulate electricity trading among them.

1.3 Objectives

Now as the subject has been defined, these are the main objectives that are expected to be achieved through this thesis:

- To develop a simulation software that could simulate electricity trading among microgrids
- To simulate and verify the tradability of energy among the microgrids using different test cases
- To check how the microgrids could benefit technically and economically
- To make some useful conclusions that could help in promoting this work further

1.4 Research Method

The research method chosen for this study is computational modelling. A computer program has been written using C programming language. A pseudo data set of electricity demand and generation in a microgrid over a period of 24 hours is made. The data set could be replaced by the actual data set of any microgrid. The program generates required number of supply and demand data sets of dummy microgrids, and simulates electricity trading among all the microgrids. Parameters of interest are exported by the program to a text file, which is used for further analysis and to make useful conclusions.

1.5 Assumptions

There are various factors that may become challenges before actually starting electricity trading among the microgrids. However, if taken seriously and handled carefully, then these problems are not permanent barriers and assumptions have been made to permit the development of simulator.

1.5.1 Use of National Grid

It is not a must, but a good idea to connect the microgrids to each other through national grid. It does not only increase the security of supply but the embedded systems like CHP could be run at a level where their efficiency is maximum, so their excess energy at maximum efficiency run could be exported. Also, when thousands or even more of the microgrids would be trading electricity with each other, it is supposed impossible without using the main national grid. But there are few difficulties in doing that, like the control and protection of the power systems. The national grid is so far equipped with control and protection system to deal with one directional flow only. The bi-directional flow of power needs more control and protections. For this thesis, it has been assumed that the national grid is already equipped to support such a flow.

1.5.2 Control System

A control system monitors the supply, demand and safety parameters of power system and takes necessary action if required to keep the whole system stable. It is an agreed point that there is need of an improved control system. There will be controls required at various levels such as site-level control and device-level control. But a centralized control system can be beneficial, as the dispatching system could be integrated with it, to make electricity fairly tradable among a number of microgrids. For this thesis, it has been assumed that such a control system is already available.

1.5.3 Timestamping

In demand of fair trading, the timestamping plays a vital role. It has been assumed that the timestamps of control systems in the microgrids are synchronized with the timestamps of assumed control system. In case of a difference, the trading system could not get proper information of available energy from a microgrid for a given period of time. Timestamping synchronization is possible by locking the equipment with the timebase of global positioning system. This is also important when the microgrid runs in island mode, and connects back to the main grid later.

1.5.4 Electricity Price

It has been assumed that the price of electricity from microgrid must be lesser than national grid electricity price to make it competitive. Another assumption is that the trading price of microgrid electricity is fixed through legislation. However, in reality the trading environment may be different where the electricity will be traded among the microgrids through competitive bidding. But in that case, the system may become complex with the presence of a large number (say 10,000) of bidders, and there will be a need of such mechanisms which would ensure that energy trade is completed within a reasonable time, thus avoiding of any chances of electricity wastage. An intelligent bidding system could possibly be developed to handle this issue.

Chapter TWO: Software Development

In the first chapter, a brief look was taken at the challenges and possible future trends of energy markets, conventional and renewable energy sources, etc. New and developing approaches like distributed generation and microgrids were explained with views from different thinkers, researchers and organizations, and so the need was identified to simulate electricity trading among the microgrids. The reasons for necessary assumptions were also given. The next step now is to develop a simulator. In this chapter, different stages for the development of simulation software have been described. Different factors have been explained in detail, which were considered to make this software give realistic results. At the end, the testing and validation of software is discussed.

2.1 MGET-SIM (Microgrid Energy trading Simulator)

MGET-SIM or Microgrid Energy trading Simulator is the software developed to simulate energy trading among the microgrids. Now there might be a question why use the term 'energy trading' rather than 'electricity trading', so the reason is, this simulator has the capability to simulate the trading of energy not just electricity. For example, in case of excess heat energy available in microgrids, that could also be traded among them. Similar to electricity, a microgrid may have generation and demand of heat energy. So the software shall be equally useful to simulate that if given with data in the appropriate form.

While designing the software, several factors were considered to be included in it to make it give realistic results. A brief look at these factors with their justifications is presented as follows.

2.1.1 Microgrid Generation / Demand Data

The electricity generation and demand data of one microgrid is taken as seed to further functions. The seed data set consists of hourly values of electricity generation and demand for a single day. For this thesis, a pseudo data set was made, considering an office building as a microgrid, and used for simulations. The data set is not real, but still it has been designed with consideration of variations in demand due to office opening & closing hours, lunch time, etc. It also accounts for variations in electricity generation capacity due to shutdown or standby of some of the micro-sources. The physical unit assumed for electricity generation and demand is kWh.

2.1.2 Number of Microgrids in the System

Trading electricity among microgrids is a novel idea, so presently there are no such systems controlling electricity trading among microgrids. But whenever such system is designed, it should have the capability to deal with any number of microgrids. It could be only two microgrids in a model village, a few microgrids in a small town, or thousands of microgrids over the whole country. The simulator should also have the flexibility that it could simulate electricity trading among any given number of microgrids. MGET-SIM has been designed in such a way that it can generate up to one thousand dummy microgrids for simulation. However, the source code can be modified to generate any number of dummy microgrids, if required. When the software is run, the user is prompted to enter the number of dummy microgrids that are wished to be generated by the software.

2.1.3 Variability in Size of Dummy Microgrids

The microgrids in the system would not be of exactly similar sizes to each other in terms of their electricity demand and generation. There may be a superstore with a few extra kilowatt-hours to a multi-story commercial building with hundreds of excess kilowatt-hours at the same time in a day. The demand could also have the same property. In MGET-SIM, the user is prompted to choose if the variability in sizes of dummy microgrids is required to be low, medium or high. The software uses the data set of given microgrid to generate the data sets for dummy microgrids.

When the user opts for low variability in size, the program generates each value in dummy microgrids' data from as low as 0.5 times to the seed data, to as high as 1.5 times the value of seed data. For example, if the electricity generation is 10 kWh in the seed data set, the dummy grid's electricity generation will be in the range of 5 kWh (i.e. 0.5 x 10 kWh) to 15 kWh (i.e. 1.5 x 10 kWh). A similar example can be seen in Figure.3.

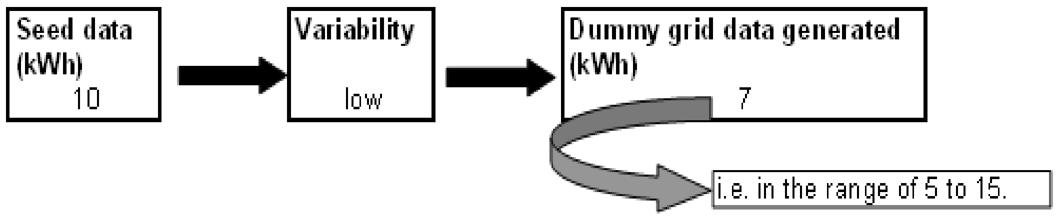

Figure.3 – Low Variability in Sizes of Microgrids

When the user opts for medium variability in size, the program generates each value in dummy microgrids' data from as low as 0.3 times to the seed data, to as high as 3 times the value of seed data. For example, if the electricity generation is 10 kWh in the seed data set, the dummy grid's electricity generation could be in the range of 3 kWh (i.e. 0.3 x 10 kWh) to 30 kWh (i.e. 3 x 10 kWh). A similar example can be seen in Figure.4.

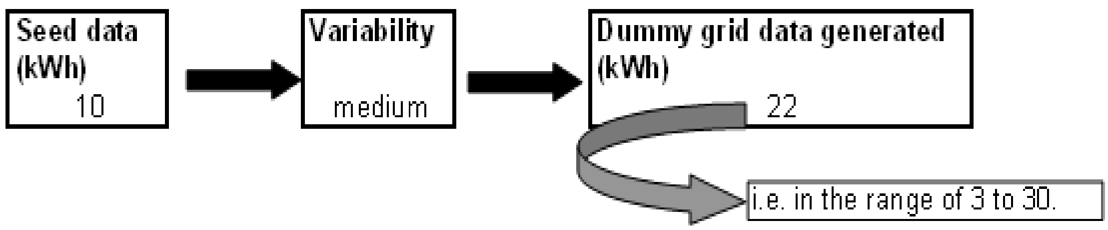

Figure.4 – Medium Variability in Sizes of Microgrids

When the user opts for high variability in size, the program generates each value in dummy microgrids' data from as low as 0 times to the seed data, to as high as 10 times the value of seed data. For example, if the electricity generation is 10 kWh in the seed data set, the dummy grid's electricity generation will be in the range of 0 kWh (i.e. 0 x 10 kWh) to 100 kWh (i.e. 10 x 10 kWh). A similar example can be seen in Figure.5.

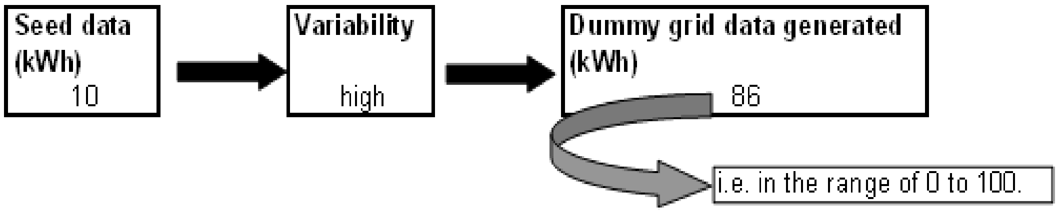

Figure.5 – High Variability in Sizes of Microgrids

2.1.4 Possibility of Equipment Failure

There may be various reasons a microgrid could go down and out of the whole trading system, and so each microgrid may not be generating electricity at all times. A few of the reasons may be equipment failure, maintenance, scheduled outages, etc. A factor has been introduced in MGET-SIM, called 'equipment failure factor', which accounts for all these issues when a microgrid's generation goes to nil. In the start of program, the user is prompted if this factor should be used when generating the data sets for dummy microgrids. If the user chooses 'yes' for this option, then the electricity generation of some microgrid/microgrids may become zero at some random timestamp as can be seen in the figure.6.

2.1.5 Consideration of Intermittence of Renewable Energy Sources

The intermittence of renewable energy sources is one of the major reasons why renewables are hardly considered to be used as sole energy source. The frequent variations in wind velocity make it impossible to have a constant power output. The inconsistency of solar intensity is a barrier in its wider usage, and it is available in the

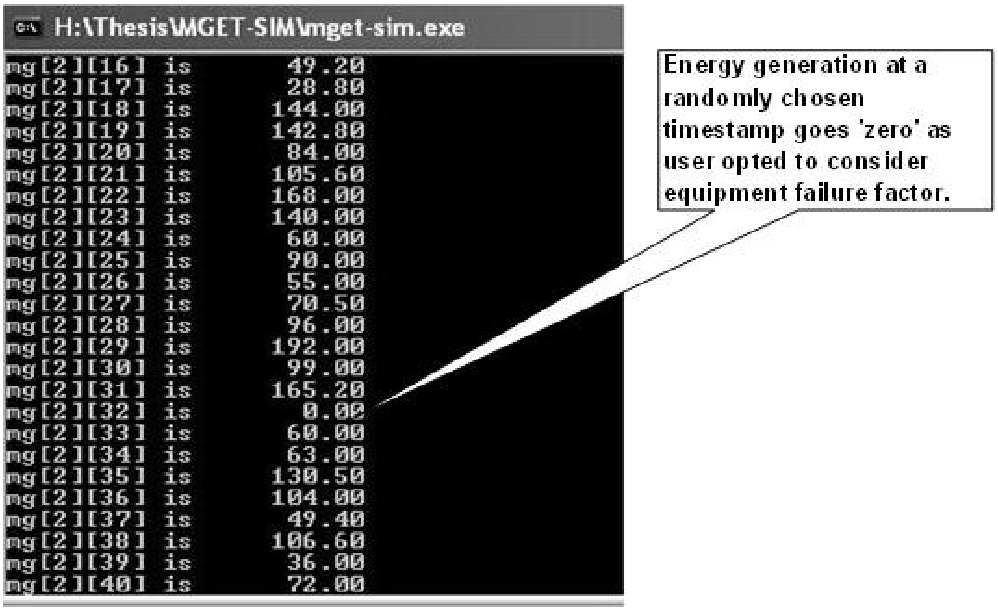

Figure.6 – MGET-SIM: Equipment Failure at Random Timestamp

day time only. Similar issues are there with other forms of renewables. These are the reasons which show that the microgrids installed with some renewable energy source would not offer supply as per their full capacity. This means reductions in the supply.

In MGET-SIM, a factor has been introduced called as 'Renewables intermittence factor'. In the start of program, the user is prompted if this factor should be used when generating the data sets for dummy microgrids. If the user chooses 'yes' for this option, then the electricity generation from microgrids may be reduced up to a maximum of 30% reductions. For example, if the energy generation was 10 kWh, then after using this factor, it will be in the range of 7 kWh to 10 kWh.

2.1.6 Electric Supply from the National Grid

Trading electricity among the microgrids would not mean if there is no need of electricity from the national grid public electricity supply, as it may be used as an alternative source of electricity when the electricity exported from the microgrids is unable to meet the demand. Also, at this stage, there is need to distinguish between the microgrids with excess electricity available and microgrids in demand of electricity. The microgrids with excess electricity have been named as ‘exporter microgrids’ and the microgrids with electricity demand as ‘importer microgrids’. In MGET-SIM, if the electricity available from exporter microgrids is not able to meet a demand from importer microgrid, then the demand will be met from the national grid’s public electricity supply.

2.1.7 System Economics

The importance of electricity trading among microgrids has been discussed and it seems useful technically and environmentally. But it has to be appealing economically as well to attract the financing bodies and the public as well. People started to switch to hybrid cars in USA when energy price went up to $5 per gallon and stopped using their gas-guzzlers that they loved to use. So economics can change the habit the way energy is consumed. In the last chapter, the necessary steps from legislative bodies and policy makers needed to promote such electricity trading will be discussed. At this stage, some of the features of MGET-SIM, which would help in checking the economical benefits of trading electricity among microgrids, are being discussed. However, a detailed economic evaluation of such a system was done by Zoka et al [16] who considered installation, operation, microgrid construction and power interruption costs, and found that a microgrid with an optimal operation of distributed energy sources is economical than each consumer having an independent resource, and possible sale of electricity would increase the economic benefits further.

2.1.8 National Grid and Microgrids Electricity Prices

The user is prompted by the program to enter the electricity price for the national grid public electricity supply and the microgrids electric supply. It is logical that the price of electricity from the microgrids must be less than electricity price from the national grid to make microgrids’ electricity competitive. The program does not accept if the user enters such electricity prices where the price of electricity from microgrids is higher than or equal to the national grid electricity price. The program shows an error in this case. At this stage, it was also assumed that there is a fixed price of electricity from national grid and microgrids.

2.1.9 Peak/Off-Peak Rates

The electricity rates may change at different times in a day due to various reasons. One of the reasons may be when electricity availability is less than demand, so the price may increase. Another reason if the electricity demand is less than its availability, so the price may decrease. Another factor that may affect the rates is high demand with high availability, as the price may be kept low for customers with such a demand.

The program prompts the user if different electricity rates should be considered in day and night. The default setting is that, if the user chooses ‘yes’ for this option, then the electricity rates from all grids become half in the first six hours of the day i.e. 12:00 a.m. to 06:00 a.m. However, MGET-SIM has the flexibility that different electricity prices for each hour of the day can be set. All the user has to do is to modify the corresponding text file in the program folder. The file contains 24 values, one for each hour of the day. By default, the first six values are ‘0.5’ that means half rates in the first six hours, whereas remaining eighteen values are ‘1.0’ that means full rates in the remaining eighteen hours as presented in figure.7. The user can modify value for each hour to change the rates.

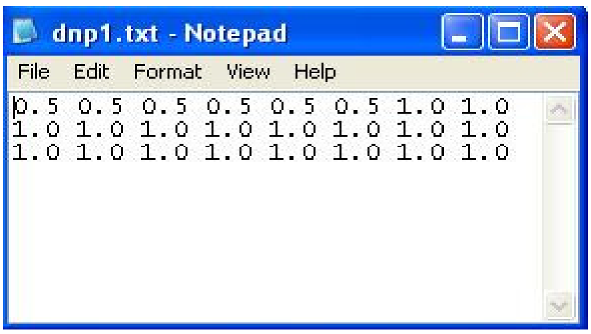

Figure.7 – Source Text File for Different Peak/Off-Peak Rates

For example, a user enters 10 pence/kWh as the national grid electricity price, and 7 pence/kWh as the microgrid electricity price. The user now changes the first value in the corresponding text file from 0.5 to 0.7. It will now mean that, when simulating, the software will take the electricity price in first hour as 7 pence/kWh (i.e. 0.7 x 10 pence/kWh) for the national grid, and 4.9 pence/kWh (i.e. 0.7 x 7 pence/kWh) for the microgrid.

The user also changes the second value in the same file from 0.5 to 1.5. For the second hour, the software will take the electricity price as 15 pence/kWh (i.e. 1.5 x 10 pence/kWh) for the national grid and 10.5 pence/kWh (i.e. 1.5 x 7 pence/kWh) for the microgrid.

2.2 How MGET-SIM Works

The first step in the development of the simulator was to develop the algorithm. There were a number of revisions of the algorithm as the factors were added and removed after consideration. After all the factors discussed above had been finalized, the algorithm was finally developed. Figure.8 (a) and figure.8 (b) present the flowchart of the software. The written logic on which the software works is as follows.

This computer program has been designed to take input from a text file (supply & demand data of a microgrid); with some user inputs, and use it to generate electricity generation & demand data sets for dummy microgrids.

The user is asked by the program to provide the following information:

- No of dummy microgrids to be generated.
- Variability in size of dummy microgrids from the given microgrid (low, medium or high).

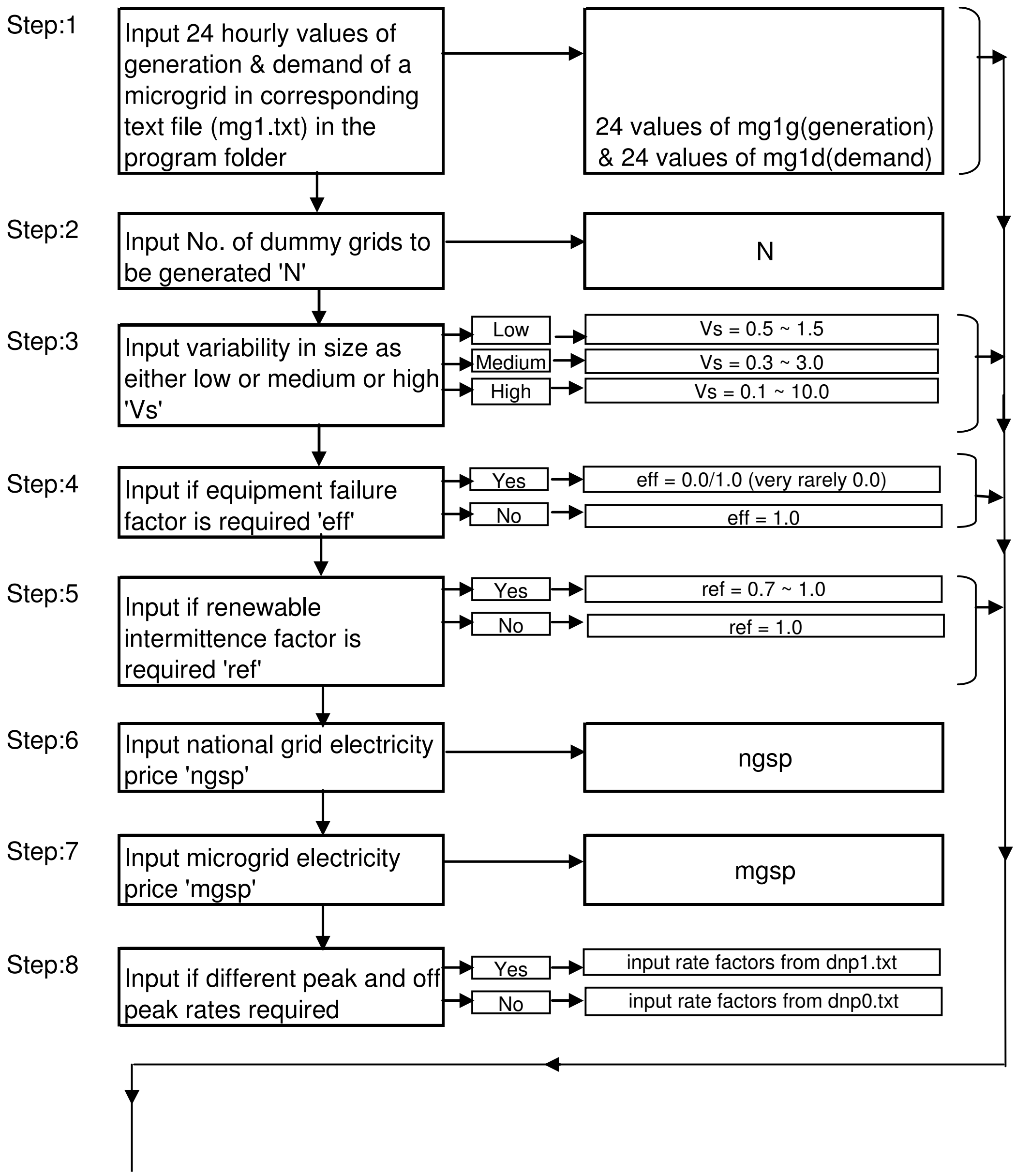

Figure.8 (a). – MGET-SIM Flow Chart

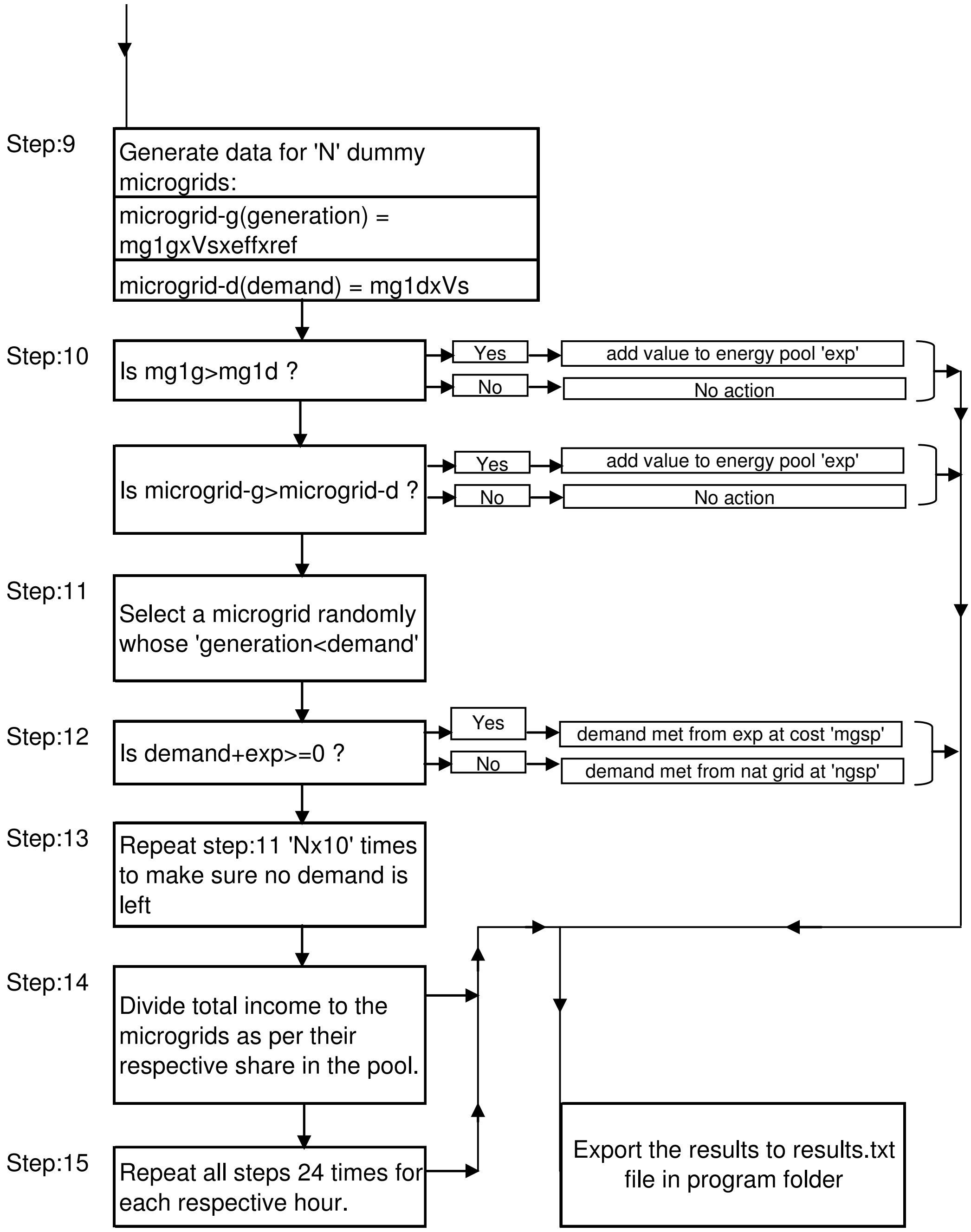

Figure.8 (b). – continued MGET-SIM Flow Chart

- Intermittence of supply from renewable sources (yes/no: if yes, supply reduces)
- National grid electricity price
- Microgrid electricity price (which must be lower than the national grid's electricity price)
- Day/night price plans, which is like having different peak and off-peak rates (yes/no: if yes, half price from 12 a.m. to 6 a.m. in this thesis, but modifiable by the user)

On the basis of above information, the program generates the data for dummy microgrids. The detailed explanation is available in Appendix.2. Once the electricity generation and demand data is available for each microgrid, the program calculates the amount of energy that is to be exported or imported. If a microgrid has surplus, its surplus amount is added into an electricity pool that is common for all microgrids with surplus. After this, the program randomly selects one of the microgrids with electricity demand, and meets its demand from the microgrids' surplus electricity pool. If the pool can not satisfy its demand, then its demand will be met from the national grid public electricity supply.

The result output from the program is exported to a text file generated in the program folder. This file will give user the information about

- How much electricity trading was carried out among the microgrids in each hour
- How much electricity was available in electricity pool
- How many demands of electricity from microgrids were satisfied from the pool, and at what cost

The available results in this text could be used for further analysis and obtain useful information about this trading.

2.3 Validation

The software validation is necessary to check if the simulation program is suitable for its intended purpose. As the programming code for MGET-SIM has been written, now the software needs to be validated so it could be trusted and used for simulating electricity trading.

In software validation, there are various approaches and techniques. The validation of MGET-SIM was done using the analytical approach. There are various reasons for doing this. First of all, the software is only one of its types and it is not possible to validate it by comparing with similar and accredited softwares already available. Second, there was no physical test bed available that could be used to compare it with the software results. In analytical approach, the coding is simplified and tested whether it serves its purpose.

As random numbers with different ranges are generated at various stages in this software, so the first requirement was to simplify the model. The model was simplified so its results become comparable to the results calculated using a page, pen and simple calculator. The simplified approach was to:

- Replace random numbers with constant numbers so these could be used in comparison of results
- As a separate additional check, test each function separately
- Another additional check separate from previous checks, use of different seed data file

Tests were designed and run, with random numbers replaced by constants in the computer program. Two examples of these tests are given here.

The microgrid ‘1’ in the test is the microgrid in the seed data set. Its data was used to generate data for microgrid ‘2’. The constants in place of random numbers were taken as ‘1.1’ for variability in size for both electricity demand and generation, ‘1.0’ for equipment failure and '0.7' for renewables intermittence and dummy microgrid was generated. Formulae used to generate data for microgrid '2' can be seen in details of the program in Appendix.2. The given seed microgrid and dummy microgrid data are given in table.2.

Microgrid No.	Energy Generated in kWh (x)	Energy Demand in kWh (y)
1	80	65
2	61.6	71.5

Table.2 – Test 1

The program checked if each of the microgrids had an electricity surplus or demand. In this test, the surplus electricity of microgrid '1' was sent to the microgrid electricity pool. Then the pool had more electricity than the demand of microgrid '2', so its demand was met from the pool at the price of microgrid electricity rate. There was no electricity imported from the national grid public electricity supply. The calculations by hand were compared side by side with the program results and found same. The results of the test are also shown in table.3.

Microgrid No.	Energy Generated in kWh (x)	Energy Demand in kWh (y)	x – y	Earning (pence)	Payment (pence)	Nat. Grid Earning (pence)
1	80	65	15	69.3	0.0	0.0
2	61.6	71.5	-9.9	0.0	69.3	

Table.3 – Results of Test 1

Another test was performed using same microgrid '1' seed data and same constant values in place of random numbers. The only change was that the variability in size was changed from '1.1' to '1.5' for microgrid '2' electricity demand only. So now microgrids' electricity pool was not able to meet the demand of microgrid '2'. The given seed microgrid and dummy microgrid data are given in table.4.

Microgrid No.	Energy Generated in kWh (x)	Energy Demand in kWh (y)
1	80	65
2	61.6	97.5

Table.4 – Test 2

This time the microgrids' electricity pool had less electricity than the demand of microgrid '2', so the demand was met by importing electricity from the national grid public electricity supply at a price higher than microgrid electricity price. There was no electricity imported from the microgrids' electricity pool. The calculations by hand were compared side by side with the program results and found same. The results of this test are also shown in table.5.

Microgrid No.	Energy Generated in kWh (x)	Energy Demand in kWh (y)	x – y	Earning (pence)	Payment (pence)	Nat. Grid Earning (pence)
1	80	65	15	0.0	0.0	359.0
2	61.6	71.5	-35.9	0.0	359.0	

Table.5 – Results of Test 2

There were several tests performed like this and the results matched in each case. The functions used in different steps within the program were tested separately and found working accurately. So it has been found that the software is able to generate dummy microgrids' data and simulate electricity trading among the microgrids. Also, there were different data sets taken as seeds to ensure that MGET-SIM works with every given microgrid data set, and it was observed that it can work with any data set with some reasonable values of demand and generation as in a microgrid. It is not to be used with seed data sets from electricity sources other than microgrids.

Chapter THREE: Simulations & Results

In the previous chapters, possible solutions were discussed to meet the latest challenges to the energy industry. Microgrids, a community level embedded generation system, were highlighted and the need to simulate electricity trading among them was identified. As part of this thesis, the software MGET-SIM was developed to simulate electricity trading among microgrids through the national grid. In this chapter, the simulations will be discussed which were carried out using MGET-SIM. The purpose of testing, the effects of various factors, their simulations and their results will be discussed in detail.

3.1 Cases for Simulations

After the development of software, several cases were designed. The purpose of these cases was to not only to simulate electricity trading among microgrids but also to check how microgrids may behave under the influence of different factors, and the potential benefits of having such a system. After the simulation of all these cases, the ideal case was designed and simulated, which is based on conditions where microgrids are best utilized.

Each case has its own purpose, simulation and results. The cases are designed to understand the effects of following factors:

- Effect of number of microgrids
- Effects of variability in sizes
- Effect of equipment failures
- Effect of renewable energy intermittence
- Effect of separate price plans for peak/off-peak timings

3.2 Goodness Parameters

For each factor, three parameters shall be evaluated to test how good the proposed microgrid electricity trading system is working in each case. These parameters are as follows:

3.2.1 Electricity Wasted in the Microgrids Electricity Pool

This is the percentage of electricity that has been wasted out of the total electricity generated. It is calculated using the below formula:

$$\text{Electricity wasted in the pool (\%)} = \left[1 - \frac{\text{Electricity consumed from the pool}}{\text{Electricity generated in the pool}} \right] \times 100$$

3.2.2 Economic Loss

It is a factor that is specific to the microgrid whose data is provided as the seed to MGET-SIM. It represents the percentage of the difference of amount this microgrid has to pay for the electricity it imports in present system to the amount it would have to pay in the new microgrid electricity trading system. It is calculated using the below formula:

$$\text{Economic Loss (\%)} = \left[1 - \frac{\text{income (old system)} - \text{income (new system)}}{\text{income (old system)}} \right] \times 100$$

A negative sign in economic loss % would mean additional economic benefit a microgrid is earning with the new system after paying for its electricity imports. For example, 10% economic loss means the microgrid had to pay only 10% of the amount now in the new system than it had to pay in the previous system with no electricity trading taking place among the microgrids. In case of negative values of economic loss, like a -30% economic loss, it would mean that the microgrid did not only pay for all its imports but also earned an additional 30% of that amount that it actually had to pay for its imports.

3.2.3 Electricity Imported from the National Grid

It represents the percentage of total electricity imported from the national grid by all of the microgrids in the system out of their total consumption. Electricity is imported from the national grid whenever the microgrids' electricity pool is unable to meet the demands. It is calculated using the below formula:

$$\text{Electricity import from national grid (\%)} = \left[\frac{\text{Total import from national grid}}{\text{Total consumption}} \right] \times 100$$

3.3 Simulations & Results

The cases were designed in such a way as to test each factor one by one. Like when effect of number of microgrids is being checked, the other factors are not considered at that time.

3.3.1 Effect of Number of Microgrids

There were four simulations run to check the effect of number of microgrids on a microgrid electricity trading system. The three cases are presented in table.6.

Electricity wasted in the Pool

It was observed that increasing the number of microgrids in the system would decrease the amount of electricity wasted in the microgrids' electricity pool. Table.7

Inputs	**Case 1**	**Case 2**	**Case 3**	**Case 4**
Number of Dummy Microgrids	3	10	50	100
Total Microgrids	4	11	51	101
Variability in Size	medium	medium	medium	medium
Equipment Failure Factor	No	No	No	No
Renewables Intermittence Factor	No	No	No	No
Different Peak/Off-Peak Rates	No	No	No	No
National Grid Electricity Price (pence/kWh)	10	10	10	10
Microgrids Electricity Price (pence/kWh)	7	7	7	7
*Note: the electricity prices are assumed values which could be different, but kept constant throughout this thesis.				

Table.6 – Cases to Check the Effect of Number of Microgrids

and figure.9 gives a clear picture of the simulation results.

From the statistics presented in table.7 and the trend shown in figure.9, it was seen that electricity wastage was high i.e. 96% in case of very few microgrids. However, with the increasing number of microgrids, the reduction in electricity wastage is steady. It shows that a system with at least 10 microgrids seems to function reasonable, and it was concluded that electricity wastage reduces by increasing the number of microgrids in the system.

Case	**N**	**Electricity wasted in the Pool**
1	3	96%
2	10	86%
3	50	82%
4	100	78%

Table.7 – Electricity Wastage Results of Number of Microgrids Cases

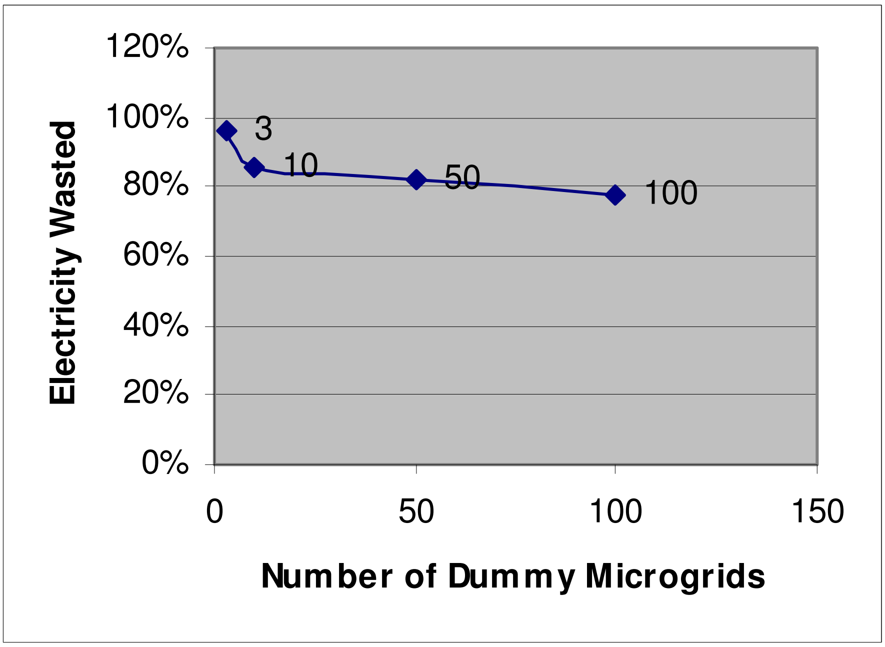

Figure.9 – Electricity wasted vs. Number of Dummy Microgrids

Economic Loss

It was observed that increasing the number of microgrids in the system would decrease the economic loss of the given microgrid. Table.8 and figure.10 give a clear picture of the simulation results.

Case	N	Economic Loss
1	3	60%
2	10	48%
3	50	46%
4	100	42%

Table.8 – Economic Loss Results of Number of Microgrids Cases

From the statistics presented in table.8 and the trend shown in figure.10, it was concluded that similar to electricity wastage, economic loss decreases by a good amount as the number of microgrids are increased. The fact is, as there are more

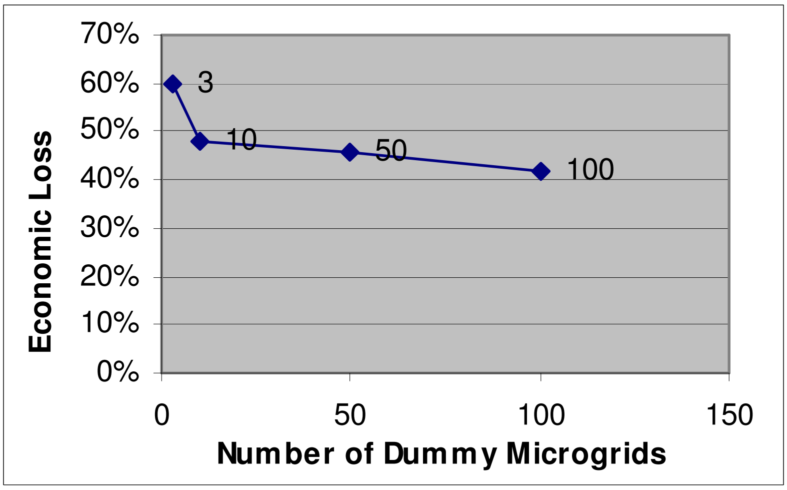

Figure.10 – Economic Loss vs. Number of Dummy Microgrids

microgrids available in the system, more electricity of the given grid will be consumed thus increasing its economic benefits. Figure.10 shows that at least 10 microgrids will improve the system by reducing significant amount of economic loss.

Electricity imported from the National Grid

It was observed that increasing the number of microgrids in the system would produce a significant decrease in electricity imports from the national grid. It was shown that having more and more microgrids in the system make them rely less on the public electricity from national grid and more on each other thus getting cheaper electricity. Table.9 and figure.11 give a clear picture of the simulation results.

Case	N	Electricity imported from the National Grid
1	3	86%
2	10	51%
3	50	36%
4	100	28%

Table.9 – Electricity import Results of Number of Microgrids Cases

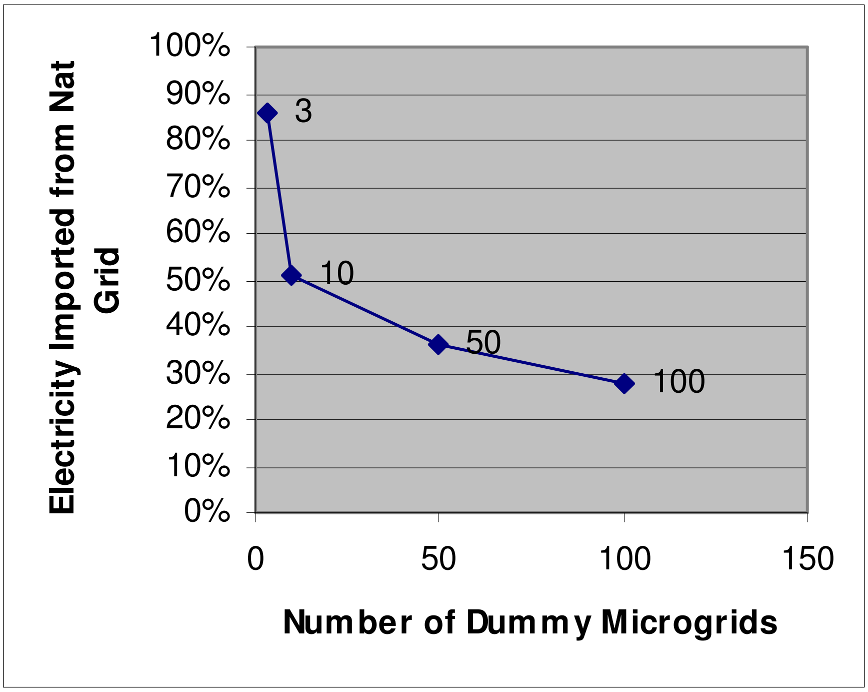

Figure.11 – Electricity import vs. Number of Dummy Microgrids

From the statistics presented in table.9 and the trend shown in figure.11, it was seen that the electricity imports from national grid were decreased by a good amount i.e. more than one thirds as the number of dummy microgrids were increased from 3 to 10. Even after that, increasing the number of microgrids further decreased electricity imports from national grid at a good rate as can be seen in figure.11.

From the results of above four cases that checked the effect of number of microgrids on the microgrids' electricity trading system, it was found that increasing the number of microgrids is important to make the effective use of system, with at least 10 microgrids available every time. Also, in the next cases to check other factors, 10 microgrids will be taken in the simulations consistently.

3.3.2 Effects of Variability in Sizes

Three simulations were carried out to check the effect of variability in microgrids' sizes on a microgrid electricity trading system. The details of these cases have been presented in table.10.

Inputs	Case 1	Case 2	Case 3
Number of Dummy Microgrids	10	10	10
Total Microgrids	11	11	11
Variability in Size	low	medium	High
Equipment Failure Factor	No	No	No
Renewables Intermittence Factor	No	No	No
Different Peak/Off-Peak Rates	No	No	No
National Grid Electricity Price (pence/kWh)	10	10	10
Microgrids Electricity Price (pence/kWh)	7	7	7
*Note: the electricity prices are assumed values which could be different, but kept constant throughout this thesis.			

Table.10 – Cases to Check the Effect of Variability in Size

As in previous cases, the factors other than variability in size were either not considered, or kept constant.

Electricity wasted in the Pool

It was observed that as the variability in sizes of microgrids increased, the amount of electricity in the microgrids' electricity pool was less wasted. It showed that if there are large variations in the generation and demand of electricity, more of microgrids' electricity will be consumed. Table.11 and figure.12 give a clear picture of the simulation results.

From the statistics presented in table.11 and the trend shown in figure.12, a linear decrease was observed in the electricity wastage as the variability in size of microgrids was increased.

Case	Variability	Electricity wasted in the Pool
1	low	91%
2	medium	86%
3	high	81%

Table.11 – Electricity wastage Results of Variability in Size Cases

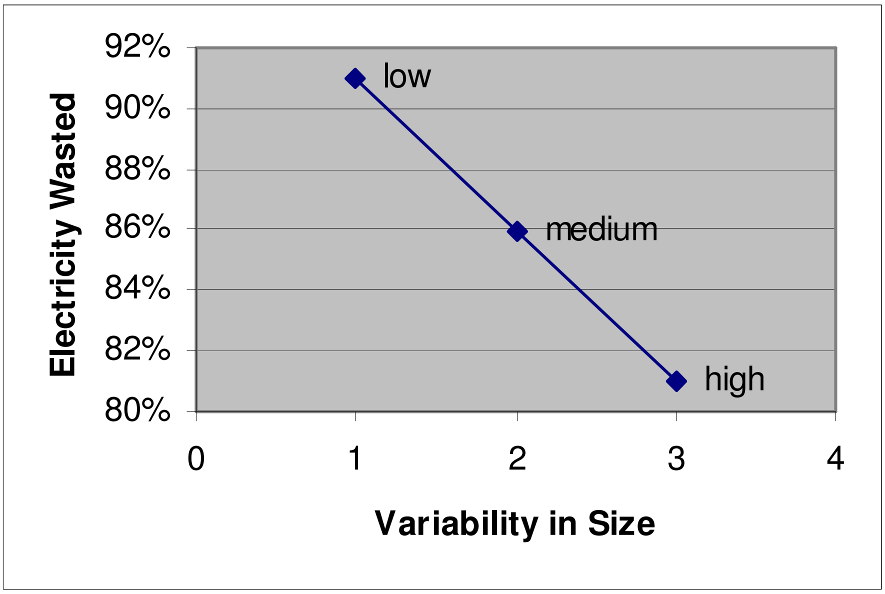

Figure.12 – Electricity wasted vs. Variability in Size

Economic Loss

It was observed that increasing the variability in size of microgrids decreased the economic loss of given microgrid. This must be due to the fact that higher demands are available for given microgrid's electricity as variability increases. Table.12 and figure.13 give a clear picture of the simulation results.

From the statistics presented in table.12 and the trend shown in figure.13, it was concluded that the economic loss decreased as the variability in sizes was increased. The economic loss of the given grid decreased even sharply as the variability in size was changed from 'medium' to 'high'.

Case	Variability	Economic Loss
1	Low	59%
2	Medium	48%
3	High	35%

Table.12 – Economic Loss Results of Number of Microgrids Cases

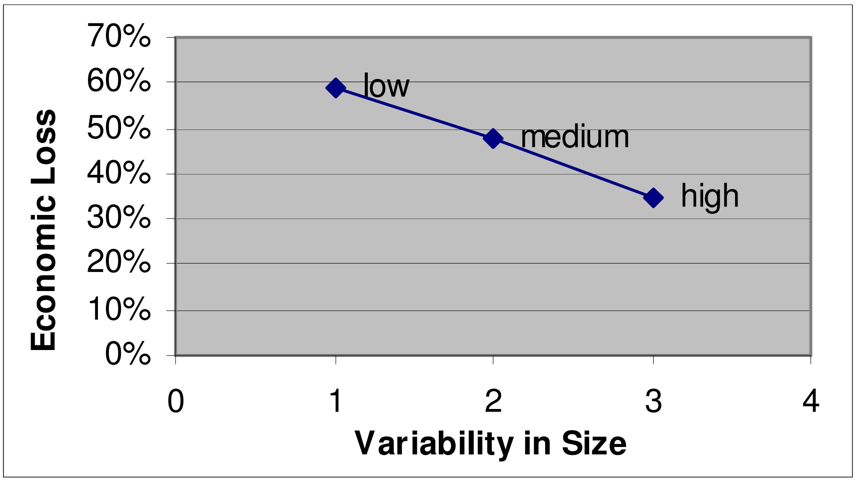

Figure.13 – Economic Loss vs. Variability in Size

Electricity imported from the National Grid

It was observed that increasing the variability in size will affect the electricity import from the national grid by a little amount, and it can either increase or decrease as the increasing variability is both in the electricity demand and generation of the micrograms. Table.13 and figure.14 give a clear picture of the simulation results.

Case	Variability	Electricity imported from the National Grid
1	low	49%
2	medium	51%
3	high	44%

Table.13 – Electricity import Results of Variability in Size Cases

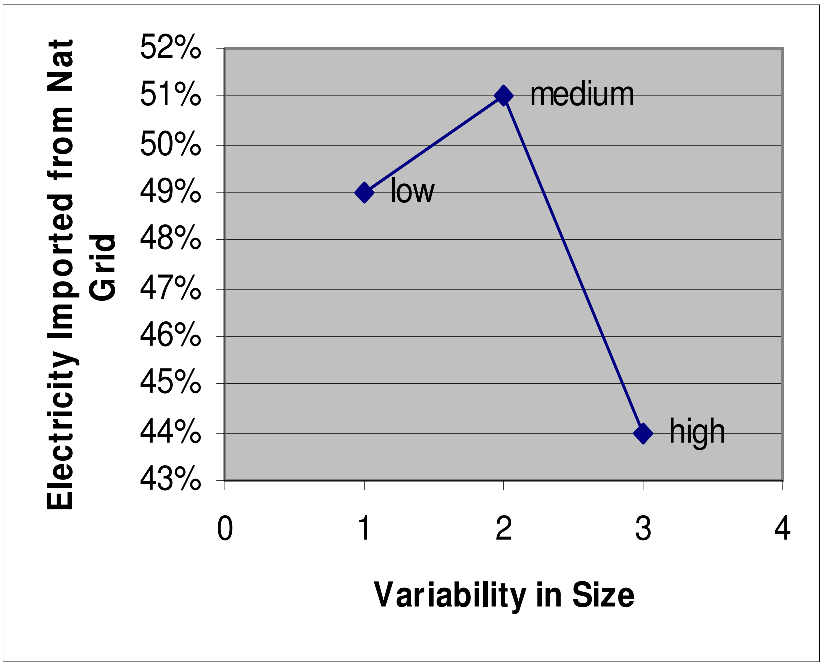

Figure.14 – Electricity import vs. Variability in Size

From the statistics presented in table.13 and the trend shown in figure.14, it was concluded that electricity imports from the national grid can go in either upward or downward direction with increasing variability in sizes of microgrids. The reasons may be that, sometimes this factor can increase the demand which will be higher than availability of electricity in microgrids' electricity pool so the electricity will be imported from the national grid's supply. On the other side, this factor can also increase electricity supply resulting in less electricity imports from the national grid.

3.3.3 Effect of Equipment Failure

There were two simulations performed to check the effect of considering equipment failure factor on the microgrids' electricity trading system. The details of the two cases have been presented in table.14.

<u>**Inputs**</u>	<u>**Case 1**</u>	<u>**Case 2**</u>
Number of Dummy Microgrids	10	10
Total Microgrids	11	11
Variability in Size	medium	Medium
Equipment Failure Factor	No	Yes
Renewables Intermittence Factor	No	No
Different Peak/Off-Peak Rates	No	No
National Grid Electricity Price (pence/kWh)	10	10
Microgrids Electricity Price (pence/kWh)	7	7
*Note: the electricity prices are assumed values which could be different, but kept constant throughout this thesis.		

Table.14 – Cases to check the Effect of Equipment Failure

As in previous cases, the factors other than equipment failure factor were either not considered, or kept constant.

Electricity wasted in the Pool

It was observed that considering equipment failure factor in the microgrids resulted in an increase in electricity consumption and decrease in electricity wastage. It was due to the fact that that when a microgrid went down because of equipment failure or any other reasons, the demand was still there thus increasing the amount of electricity consumption from the microgrids' electricity pool. Table.15 and figure.15 give a clear picture of the simulation results.

Case	**E,F.F**	**Electricity wasted in the Pool**
1	No	86%
2	Yes	82%

Table.15 – Electricity wastage Results of Equipment Failure Cases

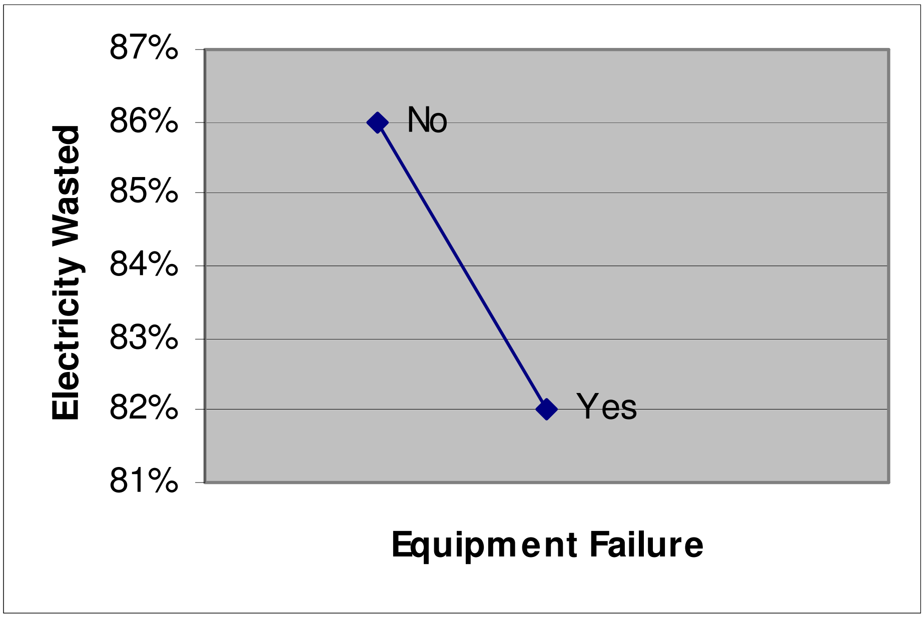

Figure.15 – Electricity wasted vs. Equipment Failure

From the statistics presented in table.15 and the trend shown in figure.15, it was concluded that there was a valuable decrease i.e. 4% in electricity wastage by considering the equipment failure factor.

Economic Loss

It was observed that considering equipment failure factor resulted in reduction in economic loss of the given grid. The economic loss of the given grid was reduced by half the amount when equipment failure factor was considered. Table.16 and figure.16 give a clear picture of the simulation results.

Case	E,F.F	Economic Loss
1	No	48%
2	Yes	24%

Table.16 – Economic Loss Results of Equipment Failure Cases

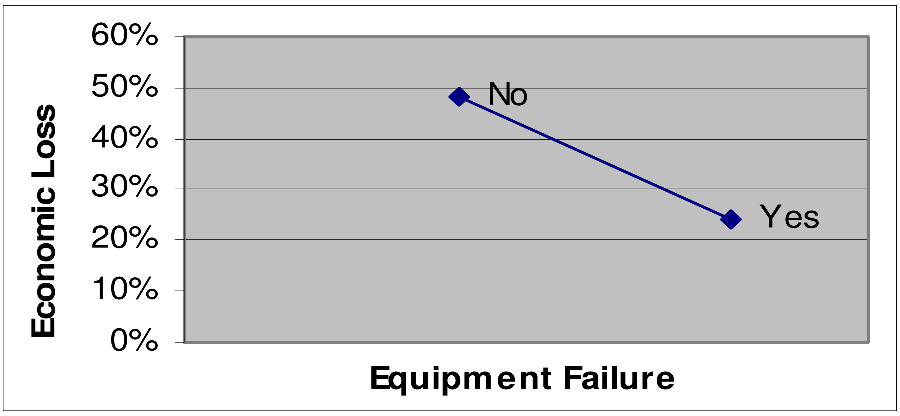

Figure.16 – Economic Loss vs. Equipment Failure

From the statistics presented in table.16 and the trend shown in figure.16, it was concluded that economic loss of the given grid reduces by considering equipment failure factor. The reason of this reduction is that, when some of the microgrids are not available, the share of the given grid in the microgrids' electricity pool becomes larger than usual. Another reason is that there is increased demand of its electricity than normal as there is less supply in the market, thus its economic loss decreases.

Electricity imported from the National Grid

It was observed that considering equipment failure factor results in a 2% increase in the electricity imports from the national grid. The electricity imports from the national grid increased just by 2% showing increased demand of electricity from the microgrids. Table.17 and figure.17 give a clear picture of the simulation results.

Case	**E,F.F**	**Electricity imported from the National Grid**
1	No	51%
2	Yes	53%

Table.17 – Electricity import Results of Equipment Failure Cases

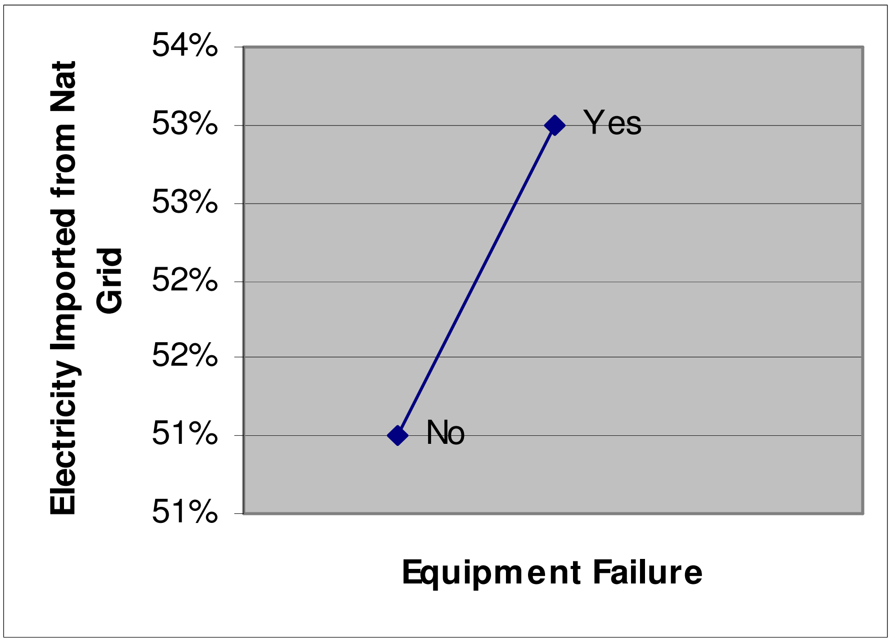

Figure.17 – Electricity import vs. Equipment Failure Case

From the statistics presented in table.17 and the trend shown in figure.17, it is evident that electricity imports from the national grid increase by a small amount i.e. 2% when equipment failure factor was considered. The reason for this increase is that there was less energy in the microgrids' electricity pool than usual due to some microgrid failures, but the demands were the same, and so this energy shortage was dealt by importing electricity from the national grid. So it was concluded that if the equipment failures increase due to any reason, then the electricity imports from the national grid will further increase.

3.3.4 Effect of Renewable Energy Intermittence

There were two simulations run to check the effect of renewable energy intermittence factor on the microgrids' electricity trading system. The details of these two cases have been given in table.18.

Inputs	**Case 1**	**Case 2**
Number of Dummy Microgrids	10	10
Total Microgrids	11	11
Variability in Size	medium	Medium
Equipment Failure Factor	No	No
Renewables Intermittence Factor	No	Yes
Different Peak/Off-Peak Rates	No	No
National Grid Electricity Price (pence/kWh)	10	10
Micrograds Electricity Price (pence/kWh)	7	7
*Note: the electricity prices are assumed values which could be different, but kept constant throughout this thesis.		

Table.18 - Cases to check the Effect of Renewables Intermittence

As in previous cases, the factors other than renewables intermittence factor were either not considered, or kept constant.

Electricity wasted in the Pool

It was observed that considering renewables intermittence factor resulted in a 7% decrease in electricity wastage from the microgrids' electricity pool as more electricity from the pool was consumed by the microgrids. Table.19 and figure.18 give a clear picture of the simulation results.

Case	**R.I.F**	**Electricity wasted in the Pool**
1	No	86%
2	Yes	79%

Table.19 – Electricity wastage Results of Renewables Intermittence Cases

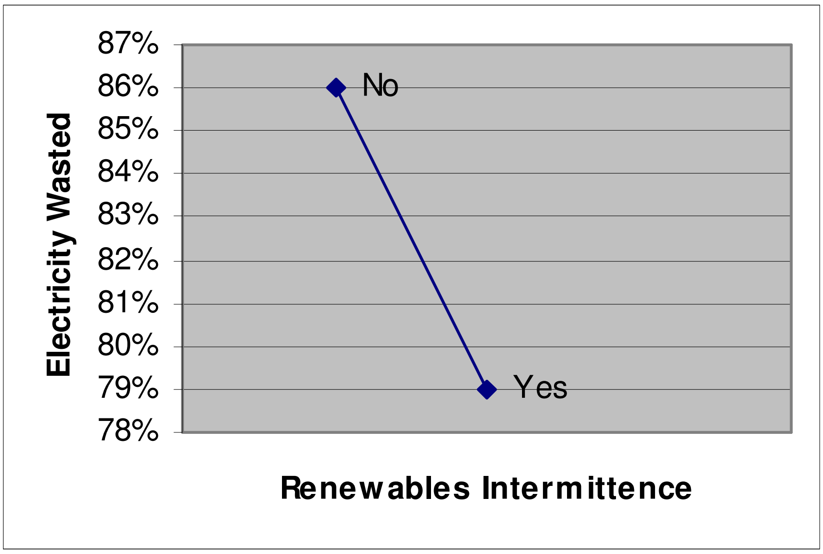

Figure.18 – Electricity wasted vs. Renewables Intermittence

From the statistics presented in table.19 and the trend shown in figure.18, it was concluded that electricity wastage from the microgrids' electricity pool is reduced by considering renewables intermittence factor. There was less electricity supply due to the intermittence of renewable sources but the demand was still as usual, so the consumption of microgrids' electricity increased thus resulting in a decrease in electricity wastage.

Economic Loss

It was observed that the economic loss of the given microgrid reduced from 48% to 10% by considering renewables intermittence. The difference was 38% which is not just a small reduction. Table.20 and figure.19 give a clear picture of the simulation results.

Case	R.I.F	Economic Loss
1	No	48%
2	Yes	10%

Table.20 – Economic Loss Results of Renewables Intermittence Cases

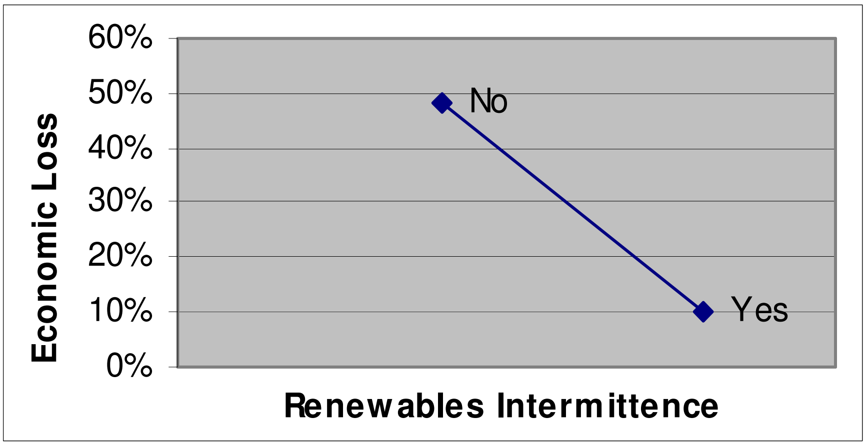

Figure.19 – Economic Loss vs. Renewables Intermittence

From the statistics presented in table.20 and the trend shown in figure.19, it was concluded that economic losses of the given microgrid decrease steeply when renewables intermittence factor is considered. The reason of this benefit for the given microgrid is the increased share of its electricity in the microgrids' electricity pool.

Electricity imported from the National Grid

It was observed that considering renewables intermittence factor resulted in increased imports of electricity from the national grid. The 12% rise in electricity imports from the national grid showed a major increase. Table.21 and figure.20 give a clear picture of the simulation results.

Case	R.I.F	Electricity imported from the National Grid
1	No	51%
2	Yes	63%

Table.21 – Electricity import Results of Renewables Intermittence Cases

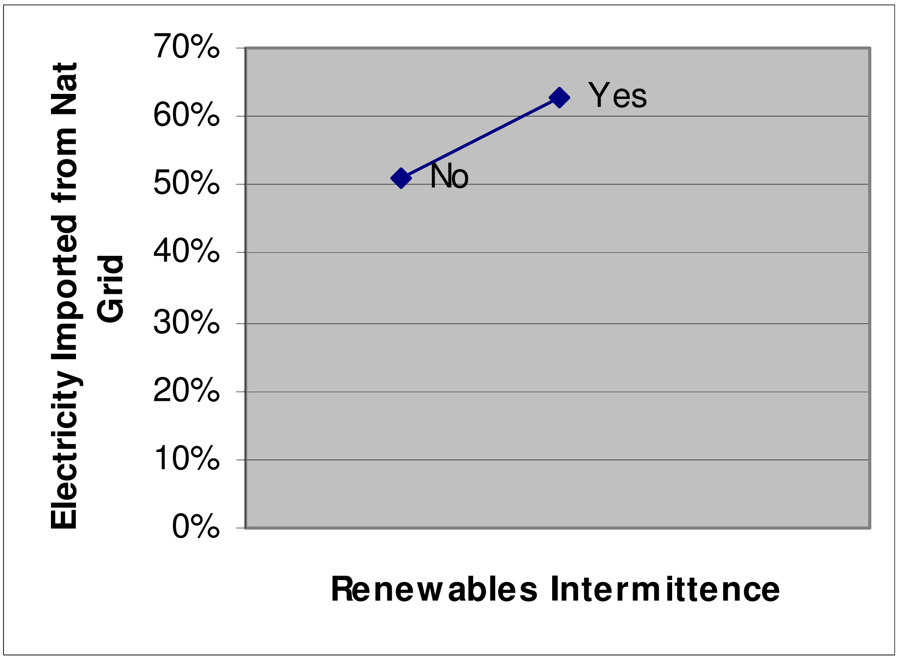

Figure.20 – Electricity import vs. Renewables Intermittence

From the statistics presented in table.21 and the trend shown in figure.20, it was concluded that electricity imports from the national grid increase when renewables intermittence factor is considered. The reason for this increase is that, it was assumed for this system that every microgrid has some share of its electricity generated from renewables. So considering renewables intermittence factor caused reductions in electricity generation from most of the microgrids in the system and increased imports from the national grid.

3.3.5 Effect of Separate Price Plans for Peak/Off-Peak Timings

There were two simulations run to check the effect of considering different peak and off-peak rates in a microgrid electricity trading system. The details of these simulations have been given in table.22.

As in previous cases, the factors other than peak/off-peak rates were either not considered, or kept constant.

Inputs	**Case 1**	**Case 2**
Number of Dummy Micrograds	10	10
Total Microgrids	11	11
Variability in Size	medium	Medium
Equipment Failure Factor	No	No
Renewables Intermittence Factor	No	No
Different Peak/Off-Peak Rates	No	Yes
National Grid Electricity Price (pence/kWh)	10	10
Micrograds Electricity Price (pence/kWh)	7	7
*Note: the electricity prices are assumed values which could be different, but kept constant throughout this thesis.		

Table.22 – Cases to Check the Effect of Separate Price Plans

Hence this factor only affects the economic aspects of the system, so only economic losses were observed to compare the system behaviours in the two simulations.

Economic Loss

It was observed that considering different peak and off-peak rates resulted in a significant increase in the economic losses of the given microgrid. There was a rise of 11% in the economic loss when different rates were considered. Table.23 and figure.21 give a clear picture of the simulation results.

Case	D.N.P	Economic Loss
1	Yes	48%
2	No	37%

Table.23 – Economic Loss Results of Separate Price Plans Cases

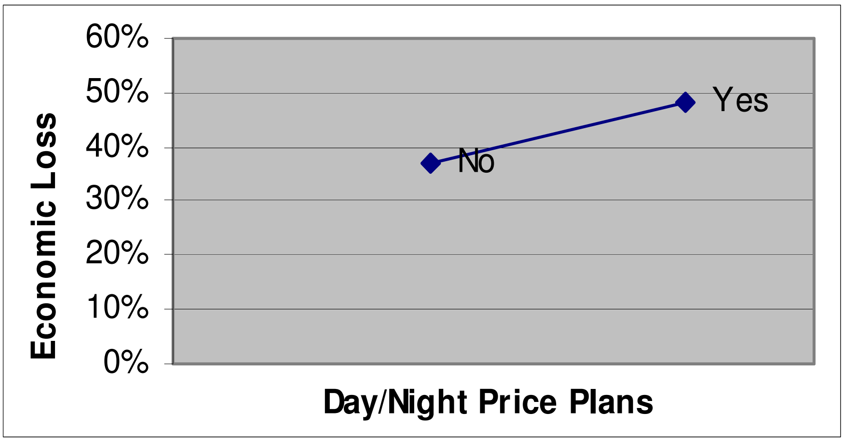

Figure.21 – Economic Loss vs. Day/Night Separate Price Plans

From the statistics presented in table.23 and the trend shown in figure.21, it was concluded that economic loss of the given microgrid increase by considering separate price plans. The reason behind this increase is that electricity is available to the microgrid at cheaper rates in the times when it already has excess electricity, and so its electricity is sold through the pool at lower rates than normal. In the times when the given microgrid had a demand, there were no reductions in the rates.

3.3.6 A Case Designed on the Basis of All Previous Results

On the basis of observations from all the previous simulations, a new case was designed. The specifications of input data for the simulation were based on conclusions from previous simulations. The case specifications are given in table.24.

The results from this simulation will reflect how the microgrids' electricity trading system would work in reality with a number of microgrids in the system, having high variability in their sizes. Some of the microgrids may go down due to equipment failure, and the electricity generation from these microgrids will also be affected by the intermittence of their renewable sources. Different peak and off-peak rates were not considered in this case to ensure that economic benefits of the given microgrid are not reduced.

Inputs	**Case**
Number of Dummy Microgrids	100
Total Microgrids	101
Variability in Size	High
Equipment Failure Factor	Yes
Renewables Intermittence Factor	Yes
Different Peak/Off-Peak Rates	No
National Grid Electricity Price (pence/kWh)	10
Microgrids Electricity Price (pence/kWh)	7
*Note: the electricity prices are assumed values which could be different, but kept constant throughout this thesis.	

Table.24 - Final Case

The results of the final case can give a better picture of how electricity trading among microgrids in the real world could be. The results of the goodness parameters are now given. Also refer to Figure.22 which shows the results comparison.

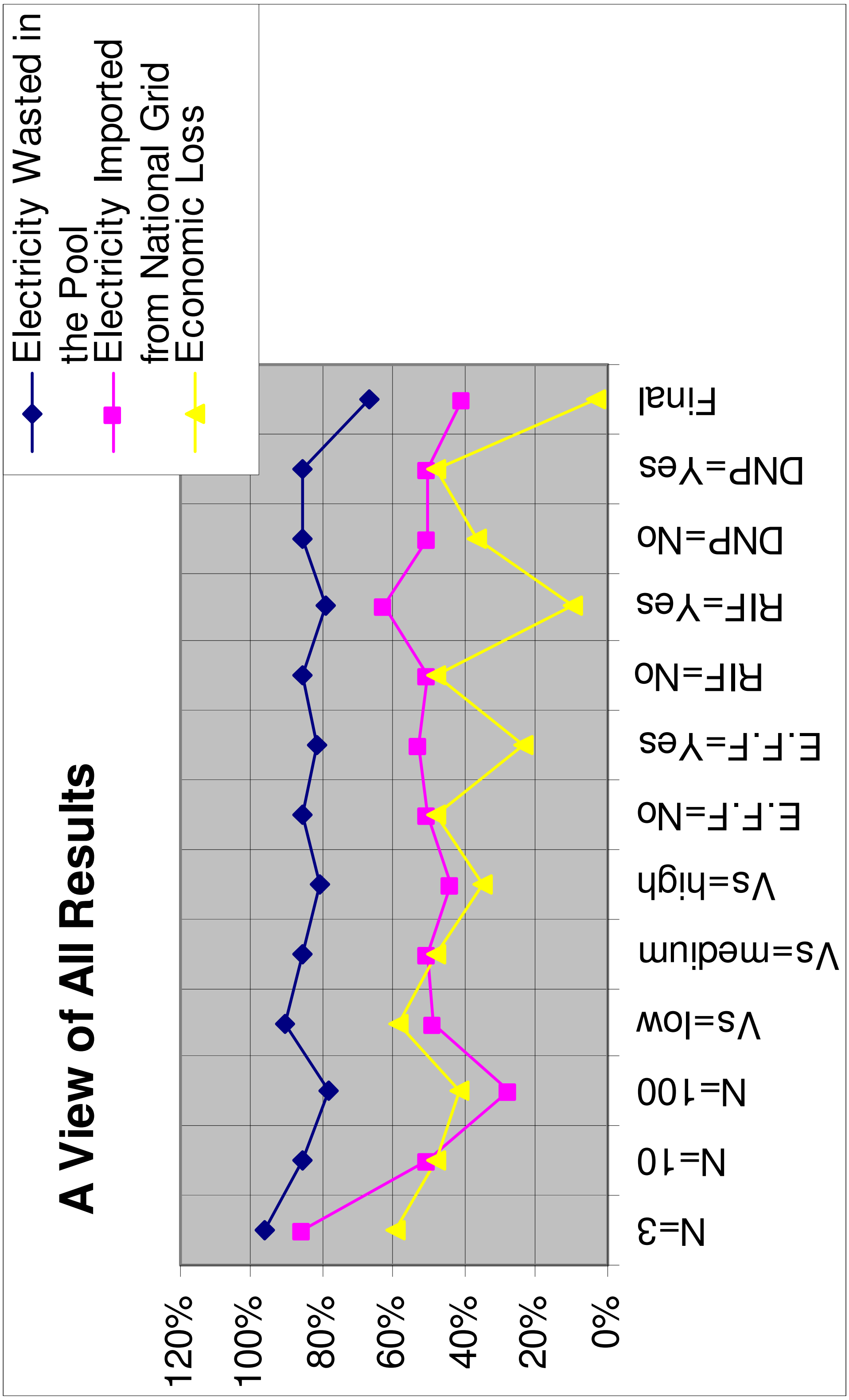

Figure.22 - Results Comparison

Electricity wasted in the Pool

It was observed that, as expected, least electricity was wasted in the last case i.e. 67%. It showed that with a real microgrids' electricity trading system, with size variability, equipment failures, renewables intermittence and large number of microgrids, electricity wastage would be reduced and most of the amount of electricity generated from the a microgrid will be consumed by other microgrids. It was also concluded from the results that by increasing the number of microgrids in the system and raising the variability in their sizes, the electricity wastage can further be reduced.

Economic Loss

The least figure of economic loss of the given grid was observed in the final case. It was observed that only 3% economic losses occurred when simulated with the specifications in the last case. From this and all the previous results, it was also concluded that economic benefits can be increased further with more microgrids in the system, higher variability in their sizes, with normally occurring equipment failures and renewables intermittence. Day and night separate price plans can also benefit a microgrid if the prices are lower in such timings when its generation is less than its own demand, so it could buy electricity at cheaper prices.

Electricity imported from the National Grid

In the last case, only 41% of the total energy demand was imported from the national grid which was better than most of the previous cases. This was the second lowest value in the whole bunch of simulations performed for this thesis. The only value lower than this was 28% which was obtained when simulation was performed only to check the effect of number of microgrids with 100 microgrids in the system, but other important factors like renewables intermittence and equipment failure were not considered, and the variability in microgrids' sizes was also medium in that simulation. So it was concluded that in a realistic picture, similar to the final case, the electricity imports for microgrids from the national grid can be lesser than half of their total demand.

From all the simulations and results, valuable information was obtained. This information is aimed to be used to make useful conclusions in the next chapter.

Chapter FOUR: CONCLUSIONS & FUTURE WORK

In the previous chapters, possible solutions were discussed to meet the latest challenges to the energy industry. Microgrids, a community level embedded generation system, were highlighted and the need to simulate electricity trading among them was identified. As part of this thesis, the software MGET-SIM was developed to simulate electricity trading among microgrids through the national grid. Different cases were designed to check various aspects of the proposed electricity trading system, and simulated using the software MGET-SIM. The obtained results were presented in the form of tables and graphs, and discussed in detail. In this chapter, the answers to the related hypotheses are presented in the light of simulations' results. The next in this chapter are the overall conclusions obtained from this research based project. In the last part of this chapter, some future work has been proposed.

5.1 Is electricity trading possible among microgrids?

Yes, electricity trading is possible among microgrids. As discussed in the previous chapter, there were over 100 simulations performed (including the cases for the given microgrid data, use of different seeds, different validations, etc) and the electricity was traded successfully in each case. The random nature of size variability in the whole system, renewables intermittence and equipment failures were considered separately and then together, and they were not found capable to stop the trading in any case. It can also be assumed that like electricity, low grade heat energy could also be traded using the same concept.

5.2 Is every demand satisfied?

Yes. As the results of simulations prove, every demand was satisfied. Their source of electricity was preferably a microgrid through the electricity pool, which served the demands in most of the cases, and otherwise the demand was satisfied from the national grid's public electricity supply. So every microgrid had more security of supply, by having two sources of electricity, the microgrids' electricity pool and the national grid.

5.3 Does it economically benefit a microgrid?

As the economic loss of given microgrid was calculated in every simulation, it was observed that the microgrid benefited economically in every case. Looking at the simulation results, it was also concluded that economic benefits can be increased further by increasing number of microgrids in the system, higher variability in their sizes, with normally occurring equipment failures and renewables intermittence. Day and night separate price plans could also benefit a microgrid if prices are lower in such timings when its generation is less than its own demand so it could buy electricity at cheaper prices.

In the model used to check the economic benefits from this system, the inputs were only the electricity selling and buying prices. However, in the future, this model could further be improved by using advanced economic models with short and long marginal costs. Also, as mentioned earlier in section 2.1.7, a detailed economic evaluation of similar system was done by Zoka et al [16] who considered installation, operation, microgrid construction and power interruption costs.

5.4 Will it work with 'N' number of microgrids?

In the cases presented in this thesis, it was shown that the system worked successfully with up to 100 dummy microgrids. However, in the validation simulations, the software worked successfully with 1000 dummy microgrids which is its present limit.

But as pointed out earlier in section 2.1.2, the software has the capability to simulate any given ‘N’ number of microgrids with some modification in its source code. The simulation results showed a better performance by the system when the number of dummy microgrids was increased, so it was concluded that by increasing number of microgrids, the performance of the system improves.

5.5 Does the simulator work with different supply & demand data sets?

Yes, as software testing results showed, it can work with any microgrid data given as seed. By the microgrid data, a data set is meant with a reasonable electricity demand as well as electricity generation. The software takes hourly values for a day for a microgrid’s electricity generation and demand and these two values in each hour must represent a 24 hours functional microgrid data.

5.6 Overall Conclusions

In the beginning of this thesis, the need was identified to simulate electricity trading among the microgrids as they appear to be a promising solution for increasing the security of supply, reliability of community based energy systems and penetration of low voltage renewable energy systems into the distribution system, thus reducing the share of depleting fossils in the energy markets and the hazardous emissions. Assumptions were made about some impeding issues and the simulator MGET-SIM was developed. Several simulations were performed to check the effects of different factors on microgrids electricity trading system and its behaviour. The main conclusions obtained from these simulations are as follows:

- Electricity is tradable among the microgrids. The stochastic nature of variable sizes of microgrids in the whole system, renewables intermittence and equipment failures can not fail the trading system in any case.

- Availability of multiple external sources of electricity, like the microgrids' electricity pool and national grid public electricity supply, increase the security of supply. Every demand was satisfied when simulated.
- Trading electricity among the microgrids is economically beneficial for them, as the microgrids can sell their excess electricity to earn money, and buy cheap electricity from the electricity pool when they have electricity demand.
- Electricity consumption can be increased from the microgrids' electricity pool by increasing the number of microgrids in the system with high variability among their generation and demand capacities. Equipment failures and renewables intermittence increase the overall electricity demand and thus consumption from the microgrid electricity pool also increases.
- Equipment failures and renewables intermittence are the factors that increase the imports from national grid's public electricity supply. Microgrids, when having electricity demand, can rely less on national grid's public electricity supply pool by increasing the number of microgrids in the system.
- Separate price plans for peak and off-peak timings are beneficial for a microgrid only in the case where the microgrid has electricity demand when the prices are off-peak i.e. low.
- The simulator MGET-SIM is useful with any given electricity generation and demand data set of a microgrid.

5.7 Future Work

In this little span of time, maximum efforts have been put to develop a useful tool to simulate electricity trading among microgrids. However, due to lack of time, some useful ideas still remain ideas and need to be worked on to support further developments in this much needed area. These ideas have been presented below.

5.7.1 Additions in the Software

5.7.1.1 Energy Storage

As pointed out at some instances in this thesis, a much need requirement of the microgrids in future will be to store energy. This energy could either be used by the microgrid itself or exported later. The energy could be stored using batteries, pumped storage, compressible gases, etc. A good choice will be to store energy and then use it to generate heat or electricity as per the demand. This will not only improve the microgrid economically but environmentally as well.

5.7.1.2 Demand Only Consumers

In the present version of MGET-SIM, the trading is done among the microgrids or between national grid and microgrids. However, in future versions, the 'demand only' consumers like a house, a shop, etc. could be introduced. The electricity from the electricity pool of microgrids could be sold to the ordinary electricity consumers through the national grid.

5.7.1.3 'N' Number of Real Data Sets

For this thesis, the seed to the software was a pseudo microgrid data set. When the real microgrid projects like those discussed in chapter.1 become functional, their real time data sets could be used as seed to the software. Another idea is to have N seeds of real data sets to the software and simulate electricity trading among them.

5.7.1.4 Simultaneous Trading of Heat and Electrical Energy

Hence MGET-SIM is an energy trading simulator, so it can also be used to simulate trading of heat energy among microgrids. A useful feature to add in MGET-SIM would be the simultaneous trading of electricity and heat energy among the microgrids.

5.7.1.5 Cost & Environmental Models

In this thesis, the economic aspects were limited to the selling and buying prices of electricity. In future, a bidding environment could be introduced like commodity trading. This feature may be integrated with the energy storage, so an intelligent microgrid could decide at what minimum price it could sell its electricity or store it otherwise. The detailed cost model could include the short and long marginal costs of the whole system. The environmental models could investigate the eco-performance of the microgrid and there could also be a rating system on the basis of environment friendliness of a microgrid.

5.7.1.6 DG in Stand-by

A microgrid could have the ability to predict through historic data if there will be no demand of its energy in the next timestamp, and shutdown part of its generating equipment or keep it in stand-by mode.

5.7.2 Policy & Legislation

To make the concept of electricity trading among microgrids a reality, there is need of concrete policies and necessary legislation from the governments. Market mechanisms are also required to support such a trading. It is a novel idea, and for new practices, financers do not like to take risks. As a first step, government has to issue reasonable funds so the research in this area could be supported and model microgrids could be made. Government needs to take at least the following steps

- Reduce the administration burdens and lengthy procedures
- Provide fundings and scholarships to promote research in this area
- Introduce incentives, subsidies and awards to promote microgrids. For example, the microgrid with lowest carbon footprint could be rewarded

- Ensure better communication between grid authorities and the microgrid owners
- Ensure the development of necessary infrastructure that is required to begin electricity trading among microgrids
- Aware the people how government is making it easier for them to build microgrids, and encourage them to build it.

In MGET-SIM, any requirements imposed by the government on microgrids could be made part of the simulator, to show how the microgrids behave to ensure they meet these requirements.

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Appendix.1

Source Code of MGET-SIM

```
/ / / / / / /  S T A R T / / / / / / /
#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,cost,costg,ghi,jk
l,mnop,inc[1000][24];
   if ((fp=fopen("mg1.txt", "r"))==NULL)
   {
      printf("Cannot open file.\n");
```

```
    }
    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)
```

```
    {
        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 micro-grids?\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);
    }
```

```
   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);
```

```
    }
// 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);
```

```
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)
```

```
{
    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)
{
```

```
    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)
{
```

```
        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)
```

```
    {
        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)
            {
```

```
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);
```

```
                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;
```

```
                }
            }
        }
        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;
```

```
    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;
}
/*
```

```
* 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
}

/ / / / / / /  F I N I S H / / / / / / /
```

Appendix.2

1. First the user has to copy a text file (should be named as mg1.txt) in the program folder. This text file contains the hourly generation/demand data of a microgrid (tab-separated values) for one day (i.e. 24 time-steps). Units are assumed as kWh. The data should be in a format like:

80.00 23.00 82.00 22.00 80.00 23.00 81.00 24.00

As an alternate option, the user can simply edit the already available mg1.txt file in the program folder with its own microgrid data.

2. The data is stored in an array 'mg[0] [48]'.

3. The user is asked for required number of dummy microgrids, say N. on the basis of user input, the program generates N number of array from mg[1] [48], mg[2] [48],… mg[N] [48]. At this moment, program is designed so it could generate up to 1000 microgrids. With little modification in the program, it could generate more.

4. The user is prompted for variability in size of dummy microgrids from the given microgrid: (1-low, 2-medium, 3-high)

- If 'low': the program generates a random number Vs. (Vs = 0.5~1.5)
- If 'medium': the program generates a random number Vs (Vs = 0.3~3.0)
- If 'high': the program generates a random number Vs (Vs = 0.1~10.0)

5. The user is asked if the impact of equipment failure is to be considered: (yes/no)

- If 'yes': the program generates a number 'eff' i.e. either '0' or '1'. (eff = 0.0 or eff = 1.0).. The Code has been modified in a way so it does not generate '0' very often.
- If 'no': the program always takes (eff = 1.0)

6. The user is asked if the intermittence of renewable energy sources is to be considered: (yes/no)

- If 'yes': the program generates a random number 'ref'. (ref = 0.7~1.0)
- If 'no': the program always takes (ref = 1.0)

7. The user is asked for the national grid electricity price in pence/kWh. It is given the name 'ngsp'.

8. The user is asked for the microgrid electricity price in pence/kWh. It is given the name ‘mgsp’.

9. The user is asked if the day/night price plan is to be considered (yes/no). The program folder contains two more files, dnp0.txt and dnp1.txt. These correspond to day/night price plans.

- If ‘yes’: the program makes an array ‘dnp[24]’ taking input from dnp1.txt.
- If ‘no’: the program makes an array ‘dnp[24]’ taking input from dnp0.txt.

10. Once the program has taken the required data from the user, it will generate values for each dummy microgrid in the mg[N][48] array in the following manner:

mg[N][0]=mg[0][0] x vs x eff x ref   Supply data of dummy grids
mg[N][2]=mg[0][2] x vs x eff x ref

mg[N][46]=mg[0][46] x vs x eff x ref

mg[N][1]=mg[0][1] x vs   Demand data of dummy grids
mg[N][3]=mg[0][3] x vs

Mg[N][47]=mgone[47] x vs

11. Now after all dummy microgrid arrays have been generated, a two dimensional array is generated which is trade[gn][gh], where gn corresponds to grid number and

gh corresponds to hour of the day. It is calculated by taking the difference of demand and supply in each hour in a grid.

trade [gn][gh] = (mg[gn][(gh*2)-2])-(mg[gn][(gh*2)-1])

12. If ‘trade [gn][gh]>0’, its value is added in the available electricity pool (exp) whose initial value is ‘0.0’ in every hour.

13. A random number ‘traderand’ is generated and if (trade[traderand][gh])<0), then the randomly selected grid’s demand shall be met from the pool. If the pool can not satisfy its demand, then its demand will be met from the national grid.