NTUA

MICROGRIDS
Large Scale Integration of
Micro-Generation to Low Voltage Grids

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MicroGrid Central Controller strategies and algorithms

Part 2 Software Description

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1. Introduction

This document describes the software developed for the deliverable DC1 "MicroGrid Central Controller strategies and algorithms" of the MICROGRIDS project. The scope of this software is to provide a flexible tool for the Microgrid Central Controller for the optimization of the Microgrid operation according to the "good citizen" policy under steady state security constraints and the load options described in the part 1 of this report.

The data are kept in a MS® Access Database created for this purpose in order not only to provide the desired flexibility in the design of the simulation tool but also programming robustness. The programming language used is MS® Visual Basic 6.A setup program for the installation of this software is prepared- as well as a presentation of the capabilities of the software-"MGCC Demo-Deliverable DC 1 v2.0.ppt".

The user can easily change the configuration of the Microgrid by the Human Machine Interface of the Simulation Tool as described in Section3. In the same way the characteristics of the units can be easily changed without affecting the execution of the algorithms. The capability of simulating different scenarios is provided to the end-users since they are able to change the Financial Constraints, or the offers of the microsources via friendly menus.

The algorithms used are described in Section 2 and Human Machine Interface in Section3. In Section 4 software installation guide lines are provided

2. Description of the algorithm and sub-routines used

2.1 Description of the algorithm

The input data for the simulation tool populate the database "MICROGRIDS.mdb", in which the forecasted demand, the offers from the microsources and the open market prices are kept. Before starting a new simulation the user can modify the configuration of the Microgrid, the data of the installed Micro Sources and the open market prices. The flow chart of the algorithm followed is shown in figure 2.1.
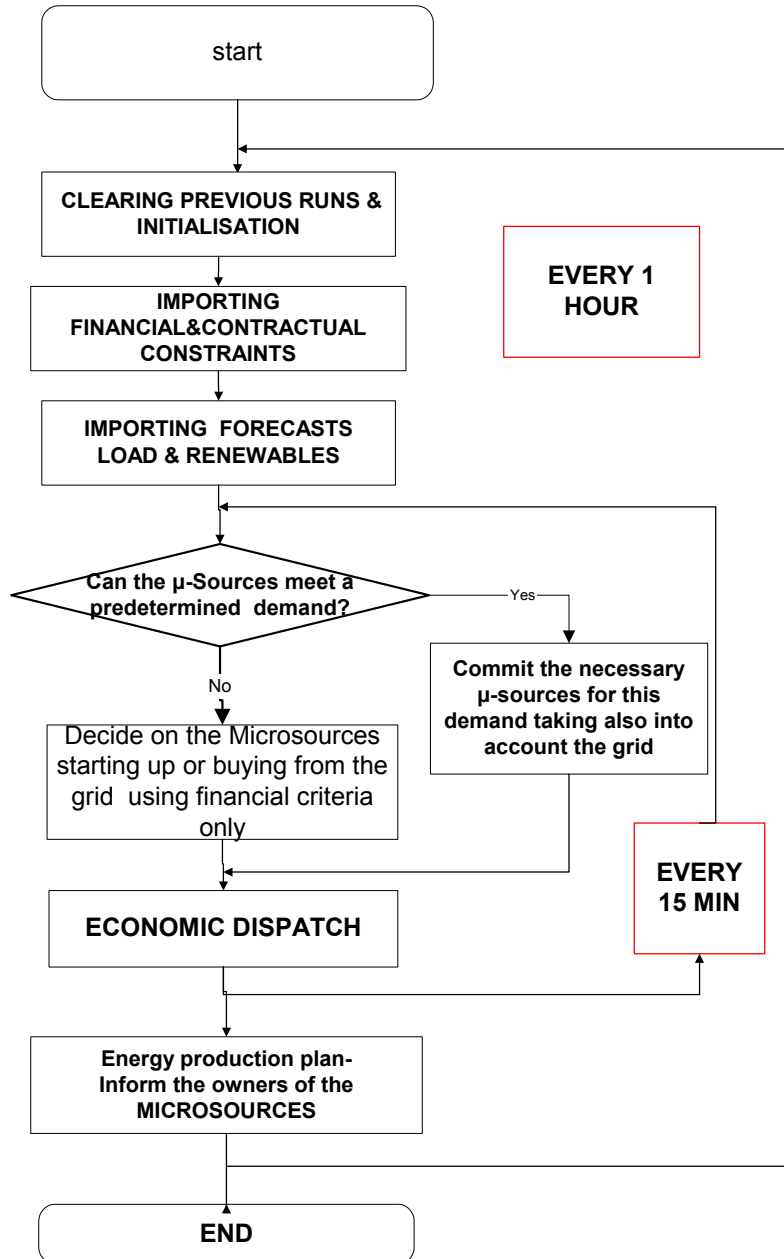

Figure 2.1 Flow chart of the Algorithm followed by MICROGRIDS Central Controller Prototype

```
                          ┌─────────────────────────┐
                          │          start          │
                          └─────────────────────────┘
                                      │
                                      ▼
              ┌──────────────────────────────┐        ┌──────────────────┐
              │  CLEARING PREVIOUS RUNS &     │        │                  │
              │       INITIALISATION          │        │  EVERY 1 HOUR    │
              └──────────────────────────────┘        │                  │
                                      │                └──────────────────┘
                                      ▼
              ┌──────────────────────────────┐
              │ IMPORTING FINANCIAL&CONTRACTUAL│
              │         CONSTRAINTS           │
              └──────────────────────────────┘
                                      │
                                      ▼
              ┌──────────────────────────────┐
              │    IMPORTING  FORECASTS       │
              │    LOAD & RENEWABLES          │
              └──────────────────────────────┘
                                      │
                                      ▼
              ┌──────────────────────────────┐
              │ IMPORTING DEMAND SIDE BIDS (DSBs)│
              └──────────────────────────────┘
                                      │
                                      ▼
                  ╱────────────────────────╲
                 ╱ Can the µ-Sources meet a  ╲  Yes
                 ╲ predetermined  demand?    ╱──────────┐
                  ╲────────────────────────╱            ▼
                              │ No              ┌──────────────────────┐
                              ▼                 │ Commit the necessary │
              ┌──────────────────────────────┐ │    µ-sources for this│
              │ Decide which Microsources will│ │ demand taking also into│
              │ start up, if active power will be│ account the grid and the│
              │ bought  from the grid and which│ │ demand side bidding  │
              │ DSBs will be accepted using   │ └──────────────────────┘
              │    financial criteria only    │
              └──────────────────────────────┘      ┌──────────────────┐
                              │                      │   EVERY          │
                              ▼                      │   15 MIN         │
              ┌──────────────────────────────┐      └──────────────────┘
              │ Update the  demand according  │
              │    to load bids accepted      │
              └──────────────────────────────┘
                              │
                              ▼
              ┌──────────────────────────────┐
              │    ECONOMIC DISPATCH          │
              └──────────────────────────────┘
                              │
                              ▼
              ┌──────────────────────────────┐
              │   Energy production plan-     │
              │   Inform the owners of the    │
              │ MICROSOURCESand the loads that│
              │      will be shed             │
              └──────────────────────────────┘
                              │
                              ▼
                  ┌─────────────────────────┐
                  │          END            │
                  └─────────────────────────┘
```
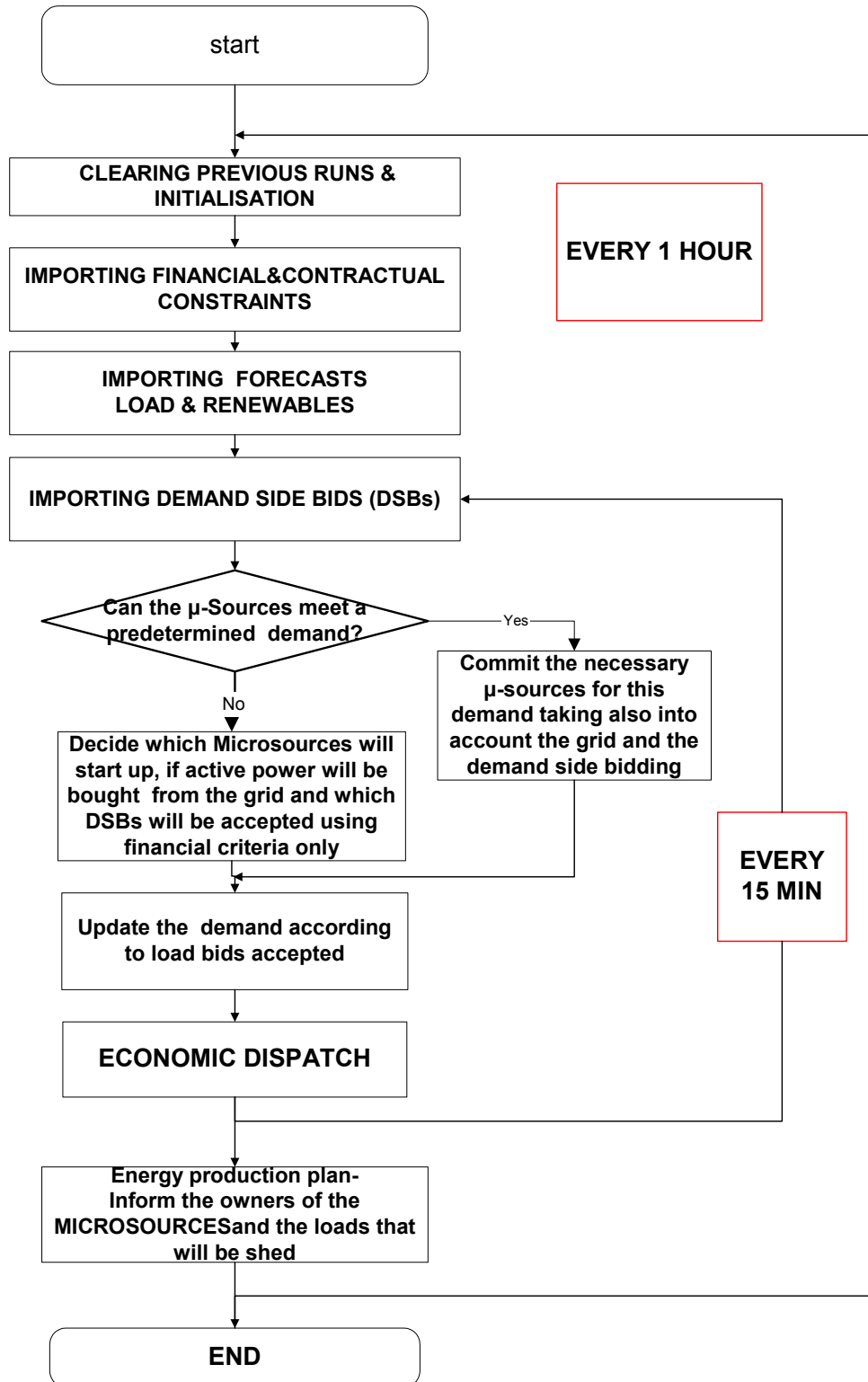
Figure 2.2 Flow chart of the Algorithm followed by MICROGRIDS Central Controller Prototype when Demand Side bidding is taken into account

Initially the data of previous runs are cleared and the initialisation of the data is performed.
Then the financial and contractual constraints according to the data of the Database(DB) are imported. Then the forecast for electricity, stored in the DB is imported in the program. The Forecasts are checked for errors,

such as extreme values, and the end-user is informed about probable causes of such errors .The forecast is then presented in tabular and Graphical forms.Instead of a forecast in Load option A, we have the aggregation of the demand that the consumers have bided.

The forecasts provided, the offers from the micro-sources and the demand side bidding values are used as inputs to the Economic Scheduling functions. These functions comprise Unit Commitment and Economic Dispatch Functions. The former decides on which units should be in operation, if active power will be bought from the grid and if any load bid is accepted. The latter decides on the set-points of the committed μ-sources. The technique used for the economic scheduling functions is based on priority lists.

The final outcome of the Economic Scheduling functions is an Energy Production Plan consisting of the settings of the μ-sources and the load finally shed for the next hours of the simulation horizon. According to this Energy Production Plan output calculations , such as costs, are performed and the results are presented in both tabular and graphical form. Other calculations can be easily made since the outputs of the program are kept in the same database. The prototype version does not allow update of the data in the Database. This is however available in the full version of the program.

2.2 Description of the software modules

2.2.1 MAIN module

The main module of the MICROGRIDS simulation tool is the scheduler. This contains the necessary sub-routines for the menus of the Human Machine Interface which are described in detail in section 3. From this module the routines performing the simulation tasks are called and executed. These routines are contained in other modules in order to provide the essential modularity of the software.
From the scheduler the following tasks are called :

1.Initialisation: Cleans the database from the data of previous runs (Cleandatabases function).
2. Import and validation of the forecast data.
3. Import of the offers of the micro sources and the prices of the open market.
4. Import of the demand side bidding
5. Economic scheduling functions.
6. Calculation of Hourly costs.
7. Calculation of costs for the whole period and for the electricity balance within the MICROGRID.
8. Steady State Security Assesment.
9. Production of output files.

2.2.2 FORECAST Module

This module is responsible for importing the forecasts and the financial and contractual constraints. In this way it is almost guaranteed that the optimisation problem solved by the Economic Scheduling functions, has a feasible solution. It consists of the following sub-routines:
Find Forecast :
It is the sub-routine that receives the data from the "forecast input" database table.
 FindErroreousData

Checks whether the demand for the whole Microgrid, exceeds the installed capacity of the microsources plus the interconnection line capacity. In such case the user is informed with an error message. The user is informed about these problems via messages like the and the simulation process pauses till either the demand or the capacities are revised.

2.2.3 UNIT COMMITMENT Module
The unit commitment performs the following tasks in the following sequence :
- Reads data about the micro sources of the system
- Reads the active power prices for this specific day as come from the open market.
- Finds whether the system can supply its own load in case of loss of grid. In such a case some microsources are committed so that the Microgrid can work in islanded mode in case of loss of grid.
- Moreover reads data about demand side bidding such as price value of the bid and amount of demand supplied or shed.
- Finds how many μ-sources should be committed to secure power supply. Thus
a)A cost Table is created
b)Unit commitment is performed

c)It is decided which load bids will be accepted or not
- The database table "CurrentStatus" is filled in
- These tasks are repeated for each step of the prediction horizon.

 Analysis of the functions:

2.2.3.1 Get Data
Data about the microsources , the open market constraints and the amount of demand that is available for shedding/supplying (option B/A) according to the bids are imported in tables. Also the previous status of the units is examined. Moreover for the renewable energy sources such as Wind power and Solar Power a related forecasted time-series is imported in order to give the upper limit of their production.

2.2.3.2 GET PRICES
In this table the coefficient Tables are calculated according to the offers of each one of the micro sources, the open market prices and the values in price units of the demand side bidding.

2.2.3.3 CreateCentralCostTable
This table contains information about the differential cost of the offers of the Microsources, the prices of the open market and the demand side bidding. This table is used as a reference table so that a copy of the financial data of the Microgrid is stored before starting the Unit commitment process

The differential cost is calculated for the maximum production of the micro-sources. This can be either the technical maximum as defines in the related static table or the maximum output due to weather conditions like the Wind or PV units. For the loads the differential cost is the value of the bid in price units For the open market the element of the table is calculated according to the maximum interconnection capacity.

If a unit is out of order, its value in that table is 1000.

The startup cost, if any, is also taken into account for the calculation of the differential cost.

2.2.3.4 Check for extreme values:
This sub-routine checks for extreme values in the data of the forecast or any values for the constraints that may lead to a non-feasible solution. Then it is found out whether the microsources can reliably meet the demand of a selected group of customers or a determined percentage of the demand if not for all the Microgrid, in case of grid disconnection. If the microsources can meet the above requirement, the necessary units for this purpose should be committed. Otherwise the units to be committed are specified according to financial criteria only. In that way a Boolean variable takes value 'True' in the former case and value 'False' in the latter case and is returned to the program in order to proceed with the commitment of the microsources and the grid.

Moreover in this function the demand that is going to be shed in case of emergency can be calculated either when there are "low" priority loads or not and this information is alos returned to the unit commitment process.

2.2.3.5 FindElecricityLimits
In this function the decision on the commitment of the units is made. The demand that the units(plus the grid) to be committed should be able to meet is the Microgrid demand for the current step plus a Reserve factor – for this application fixed at 10% of the demand . Moreover, if the steady state security concerns are taken into account and the microsources can meet a prespecified demand, then the amount of electricity the microsources should meet is taken into account. The above process is then carried out using the CommitElectricity sub-routine. Furthermore, in this function it is found which demand side bids can be accepted or not.

2.2.3.6 CommitElectricity

The microsources, the open market(considered as a huge generator) and the demand side bidding offers are set in ascending order, according to the CentralCostTable. If the microsources can meet a predetermined percentage of the demand of the Microgrid then they should be committed until this demand is met so that steady state security for this demand is maintained. This percentage may even be the total demand of the Microgrid. In that case if the open market differential cost is lower than the microsources, energy is bought from the grid but more microsources are committed in order to maintain the steady state security constraint. If this minimum demand is met but the whole demand of the Microgrid is not met then the process is continued until the total demand of the Microgrid is met.

If the microsources are not capable to meet this predetermined demand then the decisions to be made are which microsources will be used, if active power will be bought from the grid, and whether any of the

demand side bidding is going to be accepted based only on financial criteria . Therefore the units - are committed according to their ascending order until the total demand is met.

The loads that will not be served are found. If their bid is lower than the open market prices or the bids of the microsources. Then these loads are considered as a "negative" generator that reduces demand without producing electricity and are "committed" as a regular generator.

 When steady state security constraints are taken into account and the system can be secure, then some microsources are committed in order to meet this constraint, although it may not be the most economic solution. When demand side bidding is taken into account the loads that are more expensive than the open market prices but less expensive than the microsources are indicated as loads that are going to be shed in case of emergency.

Their status is written in the Database (Write2current status function) and the Economic Dispatch module is called.

2.2.4 Economic Dispatch Module

The economic dispatch performs in a similar way the tasks of the Unit Commitment module. The main difference is that the units to be dispatched are already known. The total demand is the demand to be served according to the aggregation of the load bids or the forecasted demand minus the demand shed as decided in the Unit commitment module and the demand side bidding has no other participation in this module.

Only the units committed are taken into account. These units are dispatched at least at their technical minimum. The differential cost is calculated according to the linear and quadratic offer coefficient, since the units have already been committed and the consumption of each unit will be at least the constant fuel coefficient. Therefore there is no reason for taking into account the constant fuel coefficient for optimising the dispatch level of these units.

In a similar way with the Unit Commitment module, the Economic Dispatch module has a GetData sub-routine(EDGetData),   a   GetPrices   subroutine(EDGetPrices)   and   a   Create   CentralcostTable (EDCreateCentralCostTable) subroutine that perform the same tasks as the Unit Commitment subroutines. The differences of the other sub-routines compared to the unit commitment ones are described in the following paragraphs

2.2.4.1 DispatchElectricity sub-routine

All the committed units are at least dispatched at their technical minima. Then the units are sorted according to their differential cost and are dispatched until the total demand of the Microgrid is met. In this way the most economic dispatch for the Unit Commitment will be retained.

When the Microgrid is working in an interconnected mode the committed micro sources are at least dispatched at their technical mimima. In this way there are "running' units within the MicroGrid that can compensate for the disconnection loss.

Then the Database Table data are refreshed with the new levels of dispatch.

The   results   of   the   Economic   Dispatch   module   are   stored   in   the   database   Table "OutputEnergyProductionPlan".

2.2.5 COST CALCULATION MODULE

The cost calculation module calculates the cost of energy conversion for each interval and the costs for each interval.

Production Calculation sub-routine:

This sub-routine, calculates the total production of the microsources and the cost of the demand shed if the load option B is followed..

Cost calculation sub-routine

This subroutine calculates the costs of producing energy the income for selling electricity to the grid and the expenses for buying energy from the grid

3. Human Machine Interface

3.1 Start-up Screen

The MICROGRIDS simulation tool start up screen is shown in fig 3.1. The user is informed about the capabilities of the software.
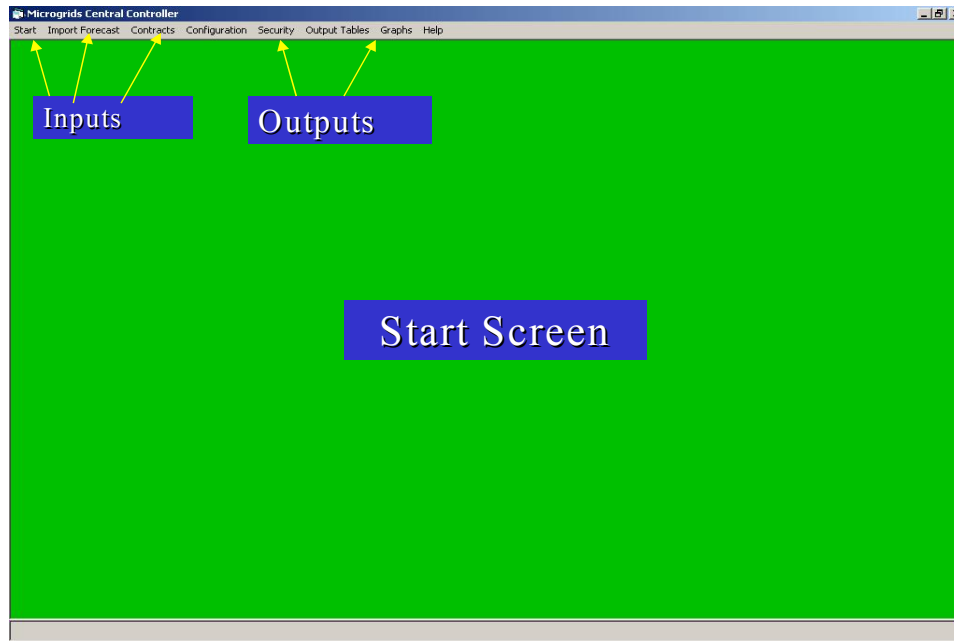
Fig.3.1. Start-up Screen

Before a new simulation starts the user can change the financial constraints, import new forecast, or change the configuration of the Microgrids.

3.2 Import Forecast Menu
This menu is currently inactive but can be used for updating either a renewable energy sources forecast or importing the load forecast for the next few hours
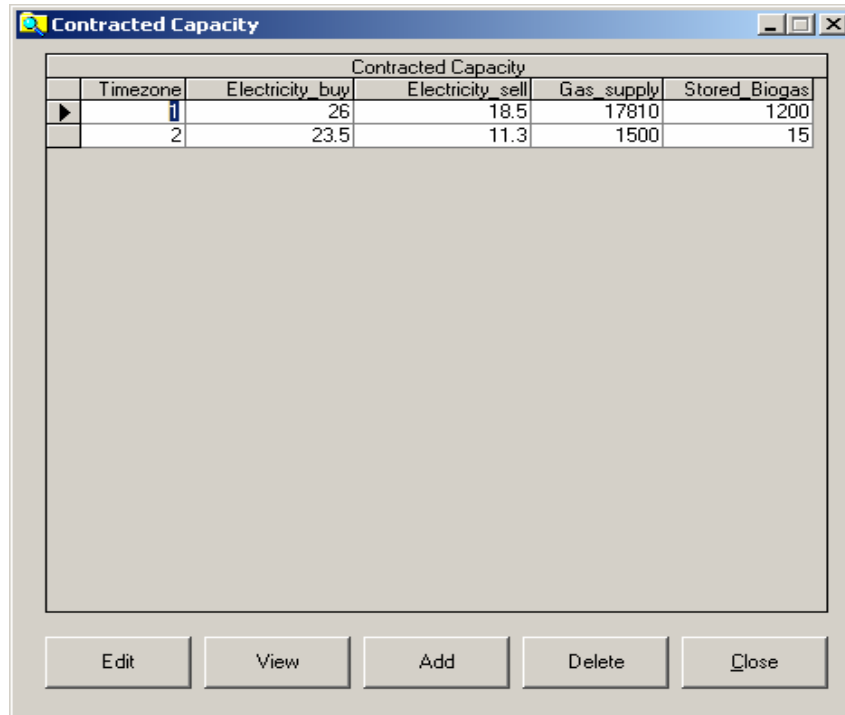
3.3 Changing financial data
The following screen provides the user with the necessary information about the contracted capacity and the prices for the time-zones.

3.3.1 Contracted Capacity sub-menu
From this sub-menu the user can view or change the contractual constraints for the simulation. The way to do so is shown in Figures 3.2 and 3.3.
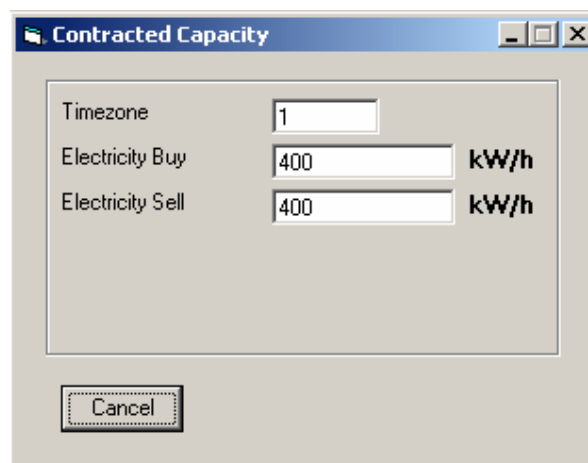
Fig 3.2 The Contracted Capacity sub-menu

Fig. 3.3The screen where the user can view information about Contracted Capacity

3.3.2 Prices sub-menu

From this sub-menu the user can change the prices for buying and selling Electricity. The way of doing so is shown in figures 3.4 and 3.5.

Fig. 3.4 Information about Electricity Prices

Fig. 3.5 Manual update of Electricity Prices

If the user wishes to be connected with an internet site or with a file that contains updated prices then clicks on the Get Prices Button and the following screen appears .
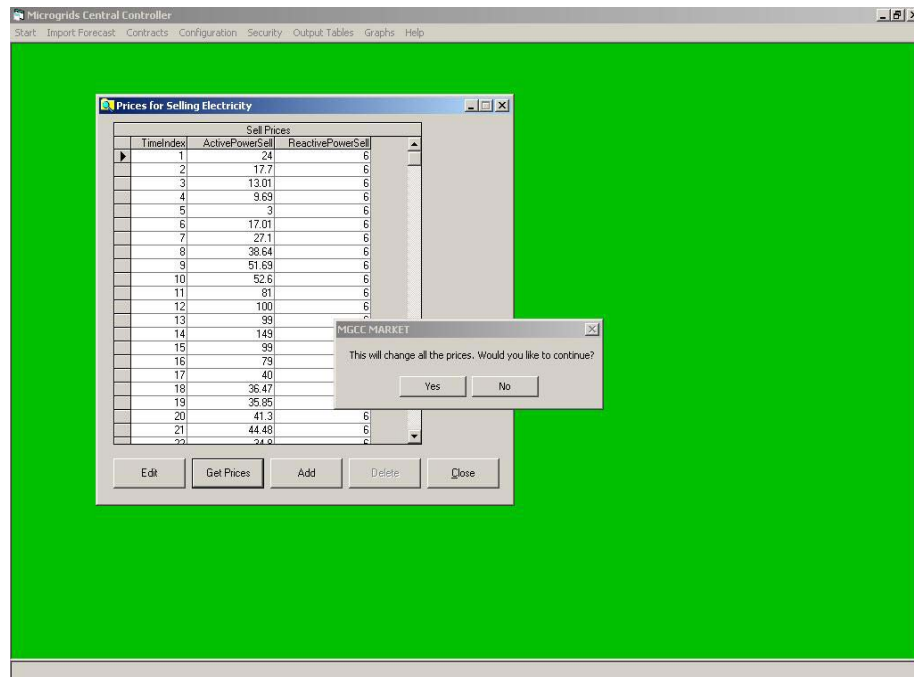
Fig 3.6 Electricity prices and automatic update of them (perhaps, internet connection)

3.4. The Configuration Menu

 From the Configuration sub-menu shown in Figure 3.7 the user can view or make changes in the configuration of the Microgrid .
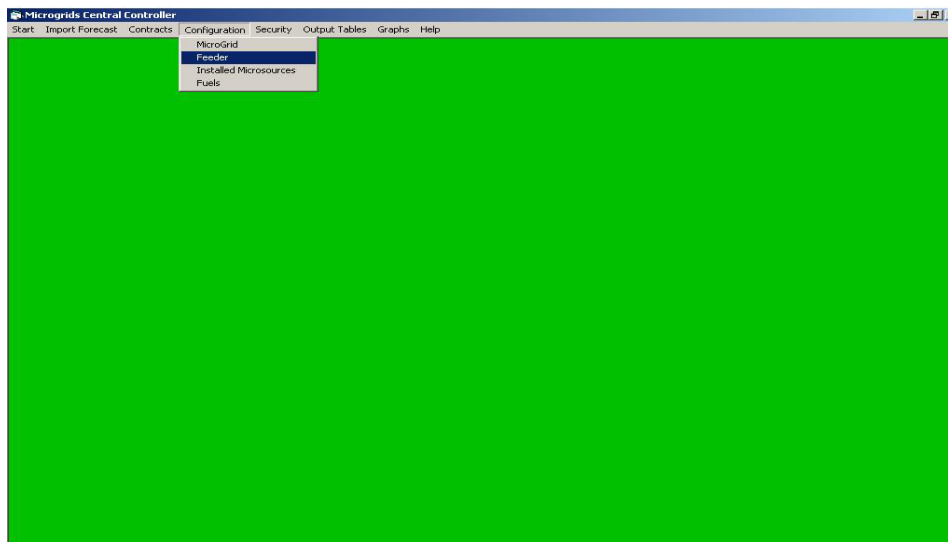
Fig. 3.7 The Configuration sub-menu

3.4.1 Microgrid sub-menu

Here changes such as the name of the Microgrid ,the number of end-users etc can be made. This sub-menu is shown in figure 3.8

Any change in the configuration is also shown in this screen. Any change in the microsources, and the Feeders made via this screen should be fully specified by the corresponding changes via the related sub-menus in order to be activated. The user is prompted to do so by the message shown in fig 9. In this way the data in the DB can be refreshed.

Fig. 3.8 The Microgrid sub-menu

Fig. 3.9 Prompt for changing the data about the micro sources

3.4.2 Feeder sub-menu
Information about the number and type of consumers, the installed capacity of micro sources, the Renewable Energy Sources installed, and the Capacity of Storage Capacity installed, is provided using this sub-menu.

Any change in the information of the microsources, should be followed by the corresponding change via the Micro Sources sub-menu. Figure 3.10 shows the relevant sub-menu.

Fig. 3.10 Feeder Information

3.4.3 Micro Sources Sub-menu
From this menu the user can view, edit or delete the Micro Source selected or even add a microsources specifying its characteristics

Fig.3.11. Micro Sources sub-menu

Information about a Micro Source is given in tabular format.

Information about the Feeder and the feeder the unit belongs to is given. Moreover a description of the type of the unit as well as a display name is given.

Information about the active and reactive power of the unit is given , as shown in fig. 3.12.

Fig. 3.12. Information about power capacity of a selected Micro Source.

The user can change the bid prices and the type of fuel of the selected unit as shown in figure 3.13 **.**Start up parameters such as time of starting up the unit are given in fig 3.14. Operational parameters such as the availability of the unit can change, as in fig3.15.

Fig .3.13 Information about Fuel and offers data of a selected Micro Source

Fig 3.14. Information about start-up parameters of a selected Micro Source
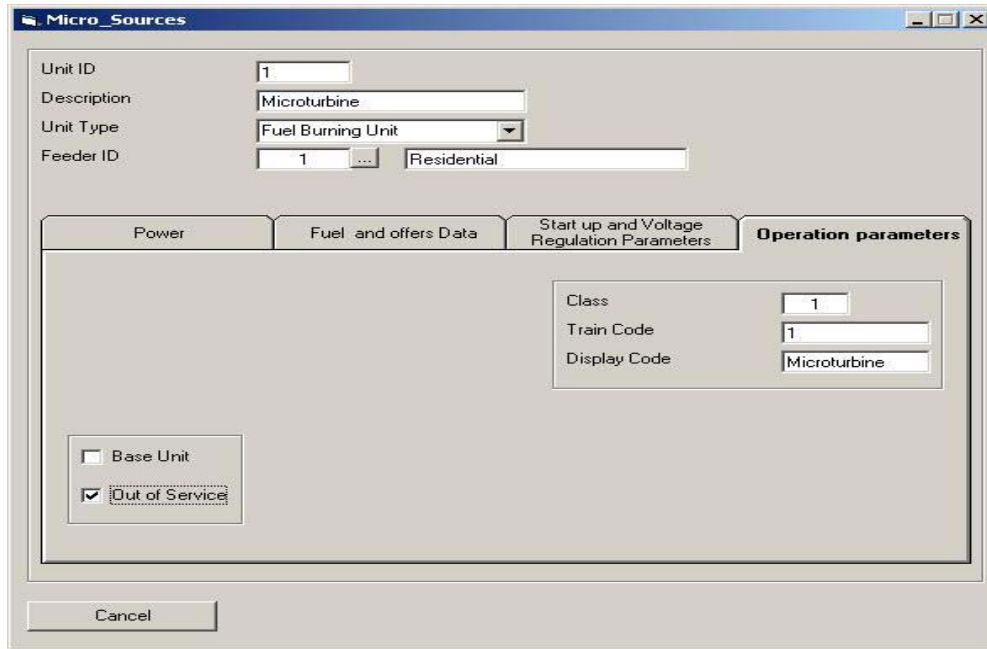
Fig. 3.15. Information about operation parameters of a selected Micro Source.

3.5 Starting a new simulation

After any possible changes in the input data, the user can start a new simulation from the start menu as Figure 3.18 shows:
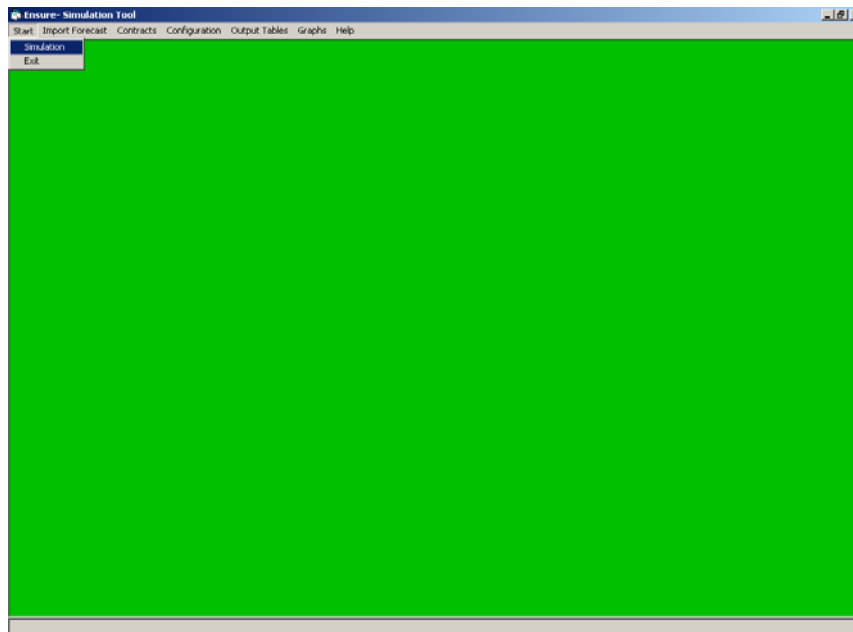
Fig. 3.18. Starting a new simulation

When these procedures for the whole prediction horizon have been completed, the results are presented in the screen as shown in fig 3.19. The user is informed about the total demand of the prediction horizon in tabular form, about the demand at hour intervals for the whole park in a graphical way. Another diagram shows the demand at Feeder level.
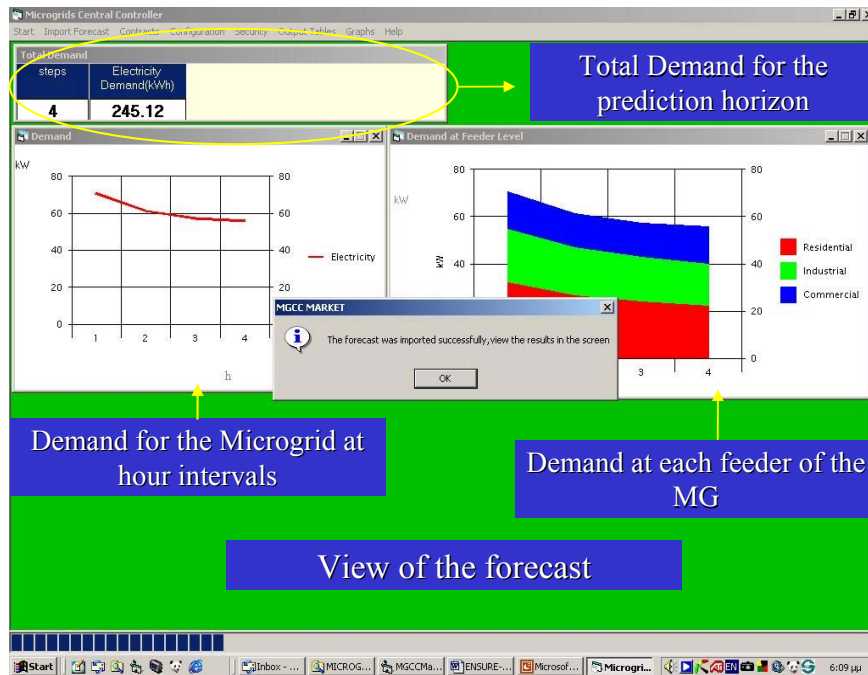
Fig 3.19.The Screen after the successful import of the Demand patterns

Next, the Economic Scheduling Procedures start and the necessary calculations are performed. In the main screen a chart with the production of the units is shown. The user can click on the chart and view the name of the unit and its current production. In the banner, in the upper part of the screen, information about the total demand and the energy balance is provided as shown in figure 3.20. From this screen the end-user can be informed about the units dispatched during the previous run (-3,-2,-1 steps) , the current moment 0 step and the steps of the optimization horizon (1,2,3,4 steps). In that way the user of the software can view the situation for the previous hour (4 quarters) and the next hour(4 quarters)
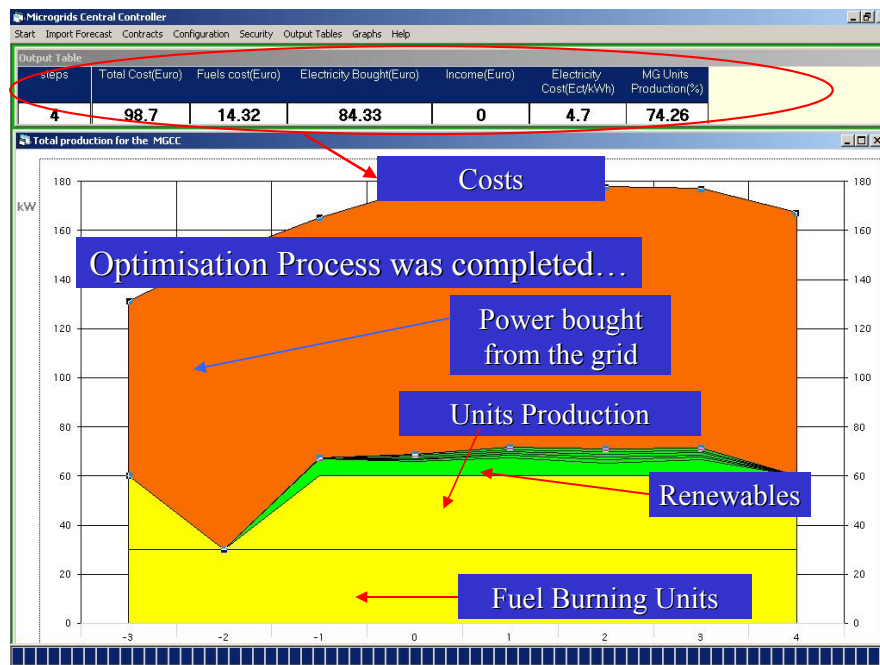
Fig. 3.20 The simulation tool has completed its process successfully

The user can access the simulation results via the Output menus, as shown in fig.3.21.

3.6 OUTPUT TABLE MENU
From this menu the user can view the output information in tabular format.

3.6.1 Costs sub-menu
In this table the user can be informed about :

-The Total cost for meeting the Microgrid demand
-The Income from selling electricity to the open market
-The cost of buying electricity from the open market
-The Fuels cost implying the cost of producing electricity from the microsources

For each step of the optimization horizon as shown in Fig 3.21

Fig 3.21.The Output costs Table

3.6.2 Electricity Balance sub-Menu

This menu is shown in fig 3.22. From this table the user can be informed for each step of the simulation horizon about :
-The total electricity Demand
-The Electricity produced by the units of the Microgrid
-The electricity bought from the grid
-The electricity sold to the Grid
-The interruption of electricity to end-users if demand side management measures are taken into account

Fig. 3.22. The Output Electricity Balance Table

3.6.3 Output Production Plan
From this table the user can be informed about the production of each unit in the Microgrids either in absolute values or in Percentage values. In Figure 3.23, the output of the units is shown in percent.

Fig. 3.23. The Energy Production Plan in Absolute Values format.

3.7.GRAPHS MENU
From the Graphs menu the user can have a quick view of the output information and make further analysis of the results.

3.7.1 Demand sub-menu
By selecting this Sub-menu the user can view once again the screen just after the completion of the import of the load patterns as shown in figure 3.19.

3.7.2 Output Production Plan sub-menu
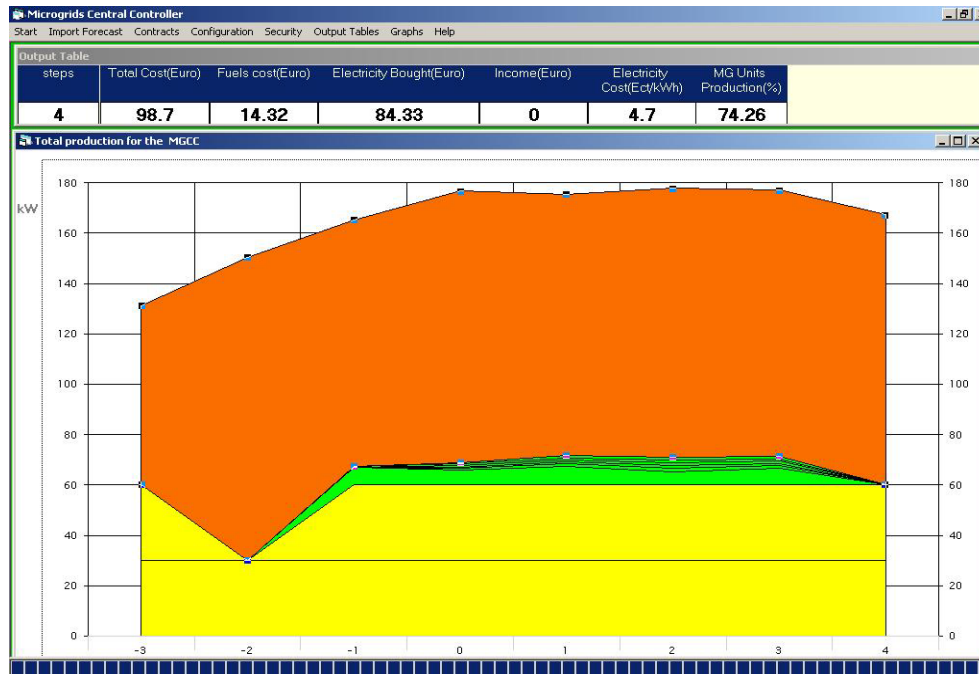The display of OutputProductionPlan after the Simulation cycle is completed is shown in Figure 3.24.

Fig.3.24 The Output Production Plan Window

3.7.3 Cost Sub-menu
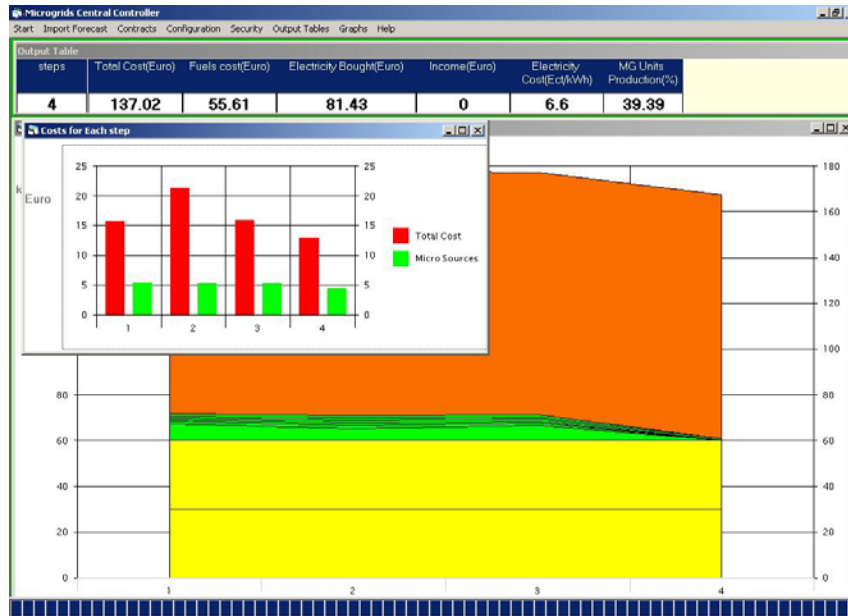This is a bar-chart provides the total cost at each step and the contribution of fuels to it.

Fig 3.25. The Screen when the user selects Cost and Unit Cost from the Graphs menu.

3.7.4 Energy Balance Sub-menu
The banner in the upper side of the screen is refreshed in order to give a view of the electricity balance of the system. This sub-menu is automatically displayed for a few seconds after the execution cycle is completed, in order to inform the user about the Energy balance of the simulation horizon. The typical energy Balance banner is shown in Figure 3.26.

| Production Balance | | | | | |
steps	Electricity Demand(kWh)	Electricity Bought(kWh)	Electricity Sold(kWh)	Units Production (kWh)	Storage
4	697.74	1253.407	0	274.809	0

Fig 3.26 Typical Energy Balance Banner.

3.7.5 Emmisions Sub-menu
The user of the software can view the emissions avoided due to the MICROGRID operation. In figure 3.27 shows how the user can access the Emissions screen
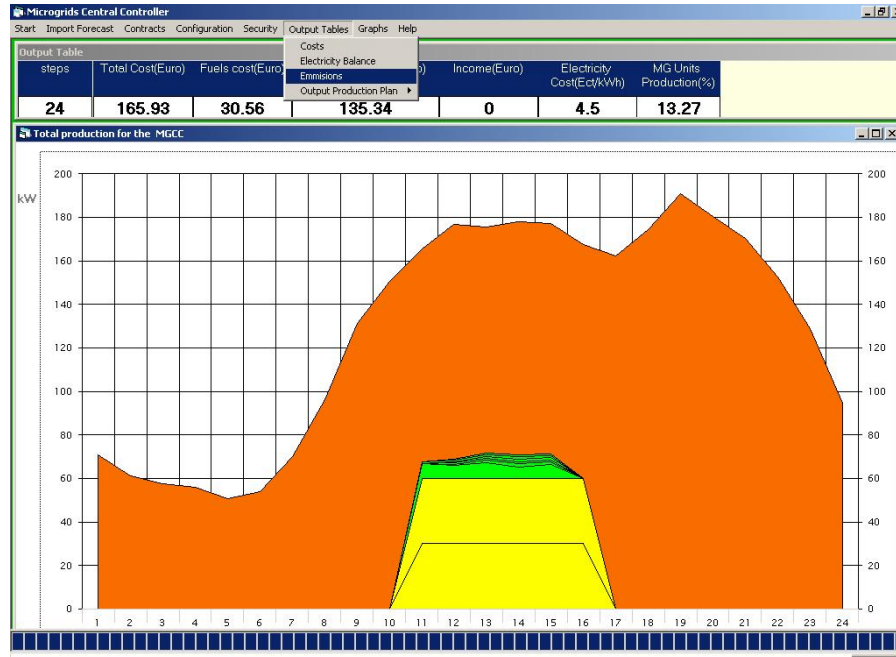
Figure 3.27 The main Screen of the software where the user can access the Emissions screen

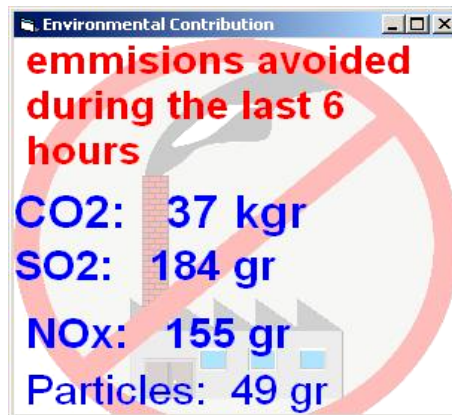A typical form describing the emissions avoided is shown in figure 3.28

Fig. 3.28 The emissions avoided because of the MICROGRID proposed operation

3.8 LOSS OF GRID MENU
From this menu the user can view the steady state security for the whole period under study when the grid is disconnected. A graph shown in fig 3.29 shows whether the system is secure or insecure.
If the value in the graph is 1 , the Microgrid for this specific step is   insecure in case of grid disconnection, if the value is 0 the Microgrid is secure.
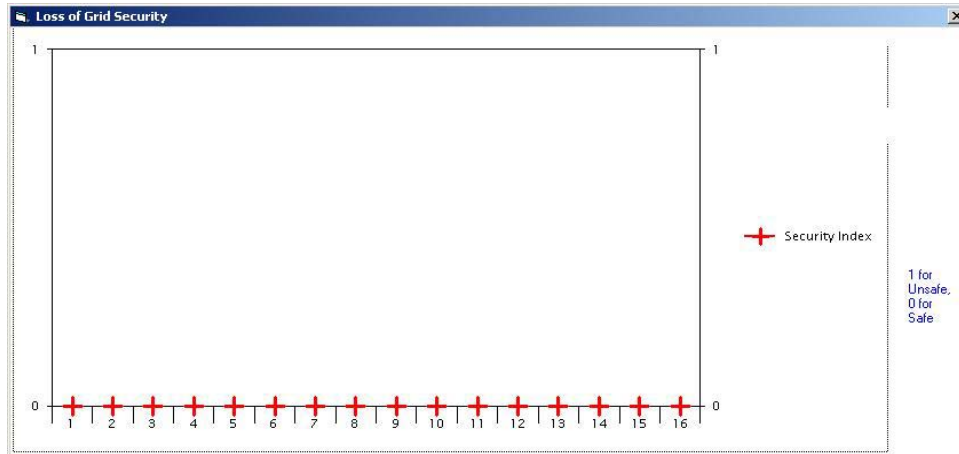

Fig 3.29 Loss of Grid Menu

When demand side bidding is applied then the end-user using the same menu can be informed about the possible load shedding
Figure 3.30 displays how much load is possibly shed in case of grid disconnection in two cases.
  a. Bids for disconnection of low priority loads are accepted (red line)
  b. There are no priority loads.(green line)
The lower curve shows the demand to be shed even if the low priority loads have been shed. The upper line shows the total demand shed in case of grid disconnection.
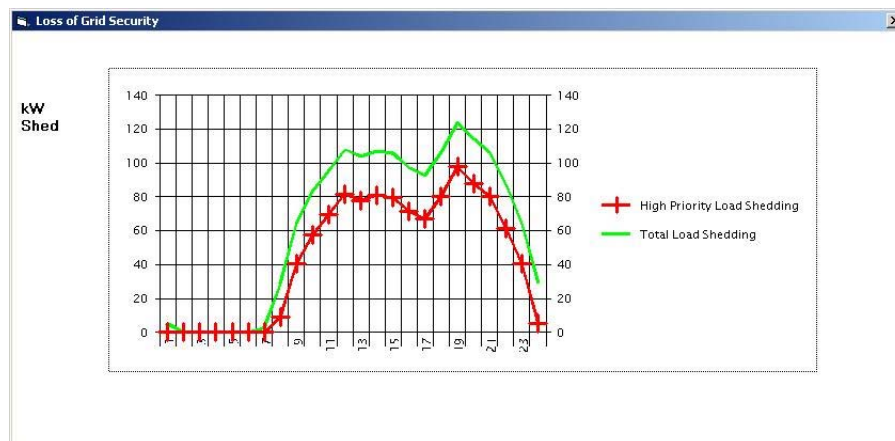

Figure 3.30. Load to be shed in case of grid disconnection

3.9. HELP MENU
The help menu contains two sub-menus
  • **Help sub-menu**
 Help provides short text with information about the capabilities of the softwae
  • **About sub-menu**
    This is a typical "about" window that describes shortly the application and information about the program version.
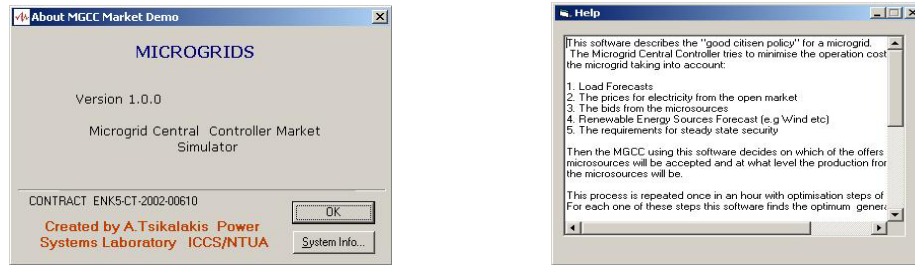 These 2 windows are shown in figure 3.31.

Fig 3.31 Help and About Forms

3.10. OUTPUT FILES

After the optimization process for the MGCC is complete the microsources owners are informed for the suggested production for the next steps at 15 minutes intervals. Therefore relevant .txt files are produced such as EnergyProduction_n.txt where n the number of the microsource. Moreover the microsource producers are informed about the prices in the open market in order to make better offer to the MGCC with the file prices*.txt.   These *.txt files are kept in the installation folder of the Simulation Tool (*default "C:\ProgramFiles\MICROGRIDS-MGCC market"*)

4. Installation guide of the MICROGRIDS prototype software tool

From the CD run the setup.exe.
The setup program will install the necessary *.dlls and libraries for the Simulation program as well as the database needed for the simulation

After copying of files (*.dlls) is complete,the setup screen is shown.

You can change the installation folder or the way you see the shortcut in the Programs Submenu.
The default folder is MICROGRIDS –Simulation Tool created within the Program Files Folder**. (e.g c:\Program Files\MGCC Market)**

During the start-up, there may exist a message of a "file –in-use", especially if you have run a program in Visual Basic just before installing the Software. In such a case press **Ignore** and continue the setup.

If for some files there are newer versions in your computer keep answering **Yes** in the form that will pop up.

The setup informs the user when the installation is complete.

The Installation has been successfully tried in Computers with Ms Windows 98®/Ms Windows 2000® with MSOffice97®/MSOffice 2000®.

The installation has not been tested in Ms Windows XP® and MsOffice XP®.

After the installation is complete go to the **Programs** menu and start from the
MICROGRIDS-Simulation Tool menu.

The password is **blank** ,just press **OK** in the form. Now you are ready for the simulation.

The software was optimised for a computer with the following characteristics :

- Intel® Pentium 4- 1.6GHz/512MB RAM
- 1024* 768 screen analysis in 17" screen
- MS Windows 2000®/MS Office 2000®.

The software has the following minimum requirements (that was the least powerful PC tested)

- Pentium MMX 166/32MB RAM
- 800*600 analysis in 15" screen
- MS Windows 98® /MS Office97®

5. Conclusions

The following characteristics of the software are considered as its main advantages :
- User-friendly

The Human Machine Interface is friendly and easy to operate, as described in section 3.
- Modular

The functions that have been developed within the Simulation Tool can be easily used in other sites or to solve similar problems. Any additions to the Software can be made without influencing the structure of the program.

This modularity can help in the incorporation of new economic scheduling modules. In this way the user can test also new modules too, without losing compatibility with the existing economic scheduling functions.
- Flexible

The use of the Database and the menus of the interface help maintaining the flexibility of the program. The user can easily add, delete or modify the existing configuration via the menus described in section 3