# Advanced Architectures and Control Concepts for

# MORE MICROGRIDS

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# Document Information

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# Executive summary

The report consists of two complementary parts. The first part addresses the biogas production tests on the Agria test case, while the second part addresses the performed microgrid field tests. In the first part of the report in brief the basis of the biogas production process and the implemented biogas production technology are explained. This part of the report also includes a short overview of the conducted laboratory and pilot site tests, as well as the findings considering the quality and characteristics of the produced biogas. In the second part of the report, a short overview of the established microgrid design is presented, followed by description of the measurement equipment and procedures. The last part of the report addresses the field tests objectives, methodology and results. The report contains results from several tests and measurements carried out on the test site.

The main achievements within the designated tasks include:

- *development of a modified biogas production technology* - The activities within this workpackage enabled broad research on biogas production process in terms of more in-depth study of the biology of the methanogenesis of organic matters from the wastewaters. The results of the research were used as foundation for design and implementation of a pilot system for biogas production, based on modified up-flow anaerobic sludge blanket (UASB) technology, developed within the framework of the project.
- *successfully established microgrid* which enabled completion of the microgrids field tests – The main objectives of this demo case were to provide and example for inclusion of a biogas plant into a microgrid, to introduce and test the microgrid concept in the power system of a country from West Balkan region and to increase the potential and awareness of Microgrid option in non-EU regions through dissemination.

Completion of the envisaged field tests enabled drawing the following general conclusions:

- microgrids with biogas plants can be successfully implemented on other similar locations in the country and in the West Balkan region;
- the benefits of heat and electricity production in biogas plants can improve fulfilment of the environmental standards related to farm waste management and greenhouse gases reduction.

## Short overview of the test location, objectives and results

### Basic information about the location

The pilot test microgrid is located in a rural area, on a pig farm, the biggest of that kind in the country. One of the measures to reduce local pollution in this area was to propose a suitable waste water treatment. The biogas is one of the by-products of the waste water treatment, so the idea to use the locally produced biogas for electricity production was the main reason for choosing this particular location. The farm already owned part of the required equipment (biogas digester and generator), but it was not in operation.

The farm itself consists of several warehouse-like stalls with ventilation, temperature control and lighting systems, administrative building and few utility buildings and storage rooms containing farm equipment. There is a connection to the 10 kV distribution network through transformer station which belongs to the farm.

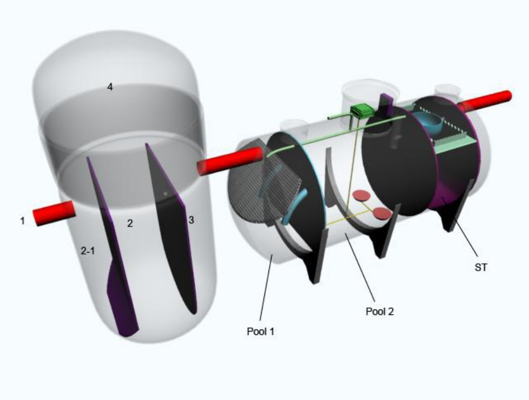
### Biogas production

Technology

- based on anaerobic waste water treatment developed by the team from Bioengineering

- can be successfully incorporated in both industrial and farm waste water treatment systems

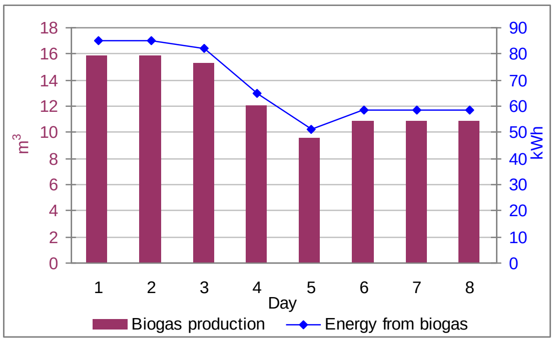
Equipment



1 - recipient shaft, 2 - methanogenic zone,
2-1 - primary sedimentation, 3 - effluent and secondary sedimentation zone,
4 - biogas collecting chamber, Pool 1 – de-nitrification pool,
Pool 2 - nitrification pool, ST - sedimentation tank

After finishing the laboratory tests, the actions for the biogas reactor activation on the test location have begun. The tests indicated that some adjustments of the equipment are needed (installation of a biogas holder). These activities were concluded with additional safety tests and measurements, after which the biogas production was successfully tested on the location.

The first tests were done with 38 $m^3$ waste water. According the measurements of the expert team from Bioengineering, the daily biogas production is estimated to vary between 10 - 16 $m^3$, with calorific value of 21.6 MJ/$m^3$ (6 kWh/$m^3$).



Biogas production on the test location

## Microgrid configuration

The pilot microgrid encompasses a part of the existing low voltage grid on the farm, including few loads and a generator. The loads within the microgrid will be supplied either by grid electricity, or by electricity produced by the generator using the biogas from the waste water treatment.

The biogas production process itself requires two electric pumps, one used to circulate the biogas through a set of heat exchange pipes when the ambient temperature is low and the other for mixing the manure. Initially, the manure is collected in a cement basin where it is mixed and transferred into the digester. After the anaerobic digestion, the produced biogas escapes through a pipe connected to the biogas holders, from where it is directed to the generator.

Biogas production process - experimental tests

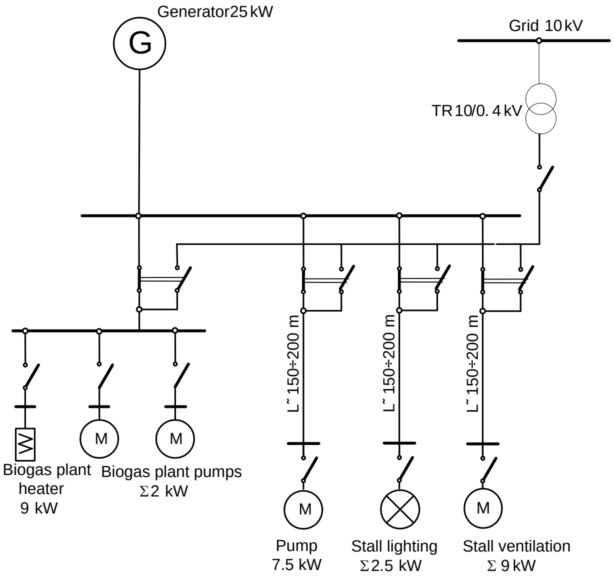
The tests on the biogas production in laboratory environment had to be conducted prior any other activity on the farm, in order to prove the project practical feasibility and to provide general information on expected biogas production. The laboratory tests referred to examination of optimal biogas production technology and investigation of its quality. The tests enabled to determine the optimal starter culture for the anaerobic digestion and the optimal fermentation temperature for higher biogas production. The laboratory tests proved that biogas with appropriate quality was produced. These analyses also enabled determination of optimal dry matter concentration of the waste water in order to achieve higher biogas production.

## Pilot microgrid - techical details

The capacity of the generator is 31.5 kVA, cosφ=0.8. According the equipment specification, the generator uses 3.9 $m^3$/hour when fully loaded and 2.0 $m^3$/hour when it is 50% loaded. The generator is applicable for supplying continuous electrical power at variable load, but no overload is permitted on generator's ratings.

The loads (except the loads from the biogas plant) are situated approximately 200 meters from the house where the main switchboard and the generator are placed.

The loads are connected by cables to the main switchbox and the switches allow two supply possibilities: by the local DG production unit or by the distribution grid. The switches also allow part of the loads to be connected to the grid and the rest to the generator, depending on the biogas production process, i.e. weather the pumps and the heater are needed simultaneously.



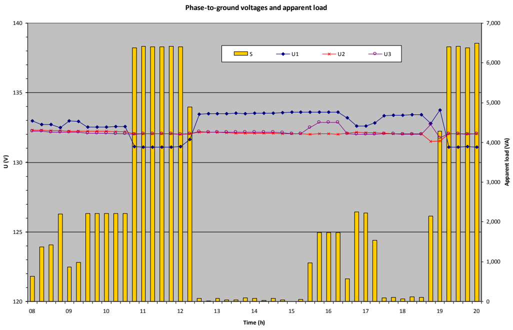
Pilot microgrid single line diagram

## Microgrid operation - field tests

The first set of tests was dedicated to assessment of the generator behaviour considering different operating conditions. These tests were done in order to determine if there were any faults on the equipment and it showed minor faults with some valves, which were resolved rather quickly. For these tests LPG was used as a fuel, because in that period there was no biogas production.

The next set of tests addressed the microgrid operation in isolated mode using biogas as a fuel. The tests were performed with unbalanced loads consisted of electric motors and heaters. During the tests, the voltages, currents, active and reactive power, power factor, total harmonic distortion (THD) and frequency were measured. As measuring equipment Iskra-MIS MC 750 Network recorder was used.

The results from the 12 hours operation of the network in isolated mode have shown that all voltages are kept in narrow margin, the frequency changes slightly with the variation of the load and it is kept at 50.1 Hz. The average harmonic distortion of the voltage varies around 2.4%, which under the limit of 8% according to the EN 50160 standard. So, the microgrid is capable to supply the existing consumption with quality power.



Example of 12 hour microgrid operation

Measurement equipment

The pilot microgrid is the first grid of this type in Former Yugoslav Republic of Macedonia and will be used to promote the microgrid concept in the country and in the wider region. The test results have provided data and knowledge base which will be further used to quantify the benefits of wider deployment of these types of networks in the region.

Results:

- The daily biogas production using 1/3 of the biodigestor's total capacity is estimated to 15 $m^3$, with calorific value of 21.6 $MJ/m^3$ (or 6 $kWh/m^3$)
- The biogas production is increased by using inoculum
- The 12 hours microgrid operation in isolated mode have shown that:
  - all voltages are kept in narrow margin;
  - the frequency is kept at 50.1 Hz;
  - the average THD U varies around 2.4%.
- The microgrid can supply the existing consumption with quality power

Added values:

- From national and regional aspect: Introduction of a new concept in the power system of a country from WB region
- From the aspect of Microgrid concept and advanced RES technologies: Example for inclusion of a biogas plant into a microgrid
- From dissemination aspect of Microgrid concept: Increased potential of Microgrid deployment in non-EU regions

# Part I: Agria demo case - biogas production

## 1 Introduction

The ever growing consumption of the existing reserves of classical fossil energy sources has led to increased use of the unconventional energy sources. Using biogas for heat and electricity production has been in the research focus during the past several years, especially because of the possibility to produce biogas from waste water treatment process, and thus, to reduce the pollution.

In that context, it is very important to obtain biogas by a process of bioconversion of different waste materials from agriculture, industry and organic matters from wastewaters. A large amount of the organic waste material remains unexploited, as a result of the civilization development. These types of organic materials, in the absence of oxygen with the help of microorganisms, can be degraded to a final product, methane (biogas).

That is why the anaerobic treatment is now becoming a popular treatment method for different kinds of wastewater, because of its effectiveness in treating highly polluted wastewater and because of its economic advantages. In recent years, the number of anaerobic reactors in the world is increasing rapidly and about 72% consist of reactors based on the UASB and Expanded granular sludge bed (EGSB) technologies. Our choice of technology will be our modified UASB technology which will be described here.

This project improved the studies of the biology of the methanogenesis of organic matters from the wastewaters. This project also helped in designing, production and the application of a pilot system for biogas production located in a randomly selected farms. We tested the influence of a large number of ecological factors that act on methanogenesis. We also dedicate attention to the separation and studying of certain types of methanogenic bacteria which in form of associations participate in the anaerobic degradation of organic matters present in different microbe habitats, like the waste sludge from the digesters and rumen and the intestines from the animals. The quality of the separated biogas and hygienisation degree of the effluent was also monitored.

### 1.1 Anaerobic Processes in the UASB Reactor

There are 4 phases of anaerobic digestion in an UASB reactor

- *Hydrolysis*, where enzymes excreted by fermentative bacteria convert complex, heavy, un-dissolved materials (proteins, carbohydrates, fats) into less complex, lighter, materials (amino acids, sugars, alcohols, etc).
- *Acidogenesis*, where dissolved compounds are converted into simple compounds, (volatile fatty-acids, alcohols, lactic acid, $CO_2$, $H_2$, $NH_3$, $H_2S$) and new cell-matter.
- *Acetogenesis*, where digestion products are converted into acetate, $H_2$, $CO_2$ and new cell-matter.
- *Methanogenesis*, where acetate, hydrogen plus carbonate, formate or methanol are converted into $CH_4$, $CO_2$ and new cell-matter.

### 1.2 UASB Design

In general, there are two ways to design an UASB reactor

1. If input COD: 5,000 - 15,000 mg/l or more, the design method should be used based on Organic Loading rate, (OLR)
2. If input COD < 5000 mg/l, the design method should be calculated based on velocity.

### 1.3 Operation

The optimum pH range is from 6.6 to 7.6. The wastewater temperatures should not be < 5 °C because low temperatures can impede the hydrolysis rate of phase 1 and the activity of methanogenic bacteria.

It is important always to maintain the ratio of COD: N: P = 350:5:1. If there is a deficiency of some of these nutrients in the wastewater, nutrient addition must be made to sustain the micro-organisms. Chemicals that are frequently used to add nutrients (N, P) are $NH_4H_2PO_4$, $KH_2PO_4$, $(NH_4)_2CO_3$ etc.

Suspended solid (SS) can affect the anaerobic process in many ways:

- Formation of scum layers and foaming due to the presence of insoluble components with floating properties, like fats and lipids.
- Retarding or even completely obstructing the formation of sludge granules.
- Entrapment of granular sludge in a layer of adsorbed insoluble matter and sometimes also falling apart (disintegration) of granular sludge.
- A sudden and almost complete wash-out of the sludge present in reactor
- Decline of the overall methanogenic activity of the sludge due to accumulation of SS

Therefore, the SS concentration in the feed to the reactor should not exceed 500 mg/l. The pH will be reduced and the buffer capacity of wastewater may have to be increased to provide alkalinity of 1000 – 5000 mg/l $CaCO_3$.

## 2 Biogas pilot plant

The biogas production process is based on anaerobic waste water treatment developed by one of the INCO partners in the project, Bioengineering d.o.o. The technology that is used at the Agria industrial group was also patented in the Former Yugoslav Republic of Macedonia in 2005, and it was also rewarded as patent of the year in the country. It is now successfully incorporated both in industrial and farm waste water treatment systems. Within the framework of the project, the biogas production process was tested in laboratory environment, using a small pilot model with manure collected on the farm, which results were used in constructing and conducting vital number of tests and experiments in the biogas pilot plant.

The biogas pilot plant (reactor) is consisted of insulated steel cylinder above ground and it is located remotely to the pig farm. Apart from the need of regular maintenance and cleaning of the manure inlet pipe, no other major activities are required for this part of the system. The bio-digester is located next to the object where the generator set is installed and is connected directly to the heat pipeline. This technology of combined aerobic and anaerobic wastewater treatment can also be incorporated in rural industrial and farm wastewater treatment plants. The biogas plant accepts the surplus sludge from the industrial wastewater, the biomass from the pig farm. The produced biogas is than transformed into electricity with the usage of a generator.

### 2.1 Performed activities

During the first half of 2009, BIG has been testing the quality of the manure collected form the farm. The tests have been undertaken in laboratory conditions using new anaerobic digestion technology and the characteristics of the produced biogas have been examined.

- The process of methanogenesis was conducted by anaerobic granules from the collection of the laboratory of microbiology, at the Starter culture (methane tank), and anaerobic mixed culture from the farm lagoon.

- For the conducting of the laboratory tests target farm wastewater was used with 5 %, 10 %, 15% and 20 % starter culture dry matters on different temperatures.

- To conduct the tests, 1000 cm3 Zeykus chambers were used, with working volume of 500 cm3, as well as conventional UASB reactor with a working volume of 3 l, shown on. The extracted biogas was accumulated in graduated cylinders, previously filled with an acidic saturated solution of NaCl.

- The chemical analyses were conducted in accordance with the APHA (American Public Health Association) standard. The following parameters were monitored: total dry, organic and mineral matters, total nitrogen, COD, BOD5, nitrite, nitrate and ammonium nitrogen, phosphates and biogas.

- Starter culture selection was done and the optimal concentration of the same startle culture was determined

- Optimal dry mater concentration of the WW for higher biogas production was tested

- Optimal temperature for optimal fermentation and high biogas production was determined

The results gathered from the laboratory test of the wastewater during the first half of 2009, were the foundation for activation of the pilot system (reactor) for anaerobic fermentation of the Agria Group wastewater.

For a good start up of the process several suitable preparations were required, such as:

- Conduction of a water test (cold test)
- Monitoring of the water and sludge pumps condition
- Monitoring of the electrical installations
- Monitoring of the piping system of the reactor

## 2.2 Lessons learned

After the conducted control of the system, it was decided that the system it self has got a lot of flaws and errors, including:

- Biogas collector was missing
- Purification system for removal of $H_2S$ from the biogas (biogas purification) was also missing
- Poor construction and maintenance of the piping system in the reactor.

After the removal of all these flaws and technical errors from the reactor, the activities of the next phase were performed, i.e. filling the reactor with wastewater. The procedure was conducted several times. In the next section, the results form the tests when the system was filled with 30.4 $m^3$ of wastewater from the farm and 7.6 $m^3$ previously adapted anaerobic culture are presented. The process was conducted on ambient temperature from 18-22 $C^0$, for a period of 36 days.

# 3 Results

For conduction of the anaerobic fermentation and biogas production we used the solid waste and wastewater from the pig farm “Agria-Group” Gradsko. The process of fermentation was conducted discontinuously in a vertical anaerobic reactor. The reactor is connected to a concrete lagoon with a pipe network with total volume of 9.6 $m^3$. The wastewater from the lagoon is inserted into the reactor with a help of a sludge pump. The reactor is connected with two plastic barrels which are filled with biogas purification solution. The produced biogas from the reactor passes trough this solution and than flows trough a volume measuring system so we can determine the daily production of biogas. After that the produced biogas is transformed into electrical energy.

The reactor was filled with wastewater with volume of 38 $m^3$, from the lagoon. One fifth (7,6 $m^3$) of this volume was consisted of previously activated anaerobic culture (inoculum) prepared by BIG. We also conducted the same biogas production method with the same wastewater and inoculum concentration in small laboratory reactor, so we can compare and predict the methanogenic process that will be performed in the pilot system.

Based on the daily biogas production in the laboratory, we managed to predict the biogas production volume from the pilot reactor in Agria. The temperature that we used in the laboratory conditions was the same as the ambient temperature in the pilot reactor, and that temperature varied from 18.0 ° C - 21.8° C. The pH value was from 7.23 - 8.20. The next few tables describe the dry mater percentile composition of inorganic and organic matters, from which values the biogas production depends. Several samples were tested, like sediment, filtrate and pure sample from the inoculum, and sediment, filtrate and pure sample from the wastewater that was inserted on monthly bases in the pilot reactor.

Table 1 Sediment from pilot reactor inoculum

| Dry matters (%) | Inorganic matters (%) | Organic dry matters (%) |
|---|---|---|
| 27.82 | 8.69 | 19.13 |
| 28.22 | 9.677 | 18.543 |
| 27.67 | 8.92 | 18.75 |
| Total<br>27.90 | Total<br>9.098 | Total<br>18.802 |

Table 2 Filtrate from pilot reactor inoculum with PH=7.78

| Dry matters (g/l) | Inorganic matters (g/l) | Organic dry matters (g/l) |
|---|---|---|
| 2.88 | 1.84 | 1.04 |
| 3.01 | 1.85 | 1.16 |
| 3.35 | 2.19 | 1.16 |
| Total<br>3.08 | Total<br>1.96 | Total<br>1.12 |

Table 3 Pure inoculum from pilot reactor with PH=7.23

| Dry matters (%) | Inorganic matters (%) | Organic dry matters (%) |
|---|---|---|
| 2.7 | 0.8 | 1.9 |
| 2.79 | 0.899 | 1.891 |
| 2.64 | 0.8832 | 1.7568 |
| Total 2.71 | Total 0.86 | Total 1.85 |

Table 4 Sediment from wastewater sample from the pilot reactor

| Dry matters (%) | Inorganic matters (%) | Organic dry matters (%) |
|---|---|---|
| 20.12 | 5.03 | 15.09 |
| 21.489 | 4.89 | 16.599 |
| 24.296 | 5.11 | 19.186 |
| Total 21.96 | Total 5.01 | Total 16.95 |

Table 5 Filtrate from wastewater sample from the pilot reactor with PH=8.20

| Dry matters (g/l) | Inorganic matters (%) | Organic dry matters (%) |
|---|---|---|
| 4.1 | 1.75 | 2.35 |
| 3.99 | 1.88 | 2.11 |
| 2.72 | 1.22 | 1.5 |
| Total 3.6 | Total 1.616 | Total 1.984 |

Table 6 Pure sample from wastewater sample from the pilot reactor with PH= 7.23

| Dry matters (%) | Inorganic matters (%) | Organic dry matters (%) |
|---|---|---|
| 4.875 | 0.99 | 3.885 |
| 4.94 | 1.086 | 3.854 |
| 5.14 | 1.089 | 4.051 |
| Total 4.985 | Total 1.055 | Total 3.93 |

For a period of 36 days in ambient temperature conditions, the total biogas yield of 202.6 $m^3$. The first 10 days there were 10-16 $m^3$/d of biogas produced and after that the biogas production declined on average to 7.6 $m^3$/d.

The following table shows the Biogas yield values from the laboratory reactor and from the Agria farm reactor.

Table 7 Biogas yield from the laboratory reactor and Agria farm reactor

| Day | Date | Daily production of biogas in $cm^3$- Lab. Reactor | Daily production of biogas in Agria - $m^3$ | t ° C |
|---|---|---|---|---|
| 0 | 06.10 | 0 | 0 | / |
| 1 | 07.10 | 1250 | 15.8 | 19 |
| 2 | 08.10 | 1250 | 15.8 | 19.4 |
| 3 | 09.10 | 1200 | 15.2 | 19.1 |
| 4 | 10.10 | 950 | 12.03 | 19.3 |
| 5 | 11.10 | 750 | 9.5 | 19.8 |
| 6 | 12.10 | 850 | 10.8 | 19.2 |
| 7 | 13.10 | 850 | 10.8 | 19.2 |
| 8 | 14.10 | 850 | 10.8 | 18.5 |
| 9 | 15.10 | 600 | 7.6 | 19.6 |
| 10 | 16.10 | 550 | 6.96 | 18.0 |
| 11 | 17.10 | 550 | 6.96 | 18.2 |
| 12 | 18.10 | 550 | 6.96 | 20.4 |
| 13 | 19.10 | 550 | 6.96 | 20.0 |
| 14 | 20.10 | 400 | 5.06 | 20.8 |
| 15 | 21.10 | 200 | 2.53 | 20.8 |
| 16 | 22.10 | 350 | 4.43 | 20.0 |
| 17 | 23.10 | 200 | 2.53 | 20.4 |
| 18 | 24.10 | 400 | 5.06 | 20.0 |
| 19 | 25.10 | 150 | 1.9 | 21.4 |
| 20 | 26.10 | 250 | 3.16 | 21.3 |
| 21 | 27.10 | 300 | 3.8 | 21.6 |
| 22 | 28.10 | 200 | 2.53 | 21.3 |
| 23 | 29.10 | 250 | 3.16 | 21.4 |
| 24 | 30.10 | 250 | 3.16 | 21.5 |
| 25 | 31.10 | 150 | 1.9 | 21.8 |
| 26 | 1.11 | 250 | 3.16 | 21.5 |
| 27 | 2.11 | 200 | 2.53 | 21.1 |
| 28 | 3.11 | 350 | 4.43 | 21.5 |
| 29 | 4.11 | 150 | 1.9 | 21.8 |
| 30 | 5.11 | 150 | 1.9 | 20.2 |
| 31 | 6.11 | 100 | 1.26 | 21.2 |
| 32 | 7.11 | 200 | 2.53 | 21.7 |
| 33 | 8.11 | 200 | 2.53 | 21.9 |
| 34 | 9.11 | 150 | 1.9 | 22.2 |
| 35 | 10.11 | 300 | 3.8 | 22.1 |
| 36 | 11.11 | 100 | 1.26 | 20.0 |
| **Total** |  | **16000** | **202.59** |  |

Figure 1 Burning the produced biogas from the Agria farm reactor

The biogas laboratory and pilot tests started in the autumn period of the year, and finished in the winter period. We concluded that after the first phase of biogas production the inoculum that we used underwent an adaptation process which resulted in higher biogas production. The adaptation period of the inoculum was a crucial moment for the laboratory and pilot biogas yield. In the following figures we can see a comparison of the biogas production velocity under a certain period of time, both in laboratory and pilot conditions. When the adaptation period ends, we receive the highest biogas production that can be expected from the Agria pig farm wastewater. Also from the figures we can see two major spikes of biogas production which point out the two biogas yielding stages in the four step anaerobic fermentation, the acetogenic and the methanogenic phase.

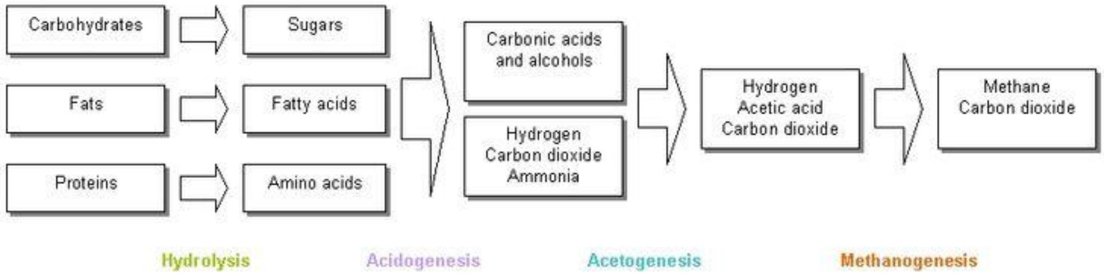


Figure 2 The key process stages of anaerobic digestion

We can conclude that the Agria pig farm has an excellent potential for biogas production with excellent quality and high velocity using the combined technology for biogas production that was developed under the frame of this project.

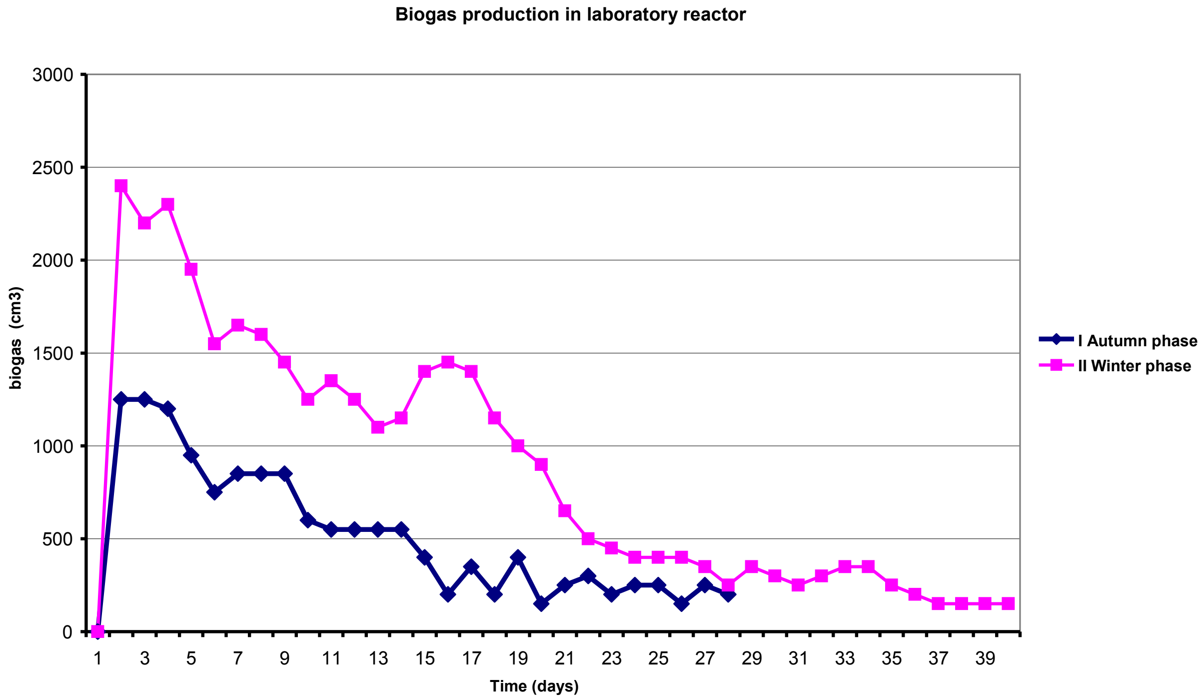


Figure 3 Biogas production in laboratory reactor before inoculum adaptation (Autumn phase) and biogas production after inoculum adaptation (Winter phase)

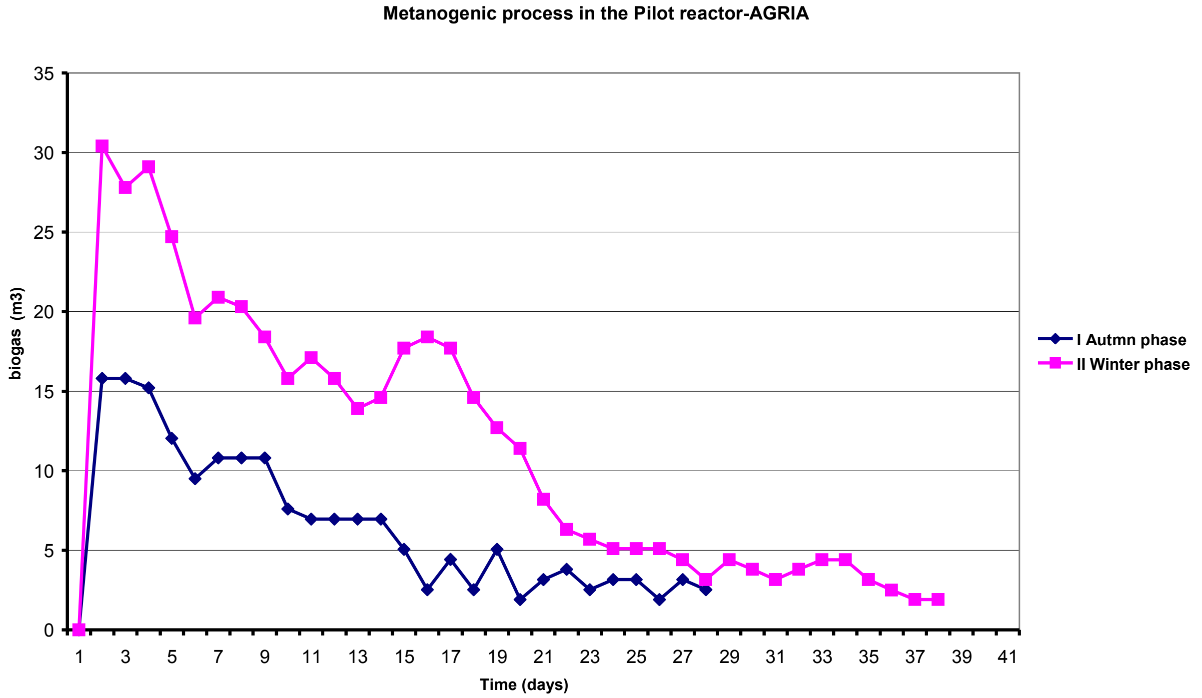


Figure 4 Biogas production in pilot reactor before inoculum adaptation (Autumn phase) and biogas production after inoculum adaptation (Winter phase)

# Part II: Agria field tests

## 1 Introduction

The Agria microgrid is located in a rural area, on a pig farm, probably one of the biggest of that kind in the country. Farms are significant contributors to pollution because of the large amounts of waste they produce daily. According to the new national legislation, the Integrated Pollution Prevention and Control negotiations between farm owners and officials have already started and the owners are required to fully apply the agreed pollution reduction measures by the end of 2014. One of the measures to reduce local pollution is to apply a suitable waste water treatment (WWT). Not only that WWT is proven to be an efficient way to reduce pollution, but the biogas, as one of the by-products of the process, can be used to supply the local consumers with electricity and/or heat.

Pressed by the forthcoming legislation, farm owners are now interested in pilot projects in order to estimate the financial and technical requirements of applying WWT on their farms. This was one of the main drivers of the collaboration with the Agria industrial group, which is the owner of the farm. Their farm was already equipped with a small biodigester and a waste collector system, but they were not in operation. The owners were already introduced to the idea to use the locally produced biogas for electricity production and supply part of the loads on the farm, so they willingly accepted the proposal to establish and test a pilot microgrid on their farm.

Figure 5 AGRIA Farm – view to the stalls and the biodigester

On the other hand, the possibility to test a microgrid with a biogas plant and to apply WWT based on anaerobic digestion was the main driver for the INCO partners to propose the location as test pilot microgrid. It is worth mentioning that this is the first microgrid test location in the wider region, which offers possibilities for further research in the area.

### 1.1 Basic information

The farm consists of several warehouse-like stalls with ventilation, temperature control and lighting systems, administrative building and few utility buildings and storage rooms containing farm equipment. The farm is connected to the 10 kV distribution network through transformer station which belongs to the farm. The provisional position of the objects on the farm is depicted in fig. 2.

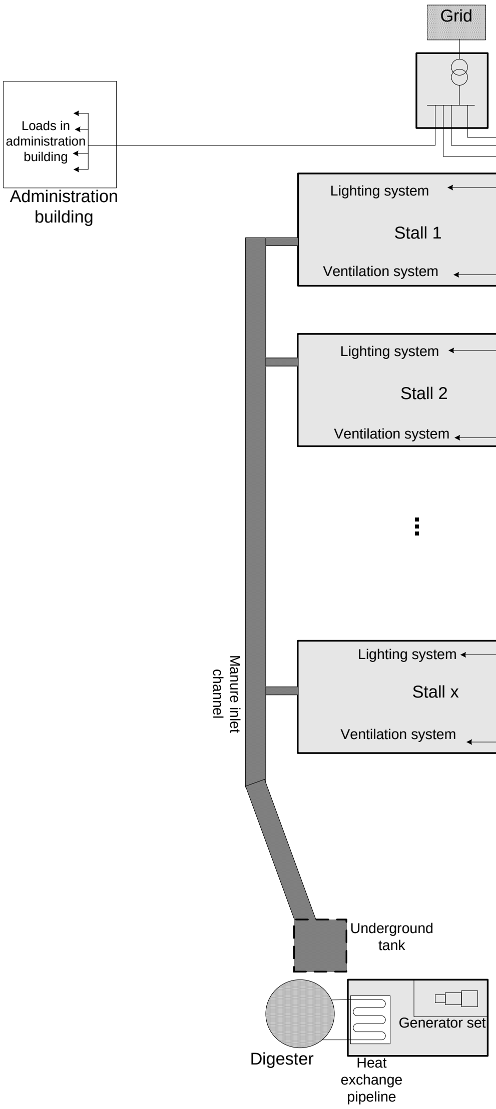


Figure 6 Position of the objects on the test location

The farm is constructed as an indoor animal breeding system and it allows for easy collection of waste through a waste collection inlet. As depicted in fig. 2, the inlet channel is used for transportation of the manure to an underground tank, which is connected to a bio-digester through a pipe system. The heat exchange system and the generator set are placed in a small house in the vicinity of the farm. The generator can use both the biogas produced from the waste management on the farm or natural gas, LPG or other similar fuels.

## 2 Biogas production process – short overview

The biogas production process is based on combined aerobic and anaerobic waste water treatment developed by one of the INCO partners in the project, Bioengineerig d.o.o. The technology they proposed can be successfully incorporated both in industrial and farm waste water treatment systems. Within the framework of the project, the biogas production process was tested in laboratory environment, using a small pilot model with manure collected on the farm. Fig. 3 presents the separate parts of the bio-digester on a model similar to the real biogas plant installed on the farm.

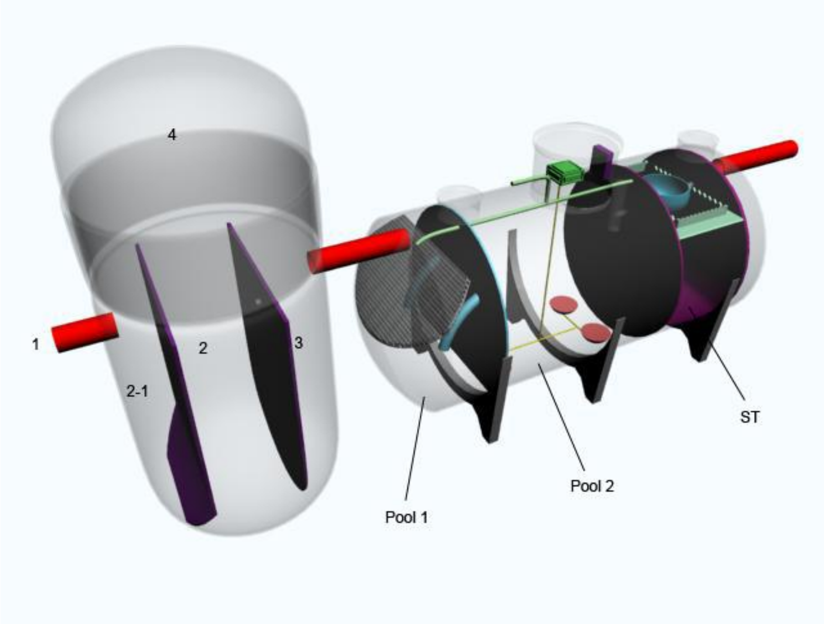


Figure 7 Equipment for biogas production:
1 - recipient shaft, 2 - methanogenic zone, 2-1 - primary sedimentation, 3 - effluent and secondary sedimentation zone, 4 - biogas collecting chamber, Pool 1 – de-nitrification pool, Pool 2 - nitrification pool, ST - sedimentation tank, (from Bioengineering project documentation)

The biogas production system, the laboratory and field biogas production tests are explained in details in the Part I of this report. Here, only the basic information about the process is presented, in order to provide a better overview of the microgrid design and operation.

## 2.1 Laboratory tests

The tests on the biogas production in laboratory environment had to be conducted prior any other activity on the farm, in order to prove the project practical feasibility and to provide general information on expected biogas production. The laboratory tests were performed by the Bioengineering team. They referred to examination of optimal biogas production technology and investigation of its quality. The tests enabled to determine the optimal starter culture for the anaerobic digestion. The optimal fermentation temperature for higher biogas production was also determined. Afterwards, the quality of the produced biogas was examined. The chemical analyses were conducted in accordance with the American Public Health Association standard. The following parameters were monitored: total dry, organic and mineral matters, total nitrogen, chemical oxygen demand (COD), biochemical oxygen demand (BOD 5), nitrite, ammonium nitrogen and phosphates. The laboratory tests proved that biogas with appropriate quality was produced. These analyses also enabled determination of optimal dry matter concentration of the waste water in order to achieve higher biogas production.

## 2.2 Biogas production field tests

After finishing the laboratory tests, the actions for the biogas reactor activation on the test location have begun. The tests indicated that the biogas production process can be improved by installing biogas holders. The size of the biogas holders was calculated from the laboratory test results. The holders have been designed and manufactured and now the digester is connected to two gas holders, which continue to the heat exchange pipe system. In that context, fig. 4 presents the actual situation on the pilot site, i.e. the real plant in relation to the other objects on the farm.

The installation of the gas holders was concluded with additional safety tests and measurements, after which the biogas production was successfully tested on the location.

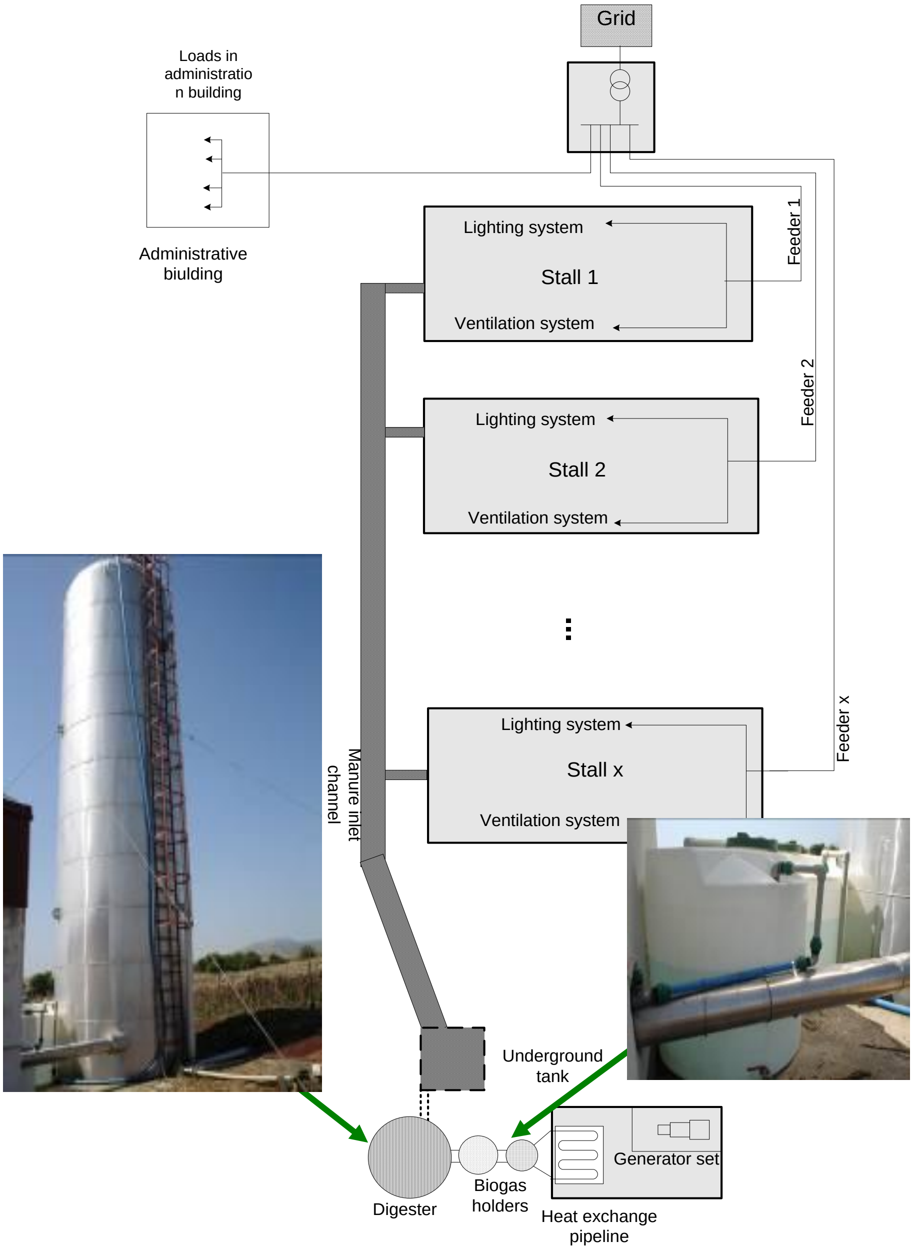


Figure 8 Biogas production plant at the test location Agria

The starting biogas production tests were done using only partial capacity of the inlet channel and the underground tank. The tests with 38 $m^3$ of waste water showed biogas daily production of 10-16 $m^3$, with average calorific value of 21.6 $MJ/m^3$, only slightly below the estimated values from the laboratory tests. On Fig. 5 below, the biogas production at the test location in 8 consecutive days and the energy produced from the biogas in that period are presented.

The biogas production process is by weather conditions to some extent, but the field tests proved it is a rather stabile cyclic process having its peak days at the first 5-6 days since the beginning of the anaerobic digestion, i.e. after feeding the underground tank with waste water. The biogas production decreases slowly and the whole process ends in about 30 days, when the system needs to be fed with waste water again.

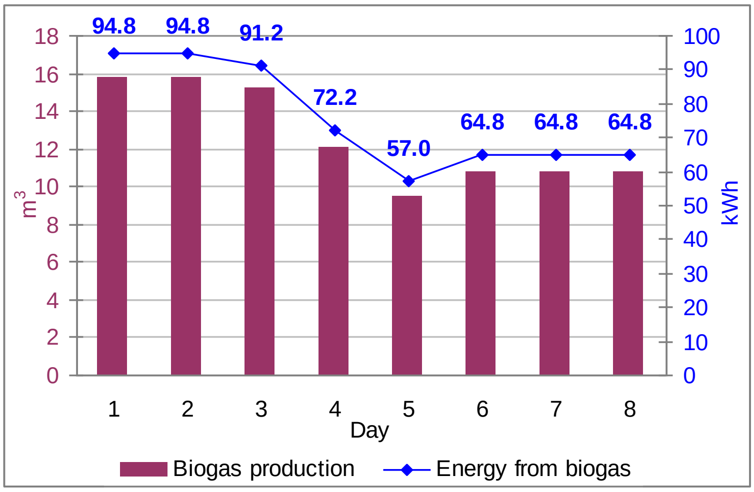


Figure 9 Biogas production in 8 consecutive days

More detailed information on field tests for biogas production is presented in Part I of the report.

## 3 Pilot microgrid design overview

The pilot microgrid encompasses a part of the existing low voltage grid on the farm, including few loads and a generator. It is envisaged that the loads within the microgrid will be supplied either by grid electricity, or by electricity produced by the generator using the biogas form the waste water treatment. The single line diagram of the pilot grid is presented in fig. 5.

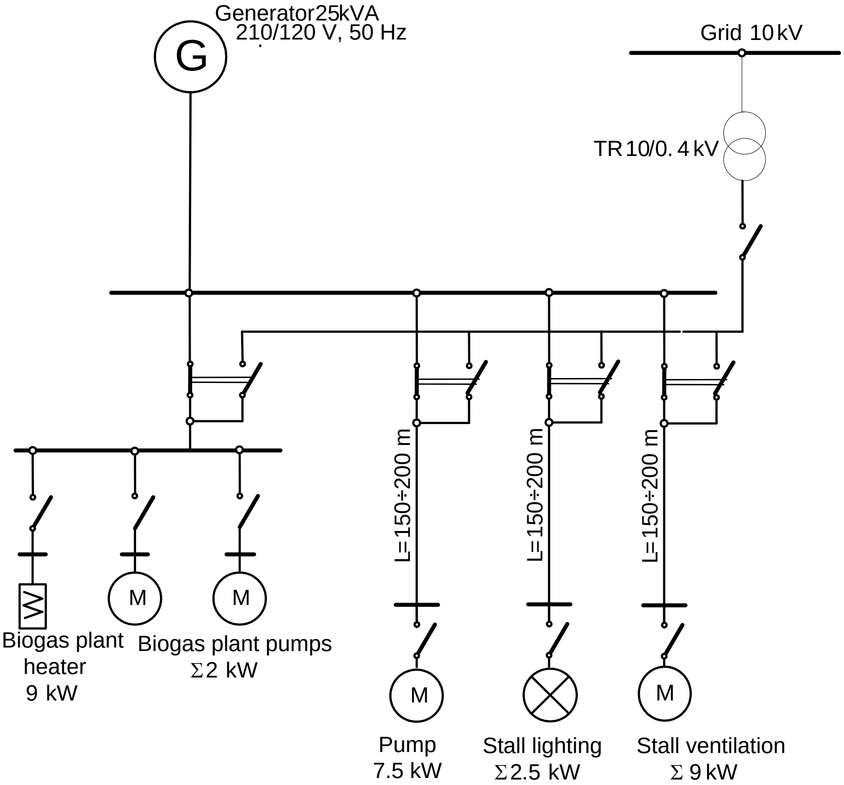


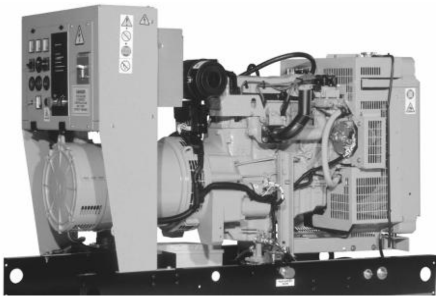
Figure 10 Single line diagram of the Agria pilot microgrid

The biogas production process itself requires two electric pumps, one used to circulate the biogas through a set of heat exchange pipes when the ambient temperature is low and the other for mixing the manure. Initially, the manure is collected in a cement underground basin where it is mixed and transferred into the digester. After the anaerobic digestion, the produced biogas escapes the digester through a pipe connected to the biogas holders, from where it is directed to the generator. During winter time, a heater is also needed in order to provide appropriate conditions for biogas usage.

The biogas under pressure is fed in the generator by a pipe ending with an inlet valve. There is no additional reservoir for the gas and the engine is equipped with gas pressure regulator and a shutoff valve. According the equipment specification, the generator uses 3.9 $m^3$/hour when fully loaded and 2.0 $m^3$/hour when 50% loaded. The generator is applicable for supplying continuous electrical power at variable load, but no overload is permitted on generator's ratings. The generator data are presented in tab. 1 below.

Table 8 Generator characteristics

| Rated Power :<br>(stand by) | 31,5 kVA<br>25 KW; cosφ=0,8 |
|---|---|
| Rated Voltage: | 208/120V; 3 phases |
| Rated Current: | 87 A |
| Rated R.P.M.: | 1000 |
| Max. ambient temperature: | 25 °C |
| Alternation connection: | P_STAR |
| Insulation class: | H |
| Excitation Voltage: | 39 V |
| Excitation Current: | 2 A |
| A.V.R. | R230/A |



The generator is part of the equipment which was installed on the farm in the framework of another project. The generator's ratings are tailored for the US market, so few minor modifications were made to the generator even before the beginning of the project. Because of the generator's ratings, the loads are connected to phase to phase voltage.

Prior the field tests, few modifications were made in the wiring in the switchboxes and few connections between the loads were modified with the aim to provide adequate testing conditions. The loads are connected by cables to the main switchbox and the switches allow two supply possibilities: by the local DG production unit or by the distribution grid. The switches also allow part of the loads to be connected to the grid and the rest to the generator, depending on the biogas production process, i.e. weather the pumps and the heater are needed simultaneously. The loads comprise a pump, located in the vicinity if the last stall and part of the lighting and ventilation system in the stalls. The loads are situated approximately 200 meters from the house where the main switchboard and the generator are placed.

## 4 Description of the measurement equipment and measuring procedures

The measurements on the pilot site were made using appropriate equipment including: network recorder (meter), current transformers, switches and additional different types of meters. The equipment was used to record the microgrids characteristics, including voltages, currents, active and reactive power, power factor, total harmonic distortion (THD), frequency, etc.

### 4.1 Measurement equipment

The network recorder used during the tests is of type Iskra – MIS MC 750, presented on fig 6. The network recorder is intended for measuring, analysing and monitoring single-phase or three phase electrical power networks. It is fully compliant with the SIST EN 61010-1, 60529, 50160, 62052-11, 62052-21 Standards.

Figure 11 Network recorder – users interface and recorder integrated in a measuring set

The device [1] can be utilized in measuring voltages, currents, power, power factor, frequency, phase angle, THD, energy, etc, with accuracy class of 0.5. It records up to 32 measuring quantities and 32 alarms in the internal memory and measures more than 140 electrical quantities. The device measures RMS value according to the principle of fast voltage and current signals sampling. A built-in microprocessor calculates measured values from the measured signals. The network recorder is also capable of storing 100,000 deviations of measured values which enables easier detection of problems in the network.

The recorder uses standard MODBUS and DNP3 communication protocols, RS 232/ RS 485 with up to 115,200 bits/s or Ethernet communication and universal AC power supply, which makes the device easy to use in different environments. The recorder has 4 inputs or outputs (tariff inputs, analogue, pulse or alarm outputs). The recorder has an automatic range of nominal current up to 5 A and nominal voltage up to 500 V and capability to record 128 samples in one period.

The producer has provided complementary software – MIQEN, which is intended for supervision of the recorder on PC. Recorder setting, display of measured and stored values and analysis of stored data in the meter are possible via the serial or Ethernet communication. The information and stored measurements can be exported in standard Windows formats.

The measurement equipment was fully prepared and tested before the field tests. In that period the measurement procedures and recording parameters were also prepared.

Figure 12 Measurement equipment tests

## 4.2 Measurement procedures

The measurements were done according earlier prepared record files (Recorder A and B) which enable measurement and calculation of the needed network data. The record files presented in table 2 and table 3 were created for use with the MIQEN software.

Table 9 Recorder A – measurement parameters, average values per minute

| Setting | Value |
|---|---|
| Storage interval (min) | 1 |
| MD Time constant 1-8 (min): | 15 |
| MD Time constant 9-16 (min): | 15 |
| 1. Record parameter: | Voltage $U_1$ |
| 2. Record parameter: | Voltage $U_2$ |
| 3. Record parameter: | Voltage $U_3$ |
| 4. Record parameter: | Current $I_1$ |
| 5. Record parameter: | Current $I_2$ |
| 6. Record parameter: | Current $I_3$ |
| 7. Record parameter: | Current $I_1$ (Direction) |
| 8. Record parameter: | Current $I_2$ (Direction) |
| 9. Record parameter: | Current $I_3$ (Direction) |
| 10. Record parameter: | Power Angle $U_1$-$I_1$ |
| 11. Record parameter: | Power Angle $U_2$-$I_2$ |
| 12. Record parameter: | Power Angle $U_3$-$I_3$ |
| 13. Record parameter: | THD $U_1$ |
| 14. Record parameter: | THD $U_2$ |
| 15. Record parameter: | THD $U_3$ |
| 16. Record parameter: | Frequency f |

Table 10 Recorder B – measurement parameters, average values per minute

| Setting | Value |
|---|---|
| Storage interval (min) | 1 |
| MD Time constant 1-8 (min): | 15 |
| MD Time constant 9-16 (min): | 15 |
| 1. Record parameter: | Real Power $P_1$ |
| 2. Record parameter: | Real Power $P_2$ |
| 3. Record parameter: | Real Power $P_3$ |
| 4. Record parameter: | Reactive Power $Q_1$ |
| 5. Record parameter: | Reactive Power $Q_2$ |
| 6. Record parameter: | Reactive Power $Q_3$ |
| 7. Record parameter: | Power Factor $\cos\varphi_1$ |
| 8. Record parameter: | Power Factor $\cos\varphi_2$ |
| 9. Record parameter: | Power Factor $\cos\varphi_3$ |
| 10. Record parameter: | Total Power Factor |
| 11. Record parameter: | Total Real Power |
| 12. Record parameter: | Total Reactive Power |
| 13. Record parameter: | THD $I_1$ |
| 14. Record parameter: | THD $I_2$ |
| 15. Record parameter: | THD $I_3$ |
| 16. Record parameter: | Internal temperature t |

The measured values are stored according the predefined settings allowing easier access and further analyses.

## 5 Field tests – objectives, methodology and results

Within the MORE MICROGRIDS project, the Agria demo case is used to achieve the following main objectives:

- From the aspect of Microgrid concept and advanced RES technologies the aim is to provide an example for inclusion of a biogas plant into a microgrid.
- To introduce and test the microgrid concept in the power system of a country from West Balkan region.
- To increase the potential and awareness of Microgrid option in non-EU regions through dissemination

The achievement of these objectives was only possible after the following developments were made on the pilot location:

- investigations on optimal design and construction of the biogas plant were undertaken,
- biogas plant safety tests and monitoring were performed,
- the pilot microgrid was fully established.

The completion of these tasks enabled the commencement of the testing period on the pilot location, with the main objective to validate the isolated mode of operation. During each test, several network parameters were monitored and measured, using the equipment and measurement procedures already described in the previous section of the report.

The field tests were done in September 2009 and included several different tests. Part of the tests were done with the aim to record the network parameters under specific conditions while the rest of the tests were used to investigate the microgrid operation during everyday farm activities, while loads are switched on and off without predefined scenario.

Figure 13 Measurements at the Agria test location

### 5.1 Field tests with unbalanced loads

The first set of tests was undertaken with the aim to check the microgrid operation with three phase unbalanced loads. This microgrid would normally operate as unbalanced three phase network, so this is the main reason for performing these tests. Heaters with potentiometers were used to simulate unbalanced loads on three phases. The network meter was used to measure and record the network parameters, according the defined measurement procedures. In this section, the results from one of these tests are presented.

At the beginning, the three phases were equally loaded, with about 1.8 kW. Shortly after, the loads were reduced considerably and than, each of the phases was loaded in a manner that allows the microgrid to operate as an unbalanced network. In the first 30 minutes, the highest load was switched on the second phase. The similar procedure was repeated again in the next 30 minutes, but higher loads were switched both on the first and the second phase. The procedure for increasing loads ended with gradually switching the loads on the third phase. In the last hour of the test, the reverse procedure was performed, i.e. the loads were gradually reduced. The whole process is presented on fig. 11, which shows the active and reactive powers on all three phases during the test. The values presented on fig. 11 are 15 minute average values.

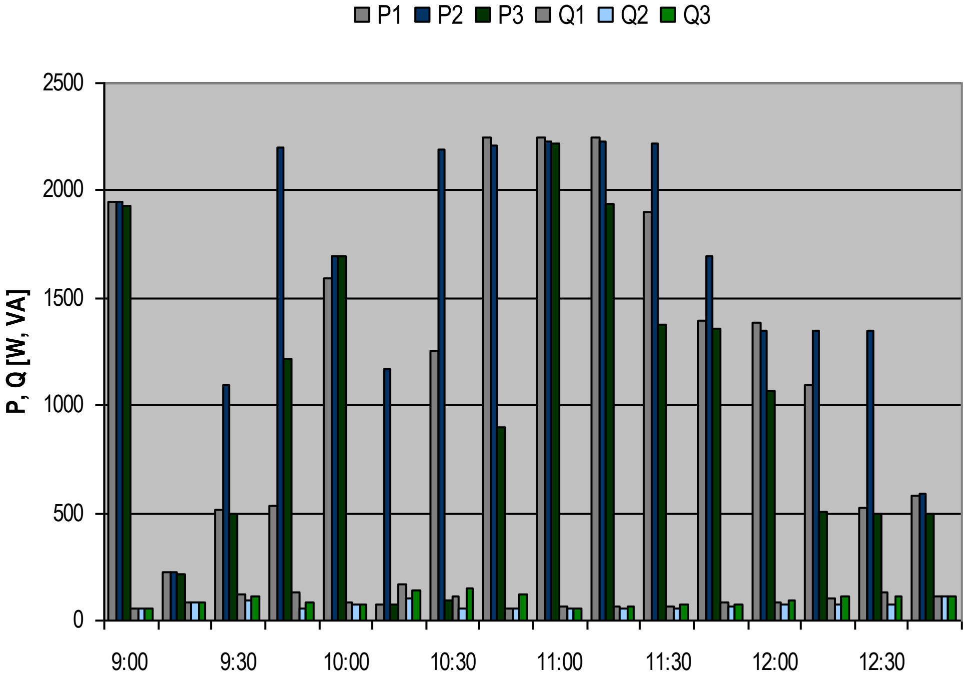


Figure 14 Loads switching during field tests with unbalanced loads

During the tests several network parameters were recorded and the analyses showed that they were all kept in relatively small margins. Figure 12 presents the average values of phase to ground voltages in relation to switching loads.

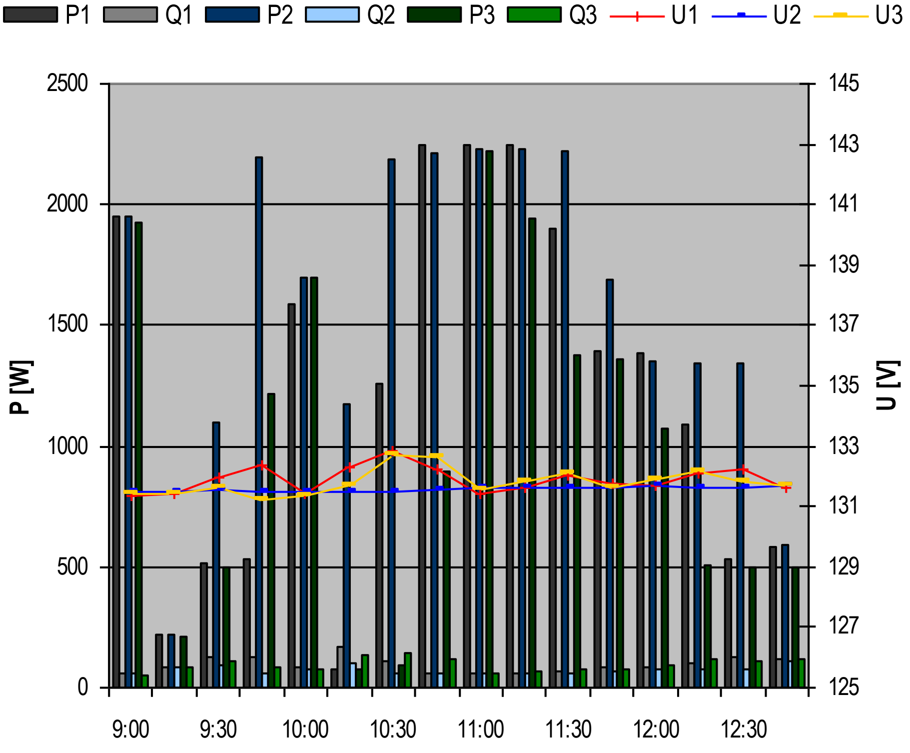


Figure 15 Phase-to-neutral voltages during test with unbalanced loads

As shown in the picture, the phase voltages change slightly when the additional load is switched on and off in the network, but the values are kept in very narrow margins. Similarly, the currents in all three phases were also recorded and they're presented in fig. 13, again as 15 minute average values.

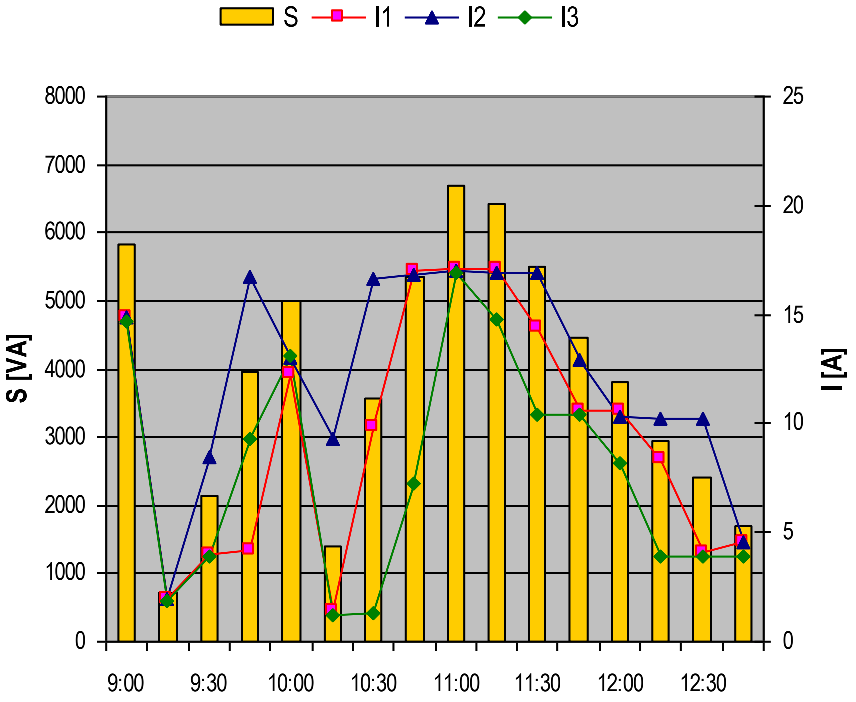


Figure 16 Currents and apparent loads

The frequency is one of the most important parameters for the isolated mode of operation. The measurements have proven that during switching the loads on and off, the frequency changed, but in a rather small margin, i.e. in the range of 50.05-50.11 Hz, which is acceptable for isolated grids. The measured frequency is presented in fig. 14.

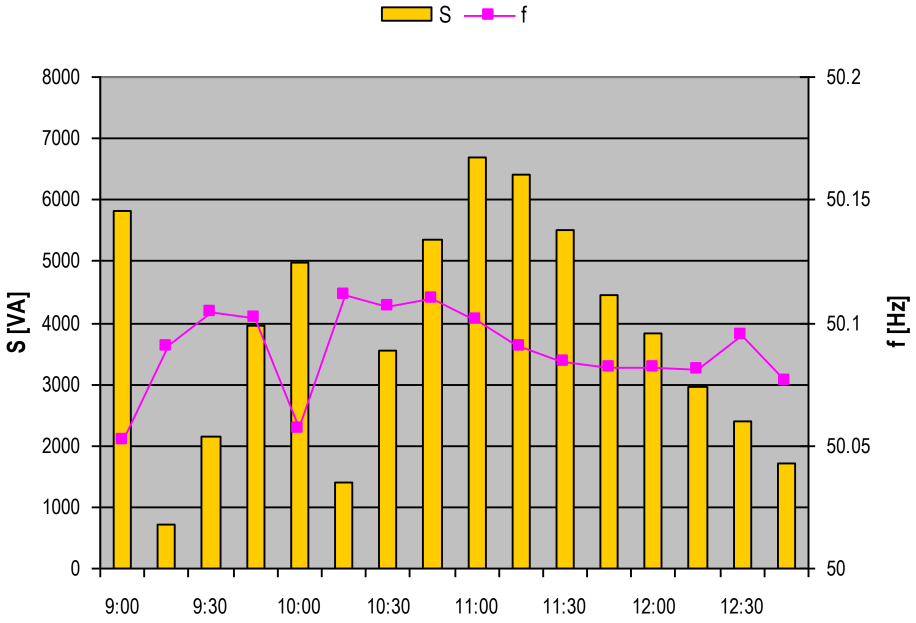


Figure 17 Frequency and apparent loads

The frequency changes slightly when load is switched on or off, as it happens for example in 10:00 when loads are switched on in phases 1 and 3 and about 1kW is switched off in phase 2.

The measured parameters have proven that the network during the tests performed satisfactorily. The voltages were kept in narrow margins due to the generator's automatic voltage regulator [2] which maintains the voltage within ±0.5% for three phase and ±1.0% for single phase at steady state from no load to full load. The voltage regulator also provides fast recovery from transient changes. Beside the voltage regulation, the generator is capable of normal operation with frequency variation of ±2.5% for constant load and no load to full load.

During the tests, THD measurements were also conducted. The total voltage and current harmonic distortion were measured. The results showed that the measured values were within the limits defined in international standards. Fig. 15 presents the measured total voltage harmonic distortion values (THD u). It is important to notice that the generator itself produces certain waveform distortion which should be less than 4%.

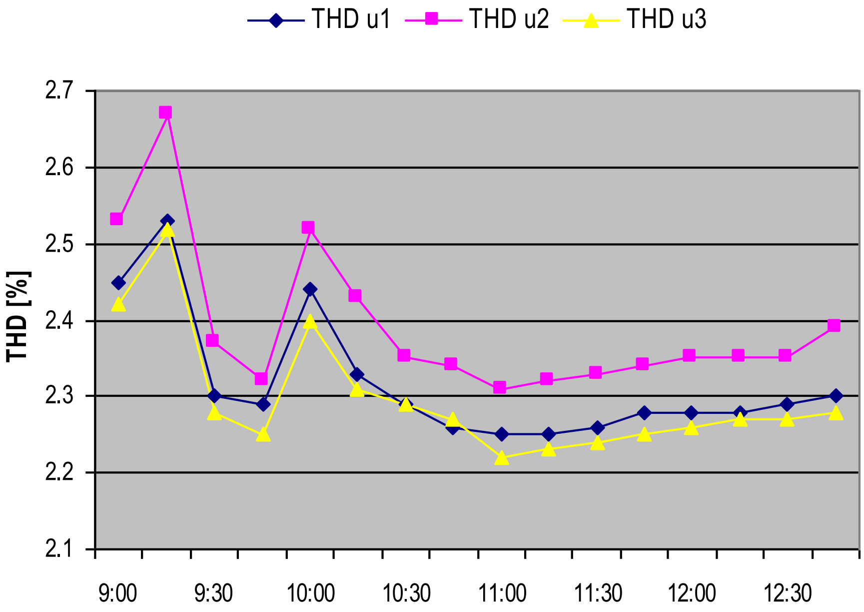


Figure 18 Phase voltage THD

The measured voltage THD is well within the limits adopted in the international standards for voltage characteristics in public distribution systems [3], because according the EN 50160 Standard, THD u in LV networks should be less than 8%.

## 5.2 Different examples of microgrid operation

In this section, the results of microgrid operation with no predefined scenarios are presented, i.e. the microgrid operation was recorded in different parts of several working days, with normal everyday activities. As in the previous section, during the tests different network parameters were measured and recorded. The results are presented as 15 minute average values.

### 5.2.1 Measurements during specific operating hours

In this section, the test results from microgrid operation measured during morning and evening hours are presented. Figure 16 depicts the voltages in all three phases and the active and reactive power per phase. At the beginning of the measurement about 2 kW were switched to the second phase. By the end of the first recorded hour, loads are switched to all three phases. During the test period, the voltages were again kept in a narrow margin, as presented in the same figure. The changes in voltage are more visible at the beginning of the measurement, when loads were switched on; afterwards the values settle at about 131,5 V.

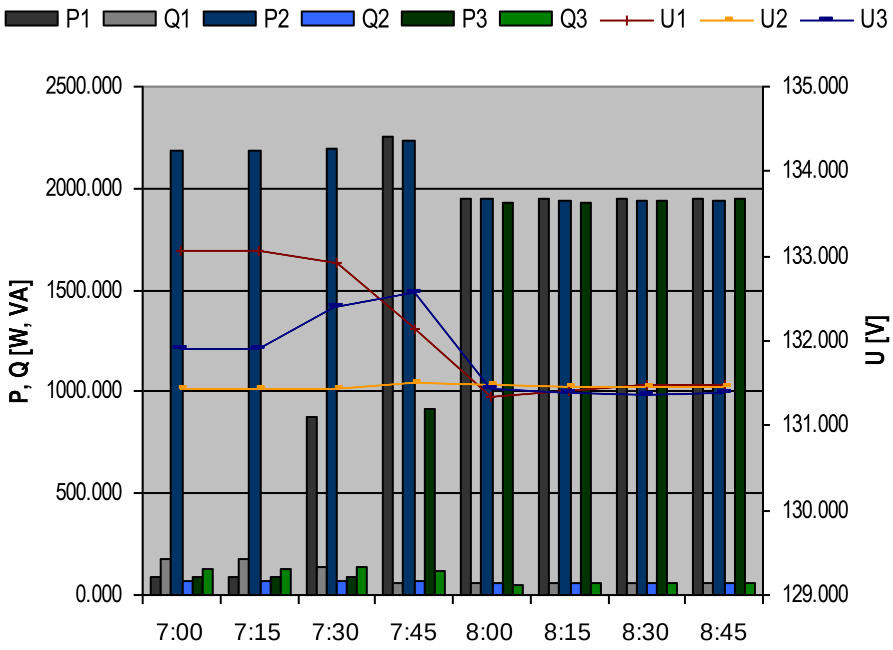


Figure 19 Phase-to-ground voltages and loads

Frequency measurements were also conducted and the results are presented in fig. 17. In this case, after the slight changes during switching the loads at the beginning of the measurement, in the last half hour the frequency settles at 50.05 Hz, which again is well in the defined limits for isolated network operation.

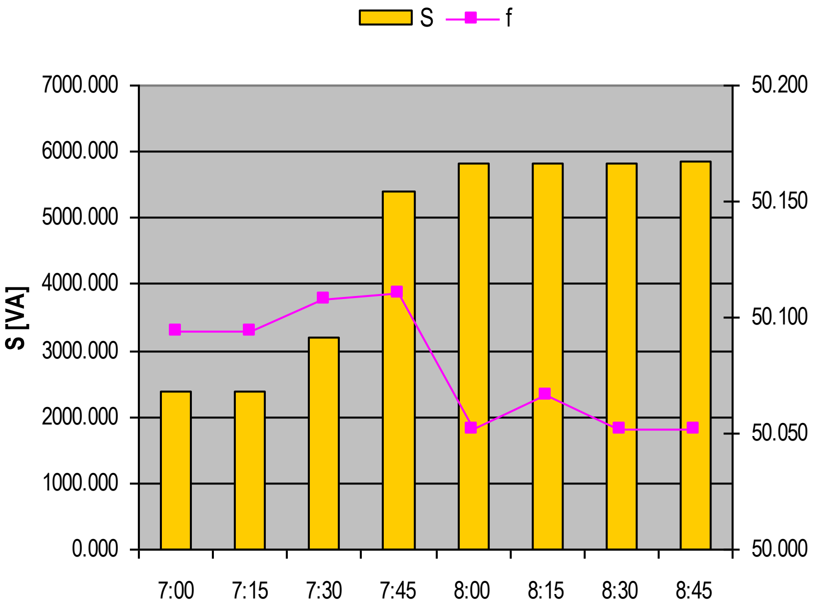


Figure 20 Frequency and apparent loads

The 15 minute average values of the currents in the three phases are presented in fig. 18. The results show the similar conclusion, i.e. that the currents in the network settle when the loads are evenly distributed among phases and no additional loads are switched.

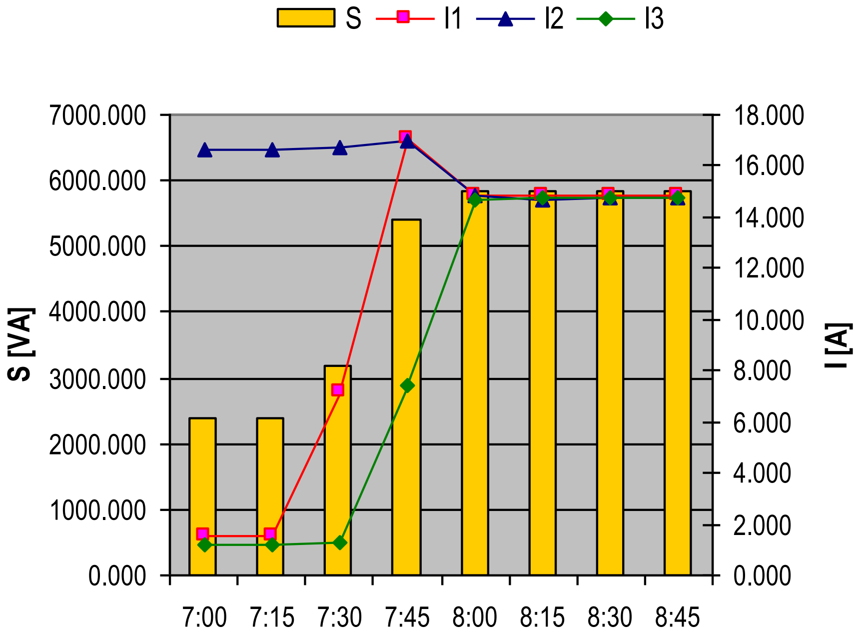


Figure 21 Currents and apparent loads

Additional tests were made during the evening hours, when the loads were being switched off. The findings were similar as in the previous test; the values of all network parameters are as expected. Fig 19 presents the phase voltages and the active and reactive powers in the microgrid during the evening hours (from 20:30 to 22:00).

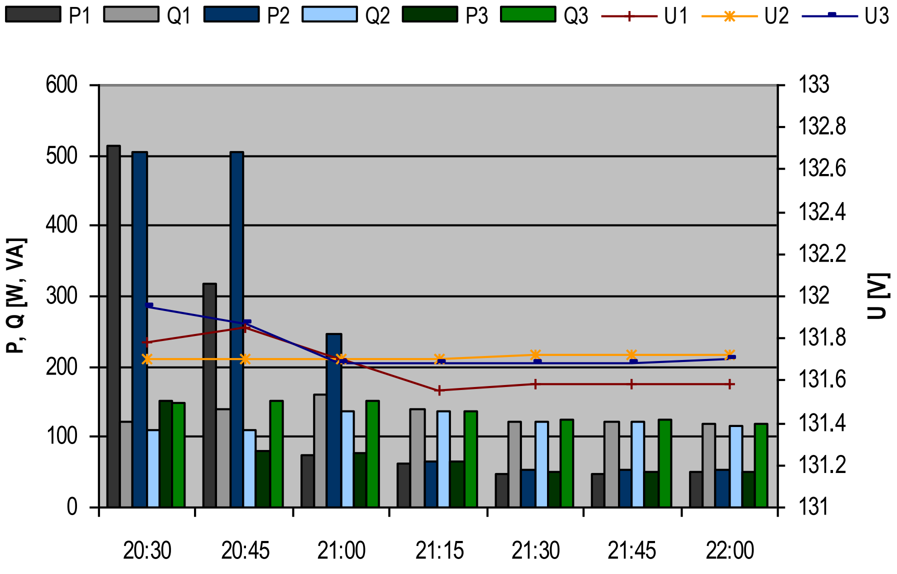


Figure 22 Phase-to-ground voltages and loads

The network is unbalanced, with loads mostly on two phases, which are reduced within the first measurement hour. The measured frequency is presented in fig. 20 and the THD in fig. 21. The frequency is slightly very stable and varies in the range of 50.076 Hz to 50.088 Hz.

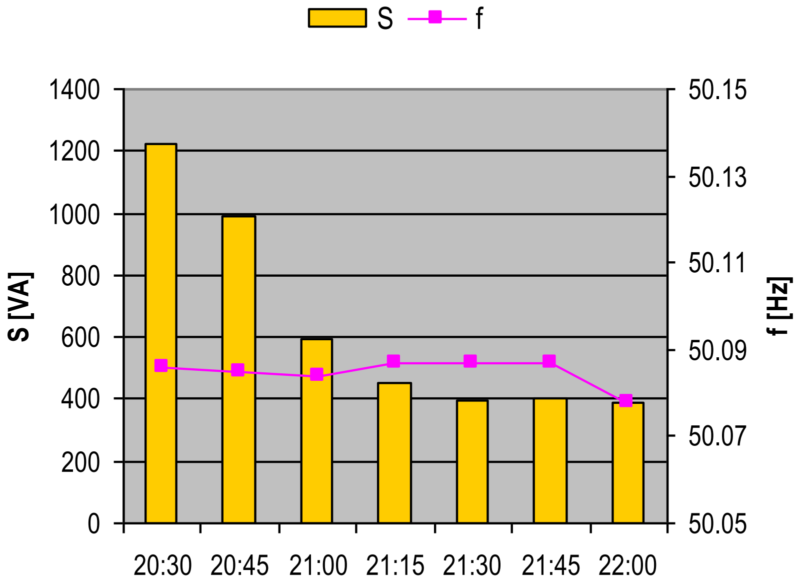


Figure 23 Frequency and apparent loads

The measurements of the currents in the three phases during the test are presented in fig. 21. The values, as in all the previous cases, are presented as 15 minute average values.

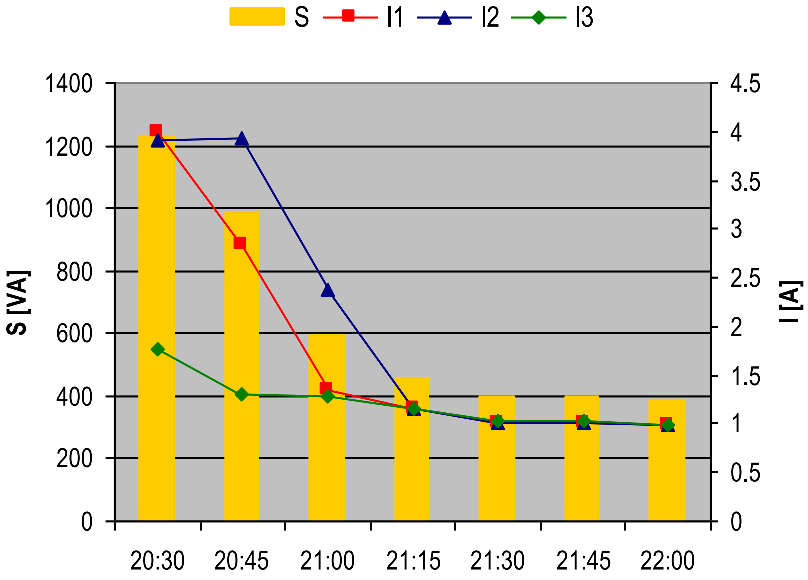


Figure 24 Currents and apparent loads

Similar to the other cases, the THD is also in the requested limits, as shown in fig. 22.

### 5.2.2 Example of a twelve hour microgrid operation

Another interesting example of microgrid operation is presented in this section. Using the predefined measurement procedures, different network parameters were recorded. During the measurement period several different evens happened, which are clearly visible on the following figures.

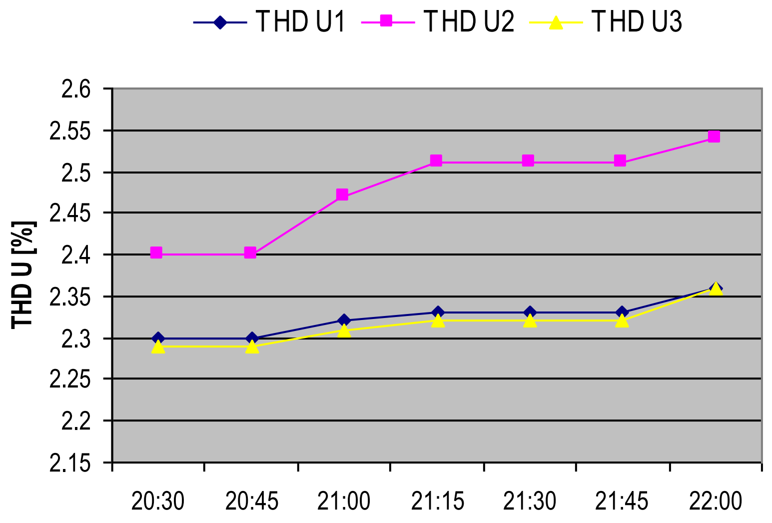


Figure 25 Phase voltage THD

The microgrid was unbalanced, and loads were switched on and off several times during the measurement period. The results showed that the network performed satisfactorily, the values of the different parameters were within the requested limits and the network was capable of supplying quality power to the loads.

The fig. 23 presents the phase to ground voltages and the apparent load, measured during 12 hour operation.

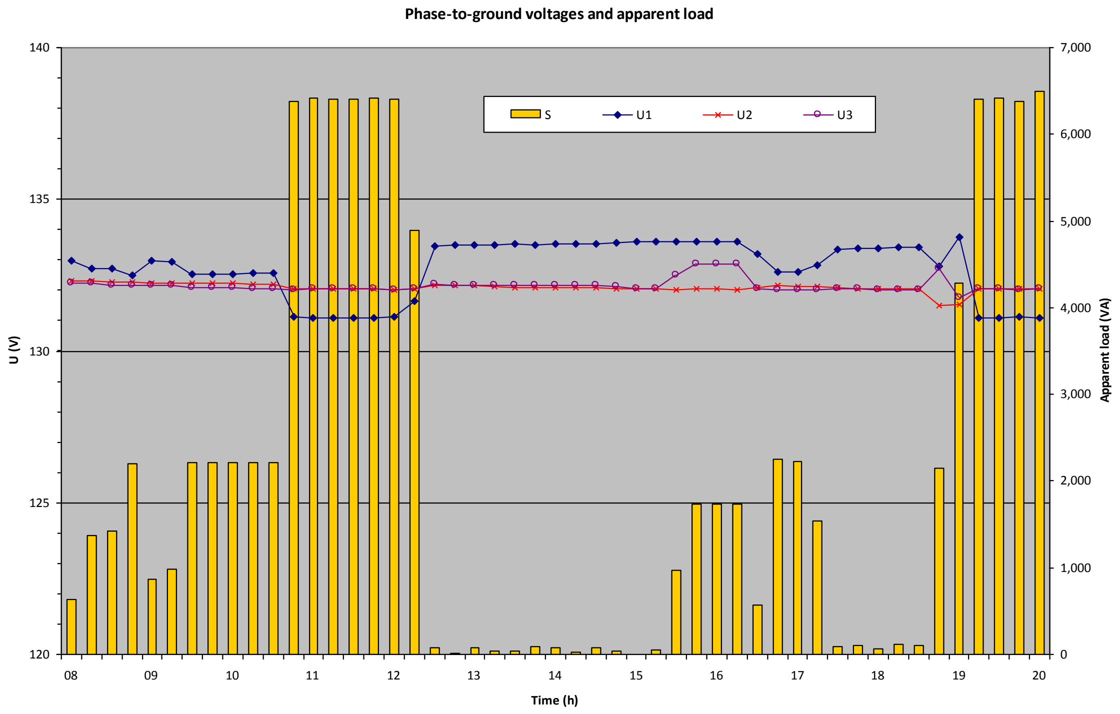


Figure 26 Phase-to-ground voltages and apparent load

The changes in voltage can be observed when changes in loads occur, i.e. at 10:45 approximately 3 kW load is switched on, mostly on phase 2, so the voltage slightly drops.

Similar changes can be observed during switching off a larger load at 12:45 and than again within the next several hours of operation.

In this case, the 15 minutes minimum values of the frequency measurements are shown in fig. 24.

Figure 27 Apparent load and lowest frequency values in 15 minutes

The measurements show that the frequency is kept at about 50.1 Hz and thath sligh changes may be observed due to sudden load changes.

Another interesting aspect of the microgrid operation was the voltage THD, presented on fig. 25.

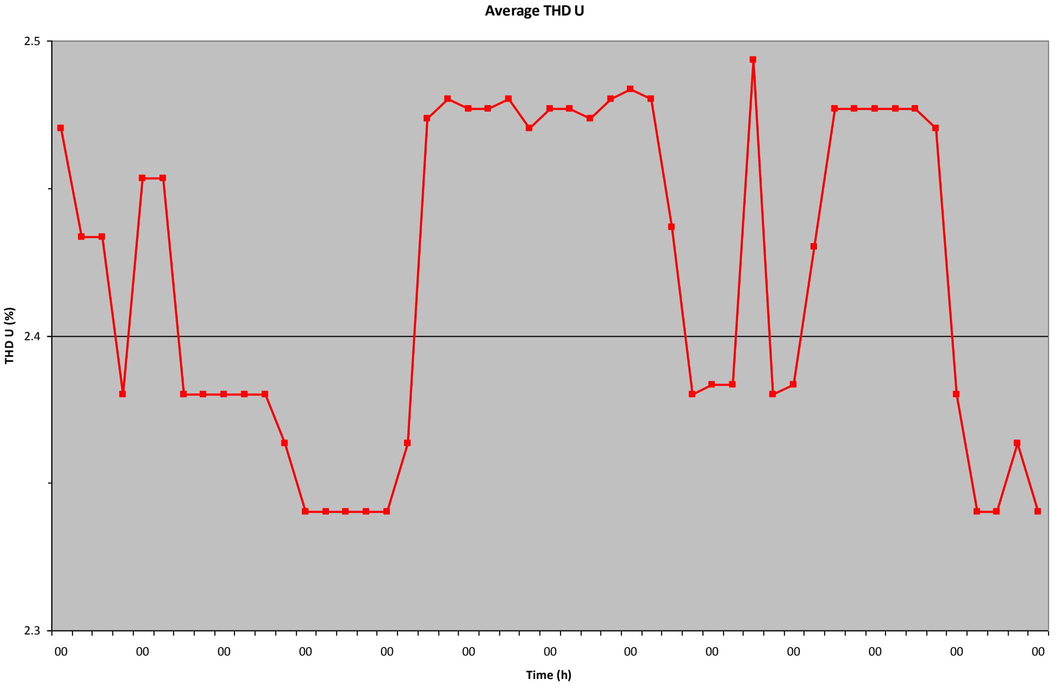


Figure 28 Average THD u

The measurements have shown results similar to the previous tests, i.e. in compliance with the international standards. In this case, the average THD u varied around 2.4 %.

## 5.3 Increasing the awareness of the microgrids concept

Among the objectives of the demo case was increasing the potential and awareness of the Microgrid option in non-EU regions through dissemination. The established microgrid test location and the completed field tests serve as foundation for further research in the area of biogas production technologies and microgrids concept.

Additional activities created favourable conditions for increasing the awareness of the microgrid concept in the country. These activities include:

- linkages with similar existing national projects (Agro-Energy, financed by Swedish Development Agency - SIDA)
- project location presented at the workshop dedicated to founding of the SmartGrids Platform.

### 5.3.1 Benefits from of the cooperation between different partners

The mutual cooperation with the farm owners has proven to be a successful way to build relation between SMEs, research institutions and industry. The cooperation was based on common interests, as already described in section 1 Introduction, of Part II of this report. The establishment of the pilot Microgrid location Agria involved collaboration between a SME, responsible for biogas production on the location, the owner of the location, i.e. pig breeding company and two research institutions.

The example of this type of collaboration is already explained in [4]. The important conclusion is that it could be easily transferred to other similar projects, if common interests for the partners exist. The farms in the region have to manage their waste and the SMEs can provide solutions for waste water management. The possibility to use the biogas for electricity/heat production for the local users is additional benefit for the partners. Further on, depending on the size of the production unit, the produced electricity could be sent to the grid, while the owner will receive payment under special RES tariff.

Other opportunities also exist. The SMEs could provide different services in the process of Microgrid implementation, as equipment, products, consulting etc, which could be easily recognized as new business opportunities. The benefits of this type of cooperation are both social and economical.

## 5.4 Field tests conclusions

The isolated operation of the established Agria microgrid was examined. Several tests have been conducted in order to investigate the microgrid operation. Common for the tests was the fact that the network was unbalanced, with several types of loads. The loads were switched into the grid according to a predefined scenario or following the normal daily activities on the farm.

The microgrid field tests have proven that the microgrid was performing adequately and was capable of supplying the loads with quality power. The measured network parameters were in the requested limits and no problems were detected during steady state operation. During the tests only partial capacity of the biogas reactor was used, but the investigations have enabled sufficient data for further operation with full capacity.

The most important conclusion of the tests is that **microgrids with biogas plants can be successfully implemented on other similar locations in the country and in the West Balkan region**. Furthermore, the **benefits of heat and electricity production in biogas plants can improve fulfilment of the environmental standards related to farm waste management and greenhouse gases reduction**, which should be seriously considered keeping in mind that the countries in the region are changing the legislative concerning environment protection in order to make it compliant with the EU legislation in this area.

Based on the experiences from the pilot microgrid, the Agria farm management considers implementation of a full size biogas plant in order to use the maximum waste potential, which proves that this type of projects could be attractive in near future.

## References:

[1] MC 750 Technical documentation, available on: http://www.iskra-mis.si/catalogue/
[2] LP&Natural Gas Generator Sets User's Manual
[3] H. Markiewicz, A. Klajn, « Voltage Disturbances, Standard EN50160 – Voltage Characteristics in Public Distribution Systems », Wroclaw University of Technology, July 2004
[4] DG3 - Report on the technical, social, economic and environmental benefits provided by Microgrids, Annex 7- Social benefits of Microgrids