MICROGRIDS: THE AGRIA TEST LOCATION

by

***Aleksandra KRKOLEVA*[a*], *Verica TASESKA*[b], *Natasa MARKOVSKA*[b], *Rubin TALESKI*[a], *and Vesna BOROZAN*[a]**

[a] Faculty of Electrical Engineering and Information Technologies, Ss. Cyril and Methodius University, Skopje, Macedonia
[b] Research Center for Energy, Informatics and Materials, Macedonian Academy of Sciences and Arts, Skopje, Macedonia

Original scientific paper
UDC: 620.97:662.767.2
DOI: 10.2298/TSCI1003747K

The paper presents the pilot Microgrid in Macedonia, developed within the framework of the MOREMICROGRIDS (EU EP6 projecet, contract No. SES6-019864) project. This Microgrid is the first of its kind being developed in the Western Balkan region and serves as pilot site for introduction and examination of the Microgrids concept in non European Union conditions. The test network consists of a part of the low voltage grid, located on a pig farm. The main electricity source for the Microgrid is a small biogas plant, which uses the biogas produced by a waste water treatment process. The paper addresses the Microgrid design, development of test scenarios and test results from the pilot location.

Key words: *Microgrid, biogas, test site*

Introduction

The increased penetration of distributed generation (DG) within the past years has been driven by several factors, including the continuous development of small generating units, the need for security and quality of electricity supply, as well as the possibility to avoid costs associated to electricity transport losses and building new transmission and distribution lines. The distributed energy sources include different types of renewable generation units (small wind turbines, solar photovoltaic modules, micro and small hydro units), as well as small generating units using natural gas or other fuels (gensets, small gas turbines, fuel cells). The positive perspectives for increased penetration of distributed energy sources are evident keeping in mind the possibilities for further use of the waste heat generated in the electricity production process by the combined heat and power systems, as well as the aims to increase the use of renewable energy sources for electricity production. For instance, the European Union aims to establish an overall binding target of 20% share of renewable energy sources in energy consumption by 2020 [1]. The benefits of DG and the challenges emerging from its wider use, have been in the research scope of EU and the other developed countries in the past few years. The actions of the

* Corresponding author; e-mail: krkoleva@feit.ukim.edu.mk

European Commission along with the research undertaken in research institutions and electricity industry are described in [2]. The other developed countries have also been promoting the use of renewable energy [3], have been examining the benefits of DG and have been using different modes to promote and increase small scale electricity and heat production [4].

The increased penetration of DG has also opened new issues regarding their operation and control within the distribution networks, especially when a large number of these units is installed and operates in the networks. Part of the research performed so far, usually relates to certain modes of operation of networks with higher DG penetration, as mentioned in [5-7], transient and stationary conditions [8, 9] and other problems. The research on these issues has initiated development of new concepts of electricity grids which are able to encompass a larger number of DG units, creating a link between production and consumption using new grid architectures [10, 11]. One of the concepts which emerged from the research undertaken in the past few years is the concept of Microgrids.

Microgrids concept

The Microgrid encompasses a part of an electric power distribution system that is located downstream of a distribution station and includes a variety of DG units, storage and different types of end users of electricity and/or heat [12-14]. The main characteristic of the Microgrid is that it operates within the distribution network, but is also capable of islanding. The Microgrid is usually connected to the power system by a point of common coupling, which enables transition from grid connected to islanded mode, and more importantly, the control mode can also shift from grid dependant to autonomous. From the grid's perspective, the Microgrid behaves as a single producer or load, but within the Microgrid, the DG units, the storage and the loads can be controlled locally, using new control methods. Typical Microgrid structure is presented in fig. 1.

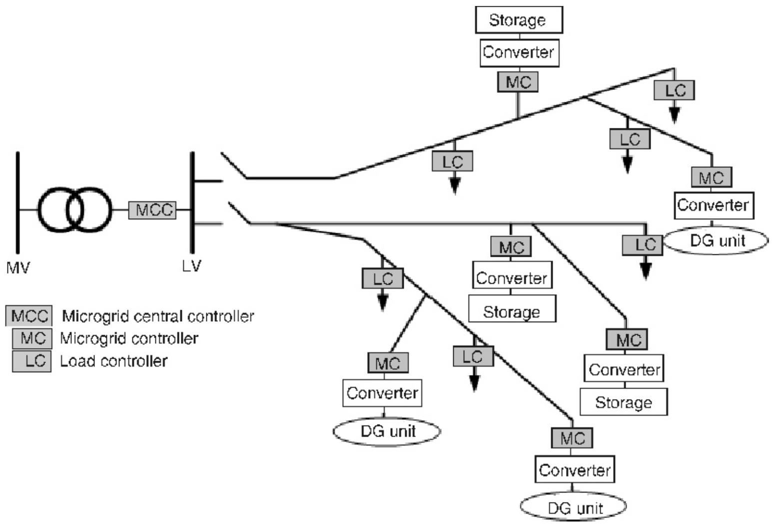

Figure 1. Typical Microgrid structure, based on [15]

The Microgrid depicted in fig. 1 is interfaced with the distribution management system on the medium voltage level. The Microgrid concept is based on unique control and operation strategies, so wider deployment will eventually depend on the development of these strategies in future. The differences between control and operation of Microgrids and conventional power systems and the novel control concepts are described in detail in [13]. Mainly, the differences emerge because of the use of DG units which are coupled to the system by converters, thus requiring different control and operation strategies from the conventional rotating machines. On the other hand, the DG units connected to the Microgrid can be dispachable or non-dispachable, so the controls, as well as the interface of these units to the grid, can also vary to a certain level. In order to estimate overall Microgrids benefits, apart from investigation of control and operation concepts, other issues in technical, economic, social and regulatory areas are also being addressed.

Projects

These issues created additional challenge for researchers both in academic and industrial circles. The cluster formed for investigation of integration of renewable energy sources and distributed generation comprised of more than 100 partners (universities, research institutes, enterprises, and others) who were involved in the following FP5 projects: SUSTELNET, DGNET, INVESTIRE, DISPOWER, MICROGRIDS, and DG FACTS. The research developed within the framework of the FP5 project MICROGRIDS continued consequently in the FP6 project MOREMICROGRIDS [15]. While research in the first project focused on the operation of a single Microgrid, investigated the control techniques and demonstrated the feasibility of the Microgrids through laboratory experiments, the successive project extended this work on several different topics: investigation of new controllers for generators and loads, development of control strategies, investigation on integration of multi-Microgrids, as well as investigation of the impact of Microgrids on existing power system operation and on future electricity network development through evaluation of technical, economical, social, and environmental benefits provided by Microgrids [16]. One of the most important aspects of the project is performing field trials of different control strategies on actual pilot Microgrids.

Microgrids test facilities

The Microgrids concept is being tested on different locations around the world. The testing facilities are dispersed in the EU, USA, Canada, and Japan [17-19]. The diverse test locations offer various possibilities to test new solutions for the Microgrids concept. So far, these sites have enabled testing of Microgrids operation with and without central controllers, inclusion of intermittent sources and use of waste heat for different purposes and have provided investigation of islanding. The test locations are also used for investigation of capabilities for matching demand and supply, added values for consumers, as well as of power and energy management strategies. Apart from conducting tests related to actual Microgrid operation, tests on equipment and components used in Microgrids are also performed. The test results enable building up extensive data which will be used for investigation of possibilities for wider deployment of the Microgrids concept.

Just within the MOREMICROGRIDS project, there are eight test locations. Six of these sites are actual parts of distribution grids in various countries and the other two are laboratory test sites. The actual grids enable testing the Microgrid operation within the existing grids, both in connected and isolated mode of operation. On the other hand, the laboratory trials are used to test specially tailored Microgrids devices (controllers, protection relays) and operation which could not be tested on actual grids.

Agria – the pilot Microgrid in Macedonia

The inclusion of three partners from Macedonia in the MOREMICROGRIDS project enabled spreading the concept to an additional region inside Europe. The proposed test location consists of a part of the low voltage grid located in a rural area, on the pig farm Agria.

The location was chosen based on several interesting aspects it offered. Farms are significant contributors to pollution because of the large amounts of waste they produce daily. According to the new national legislation, farm owners are already required to start the Integrated pollution prevention and control negotiations and to apply the necessary pollution reduction measures at these types of facilities 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 waste collector system, a small biodigester, and a generator, but they were not in operation. The owners were already acquainted with 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. 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 Macedonian partners in the MOREMICROGRIDS project to propose the location as a pilot Microgrid.

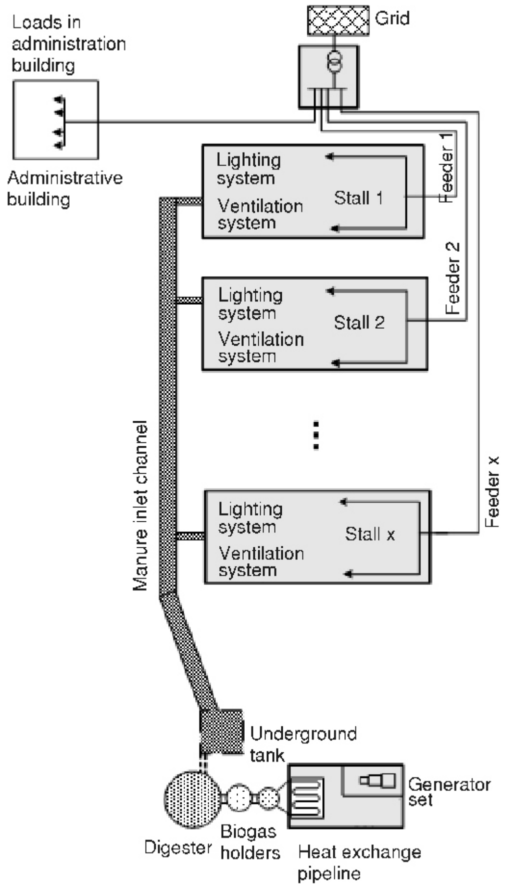

Figure 2. Position of the objects on the Agria farm

Basic information

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. 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.

The farm is constructed as an indoor animal breeding system and it allows for easy collection of waste through a waste collection inlet. The inlet channel is used for transportation of the manure to an underground tank. The tank is connected to a biodigester through a pipe system. Two gas holders are now placed between the digester and a heat exchange system, which are all connected through several pipes. The gas holders were additionally added to the biogas production system in order to improve the quality of the produced biogas. 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.

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. Figure 3 presents the separate parts of the biodigester on a model similar to the real biogas plant installed on the farm.

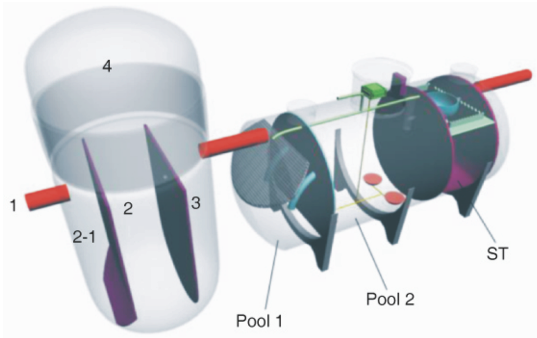

Figure 3. Equipment for biogas production
1 – recipient shaft, 2 – methanogenic zone, 2-1 – primary sedimentation, 3 – effluent and secondary sedimentation zone, 4 – biogas collecting chamber, pool 1 – de-nitrification pool, pool 2 – nitrification pool, ST – sedimentation tank

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.

After finishing the laboratory tests, the actions for the biogas reactor activation on the test location have begun. The tests indicated that the underground tank should be replaced by a better one, so biogas holders with size calculated from the laboratory test results have been designed and manufactured and than, connected to the biogas reactor and the generator. These activities were concluded with additional safety tests and measurements, after which the biogas production was successfully tested on the location. According the first tests and the analyses of the expert team form Bioengineering, the daily biogas production on the farm is estimated to 460 m^3, with average calorific value of 25.5 MJ/m^3.

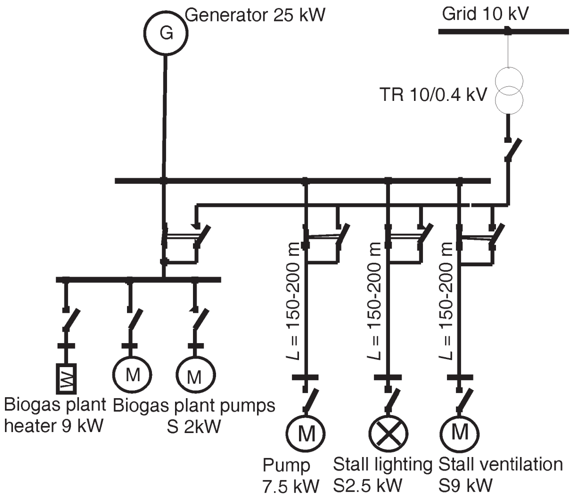

Figure 4. Pilot Microgrid single line diagram

Table 1. Generator characteristics

Rated power: (stand by)	31.5 kVA 25 kW; cosφ = 0.8
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

Pilot Microgrid design

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 from the waste water treatment.

The pilot Microgrid is depicted in fig 4. 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 continuous biogas production.

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 per hour when fully loaded and 2.0 m^3 per 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 generator data are presented in tab. 1.

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 of the last stall and a 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.

Pilot tests and results

The tests were done according previously developed test scenarios and measurement procedures. The biogas production tests were the first set of tests performed on the farm. These tests were followed by generator tests and finished with Microgrid operation tests. Some of the test results are presented in the following section.

Biogas production tests

The biogas production tests were performed using 38 m^3 of waste water. The site measurements showed biogas daily production of 10-16 m^3, with average calorific value of 21.6 MJ/m^3, which is a little below the estimated values from the laboratory tests. On fig. 5, the biogas production at the test location in eight consecutive days and the energy produced from the biogas in that period are presented.

The biogas production process is affected by weather conditions, 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.

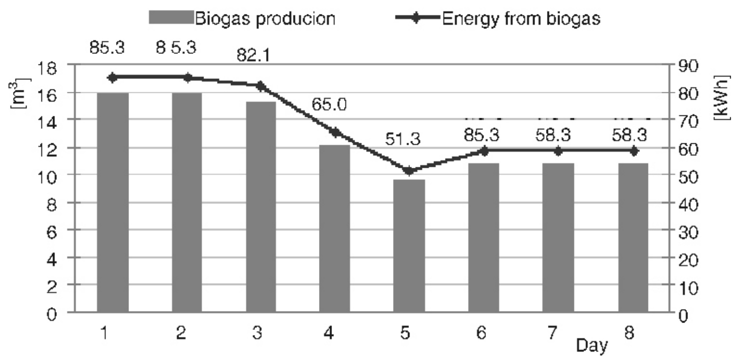

Figure 5. Biogas production on the test location in eight consecutive days

Generator tests

The generator tests were undertaken in order to assess the generator behaviour, considering different operating conditions. Prior testing the generator operation with the biogas produced on the location, it was tested with liquefied petroleum gas (LPG) in order to determine if there were any faults on the equipment. These tests showed minor faults which were resolved rather quickly. The tests also proved that the generator is prepared for further testing within the Microgrid itself. The tests presented in the next section provide information on generator behaviour within the pilot Microgrid.

Microgrid operation tests

The objectives of the Microgrid operation tests were to validate isolated operation and investigate network harmonics. In order to achieve the project objectives, the Microgrid was operated in isolated mode and the tests were done with unbalanced three phase loads consisted of motors and heaters. The measurements of voltages, currents, active and reactive power, power

Figure 6. Measurement equipment in the laboratory and at the test location

factor, total harmonic distortion (THD), and frequency were done using network recorder type Iskra-MIS MC 750. The network recorder, shown in fig. 6, 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, and 62052-21 Standards [20]. The measurements were done according to earlier prepared record files which enable measurement and calculation of the needed network data. The record files and measurement procedures are explained in detail in [21].

Microgrid operation with three phase 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.

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. 7, which shows the active and reactive powers on all three phases during the test. The values presented on fig. 7 are 15 minute average values.

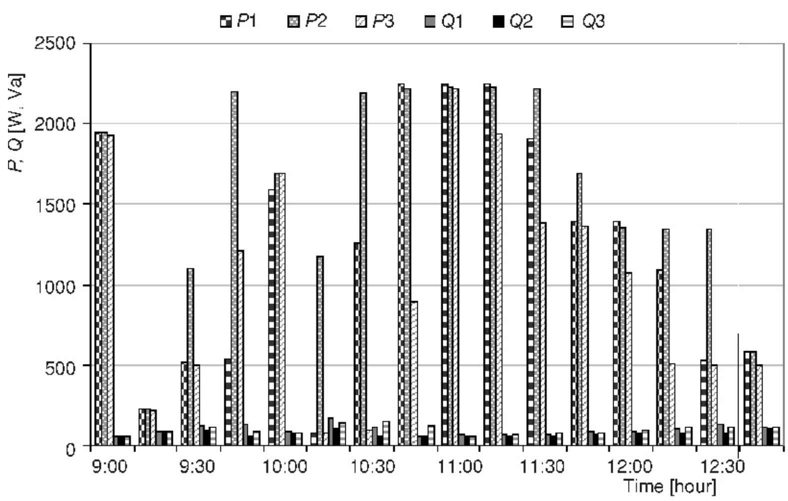

Figure 7. Loads switching during field tests with unbalanced loads

During the tests several network parameters were recorded and the analyses showed that they were all kept in relatively small margins. Figure 8 presents the average values of phase to neutral voltages in relation to switching loads.

As shown in fig. 8, 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 presented in fig. 9, again as 15 minute average values.

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

The measured parameters have proven that the network during the tests performed satisfactorily. The voltages were kept in

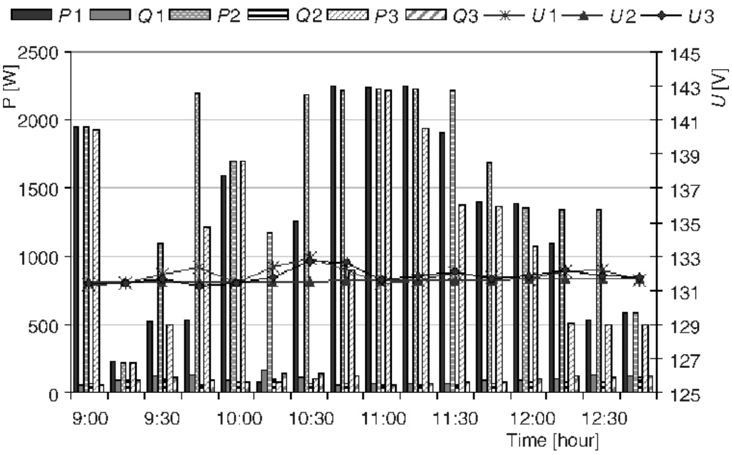

Figure 8. Phase-to-neutral voltages during the test with unbalanced loads

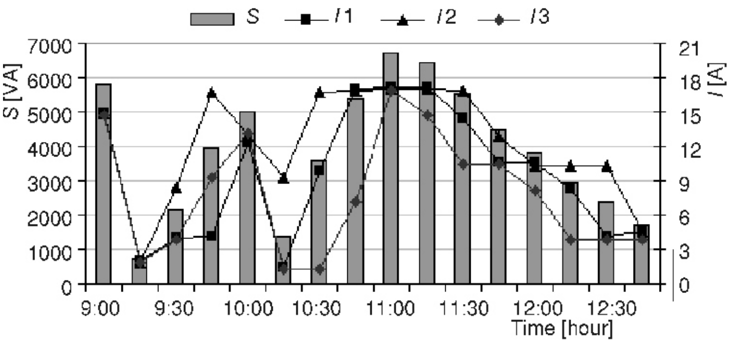

Figure 9. Currents and apparent loads

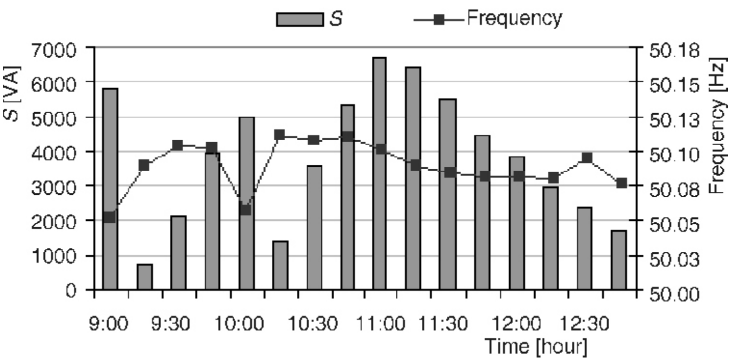

Figure 10. Frequency and apparent loads

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. Figure 11 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%.

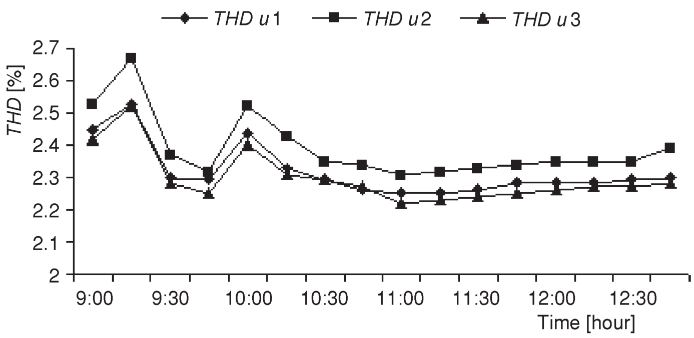

Figure 11 . Phase voltage THD

The measured voltage THD is well within the limits adopted in the international standards for voltage characteristics in public distribution systems [22], because according the EN 50160 standard, THD u in LV networks should be less than 8%.

Example of 12 hour Microgrid operation

In this section, the measurements and results of 12 hour isolated Microgrid operation are presented. During the test period the number of loads changed, *i. e.* some of the loads were switched on and off for the purposes of the tests. The measurements undertaken during the test period proved that the Microgrid was performing adequately and that it is capable to supply the loads with quality power. The measurements showed that the frequency was kept at 50.1 Hz, showing slight changes with increase or decrease of load. Keeping frequency in tight limits is very important issue in isolated mode of operation. The frequency measurements and total apparent power are presented in fig. 12.

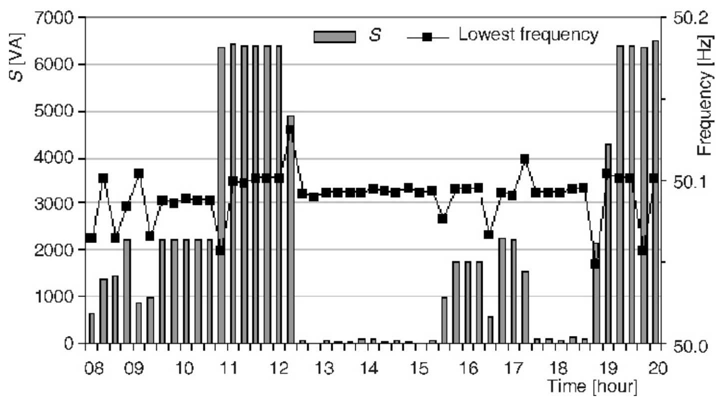

Figure 12. Three phase apparent power and lowest frequency in 15 minutes during 12 hours operation

The tests have also showed that the voltage can be kept in narrow margin when switching loads on and off. In fig. 13 the phase-to-ground voltages in the three phases are presented. The voltages are shown in relation to apparent power in order to follow more clearly the load changes in the network.

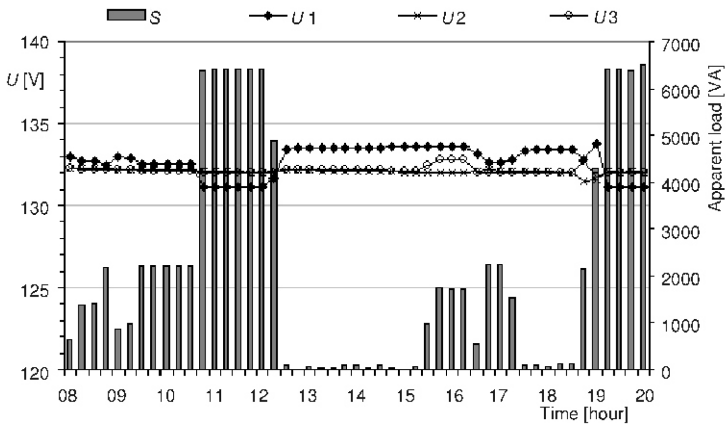

Figure 13. Phase to ground voltage measurements in three phases during 12 hours operation

As shown in fig.13, the voltage at phase one slightly drops when approximately 3 kW load is switched on at 10:45 h, mostly on phase 1. The voltage in the same phase rises as the load is drastically reduced at 12:30 h. Similar behaviour can be monitored during the whole 12 hour operation.

The THD u measurements were also performed in order to investigate power quality during isolated operation. As presented in fig. 14, average THD u varies around 2.4%, which is acceptable, as according the EN 50160 standard, the limit for THD u is 8%. Additional results from different tests are available in [21].

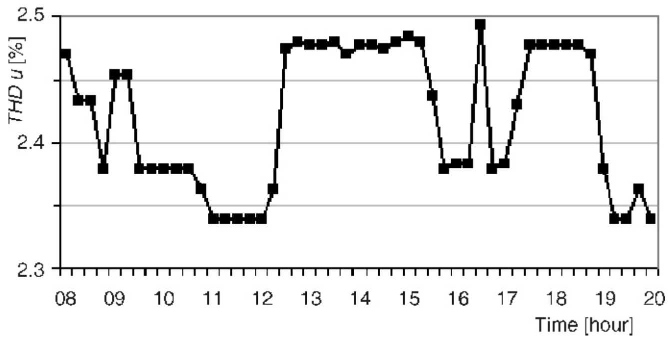

Figure 14. THD u during 12 hours operation

Conclusions

The pilot Microgrid is the first grid of that type in Macedonia and is used to test and promote the Microgrid concept in the country and in the wider region. The test facility allows performing different tests and collecting extensive base of information regarding the behaviour of the grid under different operating conditions. This test facility also provides conditions to test the waste water treatment process and the biogas production process based on anaerobic digestion. The test location will be further used to promote the new technology and to investigate the possibilities for replication on other similar locations, thus providing synergy between renewable energy projects and agriculture.

The test location also proved that Microgrids with biogas plants can be successfully implemented on other similar locations in the country and in the wider region. In addition, 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.

References

[1] ***, Directive 2009/28/EC of the European Parliament and of the Council of April 23, 2009, on the Promotion of the use of Energy from Renewable Sources and Amending and Subsequently Repealing Directives 2001/77/EC and 2003/30/EC, *Official Journal of the European Union*, L 140/16, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:140:0016:0062:EN:PDF
[2] ***, European Commission, Directorate-General for Research, "New Era for the Electricity in Europe – Distributed Generation: Key Issues, Challenges and Proposed Solutions", http://www.smartgrids.eu/documents/New-ERA-for-Electricity-in-Europe.pdf
[3] ***, Department of Energy, Five Year Plan FY 2007-FY 2011, Vol. 1, March 15, 2006, ttp://www.smartgrids.eu/documents/DOE_Office_of_Science_5%20years_plan.pdf
[4] ***, U. S. Department of Energy, The Potential Benefits of Distributed Generation and Rate-Related Issues that May Impede Its Expansion, http://www.oe.energy.gov/epa_sec1817.htm
[5] Hatziargyriou, N., *et al*., Energy Management and Control of Island Power Systems with Increased Penetration form Renewable Sources, *Proceedings*, IEEE Power Engineering Winter Meeting, 2002, New York, USA, Vol. 1, pp. 335-339
[6] Caldon, R., Rossetto, F., Turri, R.,Temporary Islanded Operation of Dispersed Generation on Distribution Networks, *Proceedings*, 39th International Universities Power Engineering Conference, 2004, Bristol, UK, Vol. 3, pp. 987-991
[7] Hsu, C.-T., Chen, C.-S., Islanding Operations for the Distribution Systems with Dispersed Generation Systems, *Proceedings*, IEEE Power Engineering Society General Meeting, 2005, San Francisco, Cal., USA, Vol. 3, pp. 2962-2968
[8] Milanovic, J. V., Kayikci, M., Transient Responses of Distribution Network Cell with Renewable Generation, *Proceedings*, IEEE Power System Conference and Exposition, 2006, Phoenix, Ariz., USA, pp. 1919-1925
[9] Krkoleva, A., *et al.*, Characteristic Responses of Distribution Network Cell: The Effect of Cell Structure and Configuration, *Proceedings on CD*, CIRED 2007, Section 4, Vienna, paper No. 0697
[10] ***, European Commission, Directorate-General for Research, Towards Smart Power Networks-Lessons learned from European research FP5 projects" http://ec.europa.eu/research/energy/pdf/towards_smartpower_en.pdf
[11] ***, European Technology SmartGrids Platform, SmartGrids: Vision and Strategy for European Electricity Networks of the Future, http://ec.europa.eu/research/energy/pdf/smartgrids_en.pdf
[12] Hatziargyriou, N., *et al*., "Microgrids", *IEEE Power Energy Magazine, 5* (2007), 4, pp. 78-94
[13] Katiraei, F., *et al*., Microgrids Management-Control and Operation Aspects of Microgrids, *IEEE Power Energy Magazine, 6* (2008), 3, pp. 54-66
[14] Driesen, J., Katiraei, F., Design for Distributed Energy Resources, *IEEE Power Energy Magazine,* 6 (2008), 3, pp. 30-39
[15] ***, Technical Annex, MOREMICROGRIDS, No 019864, Sixth Framework Programme
[16] Schwaegerl, C., *et al.*, DG3. Report on the Technical, Social, Economic, and Environmental Benefits Provided by Microgrids on Power System Operation, MOREMICROGRIDS, No 019864, 6th Framework Programme, 2009
[17] Kroposki, B., *et al*., Making Microgrids Work, *IEEE Power Energy Magazine, 6* (2008), 3, pp. 41-53
[18] Nichols, D., *et al.*, Validation of the CERTS Microgrid Concept – The CEC/CERTS Microgrid Testbed, *Proceedings*, IEEE Power Engineering General Meeting, 2006, Montreal, Que.,Canada
[19] Abby, C., *et al.*, Integration of Distributed Generation and Wind Energy in Canada, *Proceedings*, IEEE Power Engineering General Meeting, 2006, Montreal, Que., Canada
[20] ***, MC 750 Technical documentation, available on: http://www.iskra-mis.si/catalogue/
[21] Krkoleva, A., *et al*., DF9. Report on Field Tests for AGRIA Microgrid, Part II, MOREMICROGRIDS, No 019864, 6th Framework Programme, 2010
[22] Markiewicz, H., Klajn, A., Voltage Disturbances, Standard EN50160 – Voltage Characteristics in Public Distribution Systems, Wroclaw University of Technology, 2004

Paper submitted: January 8, 2009
Paper revised: May 13, 2010
Paper accepted: May 14, 2010