Stability Testing of a Small Biogas Plant in an Electric Power System

Preliminary communication

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Abstract *– The aim of this paper is to test stability of a small biogas plant in an electric power system and the possibility of island mode as well. A short description of a biogas plant with two 1 MW generators is given in the introductory part. Furthermore, generator and regulator modeling as well as modeling of the surrounding electrical grid in software package PowerWorld Simulator are described. Operation simulations of this power system show that the system is stable in terms of short-period disturbances. Finally, the possibility of island mode operation of the biogas plant loaded with part of the surrounding electrical grid in the case of blackout is tested. It is shown that island mode is possible and reasonable in the case of longer blackout.*

Keywords *– biogas plant, disturbances, generator modeling, island mode, stability*

1. INTRODUCTION

The growth of renewable energy sources as well as their integration into the power system have become significant in recent years. Energy from biomass and bioenergy can be converted to biofuels such as gas (methane and hydrogen) by using new technologies. In future, this will provide replacement of fossil fuels. In [1], an overview of the principles, reactions and applications of four fundamental thermochemical processes (combustion, pyrolysis, gasification and liquefaction) is given.

Many of renewable energy plants produce relatively small amounts of power compared to classical energy sources, like thermal power stations. In such conditions, a new stability problem arises, because the behavior of such small plants connected to the power system in the case of disturbances has not been well studied yet.

When a disturbance occurs, protective relaying may change power system configuration and the post-disturbance steady-state operating condition, if reached, may be different from the pre-disturbance steady-state operating condition [2]. As an electric power system is highly nonlinear, stability of the new operating condition is questionable. In [3], dynamic stability analysis of the biogas generation system using a nonlinear simulation model is presented. The paper examines stability of a biogas facility connected to the power grid.

In addition, in a new market structure individual plants compete with each other and may be unwilling to disclose detailed information about their generators and control systems [4].

Thus, in this paper we discuss stability of a small biogas plant in the case of sudden disturbances. Simulations are carried out in software package Power World Simulator. The tested plant consists of two cogeneration facilities, both having 1 MW synchronous generators connected to the power system (Fig. 1). The surrounding power system with local consumers is also modeled in simulation.

The rest of the power system is modeled as an infinite bus. This implies that the tested plant is a two-machine power system with local consumers connected to the infinite bus.

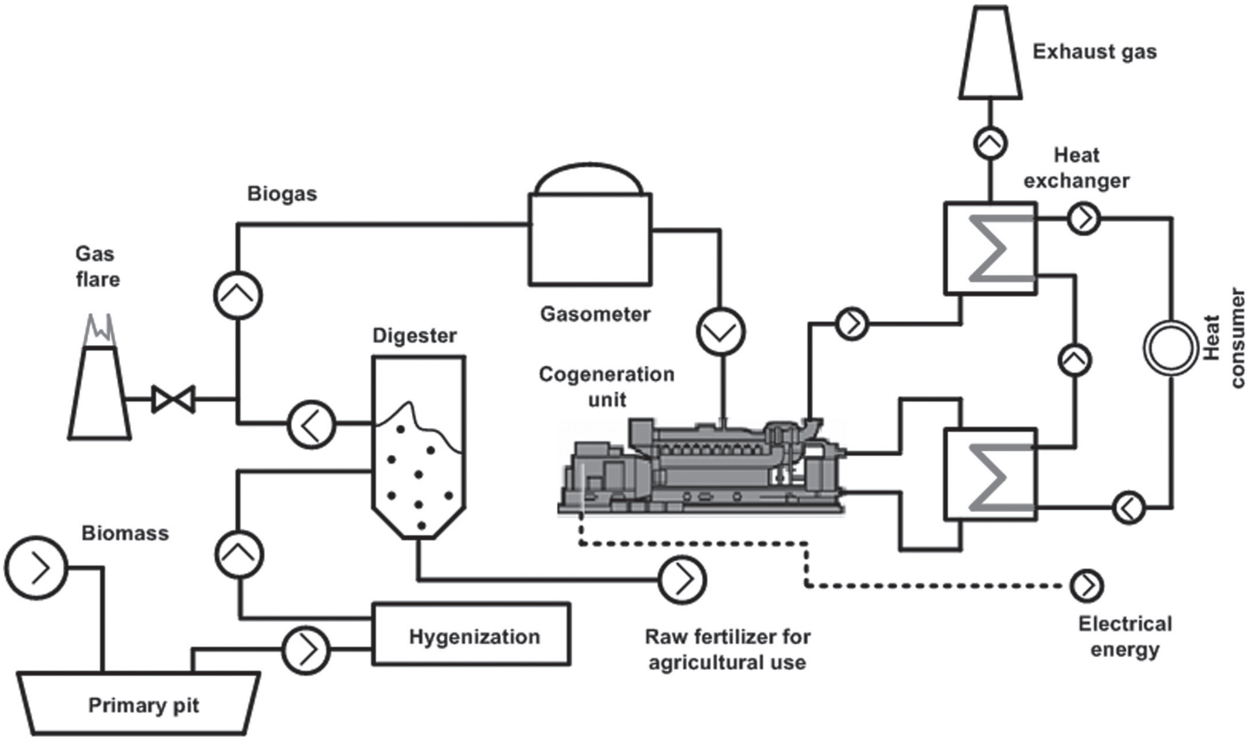

Fig.1. Scheme of the biogas facility with a cogeneration unit

2. BIOGAS PLANT INTEGRATION INTO THE ELECTRIC POWER SYSTEM

As mentioned before, growth of renewable energy sources such as biogas power plants might cause problems with integration of these plants into the power system. According to the present regulatory rules, in the case of power system blackout, the biogas plant must stop the production of electrical energy and shut down regardless of the possibility to normally continue its operation and supply surrounding consumers. This current restriction is applied mainly to deal with problems which could occur during synchronization of the biogas plant with the main power grid after elimination of the cause of the fault.

There is also a problem with optimal placement of biogas plants, which is described in [5, 6] and economic energy analysis of biogas usage [7]. In [8], analysis of the biomass based micro-turbine plant impact on stability of distribution networks and the influence of voltage instability on electrical energy consumers are given.

These problems can be solved by correct generator excitation and speed regulation system modeling and controller parameterization.

3. ELECTRIC POWER SYSTEM MODELING

An electric power system modeled in the paper, as shown in Fig. 2, consists of two cogeneration facilities (each having a 1 MW synchronous generator), transformers and consumers. The rest of the power system beginning with the nearest 35 kV bus is modeled as an infinite bus.

Consumers are modeled as impedances consuming real and inductive reactive power. Power lines are also modeled according to their impedances. In this way, the behavior of one biogas cogeneration facility may be tested in a complex system, unlike the majority of previous papers, an example of which is [2], where the rest of the power system is modeled with network resistance and inductance.

Synchronous generator modeling as well as modeling of a generator exciter and controllers will be described in the sequel.

Power World Simulator software gives us a possibility to choose a generator model as well as models of generator excitation and controllers. Generator controllers must keep the terminal voltage and frequency close to the reference value and provide sufficient damping to power oscillations at admissible operating points [9].

A controller that regulates the generator voltage level is called an Automatic Voltage Regulator (AVR). It also regulates generator reactive energy, when the generator is connected to the infinite bus.

In the case of disturbances, AVR may amplify power swings, so an additional controller called a Power System Stabilizer (PSS) is introduced. Generator frequency is regulated by Governor, a controller that influences a driving machine (turbine or internal combustion motor).

A synchronous generator excitation system is described in [10]. It usually consists of AVR, exciter, PSS, measuring elements and protection units. Various types of excitation systems exist and their categorization is given in [11].

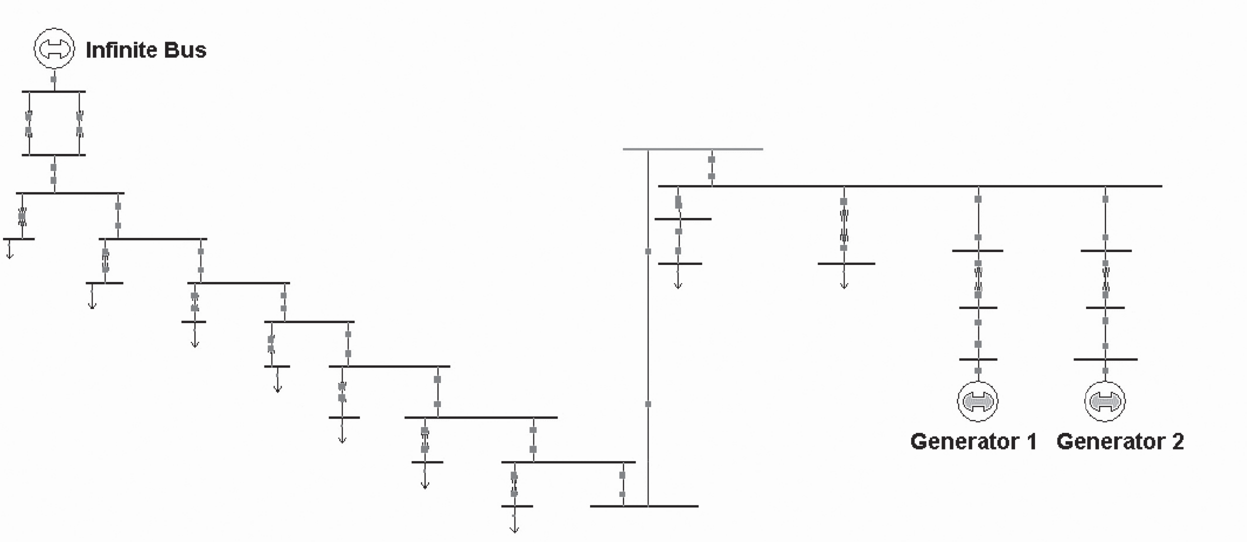

Fig.2. Power system model in Power World Simulator

3.1. SYNCHRONOUS GENERATOR MODELING

Synchronous generator models are described in detail in [12]. The selected generator model is "GENSAL", shown in Fig. 3. This two-axis model is a linearized representation of a synchronous machine with salient poles that assumes equal mutual inductance rotor modeling.

In the selected model, knowledge of the following parameters is required: direct reactance, transient reactance, subtransient reactance, subtransient time constant, direct time constant and moment of inertia. These parameters for the tested generators are given in Table 1. Other parameters needed for the model are calculated approximately considering engineering practice.

Table 1. Generator parameters

Parameter Name	Symbol	Value
Direct reactance	X_d	2.51
Transient reactance	X'_d	0.15
Subtransient reactance	X''_d	0.11
Subtransient time constant	T'_{d0}	20 ms
Direct time constant	T_{d0}	10 ms
Moment of inertia	H	18.165 kgm^2

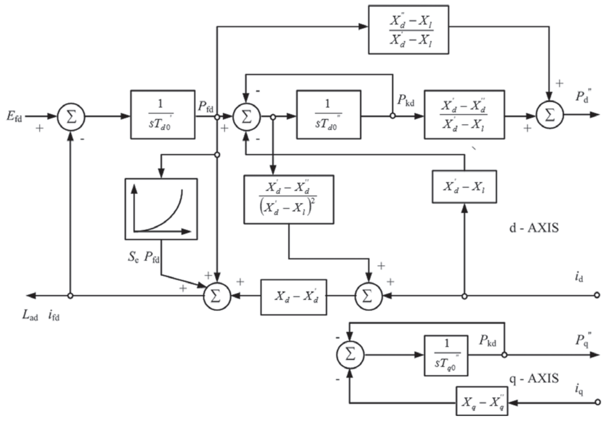

Fig.3. Generator model "GENSAL"

3.2. EXCITATION SYSTEM MODELING

For a representation of an exciter and an AVR, a simplified model "SEXS_GE" is selected. It consists of a PI controller (AVR) and a simple representation of an exciter. A rotating exciter is modeled as a constant, which is enough for testing stability of the electric power system. AVR parameters are carefully tuned so that generator output voltage attains the reference value.

PSS also consists of a PI controller and it is modeled with a Power World library model named "PQRFG". PSS parameters are tuned in such a way that in the case of transient state oscillations in the output voltage are minimal.

3.3. SPEED REGULATION SYSTEM MODELING

Paper [13] presents a model of direct supplying energy system which consists of a biogas engine, a compressor, a heat pump and a generator. It gives characteristics of a biogas heat pump and an electricity generation system under different rotation speeds.

A speed regulation system needs to be selected according to a driving machine coupled with the generator. In the case of tested facility, the driving machine is an internal combustion motor that runs on biogas. This type of motor is taken into account in the Power World Library model "DEGOV". In this model, in addition to the motor, a governor and an actuator for gas flow are also modeled. Governor parameters are tuned so that the output voltage frequency is constant in a stationary state, and has as small oscillations during transition states as possible.

4. SIMULATION RESULTS

After modeling the power system and testing stability in a stationary state, the following disturbances were simulated: infinite bus outage, one generator outage and short circuit at a generator bus.

4.1. INFINITE BUS OUTAGE

Simulation results in the case of infinite bus outage are given in Figures 4 – 6. Bus voltages fall in the case of infinite bus outage (Fig. 4.). The largest voltage drop is registered on the bus closest to the infinite bus, which is also the furthest bus from generators. All this voltage drops are still within the acceptable range of power system operation.

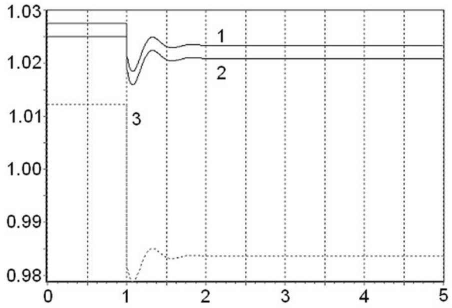

Fig. 4. Bus voltages in the case of infinite bus outage: 1 – voltage on the generator bus, 2 – voltage on the bus of the consumer closest to the generators, 3 – voltage on the bus of the consumer closest to the infinite bus

Fig. 5 shows generator load angles. In the case of infinite bus outage, load angle values decline, because part of the produced real power was sent to the infinite bus in a pre-disturbance state.

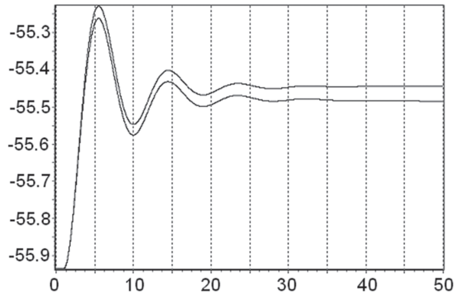

Fig. 5. Generator load angles in the case of infinite bus outage

Fig 6. shows frequency oscillations of both generators in the case of infinite bus outage. Oscillations are small and do not harm stability of the system.

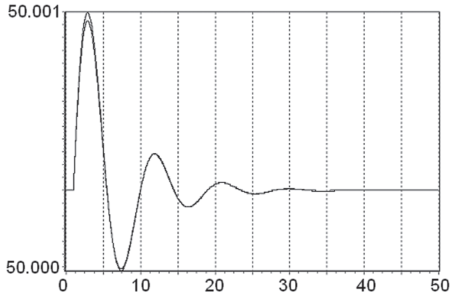

Fig. 6. Generator frequencies in the case of infinite bus outage

4.2. ONE GENERATOR OUTAGE

Simulation results in the case of one generator outage are given in Figures 7 – 9. Generator bus voltage decreases in the case of one generator outage, as shown in Fig. 7, curve 1. This decrease is also present on the bus of the consumer closest to generators (curve 2), but it is not registered on the furthest bus (curve 3).

Fig. 8. indicates that the load angle of the remaining generator increases, because more power is needed in the local power system.

Fig 9. shows frequency oscillations of the generator that remained connected to the power system. In a post-disturbance steady state the remaining generator operation point is stable, with nominal frequency of 50 Hz.

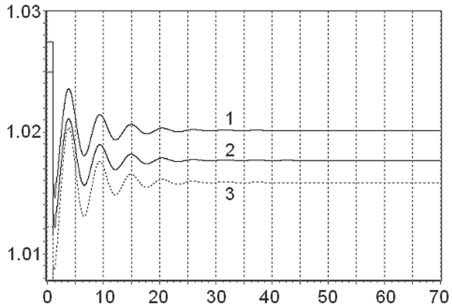

Fig. 7. Bus voltages in the case of one generator outage: 1 – voltage on the generator bus, 2 – voltage on the bus of the consumer closest to the generators, 3 – voltage on the bus of the consumer closest to the infinite bus

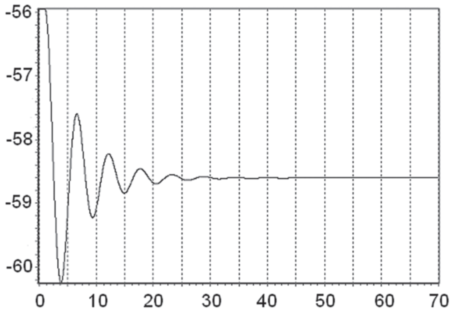

Fig. 8. Remaining generator load angle in the case of one generator outage

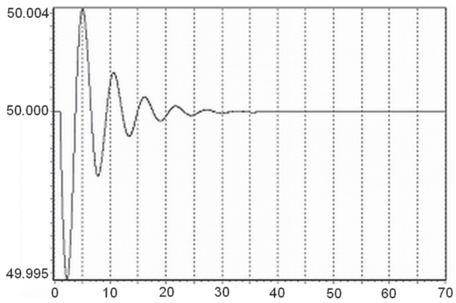

Fig. 9. Remaining generator frequency in the case of one generator outage

4.3. SHORT CIRCUIT AT THE GENERATOR BUS

Simulation results in the case of a short circuit at the generator bus are given in Figures 10 – 12. Short circuit time is cleared after 500 ms. This is the longest time of a short circuit that results in a stable post-disturbance state. Fig. 10. represents bus voltages in the case of such a fault. In a post-disturbance steady state all voltage values are equal to those before the disturbance occurred.

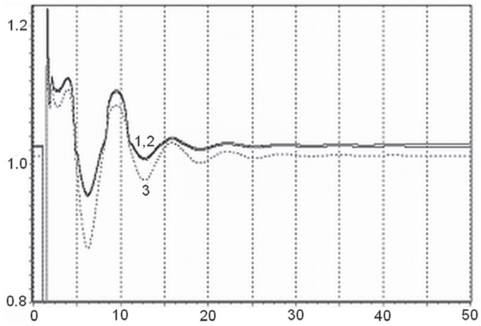

Fig.10. Bus voltages in the case of a short circuit at the generator bus: 1 – voltage on the generator bus, 2 – voltage on the bus of the consumer closest to the generators, 3 – voltage on the bus of the consumer closest to the infinite bus

Fig. 11. shows generator load angles. In the case of a short circuit, fault load angle values increase as expected. After the fault is cleared, load angles decrease and after transient state they gain values equal to those before the fault occurred.

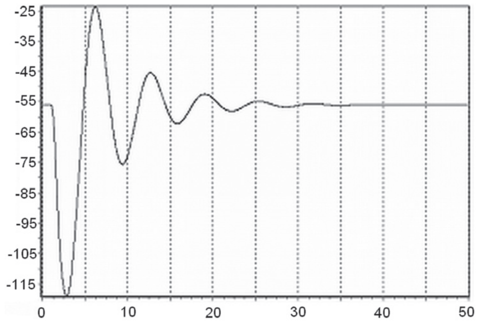

Fig.11. Generator load angles in the case of a short circuit at the generator bus

Fig. 12 shows frequency oscillations of both generators in a short-circuit fault. Similarly to the behavior of the load angle, when a fault occurs, frequency decreases (generators slow down). After the fault is cleared, generators speed up and frequency rises. In a post-disturbance steady state, frequencies reach a nominal value of 50 Hz.

In the case of short circuit occurrence it is important to monitor how generator current behaves. Fig. 13 shows that generator currents reach 160% of the nominal current during a short circuit. After the fault is cleared, currents return to pre-disturbance values.

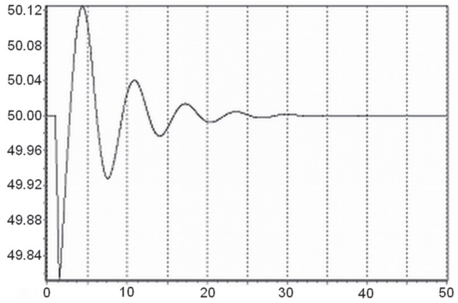

Fig.12. Generator frequencies in the case of a short circuit at the generator bus

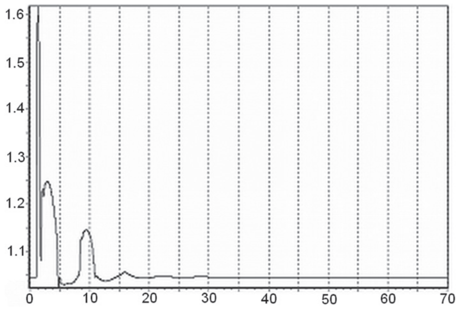

Fig.13. Generator currents in the case of a short circuit at the generator bus

5. CONCLUSION

This paper presents a new method for stability testing of a small biogas plant in the electric power system using Power World Simulation software. The main advantage of the presented stability testing is that, in addition to a detailed representation of the generator and its regulation structures, driving machine and surrounding power system elements are thoroughly modeled as well.

Simulation results show that the tested biogas plant is stable and can stand infinite bus outage, one generator outage and a short circuit lasting 500 ms. Results for infinite bus outage are most significant, because they suggest that the tested biogas plant is capable of supplying local consumers in the case of blackout, i.e. larger disturbance occurring farther in the electric power system. According to the present regulatory rules, in the case of blackout, the tested plant must stop its operation.

Further research would be concentrated on more detailed modeling and calculations to prove this thesis. If proved, these results could bring a new method for dealing with blackouts and decrease financial losses of small plants in such cases.

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