



## OPTIMIZATION FOR BIOGAS POWER PLANTS USING AUTOMATIC CONTROL OF GAS PRESSURES

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### Abstract

In many cases, gas storages on biogas power plants are not used optimally to store gas as much as their capacity. The digester is sometimes overload to store gas and the controller cannot deliver gas to other storage. Consequently, gas is often released from digester to avoid over pressure. At the end, biogas power plant has less efficiency. Hence, a mechanism to control gas pressure to make different pressure between its storages is required. Fans were used to manipulate the most majority system pressures on a biogas power plant using frequency converters. Measurements, simulations, and experiments were conducted to create a new system on a biogas power plant. A controller, Programmable Logic Controller was used to control the entire system pressure using Proportional-Integral-Derivative algorithm. When the gas pressures are not in the allowable range of pressure, then the controller changes the fans' frequency to the desired conditions. As a result, gas moves to another storage and system pressures are in the allowable range.

Keywords: control biogas pressures, biogas storages optimization, biogas system pressure.

## I. INTRODUCTION

The company biogas-weser-ems (bwe) GmbH & Co. KG built a biogas power plant in Rhede-Germany in 2010 with feeding from maize silage, chicken and pig manure. The produced biogas is delivered to two Combine Heat and Power CHP units to generate electricity. The plant was chosen because of long record of stability measurements and the owner's interest to improve the efficiency of his biogas power plant. Table 1 [1] shows detailed information of investigated biogas power plant. This research is aimed to investigate the system pressure behavior, the effect to the connected system, and to optimize gas storage utilization.

The gas pressures were very small and fluctuate (see Figure 1). The blue graph is gas pressure on digester and green graph is gas pressure on post digester. This condition leads a risk for biogas power plant such as construction damage. At the end, it can reduce lifetime of the biogas power plant. Gas storage utilization also

was the problem of this plant. Gas volume on digester was always at maximum level, while on post digester was close to minimum level.

Figure 2 shows the example gas volume conditions (in m<sup>3</sup>) on digester (red graph) and post digester (green graph) respectively to their maximum volume. Gas volume stored in digester was higher than gas volume stored in post digester. At some points, the conditions were difficult to be stored for the controller due to limitation of the acquisition process. Finally, some systematical errors for the biogas power plant were generated.

## II. METHODOLOGY

### A. Current Control System Investigation

This step is aimed to investigate current control system of biogas power plant especially the pressures controller. The installed devices on investigated biogas power plant were below:

#### 1) Fan

Small fan were used to manipulate gas pressure inside the digester and post digester tanks. There were 2 types of fan used on this research, DNG 2-4.8\_10-50Hz and DNG 3-6\_10-

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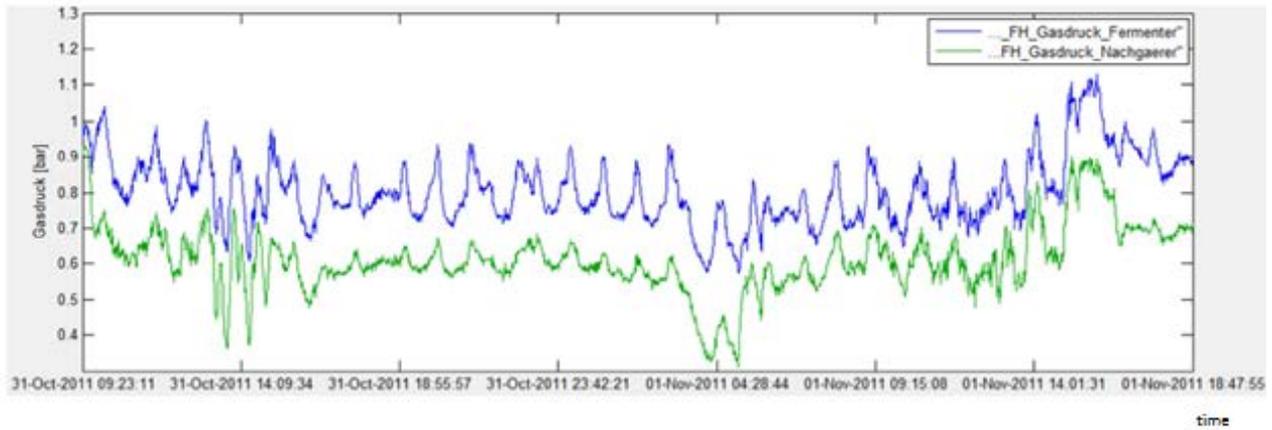


Figure 1. Gas pressure conditions in digester and post digester

50Hz type. They rotate at the same frequency, but generate different pressure [1]. In the beginning, two fans of DNG 3-6\_10-50Hz with fixed frequency at 50 Hz for digester and post digester were used. But, at the end, users decided to add frequency converter for each installed fan. User can regulate fans' frequency to the desired frequency by using frequency converters. On the other hand, the allowable regulated gas pressure was determined by the desired gas pressure between minimum and maximum range. Figure 3(a) shows installed fan on biogas power plant and Figure 3(b) shows installed fan on digester tank.

Table 1.  
Investigated biogas power plant specifications

Description	Value	Unit
<b>Digester</b>		
Diameter	22	m
Total height	6	m
Volume brutto	2,281	m <sup>3</sup>
Volume netto	1,977	m <sup>3</sup>
<b>Post digester</b>		
Diameter	32	m
Total height	6	m
Volume brutto	4,825	m <sup>3</sup>
Volume netto	4,182	m <sup>3</sup>
<b>Input</b>		
Maize silage	17	ton/day
Chicken manure	5	ton/day
Pig manure	11	m <sup>3</sup> /day
<b>Output</b>		
CHP 1	250	kW
CHP 2	250	kW
Electricity	38.8	%
Heat	45.2	%

## 2) Under/Over Pressure Relief Devices

Figure 4 shows over/under pressure relief device. The device was used to maintain system pressure by giving signal to controller to activate fan to create certain pressure.

## 3) Volume Meter

Volume meters were used due to the regulations that gas volume on digester and post digester should not exceed the standard [2].

## 4) PLC Siemens S7/300-ET200S

Programmable Logic Controller PLC could not provide biogas system pressure correctly in the beginning. Losses gas from digester tank was higher than delivered gas to post digester tank.

## 5) Manometers

Manometers were installed on digester and post digester tank. These sensors were used to measure actual pressure inside the tanks. But, they were not giving a signal to the actuators (fan) regard to the instability of system pressure. During the research, these manometers have been replaced by pressure sensors, so they could be connected to PLC.

The mechanism created by current controller was not working properly to control systems pressures of the plant. Fans were used only for single pressure. The controller could not identify the entire gas conditions and was not able to decide whether pressures should be changed or kept constant. Moreover, other gas conditions such as temperature or volume were not considered on the algorithm.

## B. Other Studies

In assistance of FH Köln, online measurements, models and optimization methods were developed. Online measurements were used to characterize the operating values and to develop implementation of Anaerobic Digestion Model 1 (ADM1) on MATLAB [3]. The intelligent system for non linear digester using Fuzzy [4] and the comparison among different types of controller such as Proportional-Integral-

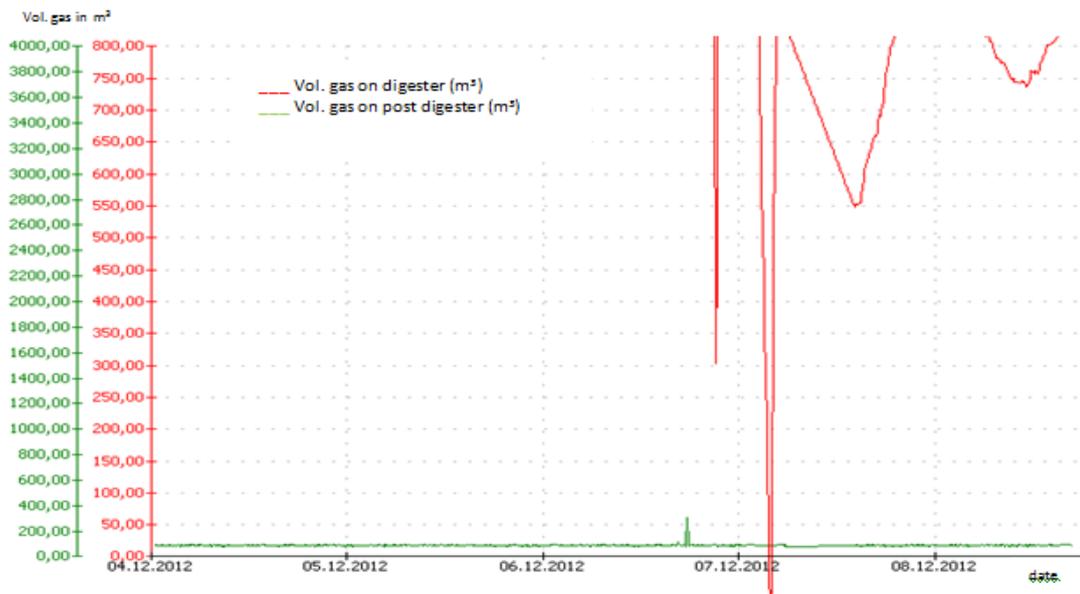


Figure 2. The comparison between gas volume in digester and post digester tank

Derivative (PID) had been investigated. PID was used to control gas pressure [5]. The model of intelligent biogas power plant including smart control from other company [6] and also in a small scale biogas power plant [7] had been investigated.

### C. Chosen Control Method

Many people used PID to control pressure [8] for Hardware-In-Loop (HIL) applications as well as for non linear input/output [9]. It could be applied on a PLC [10]. On the other hand, some researcher [11], [12] described how to use PID. They explained process control and how to manipulate variable respective to its set point using PID control algorithm. In case of investigated biogas power plant on this research, variable measurements were measured gas pressures on digester and post digester.

The manipulated variables were gas pressures and disturbances were gas temperatures. The mathematic models and step-by-step of finding PID's parameters and process could not be presented in this paper due to bwe

company's property right.

### D. PID Controller in Siemens S7/300

The Siemens S7/300 ET200S PLC was used on this research as a controller device. Simatic manager software was used to create a pressure controller program [13] and PID function block FB inside PLC. There are three different types of PID controllers on this PLC [13]. The first type is continuous control which can be found in function block FB 41. The second type is step control on function block FB 42 and the last type is pulse generator that can be found in function block FB 43.

The continuous process measurements and actions were used by applying FB 41 [13] on the controller. The algorithms of PID are internally connected in parallel and can be activated or deactivated individually. The function block FB 41 allows the controller to use P, PI, PD, or PID in manual mode or automatic mode. The entire investigated biogas power plant was modeled by FH Köln biologically and mathematically.

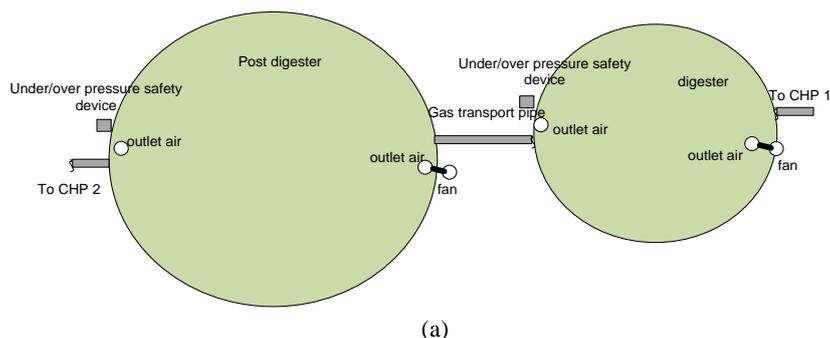


Figure 3. (a) Fan locations in a biogas power plant; (b) Installed fan on digester tank

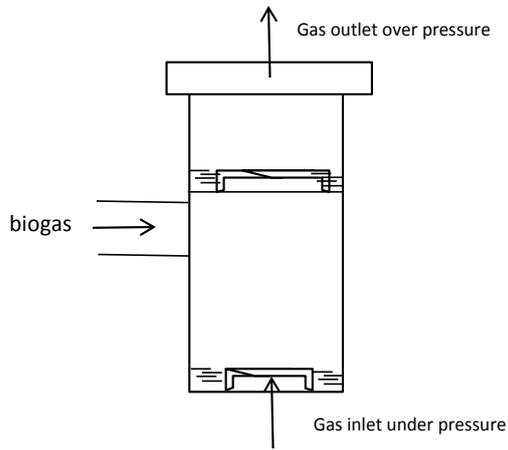


Figure 4. Over/under pressure relief device

### E. Model Algorithm

Figure 5 shows an algorithm to control gas pressure. The controller receives all values from pressure and volume sensor on digester and post digester. The values were processed in the controller. The controller decides the right actions for fans based on logic conditions. If the actual value is not in the allowable range, then adjusted pressure value is used as set point.

Figure 6 shows basic flowchart of gas pressures controller where 'a' is percent volume of gas in digester and 'b' is percent volume of gas in post digester. Total logic conditions that have been built based on gas conditions, standard and desired outputs are 162 conditions. Example logic is below: IF Volume (V) gas post digester < minimum setting percentage volume AND V gas

digester < minimum setting percentage volume AND Pressure (P) digester < minimum setting pressure AND P post digester < minimum setting pressure AND absolute differences between post digester and digester > absolute setting different pressure AND V gas digester > V gas post storage THEN P digester and P post digester should be increased.

### III. RESULT AND ANALYSIS

Step-by-step the controller operations are:

- 1<sup>st</sup> step: scanning, sensing, scaling, and categorizing of data (volumes and pressures).
- 2<sup>nd</sup> step: check conditions (less, equal, or more) then executed to the specific process (increase pressure, keep constant, or decrease pressure) individually.
- 3<sup>rd</sup> step: looping to 1<sup>st</sup> step. The controller measures the values from sensors, classifying them, processing, and then give a value to actuators.

Table 2 shows the setting PID parameters that found using Mat-lab simulation. Figure 7 shows the scaling function for gas pressure that was created on PLC. In scaling process, pressure from sensor was scaled into range between 0 and 3.5 mBar then compared to minimum pressure-maximum pressure (save as pv).

If gas pressure in digester or post digester is less than minimum pressure, then gas pressures are classified as pdig\_less or pstost\_less. If gas

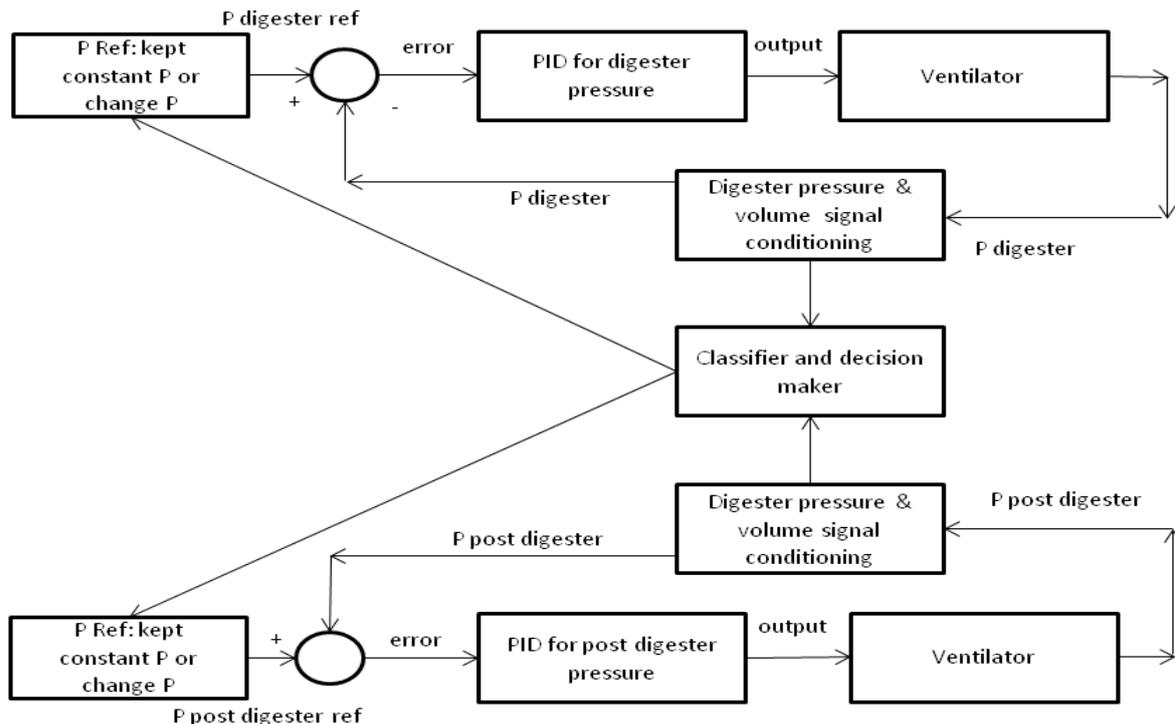


Figure 5. Block diagram of the algorithm

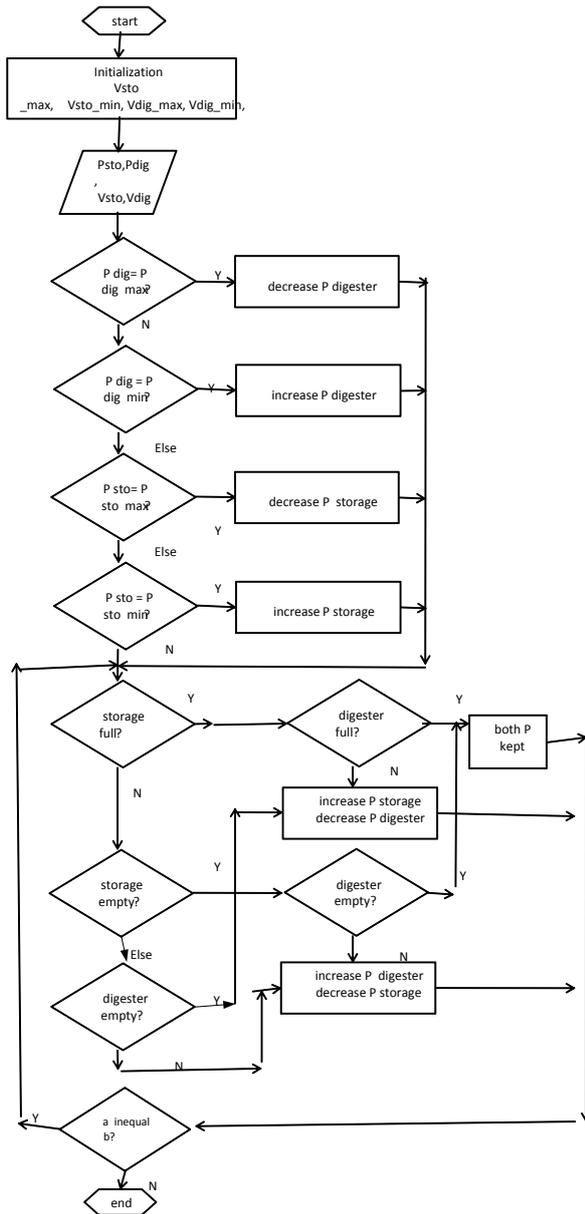


Figure 6. Basic flowchart of gas pressures controller

pressures value is in the range between minimum and maximum pressure then gas pressures are classified as pdig\_norm or psto\_normal. If the values are more than maximum pressure, then gas pressures are classified as pdig\_over or

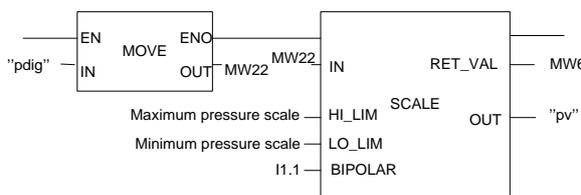


Figure 7. Function of scaling pressure

Table 2. PID parameters

Description	Value
Sample time	0.00E+00
Internal set point	0.00E+00
Process variable in	W#16#0
Manual value	0.00E+00
Proportional gain	2.00E+00
Reset time	T#20S
Derivative time	T#10S
Time lag of the derivative action	T#2S
Dead band width	0.00E+00
Manipulated value high limit	1.00E+00
Manipulated value low limit	0.00E+00
Process variable factor	1.00E+00
Process variable offset	0.00E+00
Manipulated value factor	1.00E+00
Manipulated value offset	0.00E+00
Initialization value of The integral action	0.00E+00
Disturbance variable	0.00E+00

psto\_over. Figure 8 shows a classification function of pressure condition.

The two following figures, Figure 9(a) and Figure 9(b) show scaling function for gas volume on digester and post digester with different values. Volume would be classified as V minimum if gas volume on digester or post digester is less than minimum percentage, V normal if in the range of minimum-maximum percentage, and V maximum if more than maximum percentage. The absolute difference percentage of gas volume was calculated by comparing the difference percentage of gas volume on digester and post digester. If the difference is less than minimum percentage level then the absolute difference percentage of gas volume is classified as normal, while other is classified as abnormal. An excerpt of algorithm

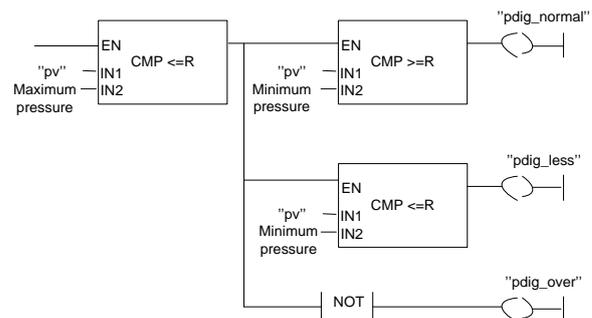


Figure 8. Classification function of gas pressures

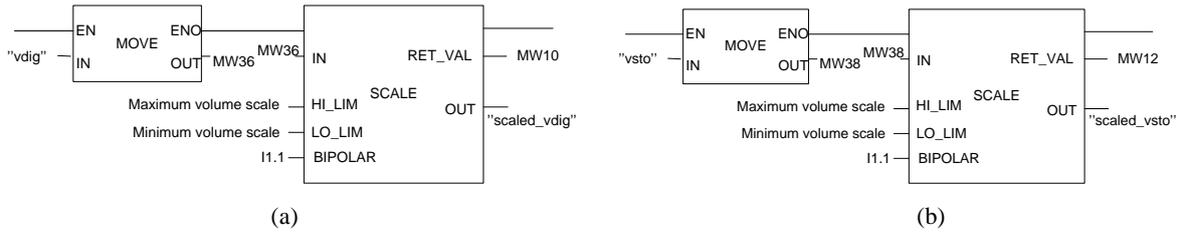


Figure 9. (a) Function of scaling volume of digester; (b) Function of scaling volume of post digester

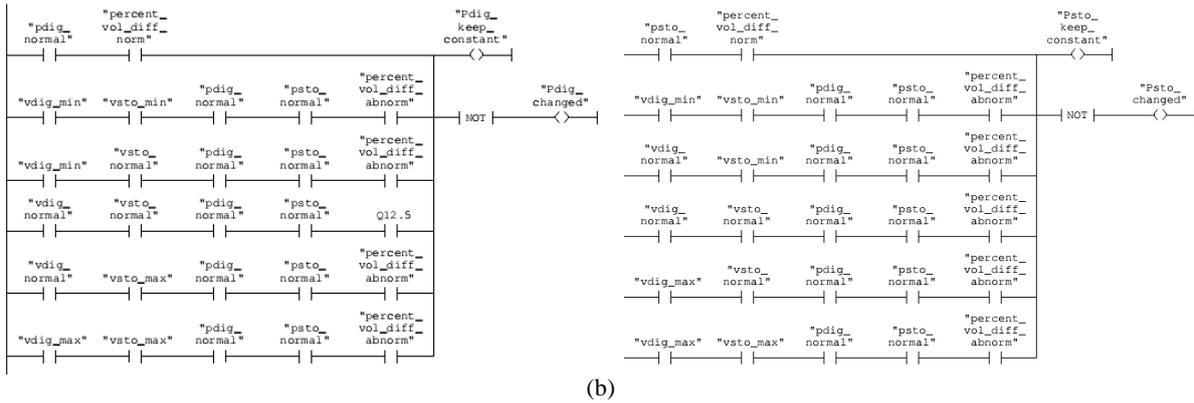


Figure 10. (a) Algorithm to choose a set point of PID in digester tank; (b) Algorithm to choose a set point of PID in post digester tank

to choose a set point for PID controller on digester and post digester is shown by Figure 10(a) and Figure 10(b). In these figures, different logics between digester and post digester tank were used based on desired condition on the biogas power plant.

As an example case: If pressure P digester is normal AND difference percentage of volume between two tanks is normal (<minimum limit) then P digester is maintained as it is. Two PID function blocks were built during this research. An example PID block for digester can be seen in Figure 11. A value of 7.1425 is used as factorization value in order to set PID result to the desired value. As a result, gas pressure on digester and post digester of new system stayed between the minimum and maximum value.

As can be seen in Figure 12, gas pressure on digester (red curve) and gas pressure on post digester tank (green curve) with new system are within allowable range of pressure. Moreover, gas volume on digester and post digester (see Figure 13) is also in the range between minimum and maximum percentage respectively to their maximum capacity. Compared to the previous system (without regulating fans' frequency), the delivered gas to post digester was found higher as well as gas volume on post digester.

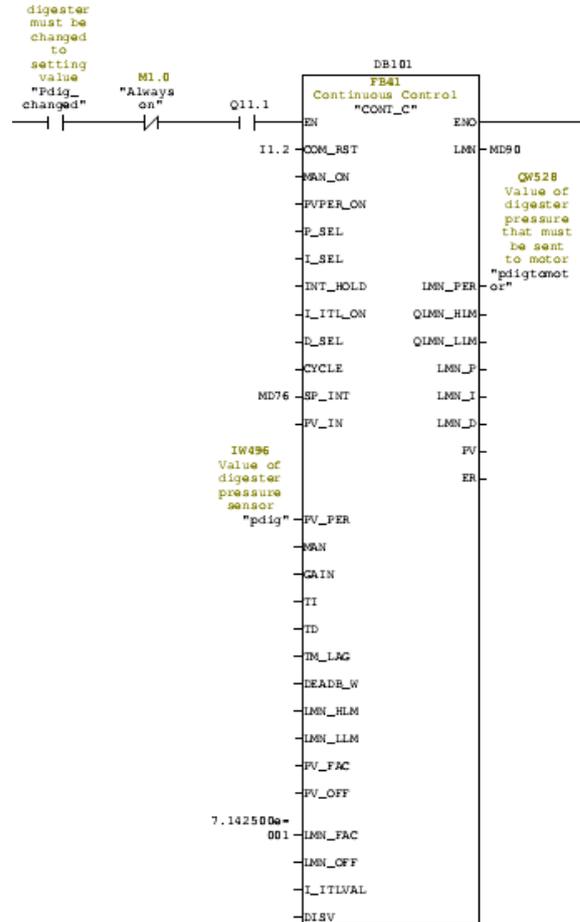


Figure 11. PID function block applied for digester

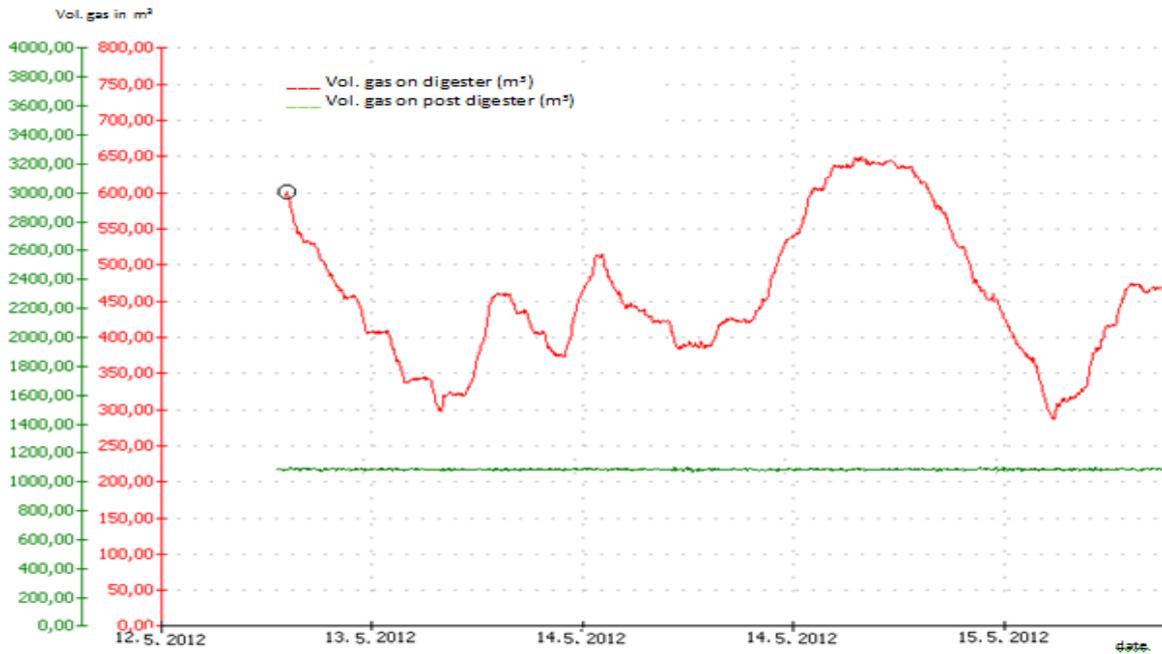


Figure 12. Gas volume conditions on digester ( red curve) and post digester (green curve) in the new system

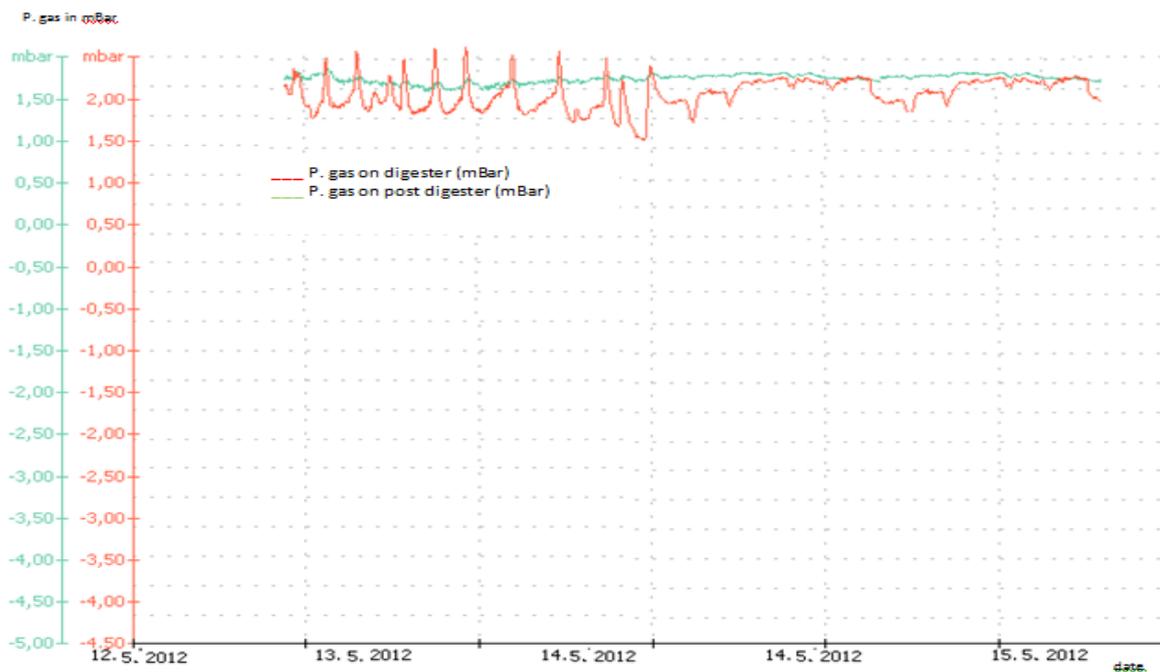


Figure 13. Gas pressure conditions on digester and post digester in the new system

#### IV. CONCLUSION

There are many aspects to optimize biogas power plant. Technically, it can be done by gas storage, engine configurations, or feeding optimization. The system pressures controller on gas storage is one of this optimization. By regulating and controlling the system pressures, the biogas power plant was able to decide actions when gas should send to CHP or just store it in the storage. In addition, PID control that was

used in this biogas power plant brought a better system than previous system. Gas pressures on digester and post digester were never reached their limits. Furthermore, gas volumes on digester and post digester were found to reach the desired volume. In addition to that, the power plant's efficiency was increased by reducing released gas on digester tank. In conclusion, the new system (after implementing PID controller) brought better effects for biogas power plant compared to the previous system.

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