DEVELOPMENT OF A FUZZY LOGIC TECHNIQUE FOR BIOGAS GENERATION OF ELECTRICAL ENERGY

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Abstract

Production of biogas energy is one of the important technical solutions that contribute to the transformation of energy system from being fossil fuel dependent to renewable energy originated. Thus, comprehensive understanding of biogas energy is necessary in order to develop an accurate and robust model that will predict and control the biogas production. This research paper develops a fuzzy logic controller model for biogas generation of electrical energy. A fuzzy logic algorithm was designed to aid power delivery to the load in order to improve the performance of the biogas system. A decision was made for fuzzy logic using three operations: fuzzification process, inference engine for rule base and defuzzification process. The model developed was simulated using MATLAB-SIMULINK. The results showed that for biogas electrical power output with fuzzy logic controller, the power output increased by 3.65 kWh, which is 45.6% increase with introduction of fuzzy logic controller. The results demonstrated the applicability of the method. The fuzzy logic controller model produced smaller deviations and exhibited a superior predictive performance on forecasting of biogas production.

Key words: Biogas Energy, Fuzzy Logic Controller, MATLAB-SIMULINK, Fuzzification, Defuzzification, Renewable Energy.

I. Introduction

Energy projects in developing countries have proved that renewable energy sources (RES) contribute to poverty alleviation as well as provide for business and employment opportunities. People are more concerned about fossil fuel exhaustion and global warming problems caused by conventional power generation. It has been depicted that electricity from RES are promising towards building a sustainable and environment friendly energy economy in the next decade [1]. In addition, consumers need to be educated on the necessity of using non-polluting cleaner energy sources while the government should make a policy that will enhance renewable energy utilization to a greater extent. If realistic models were developed to provide reliable environment friendly energy from homespun commercial and renewable energy sources, it would aid the global community and leave behind a healthy environment for generations to come [[2], [3]].

The increasing need for renewable energy, as well as limited fossil fuel reserves and the increasing concerns with the population demand for fast development in the area of renewable energy system imply a requirement for better control schemes in modern power systems [4]. In this regard, energy from biomass is seen to be one of the most promising future renewable energy sources. Biogas is accepted worldwide as one of the prime technologies for producing valuable manure and renewable energy from all kinds of

digestible biomass. After undergoing a cleaning and upgrading process, biogas can be used in form of biomethane as a renewable substitute for natural gas [[5], [6]].

In addition, the efficiency of the process is influenced by the availability of the microorganisms to the substrate which is dependent on the mixture of the biogas reactor and also by the type and structure of the feedstock as well as the operation condition. The biogas is a natural process, which takes place in moors and swamps as well as in the digestive tracts of some animals, such as cows. During the process, organic material is decomposed by microbial organisms in the absence of oxygen and turned predominantly into methane [[7], [8]].

Since the microorganisms in the biogas production process are sensitive to changes in their environment, controlling and predicting the process is challenging. Process monitoring and control is one of the methods used as improvement for development of the biogas production process [9]. Process modelling provides a better understanding of a process and its optimal working conditions. Artificial intelligence and computing techniques such as fuzzy logic (FL) or neural networks (NN) can also be used to control the biogas process and predict its outcome. In general, these techniques were used to control and to deliver the available energy in an optimal way [10].

Fuzzy logic is used in solving a wide range of control problems in power system operation because of simplicity, robustness and reliability which are essentially based on linearized mathematical models of the controlled systems. The fuzzy control method tries to establish the controller directly based on measurements, long term experience and knowledge of domain operators [11]. Fuzzy logic helps in conceptualizing the fuzziness in the system into a crisp quantifiable parameter. Thus fuzzy logic based models are used for effective energy planning. Fuzzy logic deals with reality and it is a form of many valued logic. It deals with reasoning that is approximate having also linguistic values rather than crisp values. Fuzzy logic handles the concept of truth values that ranges between completely true and completely false [[12], [13]].

The various types of membership functions normally used in fuzzy logic are ‘Λ’ triangular, ‘Π’ trapezoidal, ‘L’ function, ‘T’ function, ‘S’ function, Gaussian fuzzy set. All of these functions can be used in the modeling of energy systems. Fuzzy logic based models in energy systems can range from the most simple to the most complex.

II. Mechanism of Energy Generation Process of Biogas Energy

Biogas is a very important form of renewable energy source because its usage can be done in raw form without any process. The growing interest in biomass usage is based on the following facts [13]:

- Its contribution to poverty reduction in developing countries;
- Its ability to constantly meet energy demand;
- Its capability on delivering energy in all forms (liquid, gas, heat and electricity);
- It helps on the restoration of unproductive and degraded lands, increases biodiversity, soil fertility and water retention.
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The most common biogas energy sources are wood and wood waste, agricultural crops and their by-products after cultivation, animal wastes, municipal solid waste and food processing wastes. Currently, the available biogas resources can provide approximately 6×10^{15} Btus of energy [[13], [14]].

There are many economic benefits derived from the usage of biogas as a source for energy generation [14]:

- Inexpensive resources;
- Locally distributed;
- Price stability;
- Generation of employment opportunities;
- Biomass export opportunities;
- Potentially inexhaustible fuel resource.

Disadvantages of biogas usage [[3], [7]]:

- Biomass fuels give low energy density;
- Collection and transportation can be cost prohibitive;
- Biomass usage for energy production requires a constant supply of fuels which are bulk and must be stored near the biomass plant.

In the biogas production process, the organic material mainly built up of carbohydrates, proteins and fats are degraded in several steps to simpler compounds by microorganisms. The process is divided into four main steps: hydrolysis, acidogenic phase, acetogenic phase and methanogenic phase. In the hydrolysis, the non-water soluble carbohydrates, proteins and fats are broken down to simple sugars, fatty acids and amino acids outside the microorganisms. The products from the step are then taken up by the microorganisms and are further degraded into short-chain organic alcohols, hydrogen and carbon dioxide by acidogenic phase. In the third step, acetate is formed while the last step methanogenic microorganisms form methane mainly from acetate, carbon dioxide and hydrogen gas [[1], [4], [5], [8], [10]].

Although biomass usage for energy production is technically well established, however, it is clear that for the optimization of biomass exploitation for energy production, a decision support system is needed. This system must take into consideration biomass production as well as biomass accessibility, land uses etc. and provide managers with the optimal solution which will help them determine the best site for installing a biomass power plant.

III. General Overview of Fuzzy Logic Technique

Fuzzy logic is classified as intelligent controller derived from fuzzy set theory to deal with reasoning that is approximate rather than precise. It was developed for control operation of knowledge based systems and allows values to be defined like true or false. It is simple to implement and hence it is becoming more favorite for knowledge based system implementations. Fuzzy logic provides controlling action with fuzzy set and rules. As opposed to classical set theory where an entity either belongs or does not belong to a set, fuzzy set theory accommodates partial membership of the entity in the set. The fuzzy set is described as a class with a continuum of grades of membership [[2], [13], [14]].

A general fuzzy system has basically four components: fuzzification, fuzzy rule base, fuzzy output engine and defuzzification [1]. In fuzzification step, numerical inputs and output variables are converted into linguistic terms (such as low, high, big, small, etc.) and the corresponding degrees of one or more several membership functions are determined. Then, the output membership values are synthesized based on developed fuzzy rules (fuzzy inference). Finally, in the defuzzification step, linguistic results obtained from the fuzzy inference are translated into a real value by using the rule base provided. This phase is responsible for transforming the fuzzy results from the fuzzy system into crisp values [[9], [11], [12]].

The block diagram of the fuzzy logic implementation process is shown in Figure 1 [4]. In addition, the defuzzification method can be expressed mathematically as follows [13]:

$$(y_i)_d = \frac{\sum_{i=1}^n \mu(y_i) y_i}{\sum_{i=1}^n \mu(y_i)} \quad 1$$

where; $(y_i)_d$ is the defuzzified output, y_i is the output value (or the centroidal distance from the origin) in the i^{th} subset, and $\mu(y_i)$ is the membership value of the output value in the i^{th} subset.

Figure 1: The block diagram of the fuzzy logic implementation process

IV. Materials and Method

This study develops a fuzzy logic controller model to control the biogas power output that will satisfy the load demand constantly and effectively. A control unit was designed to calculate the optimal amount of power which can be generated from the biogas. In addition, an algorithm was designed to decide power delivery to the load as to improve the performance of the biogas system using MATLAB/SIMULINK and a Graphic User Interface (GUI) was developed for easy input of the data. The developed GUI model was used to design a fuzzy logic model. A form of output from the fuzzy controller is modified to take an action accordingly. As per the fuzzy theory and logic, a decision was made by three operations: fuzzification process, inference engine for rule base and defuzzification process.

The biogas data was generated using the equations below:

The mass of dry solid in waste is given as:

$$m_o = N_a S_w \quad 2$$

The volume of biogas is given as

$$V_b = c m_o \quad 3$$

The volume of fluid in the digester is given as:

$$V_f = \frac{m_o}{\rho_m} \quad 4$$

The volume of the digester is given as:

$$V_d = \frac{V_f}{t_r} \quad 5$$

The energy generated is given as:

$$E = \eta H_b V_b \quad 6$$

where; N_a is the number of animals that produced the dung, S_w is the solid in waste per animal per day/kg, c is the biogas yield per unit dry mass, m_o is the mass of dry input, ρ_m is the density of dry matter in the fluid, V_f is the flow rate of digester fluid, t_r is the retention time in the digester and H_b is the heat of combustion per unit volume of biogas.

V. Simulation

The study developed a program in MATLAB/SIMULINK for fuzzy logic controller model and implemented using fuzzy logic toolbox in MATLAB for load balancing.

The steps involved are:

- i. Design of a membership for fuzzy logic that analyses the increase of biogas electrical power. This task is the fuzzification of variables, which involves a domain transformation; crisp variables into fuzzy inputs. This helps to increase the biogas electrical power output.
- ii. Definition of membership functions (MF). This task is transformation which is often piecewise linear functions. A degree of MF is produced as input value to the fuzzy controller. For its directness, the linear function is embraced as the membership evaluation function of input/output. The membership function is a comprehensive analysis of the type of biogas output power to be produced. In this study the output membership functions are assumed symmetrical and the commonly used continuous centre of gravity (COG) also known as the centre of area (COA) or centroid method are applied to the defuzzification.
- iii. Designed of a fuzzy rule that sticks in the increase of biogas electrical power output. The output of the fuzzy controller is based on position of the membership function (MF) and the fuzzy rule base (FRB). The position of the membership function decides the distribution of the set parameters.

To design a fuzzy rule, the following rules are used: In conclusion.

- If power output is not enough and biogas is not produced then performance is bad.
- If power output is not enough and biogas is produced then performance is average.
- If power output is enough and biogas is not produced then performance is better.
- If power output is enough and biogas is not produced then performance is good.

VI. Discussion of Results

The simulation results are presented according to biogas electrical power output without and with fuzzy logic controller and also by comparing the biogas electrical power output with and without fuzzy logic controller.

Figure 2 shows the designed fuzzy logic controller SIMULINK model for improving biogas electrical power output.

Figure 3 illustrates the relationship between retention time and biogas electrical power output without fuzzy logic controller. The result shows that the values of biogas electrical power output without fuzzy controller for 2h, 4h, 6h, 8h and 10h retention time are 1.2 kWh, 1.7 kWh, 2.2 kWh, 2.7 kWh and 3.2 kWh respectively. The values of biogas electrical power output without fuzzy controller for 12h, 14h, 16h, 18h and 20h retention time are 3.7 kWh, 4.2 kWh, 4.7 kWh, 5.2 kWh and 5.7 kWh respectively. In addition, the values of biogas electrical power output without fuzzy controller for 22h, 24h, 26h, 28h and 30h retention time are 6.2 kWh, 6.7 kWh, 7.2 kWh, 7.7 kWh and 8.2 kWh respectively.

The relationship between retention time and biogas electrical power output with fuzzy logic controller is depicted in Figure 4. The result shows that the values of biogas electrical power output with fuzzy controller for 2h, 4h, 6h, 8h and 10h retention time are 1.45 kWh, 2.13 kWh, 2.81 kWh, 3.49 kWh and 4.17 kWh respectively. In addition, the values of biogas electrical power output with fuzzy controller for 12h, 14h, 16h, 18h and 20h retention time are 4.85 kWh, 5.53 kWh, 6.21 kWh, 6.89 kWh and 7.57 kWh respectively. The values of biogas electrical power output with fuzzy controller for 22h, 24h, 26h, 28h and 30h retention time are 8.25 kWh, 8.93 kWh, 9.61 kWh, 10.29 kWh and 10.97 kWh respectively.

Figure 5 illustrates the relationship between biogas electrical power output without fuzzy logic controller and biogas electrical power output with fuzzy logic controller. The values of biogas electrical power output without fuzzy controller of 1.2 kWh, 1.7 kWh, 2.2 kWh, 2.7 kWh and 3.2 kWh correspond to the values of biogas electrical power output with fuzzy controller of 1.45 kWh, 2.13 kWh, 2.81 kWh, 3.49 kWh and 4.17 kWh respectively. The values of biogas electrical power output without fuzzy controller of 3.7 kWh, 4.2 kWh, 4.7 kWh, 5.2 kWh and 5.7 kWh correspond to the values of biogas electrical power output with fuzzy controller of 4.85 kWh, 5.53 kWh, 6.21 kWh, 6.89 kWh and 7.57 kWh respectively. In addition, the values of biogas electrical power output without fuzzy controller of 6.2 kWh, 6.7 kWh, 7.2 kWh, 7.7 kWh and 8.2 kWh correspond to the values of biogas electrical power output with fuzzy controller of 8.25 kWh, 8.93 kWh, 9.61 kWh, 10.29 kWh and 10.97 kWh respectively.

Figure 6 shows the comparisons between biogas power output with and without fuzzy logic controller and retention time. The result shows that after retention time of 30 hour, the value of biogas electrical power output increased by 3.65 kWh, which is 45.6% increase with introduction of fuzzy logic controller. This is due to the input parameters of the biogas generated. The result obtained shows that there is an increase in biogas electrical power output when fuzzy controller is introduced in the system model.

Figure 2: SIMULINK model of fuzzy logic controller.

Figure 3: Biogas electrical power output without fuzzy controller

Figure 4: Biogas electrical power output with fuzzy controller

Figure 5: Biogas electrical power output with and without fuzzy controller.

Figure 6: Comparisons between biogas electrical power output with and without fuzzy controller.

VII. Conclusion

This study has discussed a computational technique to produce electrical power effectively from renewable sources. The study modeled a fuzzy logic controller using MATLAB-SIMULINK to improve biogas electrical power output by comparing the biogas electrical power output with fuzzy logic controller and biogas electrical power output without fuzzy logic controller. This is done by designing a SIMULINK model for improve biogas electrical power output using fuzzy logic controller and comparing the biogas electrical power output with and without fuzzy logic controller. From the result, it was deduced that there is an increase in biogas electrical power output when fuzzy controller is introduced in the system model. The results demonstrated the applicability of the method.

VIII. References

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