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Development of a Simplex Optimization Technique for Biogas Generation of Electrical Energy

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Abstract

Biogas energy production is a key technology in the development of sustainable energy supply systems aiming at covering the energy demand using renewable sources. The production can be achieved with anaerobic digestion.This paper developsa simplex optimization model for biogas energy generation. The bio-digester used to generate the biogas energy in this work is animal manure because of availability of the materials. The simplex optimization model was then developed by adding a slack variable to the biogas model in order to find a value of the decision variable for the model. This was done to find a value of the decision variable where all the constraints are fulfilled. When a feasible basic solution wasfound, the algorithm sought from new vertex to find the optimal solution. The next vertex was chosen such that the search direction was in the steepest feasible direction. The developed simplex optimization model was then used to optimize the full-scale of the biogas energy. A simplexoptimization model for biogas energy generation with a coefficient of -1.1733 and 20.639 (R square value of -0.073) was developed.The resultsshowed that the total biogas energy generated before optimization were 636.6MW and 889.49MW after optimization. The biogas energy generation was increasedby 252.89MW, which was 39.7% increase after optimization. The results showed the applicability of the optimization model which can be exploited using optimal control scheme. The outcome of the optimization result indicates that the developed model is a useful mechanism yielding an economical solution on one hand and increase in renewable energy contribution on the other.

Keywords: Biogas Energy Production, Computer Simulation, Simplex Optimization, Renewable Energy, Anaerobic Digestion, Coefficient of Polynomial.

I. Introduction

The realization that fossil fuel resources required for the generation of energy are becoming scarce and that climatic change is related to carbon emissions to the atmosphere has increased interest in energy saving and environmental protection. The fossil resources dependence of fossil is reduced based on reducing energy consumption by applying energy savings programs focused on energy demand reduction and energy efficiency in industrialand domesticfield’s spheres [1]. This is achieved by using renewable energy sources such as biogas, not only for large-scale energy production, but also for stand-alone systems. Renewable energy technologies are known to be less competitive than traditional electric energy conversion systems, mainly because of their intermittency and the relatively high maintenance cost[2, 3].

Biogas has been receiving increasing attention as an alternative to fossil fuels in solving the problems of rising energy prices, waste treatment/management and creating a sustainable energy development. This energy generation has been significantly improved over the past few years and forms a significant proportion in the generation of electric energy. Biogas energy is renewable energy made available from materials derived from biological sources, including plants and animals [4]. Biogas is a product of anaerobic digestion processes in biomass and mainly consists of methane and carbon dioxide with trace amounts of other gases. Biogas production from organic waste has an important role as a waste management system. Biogas technology plays an important role in producing energy from renewable and clean resources, in addition to its application to treat animal manure and organic waste from the industry and household sectors [5].

Biomass can readily be used in boilers to produce heat or steam to generate electricity. This is done in small scale at remote locations and in a centralized way in large production units of more than 50 Megawatts. The gas produced in this way is a well known commodity in the energy generation and chemical process industry and offers excellent options for high efficiency large scale electricity production and chemicals. However, more research is required in order to prove that power generation from biogas is both technically and economically viable [6, 7].

In order to make biogas energy production to be technically and economically viable, there is the need to apply an optimization technique that is capable of enhancing the biogas energy production effectively and more useful for system planning engineers. An optimization process aims at improving the performance of a system, so that the greatest benefits can be achieved [8]. Optimization has traditionally been used in renewable energy generation to designate a set of experiments that find the proper conditions for carrying out a method, in order to achieve the best possible responses and ensuring the best analytical characteristics. Optimization processes have been performed by monitoring the influence of one variable at a time on a given experimental response [9].

In recent years, different optimization technique have been applied to solve optimization problem of renewable energy production in which most of the techniques used focused on the reduction in the number of iterations, hence resulting in higher costs of power generation and time consumption.

Biogas Energy

Biogas energy is renewable energy made available from materials derived from biological sources, including plants and animals. In addition, biogas can be converted to other usable forms like methane gas, ethanol fuel and biodiesel fuel. Biogas power plants exist in over 50 countries around the world and supply a growing share of electricity. According to Lindkvist *et al.* [10], European countries have expanded their total share of power from biogas, such as Austria (10% of the renewable energy generation), Finland (23%), and Germany (8%), while biogas for power generation is also a growing trend in many developed countries. The trends include growing use of solid biogas pellets, use of biogas in community-scale combined heat and power plants, and for centralized district heating systems [11, 12].

The use of biogas as a source of energy has been further enhanced in recent years and special attention has been paid to biomass gasification. Therefore, the sustainability of energy generation from biogas must be assessed according to the key indicators of price, efficiency, greenhouse emissions, availability, limitations, land use and social impacts. Biogas energy generation generally provides favorable price, efficiency, emissions, availability and limitations but often has unfavorably high land and social impacts [11].

Systems Optimization

An optimization method is necessary in order to efficiently and economically utilize the renewable energy resources. Optimizing the operation of biogas energy is one of the main challenges in the field of biogasdigester. This is due to uncertain load demand, nonlinear characteristics of renewable components, the high number of variables and parameters to be considered, and the fact that the optimum configuration and optimum control strategy of the system are interdependent [8]. The operation of biogas digester is very sensitive to the mixture of the used substrates. Hence, due to the slow processes involved in generating the bio-digester energy, optimizing the biogas digester is time consuming [10].

Optimization method helps guarantee the lowest investment with full use of the biogas technologies, so that the biogas energy generation can work at the optimum conditions in terms of investment and system reliability. Optimization requires the assessment of the system's long-term performance in order to reach the best compromise for both reliability and cost. In general, since renewable energy forecasting ensures more accurate scheduling, energy storage are used to compensate the missing or exceeding scheduled production.This solution is applicable to any small size isolated power grid with large renewable energy penetrations [5, 9, 10].

Several studies have used differentmethods to solve the optimization problem of biogas energy generation. Some of these optimization methods are based on traditional approaches, such as mixed-integer and interval linear-programming, Lagrangian relaxation and quadratic programming, while a growing number of research papers tackle these problems using heuristic optimization methods, especially genetic algorithms and particle swarm optimization [12].

Alfarjani, (2012)presented an optimization method for multi-biogas energy conversion applications taking into account various technical, regulatory, social and logical constraints. PSO was applied for the optimal location and supply area for biogas-based power plants where the maximum electric power generated by the plant is considered as a constraint.Andrea*et al.,* (2017)proposed the use of vegetable biogas from greenhouse residues to produce electrical energy by the gasification process. Due to the increasing interest in biogas gasification, some models that explain the design, simulation, optimization and process analysis of gasification were presented.Bergstrom (2006) presented a binary PSO-based method to accomplish optimal location of biogas-fuelled systems for distributed power generation with forest residues as biogas source.The results outperformed those obtained by a GA when maximizing a profitability index taking into account technical constraints. Chun *et al.*(2015)applied a natureinspired algorithm for the optimal location of a biogas power plant with the aim of providing the best profit margin for investors.Martin *et al.* (2016)developed a method to assess optimal management and energy use of distributed biogas resources, considering features such as biogas resources properties, plant size effect, available technologies for power, heat and solid bio-fuels generation and quantification of potential bio-fuel consumers.

II. Materials and Method

The daily biogas energy generated by the bio-digester is calculated by multiplying the efficiency of the system with the heat of combustion per unit volume of biogas and the volume of biogas generated.

The biogas daily energy generated is given as:

$$E = \eta H_b V_b \qquad 1$$

Biogas generator sizing is given as;

$$P_{BG} = \frac{E_{BG} \times CV_{BG} \times \eta}{860 \times Hr} \qquad 2$$

where;H_b is the heat of combustion per unit volume of biogas. V_b is the volume of biogas, CV_{BG} is the calorific value of biogas (4700kcal), η is the biogas conversion efficiency, E_{BG} is the energy generated by biogas.

To calculate the variable of the simplex optimization model, the following equations are used.

Expression for the calculation of the coordinates of the new vertex (NV) obtained from a reflection is given as;

$$V = M + d \qquad 3$$

Thus, finding the coordinates of the new vertex requires adding the distance (d) value to the midpoint. However, the distance value is calculated as:

$$d = M - W \qquad 4$$

Substitute the value of d in equation (2)

$$V = M + (M - W) \qquad 5$$

$$V = 2M - W \qquad 6$$

Therefore, the new vertex is given as:

$$NV = M + \alpha(M - W) \qquad 7$$

The midpoint value regarding any number of variables is given as:

$$M = \frac{1}{N}\sum_{j \neq i}^{n} V_j \qquad 8$$

Where; N is the number of variables, i is the vertex index of the worst response and j is the considered vertex, NV represents the new vertex, M stands for the average of the best vertexes, α is the movement coefficient of the simplex and W represents the vertex with the worst response.

The simplex optimization method is originally sequential, i.e., the next stage must be conducted after evaluating the previous response, thereby making the method more suitable for the optimization of fast response systems. The fixed-size simplex optimization method consists of a regular geometric figure that does not vary in size during the displacement process for the optimum conditions. This characteristic of the basic simplexoptimization method makes choosing the size of the initial simplexoptimization method a crucial step for the efficiency of the optimization process.

III. Procedural Steps in Simplex Optimization Model

Simplex optimization is usually carried out as a problem that is considered in sequential steps. The following steps are performed in order to develop a simplex optimization model for the biogas energy generation and the flowchart of the algorithm is shown in Figure 1:

Step 1: Set the number of k variables that will lead to an initial simplex with k + 1 vertex.
Step 2: Generate the initial simplex
Step 3: Add slack variables to the biogas model (biogas generated energy and size) to find a value of the decision variable for the model.
Step 4: Identify the critical process variables or factors. The process input factors are: beating time and temperature.
Step 5: Find the limits of each factor under the experimental conditions and make the reflection of the vertex presenting the worst response.
Step 6: Obtaina new vertex with the new point, discarding the vertex that has the worst response and utilizing the previous vertices.
Step 7: Evaluate the responses again and repeat the process until the optimal region is found.
Step 8: If the new vertex obtained by reflection shows the worst response of the new simplex, then reject the second worst vertex of the previous simplex and go to step 5 else stop and print the biogas generated energy and size.

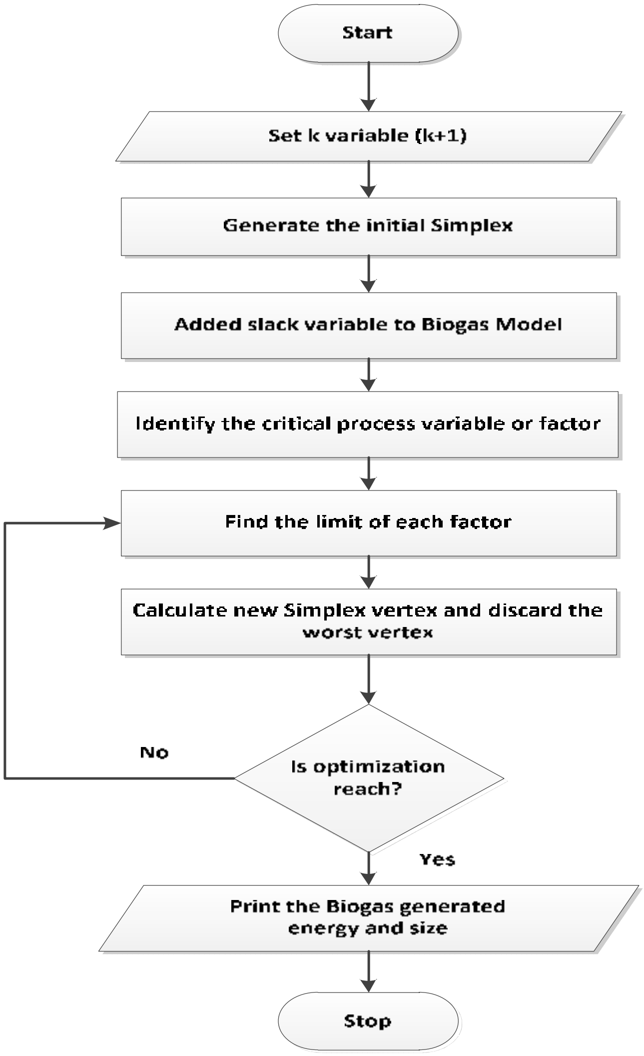

Figure 1: Flowchart of the developed simplex optimization model

IV. Simulation

The simulation analysis of the system was performed using MATLAB/SIMULINK with permissible range of number of variablesvalues of 1 to 12. The test was conducted for the system before and after optimization. The biogas energy generated and size before and after optimization, and the vertex value of the simplex optimization model were presented.

V. Discussion of Result

Figure 2a reveals the result of biogas energy generated without optimization. It was observed that the biogas energy generated increases with increase in the volume of biogas digester. The values of energy generated with the number of variables are 25.3MW, 30.9MW, 35.6MW, 40MW, 45.8MW, 50.3MW, 55.6MW, 60.3MW, 65.8MW, 70.9MW, 75.6MW and 80.5MW respectively. Figure 2b shows the relationship between the number of variables and the size of biogas generator. The size of each biogas energy generated are 4.32Mvar, 5.3Mvar, 6.1Mvar, 6.8Mvar, 7.8Mvar, 8.6Mvar, 9.5Mvar, 10.3Mvar, 11.2Mvar, 12.1Mvar, 12.9Mvar and 13.5Mvar respectively.

Figure 3a shows the result of biogas energy generated after optimization. After the optimization, the biogas energy generated was redistributed and the results indicate an improvement in the energy generated. The values of biogas energy generated are 47.6MW, 64.4MW, 60.4MW, 65.2MW, 67.2MW, 74.4MW, 80.86MW, 82.9MW, 85.8MW, 83.72MW, 86.71MW and 90.3MW respectively.The leastbiogas energy generated is 47.6MW and the highest biogas energy is 90.3MW. In addition, the results of sizes of the biogas energy generated are depicted in Figure 3b. The size for each biogas energy generated are 7.6Mvar, 11Mvar, 10.3Mvar, 11.1Mvar, 11.5Mvar, 12.7Mvar, 13.8Mvar, 14.2Mvar, 14.7Mvar, 14.3Mvar, 14.8Mvar and 15.4Mvar respectively.

Figure 4 shows the results of the simplex optimization new vertex with the number of variables. The values of the new vertex are 28.4, 31.0, 35.3, 27.0, 35.0, 55.8, 21.6, 29.9, 25.9, 25.6, 25.1, 23.0 and 18.4 correspond to the number of variable of 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12 respectively. The results obtained in each number of variables are used to support decisions that aim to reach the region of optimum response.

Figure 5 shows the comparison between the biogas energy generated with and without optimization. The biogas energy generated after optimization are 47.6MW, 64.4MW, 60.4MW, 65.2MW, 67.2MW, 74.4MW, 80.86MW, 82.9MW, 85.8MW, 83.72MW, 86.71MW and 90.3MW corresponding to the values of biogas energy generated without optimization with values of 25.3MW, 30.9MW, 35.6MW, 40MW, 45.8MW, 50.3MW, 55.6MW, 60.3MW, 65.8MW, 70.9MW, 75.6MW and 80.5MW respectively. The results show an increase in the biogas energy after optimization. The increase is due to the optimization vertex values of each number of variables.

Figure 6 depicts the relationship between the values of new vertex and corresponding biogas energy generated after optimization. The value of biogas energy generated after optimization are 47.6MW, 64.4MW, 60.4MW, 65.2MW, 67.2MW, 74.4MW, 80.86MW, 82.9MW, 85.8MW, 83.72MW, 86.71MW and 90.3MW corresponding to the new vertex values of 28.4, 31.0, 35.3, 27.0, 35.0, 55.8, 21.6, 29.9, 25.9, 25.6, 25.1, 23.0 and 18.4 respectively.

In addition, with the application of simplex optimization method, the biogas energy generated increases and the right size of the biogas generator was presented. From the result, the simplex optimization model was generated. A simplex quadratic optimization model which is $y = -1.1733x^2 + 20.639x$ is developed where x is the movement coefficient of the simplex and y is the optimal biogas energy generated with a coefficient of determination $R^2$of $-0.073\ or\ 97.3$.

The result confirmed the effectiveness of the optimization model in improving the biogas energy generated.

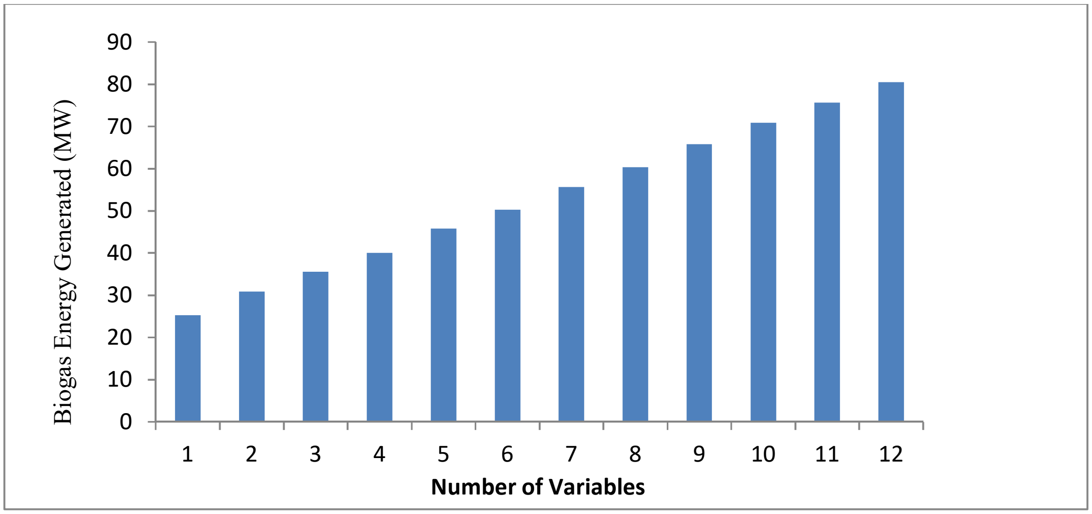

Figure 2a: Biogas energy generated without optimization

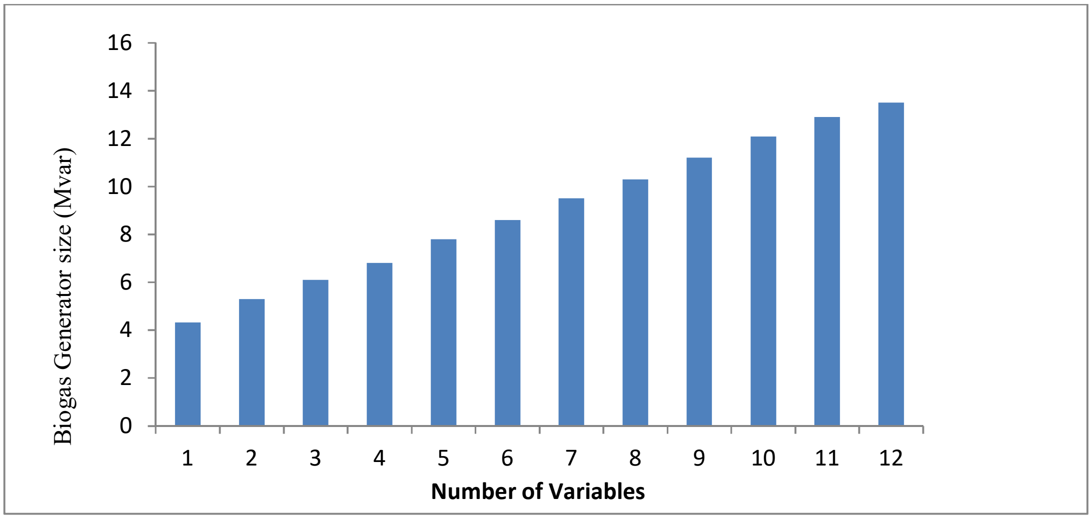

Figure 2b: Biogas generator size without optimization

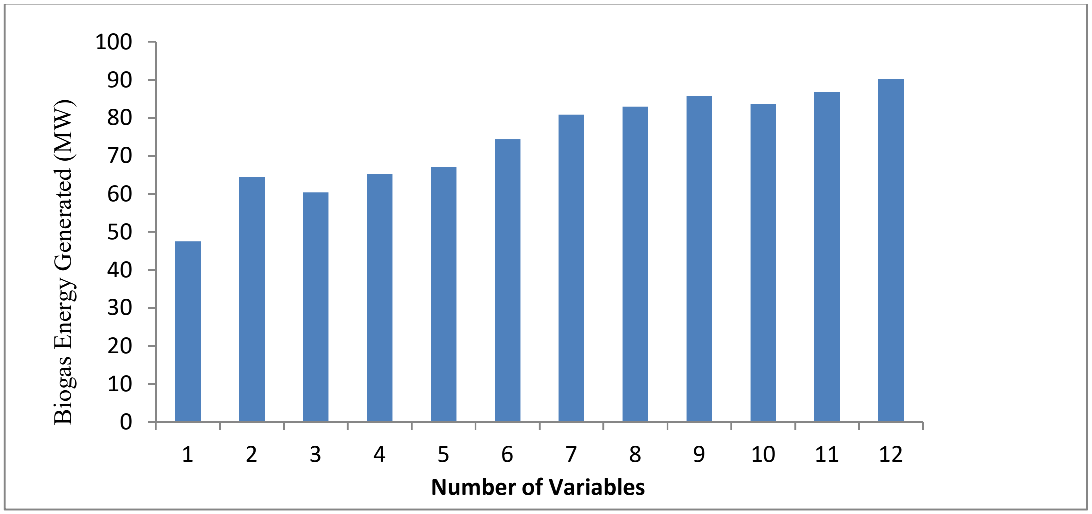

Figure 3a: Biogas energy generated after optimization

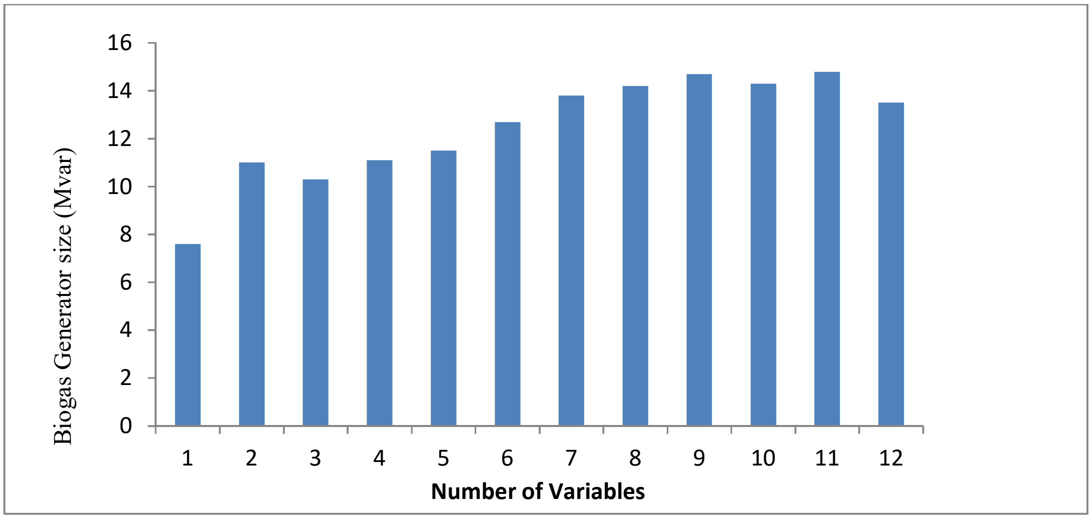

Figure 3b: Biogas generator sizeafter optimization

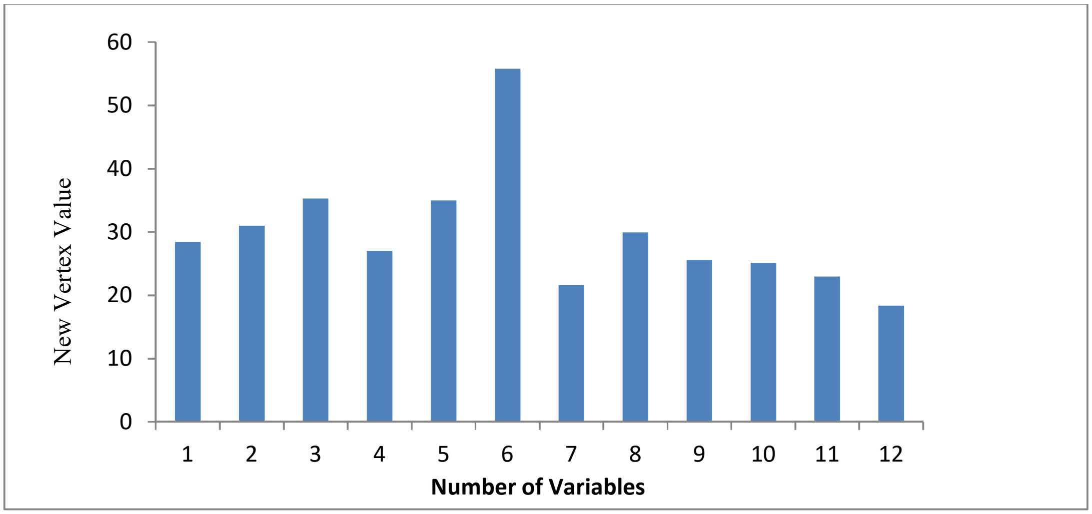

Figure 4: Simplex optimization new vertex values

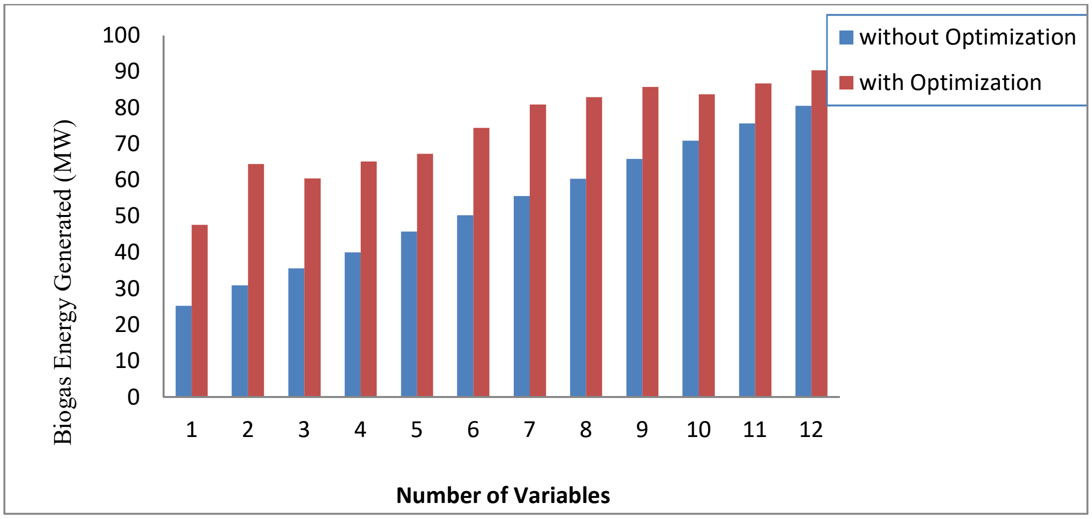

Figure 5: Comparison of biogas energy generated with and without optimization

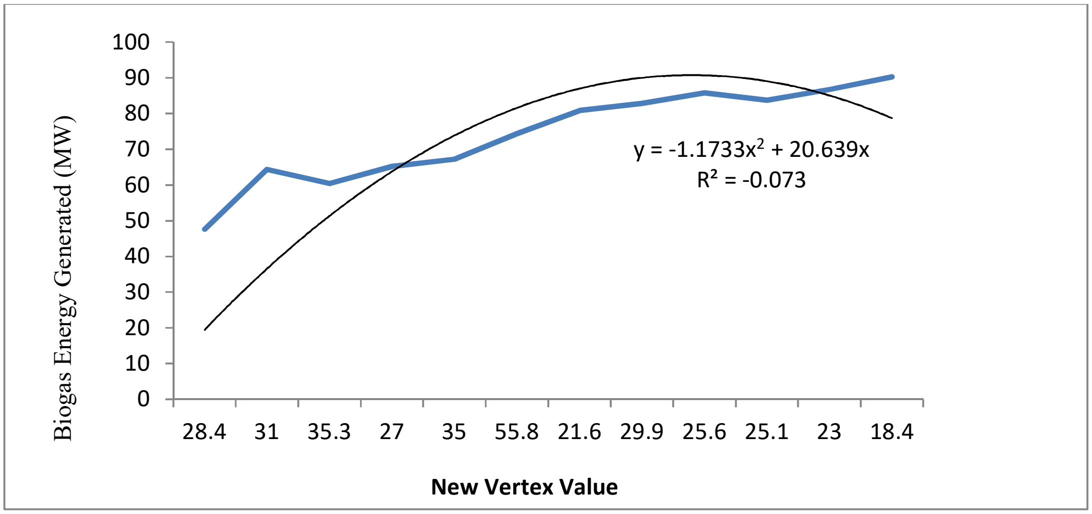

Figure 6: Relationship between biogas energy generated after optimization and new vertex value

VI. Conclusion

This paper has developed a simplexquadratic optimization model for biogas energy generation with coefficients of -1.1733 and 20.639 (as well as coefficient of determination of R^2value of -0.073) using computer simulation to optimally control the efficiency of full-scale biogas electrical energy. The simplex optimization model was developed by adding a slack variable to the biogas model to find a value of the decision variable for the optimization model. The results of the simulation are presented and discussed with and without optimization.The resultsshowed that the total biogas energy generated before and after optimization were 636.6MW and 889.49MW respectively. The biogas energy generation was increased by 2452.89MW, which is 39.7% increase after optimization. The results show the applicability of the optimization model which can be exploited using optimal control scheme.

IV. References

[1] Alfarjani F. A. (2012): “Design and optimization of process parameters in biogas production systems,” A thesis submitted for the degree of Master of Engineering (MEng), School of Mechanical and Manufacturing Engineering, Dublin City University, Pp. 1-190.

[2] Andrea M, Riccardo D. C, Isaac N. K, Simone G. S,Valeria G, Jeremiah K, Daniele V, Davide F and Davide P. (2017): “Energy Production Analysis and Optimization ofMini-Grid in Remote Areas: The Case Study of Habaswein, Kenya,” Journal Energies,Vol.10, Pp. 1-23.

[3] Banos˜ R, Manzano-Agugliaro F, Montoya F. G, Gil C, Alcayde A and GómezJ. (2011): “Optimization methods applied to renewable and sustainable energy: A review,” Renewable and Sustainable Energy Reviews, 15, Pp. 1753–1766.

[4] Bergstrom P. (2006): “Solving linear optimization problems using a simplex like boundary point method in dual space,” Department of Mathematics Lulvea University of Technology, Pp. 1-51.

[5] Bezerra M. A, Dos-Santos Q. O, Santos A. G, Novaes C. G, Ferreira L. C and De-Souza V. S. (2015): “Simplex optimization: A tutorial approach and recent applications in analytical chemistry,” Microchemical Journal, 124, Pp. 45 –54.

[6] Chun C. W, Jamaludin F. M, Zainol N. (2015): “Optimization of biogas production from poultry manure wastewater in 250 MLflasks,” Jurnal Teknologi (Sciences & Engineering), Vol. 75, No.1, Pp. 275–285.

[7] Hakan İ.T. (2015): “District heating in areas with low energy houses: detailed analysis of district heating systems based on low temperature operation and use of renewable energy,” DTU Civil Engineering Report R-283 (UK), Pp. 1-204.

[8] Harsh A.R and Singal, S. K. (2014): "Integration of renewable energy sources using Artificial Intelligent system," International Journal of Innovative Research in Science,Engineering and Technology. Vol. 3, Issue 11, Pp. 17291-17305.

[9] Johannes G. J. (2018): "Determining an appropriate electricity supply mix for the Hessequa Municipality: A system dynamics approach," Thesis presented in fulfilment of the requirements for the degree of Master ofIndustrial Engineering in the Faculty of Engineering at Stellenbosch University. Pp.1-232.

[10] Lindkvist E, Johansson M. T and Jakob Rosenqvist J. (2017): "Methodology for analyzing energy demand inbiogas production plants—a comparative study oftwo biogas plants," Journal Energy, 10, PP. 1-20.

[11] Martin Z, Gaida D and Bartz-Beielstein T. (2016): "Multi-fidelity Modeling and Optimization of Biogas Plants," Applied Soft Computer, Pp. 1-21.

[12] Taheri-Asl A. R, Malekiha M, Movassaghi K andAdani F. (2014): "New method for biogas generation from municipal wastewater treatment plant of Isfahan city, Iran," EurAsia Waste Management Symposium, 28-30 April 2014, YTU 2010 Congress Center, Istanbul/Türkiye, Pp. 1-5.