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# Anaerobic Digestion Based Modeling and Simulation of Bio Gas Fuel System

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## Abstract

The aim of is to generate electricity from biogas renewable energy for rural areas during shut down or off power blackout days. Renewable energy is of clean and sustainable nature and thus forms an alternative to fossil fuels. The burning of coal, oil and natural gas causes global warming, a disaster. It affects our planet and also the human beings on the earth. Renewable energy sector has become recent in most of the countries and hence pave a wayfor huge companies to invest. New jobs can be created for the unemployed personnel. Hence, renewable energy is proved to play an important role in bringing the unemployment scale down in most of the countries, in particular the developing ones. There are various renewable energy resources used for electricity production but biogas can be used as a fuel substitute and for energy production. The energy output can be stepped up and then connected to grid. The byproduct obtained from anaerobic digestion process is biogas, which is the combination of carbon-dioxide and methane gases. Micro turbine coupled with PMSG fed from biogas energy as input operates

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to provide continuous power supply. The transient condition occurring during increase/decrease in load is regulated using an adaptive controller and the performance of PMSG is monitored using a supervisory controller throughout the running of generator. The proposed system is modeled and the performance is simulated using MATLAB.

**Keywords:** Eleven level inverter, closed loop Sine reference pivoting, PI controller Tuning, Fruit fly algorithm, Cuckoo search heuristic algorithm, Bode analysis and Regulation with Filter characteristics

## 1 Introduction

In India most of the people live in rural areas without electricity. Making their lifestyle as standards there must be need of continuous electric supply. Every year there is a severe demand in electric supply. The greenhouse gas produced due to the electricity generation from fossil fuels has led to environmental issues, that resulted in global warming, that has to be reduced. Hence fossil fuels are replaced by renewable sources in most of the countries [1]. The necessity of renewable energy resources is required because of environmental concern and limited stock of conventional sources. Various resources available in our world are solar, wind, biomass/biogas etc. Utilization of Bio-Gas is increasingly applied nowadays. Despite various Grants, the productions of Bio- Gas production are not commercial till now and people are mostly depending on natural gas that depletes fast [2].

Biogas is the combination of methane, carbon dioxide and smaller amounts of hydrogen sulphide and ammonia [3] gases. Some commercially feasible biogas production applications can be used in future includes:

- Electricity generation with fuel cells
- Industrial cooling purpose
- Injection in the gas grids
- Transport fuel
- Production of chemicals.

Anaerobic Digestion is a natural-biological process that provides high valorization value of waste the digestate as bio-fertilizer. Modeling is the tool used to optimize the system's behavior at various conditions. The modeling approaches for wet and dry digestion systems vary because of the solid content presence. The limiting step selection for modeling can be done by substrate and microbial loadings [4].

Bio-energy obtained from biomass may play a vital role in energy conservation. Using biological, bio-electrochemical and thermo-chemical processes, bio-energy is generated. Bio-energy systems are optimized to ensure their efficiency and costs reduction [5].

The bioreactor is the main unit in which the conversion processes occur, since it operates under controlled operating conditions. The performance of bioreactors is influenced by many its mixing, structure and size and transfer characteristics and means of feed input and product removal.

There are complex multiphase exists in bioreactors [5] for various flow patterns (Liao et al. 2018b [6]. The main objective of the paper is to develop complete model that simulate a biogas-fueled power plant. The system is composed of three individual models representing a biogas reactor and a micro-turbine (MT)-generation system. Each model is implemented in software to simulate the entire power plant [7]. An adaptive controller is designed to withstand transient conditions.

According to Zhifeng et al. [8], the worldwide installed biogas plants are gaining importance with reference to the sustained energy crisis. There are complex flow patterns that exist in bioreactors vary the mass transfer and heat characteristics [9].

The biogas energy in households in Uganda was investigated by Sendegeya and DaSilva [10] hence household plants provide an alternative to petroleum-based fuels. In the biogas plant model, several factors such as stabilization and waste biodegradation needs to be considered [11]. Chen et al. (2017b) displayed a fuzzy evaluation on Anaerobic Digestion process of food waste. The evaluation was conducted by China. A two-stage model was developed by Duan et al.(2017b) [12]. The model incorporated with acidogenesis process and methano-genesis in the second was the important process in biogas generation. A comparison two-stage and one-stage operations was presented in [13].

Section 1 provides the overall introduction and the research findings from the previous work. Section 2 describes the proposed bio gas fuel using anaerobic digestion process. Section 3presents mathematical modeling for the proposed system. The simulated results are shown in Section 4 and concluded in Section 5.

## 2 Proposed System

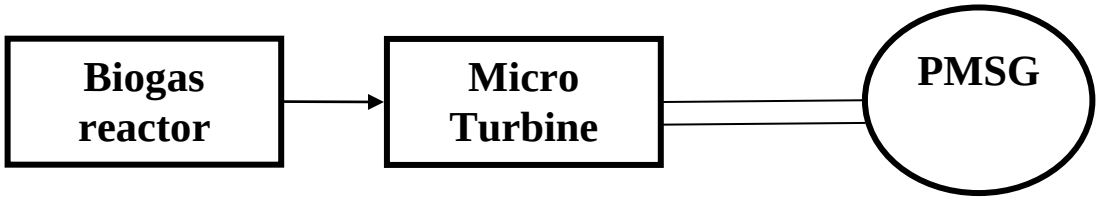


**Figure 1** Block diagram of the proposed system

The block diagram of the proposed system is shown in Figure 1.The model consists of a biogas reactor and Micro turbine coupled with a PermanentMagnet Synchronous Generator(PMSG). Initially biochemical conversion process occurs in the biogas reactor i.e.) biomass is converted into organic acids which in turn is converted into methane and carbon-dioxide. The gas methane is fed as input to the MicroTurbine, which is a small gas turbine that burns the gaseous fuel input and generate high steam energy which runs the PMSG to generate the electrical energy.

## 3 Modeling of Proposed System

The proposed system is modeled using various equations to obtain outputs such as power, torque, current and voltage of both d-axis and q-axis, slip speed and the current generated in the form of complex terms. The simple block here explains the model used for the proposed system.

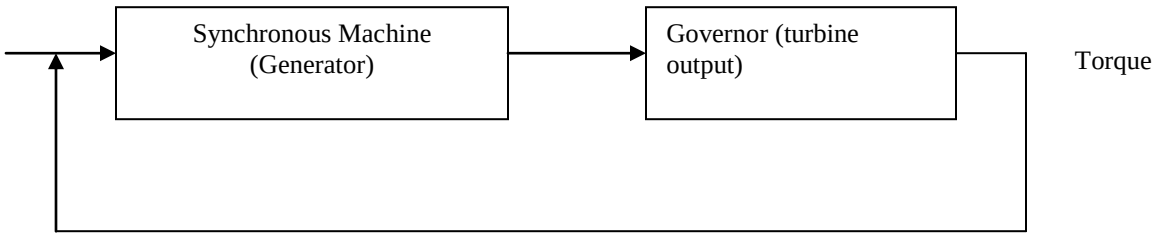


**Figure 2** Block diagram of system used in modeling

The input to the PMSG is the torque output of the turbine and also the step inputfed as input to the system and the value of the step input is given as

1 as shown in Figure 2. The mathematical modeling of the proposed system is described below.

Here the current and voltage components obtained from generator are in dqcomponents, which are then converted into abc components

The input to the dq0 components for the conversion of abc current components are expressed in eqn(1) as

$$\{(clocksignal + delta) * (id * iq * i0)\} = Inputtodq0 \quad (1)$$

Where the converted abc currents is given by,

$$ia = sqrt(1/2)*(u(1) + u(2) * cos[u(4)]) + u[3]*\sin(u(4) * sqrt\ (2/3) \quad (2)$$

$$= ibsqrt(1/2)*(u(1) + u(2) * cos[u(4)] - 2 * pi/3) + u[3]*\sin(u(4) - 2 * pi/3 * sqrt\ (2/3) \quad (3)$$

$$ic = sqrt(1/2)*(u(1) + u(2) * cos[u(4)] + 2 * pi/3) + u[3]*\sin\left(u(4) + 2 * \frac{pi}{3} * sqrt\ (2/3\right) \quad (4)$$

Where (2), (3) and (4) are the abc currents ia, ib and ic.

### *3.1 abc Voltage Components*

The input to the dq0 components for the conversion of abc voltage components are expressed as:

$$\{((clocksignal - 60) + delta) * (ud * uq * u0)\} = Inputtodq0 \quad (5)$$

Where the converted abc voltages are given by,

$$ua = sqrt(1/2)*(u(1) + u(2) * cos[u(4)]) + u[3]*\sin(u(4) * sqrt\ (2/3) \quad (6)$$

$$ub = sqrt\left(\frac{1}{2}\right)*(u(1) + u(2) * cos[u(4)] - 2 * pi/3) + u[3]*\sin(u(4) - 2 * pi/3 * sqrt\ (2/3) \quad (7)$$

$$uc = sqrt\left(\frac{1}{2}\right)*(u(1) + u(2) * cos[u(4)] + 2 * pi/3)\ u[3]*\sin(u(4) + 2 * pi/3 * sqrt\ (2/3) \quad (8)$$

Where (6), (7) and (8) are the abc voltages ua, ub and uc.

Power obtained will be the combination of currents and voltages of abc components excluding losses.

Power $= i_{abc} * u_{abc}$ (9)

Another input to generator is torque fed from turbine, which is expressed as:

$$((Wref - Wpu) * Tmo - \int 100t = Tm \quad (10)$$

Where Wpu is the d-axis voltage component
Tm = feedback input to the generator.

### *3.2 d-axis and q-axis Components*

The d-axis component is given by:

$$[(x_{dd}-x_{ddd})*(k_k*s_{ih})] - (x_d-x_{dd})*(x_{ddd}/(x_d*x_{dd}))s_{if} = Uq_{dd} \quad (11)$$

Here $s_{id} = 1/x_{ddd}-U_{qdd}$

The q-axis component is given by:

$$[(x_{qd}-x_{qdd})*(k_k*s_{ik})] - (x_q-x_{qd})*(x_{qdd}/(x_q*x_{qd}))s_{ig} = U_{ddd} \quad (12)$$

Here $s_{iq} = 1/x_{qdd} + U_{ddd}$

### *3.3 Slip Speed*

Slipspeed value is given by

$$(Tm-Te) -1/2HS*D = Wg \quad (13)$$

$$(Wg-w0/wB) = slip \quad (14)$$

The output of PMSG from d-axis and q-axis voltage and the delta value is fed as input to the Real Imag block which converts the value into complex and also fed into abs block and the output is obtained.

## 4 Simulation Results and Discussions

A SIMULINK model is developed for the proposed bio-gas fueled system. The proposed model consists of a biogas reactor unit and a micro turbine model.

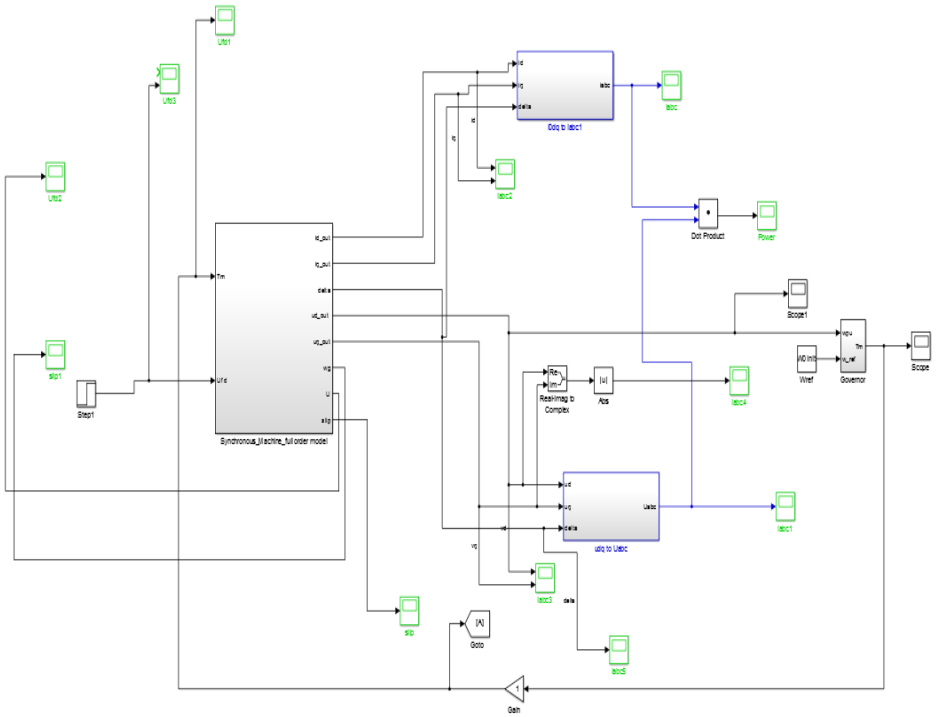


**Figure 3** Simulation diagram of the proposed system

Figure3 displays the overall simulation diagram of the proposed system. The system consists of the synchronous machine in which the input to the generator is the torque generated from the turbine. The power output will be the dot product of the current and voltage generated from the generator which is converted into abc components. A program is runned successfully and the time for generator is synchronized.

After providing the synchronization time to the generator the model starts working and the entire performance of the model is displayed as output which is simulated. The total power generated at the output is displayed in figure 4.

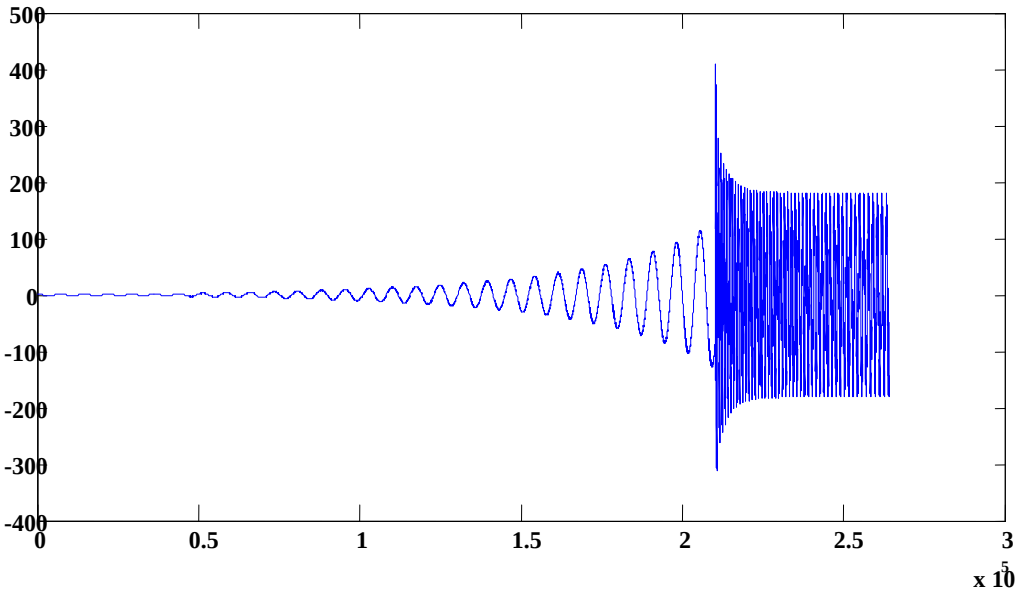


**Figure 4** Power Vs Time characteristics of the proposed model(KW-sec)

Power – Time characteristics of the proposed system is displayed in Figure 4. The output power initially rises to a peak value of 400 KW and it maintains a constant power of about nearly equal to 200 KW.

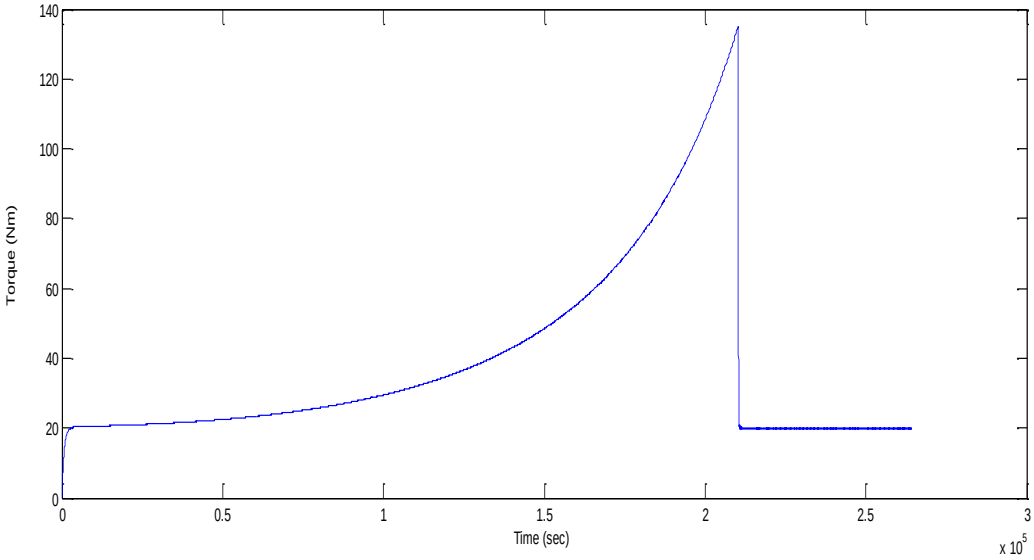


**Figure 5**Torque Vs Time characteristics of the Micro Turbine

Figure 5 displays the torque output of the turbine. A torque of about 20.18 Nm-s maintained constantly even when there is sudden rise in torque so that the motor is highly efficient with fewer amounts of losses.

Apply two reaction theories in the biogas reactor model to resolve the armature MMF, the axis parallel to rotor axis is d-axis and axis perpendicular to d axis is q-axis. The reactor output currents id and iq is displayed in Figure 6(a) and 6(b).

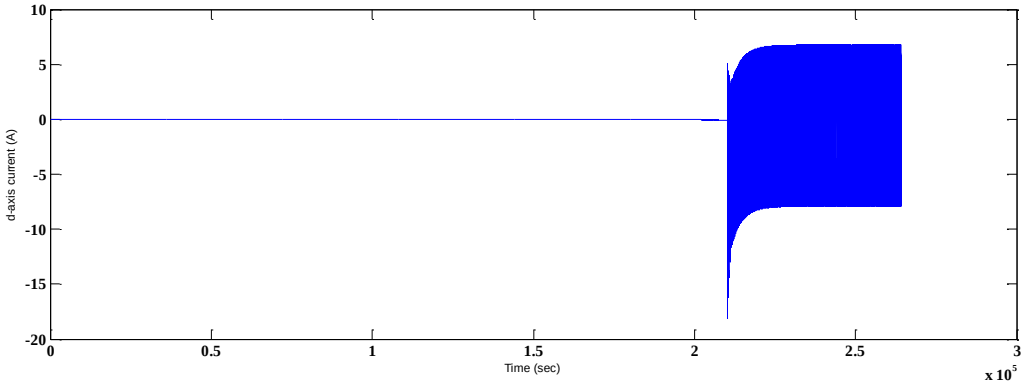


**Figure 6(a)** Direct-axis current

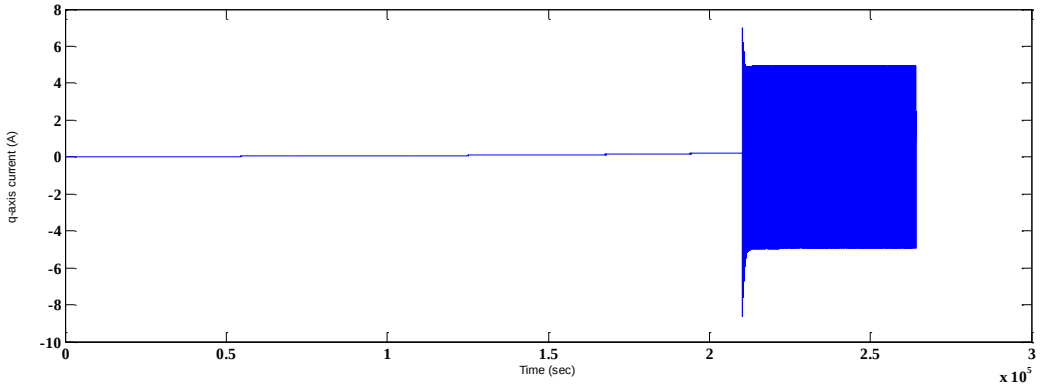


**Figure 6(b)** Quadrature-axis current

The current waveform obtained is sinusoidal. The direct axis current is obtained about 6A and the quadrature axis current is 5A which is obtained as a result of simulation.

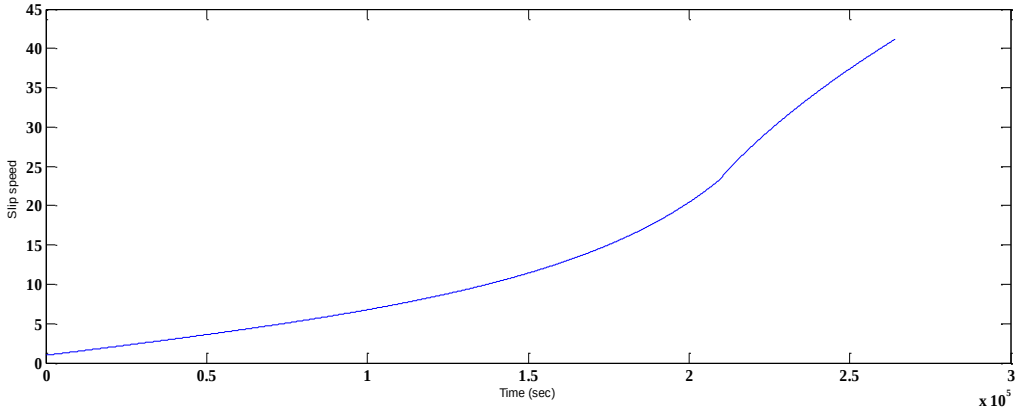


**Figure 7** Slip speed

Figure 7 displays the slip speed obtained from the reactor so as induction machine. The speed difference is the slip. The speed of the machine is about 40m/s. The output current of the reactor is converted into abc current components. The output abc current is shown in Figure 8.

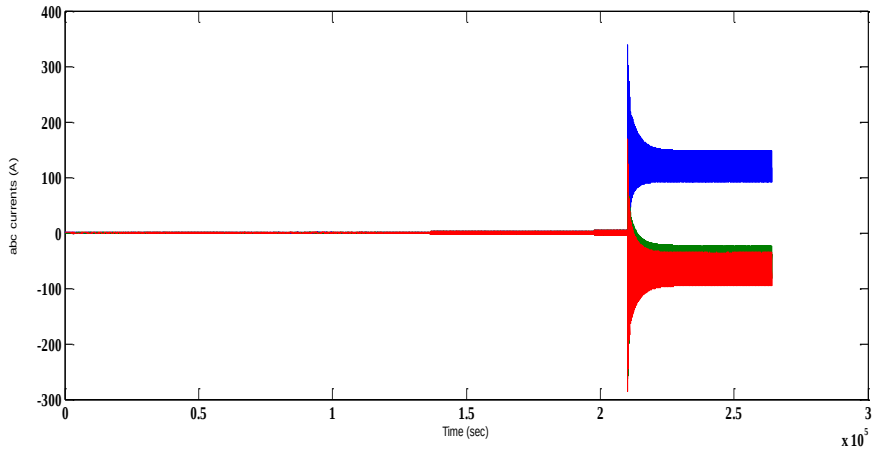


**Figure 8** abc current components

The current waveform is sinusoidal as 3-phase and the value obtained are about 200A.

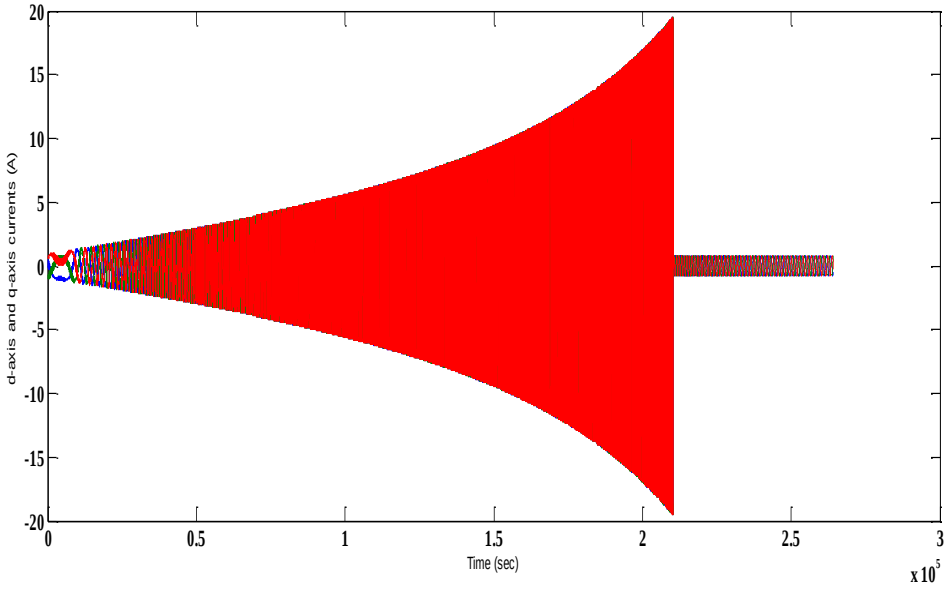


**Figure 9**Voltages of d-axis and q-axis

Figure 9 displays the voltage output of the d-axis and q-axis current. The d-axis voltage 1V and the q-axis voltage increases to 20 V and maintains the constant value of 1V. Both the voltages are in opposite direction.

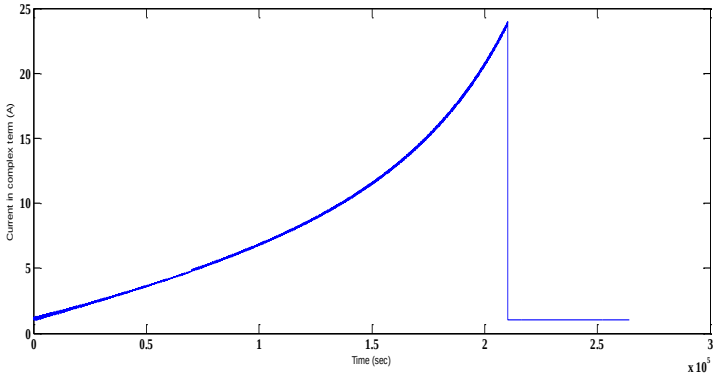


**Figure 10**Output of current in terms of complex value

Figure 10 displays the current in terms of complex value. The dq components are converted into abc components in terms of complex value.

## 5 Conclusions

This paper proposes the concept of usage of biogas plants for various applications. The principles of operation and biogas generation schemes are well given. Effective waste utilization to produce electricity are more discussed. Biogas thus generated can be used for variety of applications. The proposed model consists of micro turbine model a biogas reactor. It is proved that proposed system outperforms all other existing techniques.

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