MODELING AND ANALYSIS OF CONTROL CIRCUIT FOR BIOGAS ELECTRIFICATION TECHNOLOGY

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Abstract

For sustainable development, balanced energy portfolio is required that is suited to the economic, social, environment and resource conditions of a specific region or the whole world. Energy resources are fossil fuels, nuclear sources and renewable resources. Conventional energy resources are limited as well as they are subjected to pollution due to combustion and chemical processes. Biogas, one of the renewable resources, is produced from various biomass sources through biochemical process. Electricity and heat can be produced from it with minor clean up. Bangladesh has a plenty biomass resources which can play an important role for country's development. For electricity generation, control circuit is needed to have desired and controlled output.

This paper addresses on biogas, its biochemical processes and electricity generation process from biogas. It also shows the potential and prospects of biogas electrification technology for rural Bangladesh. Paper explore mathematical model and explain actions of control circuits those are connected to the generator though simulation.

Key Words: *Renewable energy; Biogas; Biochemical process; Electricity generation; Potentials; Mathematical model; Control circuit; DC converter.*

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1. INTRODUCTION

Natural Gas is used as main fuel for electricity generation in Bangladesh [1]. Alarming issue is that, the country's gas reserves stand at 14.16 trillion cubic feet (tcf) as of June 2015 and 12.96 bcf gases was extracted until May, 2015. If the current rate of extraction remains unchanged, the reserve would last until 2031[2].

Table -1: Installed capacity of BPDB power plants on September 2015[3]

Fuel Type	Capacity(Unit)	Total (%)
Coal	250.00 MW	2.14 %
Gas	7280.00 MW	62.31 %
HFO	2507.00 MW	21.46 %
HSD	916.00 MW	7.84 %
Hydro	230.00 MW	1.97 %
Imported	500.00 MW	4.28 %
Total	11683.00 MW	100 %

On the top of that country provides electricity to only 74% of its population and maximum people in rural areas are living, without electricity. Under this circumstance biogas based technology could be found effective for country's development [4].

Biogas technology, the generation of a combustible gas from anaerobic digestion, is a well-known technology. But producing electricity from biogas is still relatively rare in most developing countries.

Table -2: Bangladesh's power sector at a glance (June 2015) [5]

Generation Capacity	: 11,534 MW* (June, 2015)
Highest Generation	: 8,177 MW (13 August, 2015)
Total Consumers	: 17.5 Million (June, 2015)
Transmission Line	: 9,695 ckt. km
Distribution Line	: 3,26,000 km
Distribution Loss	: 11.36%
Per Capita Generation	: 371 KWh
Access to Electricity	: 74%

This document discusses electricity generation process, its potential in Bangladesh and mathematical model of the generating unit. Main objective of the study is to analysis control circuit performances.

2. RENEWABLE ENERGY

Renewable energy comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat, which are renewable (naturally replenished).

- Mainstream forms of renewable energy:
  - Wind power
  - Hydro power
  - Solar energy
  - Biomass
  - Biogas
  - Geothermal energy
- Importance of renewable energy:

- ❖ Environmental Benefits
- ❖ Energy for next generation
- ❖ Jobs and the Economy
- ❖ Energy Security

3. BIOGAS

Biogas is a flammable gas that accrues from the fermentation of biomass in biogas plants. Biogas can be produced utilizing anaerobic digesters. These plants can be fed with energy crops such as maize silage or biodegradable wastes including sewage sludge and food waste [6]. During the process, an air-tight tank transforms waste into methane that can be used for heating, electricity, and many other operations that use any variation of an internal combustion engine.

3.1 Biogas Composition

Table -3: Biogas Composition

Typical Composition of Biogas		
Compound	Chemical Properties	%
Methane	CH_4	50-75
Carbon dioxide	CO_2	25-50
Nitrogen	N_2	0-10
Hydrogen	H_2	0-1
Hydrogen sulphide	H_2S	0-3
Oxygen	O_2	0-0

Depending on temperature, there are two key processes [7]:

- ❖ Mesophilic digestion (between 20°C and 40°C).
- ❖ Thermophilic digestion(above 40°C)

3.2 Biological and Chemical Stages

The overall process can be described by the chemical reaction, where organic material such as glucose is biochemically digested into carbon dioxide (CO_2) and methane (CH_4) by the anaerobic microorganisms.

$$C_6H_{12}O_6 \rightarrow 3CO_2 + 3CH_4$$

Anaerobic decomposition of organic compounds is conducted in close cooperation of specialized bacteria of different types, including mostly hydrolyzing, digestive, acetogenic, homoacetogenic, sulfate-reducing (VI) and methanogenic bacteria.

There are four key biological and chemical stages of anaerobic digestion [7]:

- ❖ Hydrolysis
- ❖ Acidogenesis
- ❖ Acetogenesis
- ❖ Methanogenesis

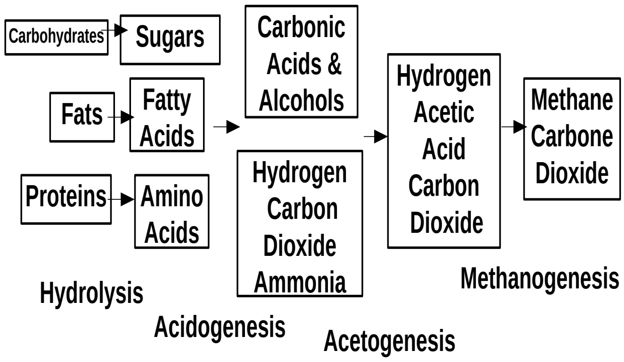

Fig-1: Biological and chemical stages of anaerobic digestion

3.3 Energy Content

Table -4: Energy Contents in Different Substrates [8]

Substrates	K Wh/Ton
Cow dung	140
Manure from pigs	180
Manure from poultry	450
Gras	810
Waste from fruits and vegetables	950
Household food waste	1.300
Food waste from restaurants	1.300
Waste from slaughterhouses	2.000
Pure carbohydrates/sugar	3.900
Proteins	4.900
Fat	8.500

3.4 Electricity Generation Process From Biogas

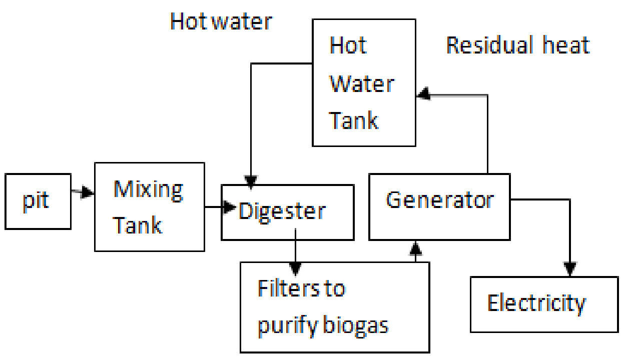

Fig.-2: Process diagram of electricity generation from biogas

- Pit is used to Store the biomass resouces.
- Mixing Tank is used to mix water and biomass resources. Different mixing percentages are needed for different substrates.
- Digester is the place where biochemical reactions are take place and as a result biogas is produced
- H_2S and moisture removal filters are used to cleap up produced gas.
- Generator produces electricity.Heat produced by the generator can be used at the hot water tank that is connected to the digester to maintain required temperature.

3.5 Types of biogas plants

- ❖ Floating cover digester
- ❖ Fixed cover digester
- ❖ The Balloon or Plastic Cover digester:
- ❖ Fiber glass biogas plant

4. Biogas potential in Bangladesh

Biogas mainly from animal and MSW may be one of the promising renewable energy resources for Bangladesh. MSW contains an easily biodegradable organic fraction (OF) of up to 40%. It is a potential source to harness basic biogas technology for cooking, rural and urban electrification to provide electricity during periods of power shortfalls[9].

Table-5: Estimation of total biogas potential in Bangladesh [9]

Cattle Dung 1) Total cattle population of Bangladesh = 23 million 2) Dung available = 230 million Kg/day 3) Gas that may be obtained = 3106 million m3(Mm3)/year 4) (1 kg of dung yields = 0.037 m3 gas, each cow yields = 10 Kg dung/day)
Poultry Litter 1) Total poultry population (Chickens+ Ducks) of Bangladesh, (234+44) =278 million 2) Total poultry litter that may be obtained = 27.8 million Kg/day 3) Gas that may be obtained = 750 Mm3/year 4) (1 kg litter yields = 0.074 m3 gas, each bird yields = 0.1 Kg litter/day)
Human Excreta 1) Total human population of Bangladesh = 140 million 2) Excreta available = 56 million Kg/day 3) Gas that may be obtained = 1512 Mm3/year 4) (1 kg excreta yields = 0.074 m3 gas, Excreta per person = 0.4 Kg per day)
Therefore total biogas potential in the country = 53Mm3/year.

Effectively using this waste, per day approximately 20.5 MWh electricity could be generated, which may play a significant role in country's energy situation.

5. MATHEMATICAL MODEL

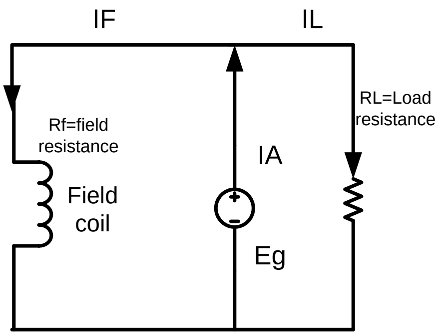

Fig-3: Mathematical model of biogas electrification technology

- Eg=generated emf (emf induced in any parallel path in armature)
- IA=Armature current
- IF=Field current
- IL=Load current
  IA=IL+IF;
- VL=Load Voltage
- VF=field terminal voltage
  Eg=VL+IA*RA;
- Ø = flux/pole in Wb (weber)
- Z = total no. of armature conductors
- P = no. of generator poles
- A = no. of parallel paths in armature
  =p (for simplex lap wound)
  =2 (for simplex wave wound)
- N = rotational speed of armature in revolutions per min. (rpm)

Generated emf, $$E_g = \frac{P \O N Z}{60 \ A}$$

$$\frac{Eg1}{Eg2} = \frac{N1}{N2} \text{ X } \frac{I2}{I1}$$

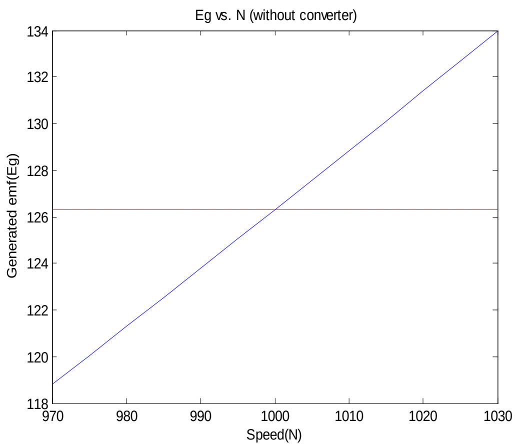

Fig-4: E_g vs. N curve

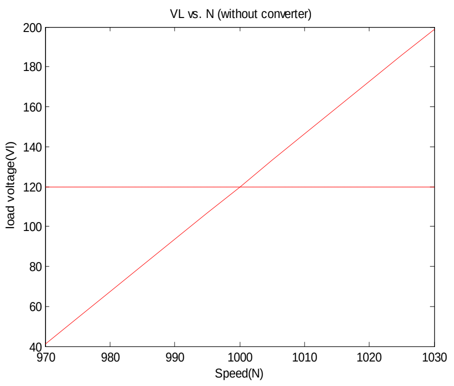

Fig-5: V_L vs. N curve

6. CONTROL CIRCUIT ANALYSIS

The normal speed of an electric power generator is maintained by a control system that balances the demand on the generator and the steam supplied to the generator, in reference to the power system frequency.

In the event when the load voltage fluctuated from the desired value, the control system is designed to recover the load voltage simultaneously to get the desired controlled output from the generator.

6.1 Buck Converter

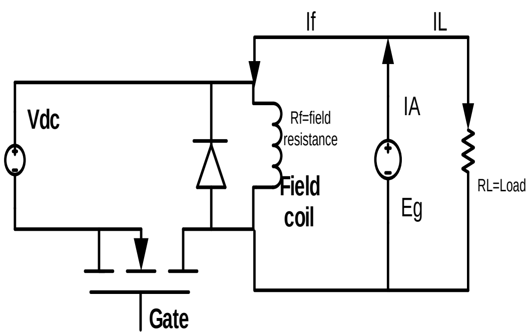

Fig-6: Generator along with buck converter

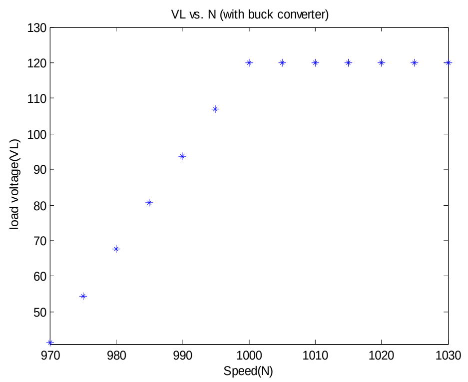

Fig-7: V_L vs. N Curve (Buck)

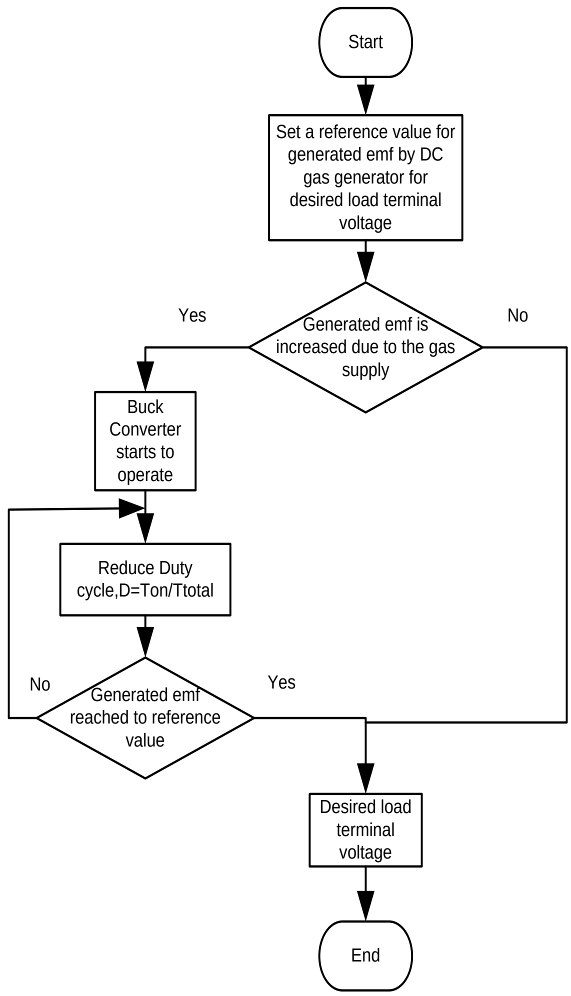

Fig-8: Algorithm for Buck controlled circuit

If the load voltage is increased from desired value, this control circuit will reduced it by changing duty cycle to protect load from over voltages.

Duty cycle=$\frac{V_{output}}{V_{input}}$

6.2 Buck-Boost Converter

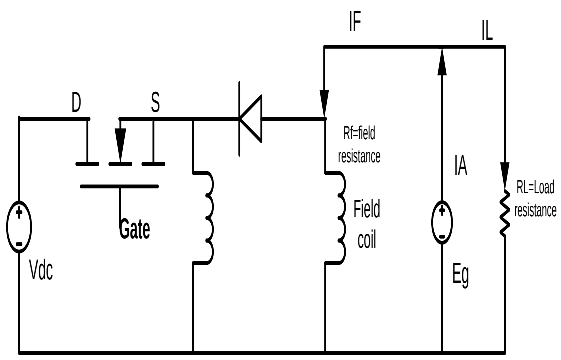

Fig-9: Generator along with Buck-Boost converter

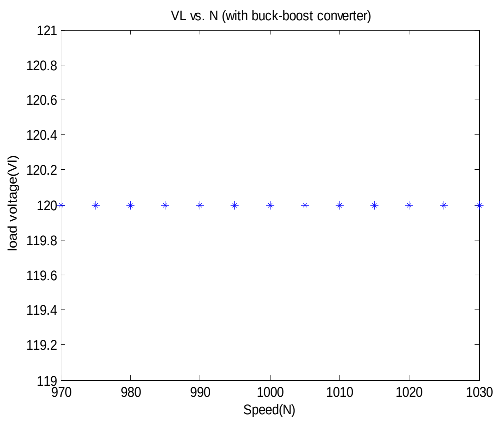

Fig-10: V_L vs. N Curve (Buck-Boost)

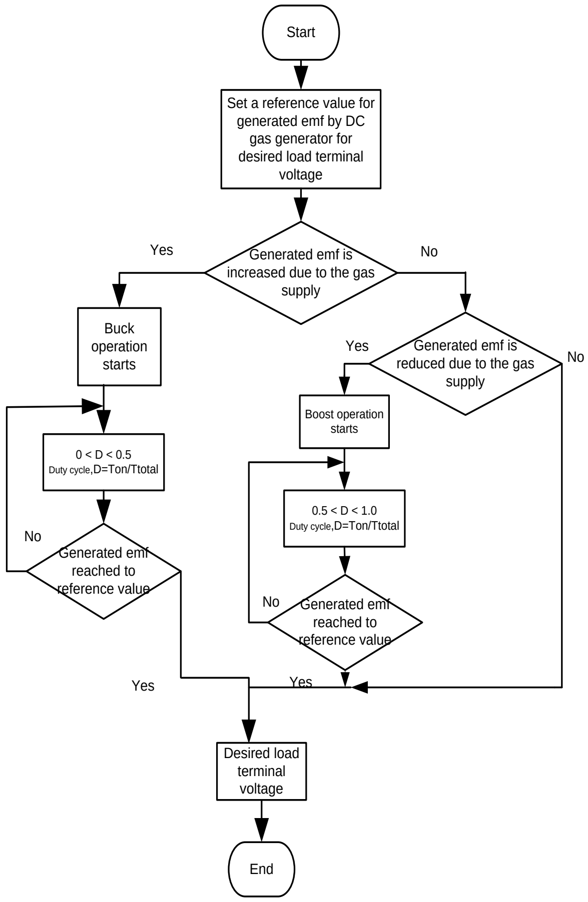

Fig-11: Algorithm for Buck-Boost controlled circuit

If the load voltage is increased or decreased from desired value, this control circuit will simultaneously reduced it or increased it by changing duty cycle to protect load from voltage fluctuations.

$$\text{Duty cycle} = \frac{V_{output}}{V_{output}+V_{input}}$$

6.3 Duty cycle

A duty cycle is the percentage of one period in which a signal is active. A period is the time it takes for a signal to complete an on-and-off cycle.

$$D = \frac{\text{on time of the signal}}{\text{Total time period of the signal}} \times 100\%$$

6.4 Overview of the whole system

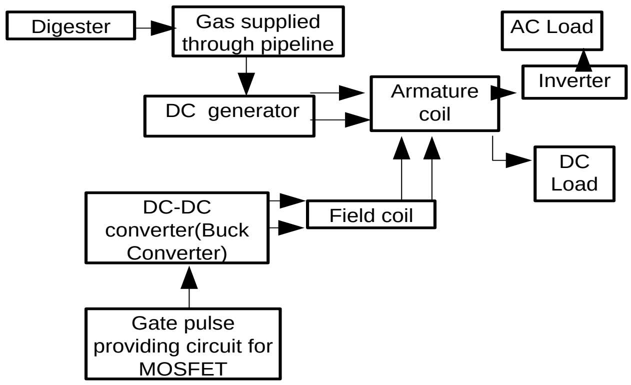

Fig-12: Overview of the whole System

7. OBSERVATION:

Table-6: Output of mathematical model and control circuits.

Without converter			Simulation is done considering 120 volt is the desired level of terminal voltage of the generator	
Speed of the prime mover(N) r.p.m	Generated emf (E_g)	Terminal voltage (V_L)	Terminal voltage (V_L) With Buck converter	Terminal voltage (V_L) With Buck-Boost converter
970	118.8244	41.4000	41.4	120
975	120.0525	54.5000	54.5	120
980	121.2870	67.6000	67	120
985	122.5278	80.7000	80	120
990	123.7749	93.8000	93	120
995	125.0283	106.9000	106	120
1000	126.2880	120.0000	120	120
1005	127.5540	133.1000	120	120
1010	128.8264	146.2000	120	120
1015	130.1051	159.3000	120	120
1020	131.3900	172.4000	120	120
1025	132.6813	185.5000	120	120
1030	133.9789	198.6000	120	120

8. CONCLUTION:

Introducing biogas electrification technology could be beneficiary in many ways:

- Small and medium plants can meet up their own power requirement in rural areas.
- Large farms can supply electricity to the national grid to reduce the electricity based problems.
- Reduce the environment pollution regarding conventional fuel based electricity generation technology
- Reduce pressure on natural gas for electricity generation
- Microcontroller based control panel can be introduced for better performing power generation system
- Cuk DC-DC converter can be used for better control over terminal voltage.

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BIOGRAPHIES

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