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(Power Engineering Stream)

Hydro/Biogas Based Distributed Generation for *Katikala* Distillation in Ethiopia, Case study at Arsi Negele

A Thesis Submitted to the School of Graduate studies of Addis Ababa Institute of Technology in Partial Fulfillment of the Requirement for the Degree of Master of Science in Electrical Engineering (Electrical Power Engineering)

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DECLARATION

I, the undersigned, declare that the thesis entitled "Hydro/Biogas Based Distributed Generation for *Katikala* Distillation in Ethiopia, Case Study at Arsi Negele" is my original work and has not previously been submitted for a degree in this or any other university, and all sources of materials contained therein have been duly acknowledged.

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This thesis has been submitted for examination with my approval as a university advisor.

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Signature

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TABLE OF CONTENT

List of Tables

List of Figures

NOMENCLATURE

ABV	Alcohol by Volume (%)
AGC	Automatic Generation Control
ALC	Automatic Load Control
ANCEDA	Arsi Natural conservation and Environmental Development Association
BP	Boiling Point of Water -Ethanol Mixture (°C)
CD	Cattle Dung
COE	Cost of Energy($/Kw)
CDM	A Customer-Driven Micro-Grid
CHP	Combined Heat And Power
DE	Distributed Energy
DG	Distributed Generation
ELCs	Electronic Load Controllers
H	Efficiency of The Plant
FACTS	Flexible AC Transmission System
GPS	Geographical Positioning System
HOMER	Hybrid Optimization Model for Energy Renewable
HHs	House Holds
IG	Induction Generators
ICE	Internal Combustion Engines
NPC	Net Present Cost ($)
NREL	National Renewable Energy Laboratory
MSW	Municipal Solid Waste
MRI	Midwest Research Institute
RF	Renewable Fraction
RPM	Revolution Per Minute
RES	Renewable Energy Source
SM	Synchronous Machine
STS	Static Transfer Switch,
VAR	Volt–Ampere Reactive

ABSTRACT

This thesis presents the design of a hydro/biogas based electric supply system as distributed generation (DG) applied for katikala distillation in significant parts of Ethiopia, case study at Arsi Negele. It also presents a design of improved technology of katikala distillation still. The work began by investigating hydro and biogas energy potentials of the site, capacity, demand and the total number of electric customers; and then compiling data from different sources and analyzing it using HOMER software. The Software simulation result showed, the most cost effective system was the hydro-grid–biogas generator set-up. For this set-up, the total net present cost (NPC) is $67019448 , the cost of energy (COE) is 0.031 $/kWh, contribution from biogas resources is 64 % and capacity shortage in kWh is 161,7020 or 0.00% .Control schemes simulation system for the proposed distributed generation system has been developed in MATLAB/Simulink. This system consists of a plant simulated by a resistive load fed at 380 V through 15KV/380V transformer from a distribution 15 kV network. The designed power of hydro, biogas and grid was 2.835 MW, 7.5 MW, and 8 MW respectively. Steady state simulation shows how the generators coordinate each other due to control scheme. When the load demand is less than 10.835 MW (grid and hydropower) , there is no active power generated by SM. When fault occurred at grid side the micro grid is disconnected from the main grid and run in island mode and biogas generator power output is the result of the difference power between load demand and hydro generator output. The design of new distillation still started by first studying theoretical back ground about *katikala* and then the proposed pot still was designed and made with available items. The distillation using new still proceeded using 12 litter fermented wash. From the test result it is noticed that the boiling temperature is stabilized first at 89 ^{o}C, which shows that the alcohol content of the wash is around 12 alcohols by volume (ABV), and then the temperature was slowly increased as the alcohol content in the wash decreases. The cooling water temperature was around 40 ^{o}C and as the cooling water temperature rises the output distillate slows down. At a temperature of 89 ^{o} C the purity of alcohol collected was 46 ABV and at 92 ^{o} C it was 43 % ABV which was equal to the best *katikala* known as *'Arefa Areke'* meaning which forms foam when shacked.

Keywords: *Distributed Generation, Distributed Resource, Micro-Grid, Small-Hydro, Biogas, Matlab/Simulink, HOMER, Grid-Connected system, Off-Grid System, katikala distillation still.*

CHAPTER ONE

1. INTRODUCTION

1.1. Background

Due to ever increasing energy utilization, rising public attention of environmental protection, and steady progress in power deregulation, alternative (renewable) resource based distributed generation (DG) systems have involved the increased consideration. Distributed generation normally ranging from 1 kW to 10 MW, they can provide both electricity and in some cases heat. It means small power generation unit based on the renewable energy, Micro turbines, and sometimes Internal Combustion (IC) engines, which is arranged near the load [1]. DG systems have a wide variety of potential benefits for both consumers and the electrical suppliers. That allows both suppliers and consumers electrical flexibility and energy security [2]. Reduced price, greater reliability, and enhanced power quality are some of benefits for customers [2].

In addition, there are many potential benefits for the energy supplier, such as released line capacity, reduced transmission and distribution overcrowding, grid investment deferment and improved grid asset utilization, and the ability of the distributed energy (DE) system to provide subsidiary services, such as voltage support and stability, volt–ampere reactive (VAR) support, and emergency reserve [2].

DG is also becoming more attractive approach since it reduces greenhouse gas emissions, improve power system efficiency and reliability and relieve today's stress on power transmission and distribution infrastructure [3]. The micro-source based DG also presents a challenge in terms of interaction to the grid, where the power electronic technology plays a vital role. The development of DG has led to a more recent concept called micro-grid, which is a systematic organization of DG systems. Compared to a single DG, a micro grid has extra capacity and control flexibilities to achieve system reliability and power quality requirements. The micro grid also offers opportunities for optimizing DG systems [3].

1.2. *Katikala* Distillation in Ethiopia

In many countries there are alcoholic beverages which are traditionally produced at the local level. This kind of production seems especially common in many African countries, where a wide variety of different beverages can be found. Many of these are produced by fermentation of seeds, grains, fruit, and vegetables or from palm trees which is a somewhat simple procedure. In

Ethiopia, being one of African countries, different types of traditional alcoholic beverages such as *Tella*, *Korefe*, *Shamita*, *Katikala/Arake* and *Borde* are produced and consumed [4, 5].

Katikala /Arake/ is one of distilled beverage. The main raw material is teff or other cereals such as germinated barley or wheat which is used to prepare the *"kita" or* thin bread. Then the bread is added to ground gesho*/Rhamnus Prinodes/*leaves and water mixture which is kept for three to four days. The mixture is then allowed to ferment for five to six days and then distilled. In the villages distillation is carried out with inefficient equipment made of gourds and wood. The local beer tella can also be distilled to produce *arake*. The *arake* can be redistilled and will then have higher alcohol content. The average alcohol content of redistilled *arake* or *Dagim Araki* is around 45%.

Debre Sina, Debre Birhan, Arsi-Negele, Bahir Dar and Assela are the most known towns which produce and distribute large amount of *katikala.* In these towns, *Katikala* production has tremendous contribution to deforestation. It also has significant health risks on women since the process involves series of tedious steps. The distillation process used to produce *Katikala* is very old and energy consuming (Figure 1.1) [4, 5].

Figure 1.1: Traditional *Katikala* Production in Arsi Negele[by the author]

1.3. Profile of Selected site

Arsi Negele district is located in the Central Rift Valley of Ethiopia, Oromia Region, in West Arsi Zone, 225 Kilometers from Addis Ababa [6]. It is at (7°21′N 38°42′E), 2043 meters above sea level. Except for the southeastern portion, the altitude of this woreda ranges from 1500 to 2300 meters above sea level; *Gara Duro* (Duro Mountain which is 3095 m high) is the highest point. There are many rivers that flow in the area including *Gedamso*, *Lephis*, *Huluka*, *Awede Jitu*, *Awede Godu*, and *Dadaba Gudo*. The *Lephis* river stream, which flows from Gara Duro (3095 m) is about 25km distance from Arsi Negele town. 1190 mm annual rain fall was registered from 1996 E.c to 2005 E.c. Figure1.2 shows selected site location.

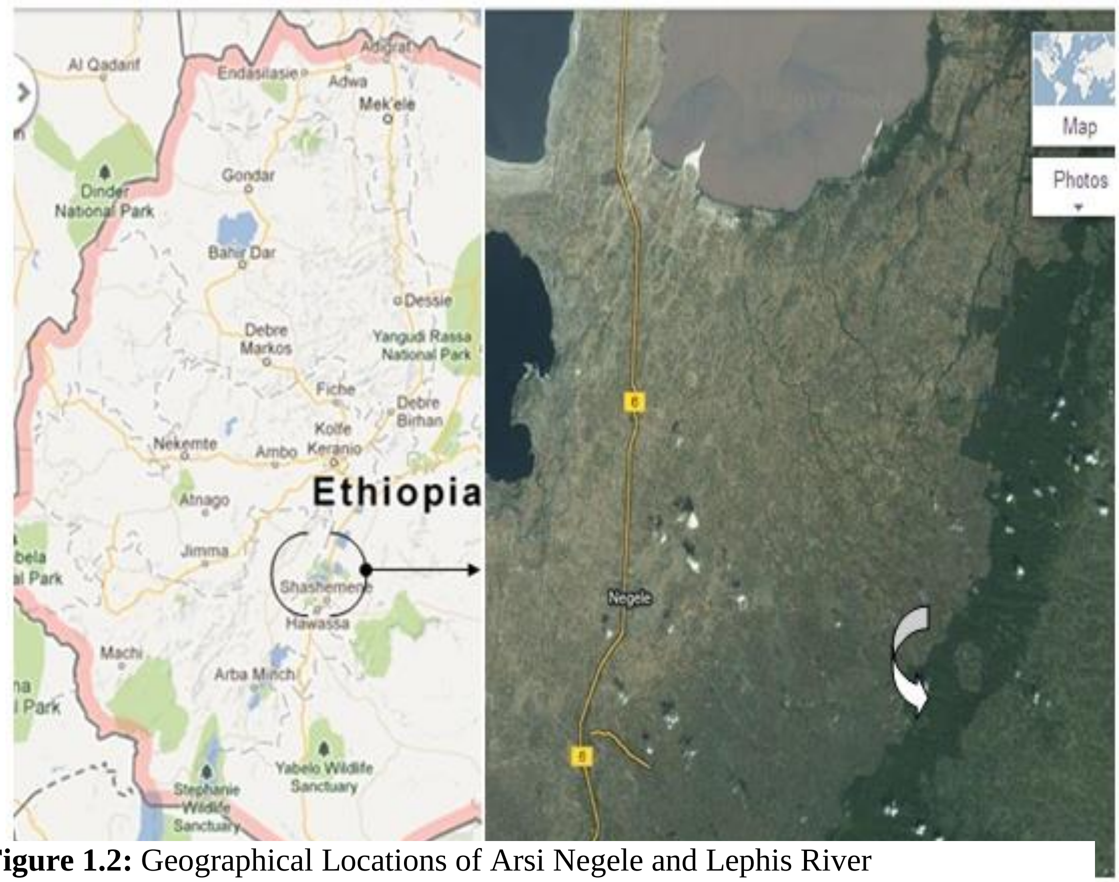


Figure 1.2: Geographical Locations of Arsi Negele and Lephis River

1.4. Statement of the Problem

Katikala production in coalition with others is a means of livelihood for most of the households in towns like Debre Sina, Debre Birhan, Arsi-Negele, Bahir Dar and Assela. Since it is highly connected to their day to day life, it is difficult to withdraw these households from this activity in a short period of time.

However, local k*atikala* production process has numerous adverse effects on environment and human health. One of the problems is indoor air pollution from burning wood, charcoal, and dung which endangers the health of the people. The production also intensifies deforestation and climatic change since it uses large amount of fire-wood as energy source. The producers use traditional material to distil the alcohol which is inefficient and time consuming. In view of the aforementioned cases, it becomes stringently necessary to look for different strategies that improve or maintain the existing benefits of *katikala* producers with the minimization of the prevailing problems. Some of these strategies could be introducing alternative energy source, introducing improved technology of *katikala* production, and separating the production place from the residence area and households.

1.5. Objective

1.5.1. General objective

The general objective of this thesis is to design hybrid small hydro/biogas based distributed generation for Arsi Negele town to replace the energy used from firewood for *katikala* production and other electric cooking appliances.

1.5.2. Specific Objectives

- To design small hydro power plant
- To design biogas power production plant
- To Integrate small hydro/biogas DG into min-grid
- To simulate the system after connecting the mini-grid to the utility main grid
- To design improved *Katikala* distillation device to replace the traditional pot and test the newly designed distillation device.

1.6. Outline of the Thesis

This thesis includes seven chapters. The introductory part discusses about the background of the study, site profile, and statement of the problem and general and specific objectives of thesis work. The second chapter covers about hydropower system and hydro resource of Arsi Negele. The third chapter discusses the basic theories of biogas system together with its potential. Chapter four, chapter five and chapter six discusses about Distributed Generation Systems and its application, Home Alcohol Distillation and Still Technology in Ethiopia, *katikala (Arake)*distillation still design respectively. The last chapter summarizes the main findings of the thesis work and recommendations.

CHAPTER TWO

2. HYDROPOWER SYSTEM AND HYDRO RESOURCE

2.1. Hydropower

Hydropower technology is a proven and mature technology. It is capable of providing electricity for 24 hours a day based on the availability of water. Hydropower systems are derived from the hydrological climate cycle, where water precipitated in high regions (mountains) develops high energy potential [7].

Power generation from water depends upon a combination of head and flow rate [8]. Both must be available to produce electricity. Water is diverted from a stream into a pipeline, where it is directed downhill and through the turbine (flow). The vertical drop (head) creates pressure at the bottom end of the pipeline. The pressurized water emerging from the end of the pipe creates the force that drives the turbine. The turbine in turn drives the generator where electrical power is produced. More flow or more head produces more electricity. Electrical power output will always be slightly less than water power input due to turbine and system inefficiencies.

Water pressure or head is created by the difference in elevation between the water intake and the turbine. Head can be expressed as vertical distance in meters, or as pressure, such as force per square meter (N/m^2 or Pa). Net head is the pressure available at the turbine when water is flowing, which will always be less than the pressure when the water flow is turned off (static head), due to the friction between the water and the pipe. Pipeline diameter also has an effect on net head.

Flow is quantity of water available, and is expressed as 'volume per unit of time', such as cubic meters per second (m^3/s). Design flow is the maximum flow for which the hydro system is designed. It will likely be less than the maximum flow of the stream (especially during the rainy season), more than the minimum flow, and a compromise between potential electrical output and system cost [8].

2.2. Schemes of Hydropower Plants

2.2.1. Conventional

Most hydropower plants are conventional in design; they use one-way water flow to generate electricity. There are two categories of conventional plants: run-of-river and storage plants [8].

a) Run-of-river plants - These plants use little, if any, stored water to provide water flow through the turbines. Although some plants store a day or weeks' value of water, weather changes, especially seasonal changes cause run-of-river plants to experience significant fluctuations in power output.

b) Storage plants - These plants have enough storage capacity to counterbalance seasonal fluctuations in water flow and provide a constant supply of electricity throughout the year. Large dams can store several years' worth of water.

2.2.2. Pumped Storage Hydropower System

The pumped storage is a system of generating electricity, also known as hydroelectric storage, which uses water that has been pumped into an elevated reservoir during the hours of low consumption to generate electricity during hours of peak demand [8]. This type of hydroelectric system is used by some power plants for load balancing. The method stores energy in the form of water (potential mechanical energy) from a lower elevation reservoir to a higher elevation. In a conventional electrical system, the low-cost off-peak electrical power is used to run the pumps and the stored water is released during periods of high electrical demand, generally with a cost benefit. In a "Renewable energy system", at time of low electrical demand, excess generation power produced by the renewable energy system (wind turbine and/or photovoltaic system) is used to pump water into a higher reservoir and then, when there is a higher demand, the water is released back in the lower reservoir through a turbine, generating electricity.

2.3. Hydro Power Classification

Hydro power projects are generally categorized in two segments i.e. small and large hydro. Different countries are following different norms keeping the upper limit of small hydro ranging from 5 to 50 MW [8]. The world over, however, there is no consensus on the definition of small hydropower. Some countries like Portugal, Spain, Ireland, Greece and Belgium, accept 10 MW as the upper limit for installed capacity. In Italy the limit is fixed at 3 MW (plants with larger installed power should sell their electricity at lower prices) and in Sweden 1.5 MW. In France the limit has been established at 12 MW, not as an explicit limit of MHP, but as the maximum value of installed power for which the grid has the obligation to buy electricity from renewable energy sources. In the UK, 20MW is generally accepted as the threshold for small hydro. Though different countries have different criteria to classify hydro power plants, a general classification of hydro power plants is shown in Table 2.1.

Table 2.1: Classification of hydropower [9]

Type	Capacity
Large-hydro	More than 100 MW and usually feeding into a large electricity grid
Medium-hydro	15-100 MW -usually feeding a grid
Small-hydro	1-15 MW-usually feeding into a grid
Mini-hydro	Above 100 kW, but below 1MW, either standalone schemes or more often feeding into the grid
Micro-hydro	From 5kW up to 100 kW, usually provided power for a small community or rural industry in remote areas away from the grid
Pico-hydro	From a few hundred watts up to 5 kW

Small hydro plants are also classified according to the “Head” or the vertical distance through which the water is made to force the turbines. Common classifications are given in Table 2.2.

Table 2.2: Hydropower classification depending on head [9]

Type	Head range
High head	100 m and above
Medium head	30 - 100 m
Low head	2 - 30 m

These ranges are not rigid but are merely means of categorizing sites. Most of the small hydro power plants are “run-of-river” schemes, implying that they do not have any water storage capability. The power is generated only when enough water is available from the river/stream.

When the stream/river flow reduces below the design flow value, the generation ceases as the water does not flow through the intake structure into the turbines. Small hydro plants may be standalone systems in isolated areas/sites, but could also be grid connected (either local grids or regional/national grids). The connection to the grid has the advantage of easier control of the electrical system frequency of the electricity, but has the disadvantage of being tripped off the system due to problems outside of the plant operator's control.

2.4. Components of the Small Hydro Power System

The components for a SHP system can be grouped in to civil work and electromechanical components. These components are presented in the following subsections [7].

2.4.1. Civil Works Components

i. **Weir and intake:** In the run-of-the river schemes, on which most of small and micro hydropower systems are based, a low diversion structure is built on the streambed prior to the intake to divert/channel the required amount of flow to the intake for power generation whilst the rest of the excess water continues to overflow it. This structure, commonly known by the name weir, is not constructed to store water, rather to increase the level of water so that the water can inter to the intake structure in a reliable and controllable way. Weirs can be constructed permanently or temporarily using traditional water management techniques. If the terrain in the vicinity of the site is relatively flat, to get the required head for power generation, the water may be conveyed by using pressure pipes or penstocks from a long distance. But this may be costly and constructing weirs to get the required head may be an economical option. The intake of a hydro scheme is a structure designed to permit and control the required amount of water flow to a water way without producing a negative impact on the local environmental and with minimum head loss [7].

ii. **Canals and Channels:** These are components of a hydropower scheme used to convey water a relatively larger distance from the stream to the inlet of the penstock, with minimum of loss of head and at minimum cost [7].

iii. **Settling Basin:** Depending on soil type and geographical feature of the area flowing river can usually carry a suspension of small particles. If these particles are not removed before they enter to the penstock pipe, they will cause damage and rapid wear to turbine runners. To remove these materials, the water flow must be slowed down in a settling basin so that the silt particles will settle on the basin floor. The deposit formed is then periodically flushed away. If they are situated at the inlet of the intake pipe, settling basins are used to prevent any sediment from the incoming water from settling in the intake or power conduit. The absence of settling basins in sites where they must be constructed will allow a large accumulation of sediments there by reducing the flow available for power generation overflowing the intake or canal thereby requiring a huge effort to clean [7].

iv. **Forebay Tank:** The fore bay is a basin located just before the entrance to the penstock and which forms the connection between the channel and the penstock. This structure can serve as a final settling basin to allow the last particles, water borne debris which either passed through the intake or were added in the canal, to settle down before entering to the penstock and to the turbine. To remove the settled particles, gates/valves are incorporated to drain the forebay [7].Depending on its size it can also serve as a reservoir to store water to cope with water demand created by a sudden increase in loading on the turbine.

v. **Penstock:** The penstock is the pipe between the fore bay and the turbine and which conveys water under pressure to the turbine and, depending on factors such as the nature of the ground itself, the penstock material, the ambient temperatures and the environmental requirements; they can be installed over or under the ground. The penstock often constitutes a major expense in the total small hydro budget, as much as 40% is not uncommon in high head installations, and it is therefore worthwhile optimizing the design. The trade-off is between head loss and capital cost. When the pipe diameter increases, the friction head lose in the pipe decreases dramatically. Conversely, pipe costs increase steeply with diameter. Therefore while designing the penstock a compromise between cost and performance must be taken in to consideration.

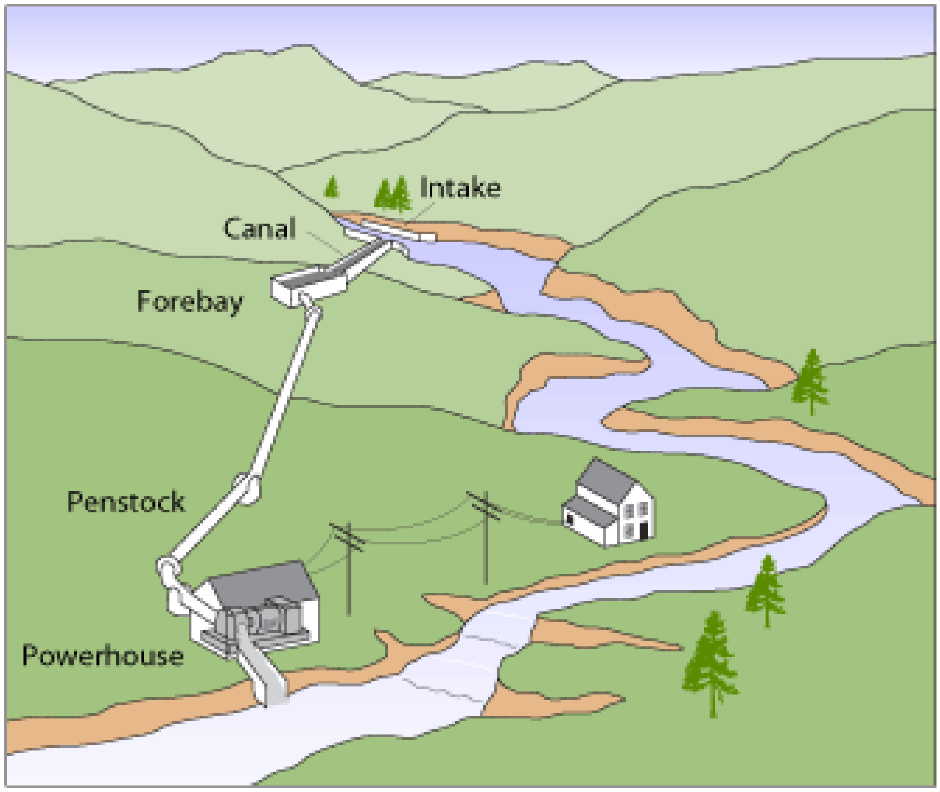


Figure 2.1: Components of Small Hydropower System [10]

2.4.2. Electro-Mechanical Components

The principal electro mechanical components of a small hydro plant are the turbine and generator [7].

i. **Turbines:** A hydro turbine is a rotating machine that converts the potential energy of the water to mechanical energy. Hydro turbines can be of impulse or reaction types, the difference being the manner of head/energy conversion [7].In "impulse turbine" the potential energy of water is converted in to kinetic energy in the nozzle before reaching the turbine. The high velocity flowing jets from the nozzle strikes the buckets of the turbine there by transferring the kinetic energy of water in the jet to mechanical/rotational energy of the turbine using the principle of "Newton's Second Law". Turbines that fall under this category are Pelton, Turgo and cross flow turbines [7]. The "reaction turbine" develops power from the combined action of pressure energy and kinetic energy of the water. The runner is completely submerged in the fluid and has nozzles that discharge the working fluid attached to the rotor of the turbine. Using the principle of "Newton's Third Law", the acceleration of the fluids leaving the nozzle produces a reaction force on the pipes, causing the rotor to move in the opposite direction to that of the fluid. Turbines that fall under this category are Kaplan, Propeller, and Francis turbines [7].In both of these turbine types, the rotary action of the water turbine drives an electrical generator that produces electrical energy or could drive other rotating machinery to use the mechanical energy directly.

ii. **Generators:** Electrical generators are electrical equipments that produce either alternating current or direct current. The basic principle in physics that makes a generator produce electricity is that when a conductor is moved across a magnetic field, a voltage pressure is developed that forces electrons to move from atom to atom[7] , i.e. either or both the magnetic field and the conductor should move so that a net effect of relative motion between the two should be present for electricity to be generated. AC generators produce electricity which is varying sinusoidal from positive peak to negative peak with constant amplitude and period while DC generators produce electricity whose current flow is in single direction and with non-varying amplitude. There are two types of AC generators suitable for use in a micro hydro electricity supply scheme. These are synchronous generators (alternator) and induction generators.

2.4.3. The Control System

Like large hydropower systems, due to continuous variation in load demand and the presence of deferent types of loads with different characteristics, the voltage and frequency of small hydropower systems may not be constant [7]. Therefore, the voltages and frequency of small hydropower systems should be kept at scheduled values. To keep these parameters at the scheduled values, the small hydropower systems should be controlled.

In a power system, usually, voltage and frequency are controlled separately. Voltage is maintained by control of reactive power of the synchronous generator with the voltage regulator built-in in most of these synchronous generators while frequency is maintained by balancing generation and demand, i.e. by balancing generation and demand of active power. The balance between generation and demand is achieved in two different ways: by controlling either the mechanical input power or the load connected to the synchronous generator. The following are deferent types of active power control systems [8].

i. **Automatic Generation Control:** Automatic generation control is achieved through different types of speed governors. The most common ones are mechanical-hydraulic, electro-hydraulic, mechanical and servo motor governors.

ii. **Automatic Load Control:** Generally, electrical loads change randomly as a result of which frequency of the system is changed randomly. It is possible to compensate the change in the electrical load, consequently the change in frequency, using ballast loads.

iii. **Flow Control:** Traditionally, flow control mechanisms similar to that of larger hydropower systems have been used to control the frequency of micro and mini hydropower systems. Nevertheless, over the last two decades, because of their complexity, slow response and costs, hydraulic or mechanical speed governors have been replaced by electronic load controllers (ELCs).

2.5. Power from Small Hydropower

To know the power potential of water in a stream it is necessary to know the flow quantity of water available from the stream (for power generation) and the available head [9].

The quantity of water available for power generation is the amount of water (in m^3 or litters) which can be diverted through an intake into the pipeline (penstock) in a certain amount of time. This is normally expressed in cubic meters per second (m^3/s) or in litters per second (l/s).Head is the vertical difference in level (in meters) through which the water falls down. The theoretical power (P) available from a given head of water is in exact proportion to the head and the quantity of water available.

$P = Q \times H \times \eta \times 9.81$ Kilowatts (kW)………………………………………………… (2.1)

Where,

P = Power at the generator terminal, in kilowatts (kW)

H = Gross head from the pipeline intake to the tail water in meters (m)

Q = Flow in pipeline, in cubic meters per second (m3/s)

η = Efficiency of the plant, considering head loss in the pipeline and the efficiency of the turbine and generator, expressed by a decimal (e.g. 85% efficiency= 0.85)

9.81=Constant and is the product of the density of water and the acceleration due to gravity (g)

This available power will be converted by the hydro turbine in mechanical power.

The losses in a hydro plant are due to the following:

i. Losses in energy caused by flow disturbances at the intake to the pipeline, friction in the pipeline, and further flow disturbances at valves and bends

ii. Loss of power caused by friction and design inefficiencies in the turbine and generator.

The energy losses in the pipeline and at valves and bends are called head losses: they represent the difference between the gross head and the net head that is available at the turbine. The head losses in the pipeline could range from 2 percent to 10 percent of the gross head, depending on the length of the pipeline and the velocity of the flow. The maximum turbine efficiency could range from 80 percent to 95 percent depending on the type of turbine, and the generator efficiency can be about 90 percent.

Usually for design purposes, the head losses can be combined with the losses in the turbine and generator, and an overall plant efficiency of 85 percent (or $\eta = 0.85$) can be used.

The type and size of a turbine for a hydropower system is different for one project than the other depending on many factors. Therefore using these factors as criteria, the type and size of turbine for a particular hydropower system can be determined [7].

The selection of type, geometry and dimensions of the turbine for a particular hydro site depends on the site characteristics; the dominant factors being the head available and the power required. Selection also depends on the speed at which it is desired to run the generator or other devices loading the generator. Some turbines like the cross-flow and the Kaplan work efficiently with a large range of flow variation while others like the propeller turbines work only for a narrow range of flow variation with their efficiency falling rapidly with a little variation in flow. Therefore this criterion may help for selection of the turbine type to be used especially in standalone SHP systems. The selection of type of turbine according to head flow and power for a hydropower site is assisted by Table 2.3 and selection criteria depending on specific speed is shown in Table 2.4.

Table 2.3: Classification of hydro turbines according to head flow and power [7]

Classification	Turbine Name	Head(M)	Flow (M^3/S)	Power Output (KW)
Impulse	Pelton	50-1000	0.2-3	50-15000
	Turgo	30-200	0.2-5	20-5000
	Cross-Flow	5-50	0.01-2	0.1-600
Reaction	Kaplan and Propeller	3-40	3-20	50-500
	Francis Radial Flow	40-200	1-20	500-15000
	Francis Mixed Flow	10-40	0.7-10	100-5000

Table 2.4: Selection of turbine based on specific speed [7]

Type Of Runner	Specific Speed(rpm)
Pelton	12-30
Turgo	20-70
Cross-Flow	20-80
Kaplan And Propeller	340-1000
Francis	80-400

2.6. Hydropower Potential in Ethiopia

Because of the many rivers flow in the country, Ethiopia is often described as the water tower of Eastern Africa. It was estimated that the country has a hydropower potential of 45,000 MW (installable potential) [11]**.** In the past years, the Ethiopian Electric Power Corporation was concentrating on large hydro systems and they are meant to feed the national grid. Still it is going on power production with these systems having almost no room for small, mini and micro scale hydropower systems, which is more suited to rural electrification. Of the above exploitable potential in the country, about 1500 MW to 3000 MW would be suitable for small scale power generation including Pico and Micro hydropower. Of this, about 1000 projects of micro hydropower with a typical capacity of 100 kW are revealed. At present, there are only about ten small-scale hydroelectric plants (0.25-1 MW capacity) in the entire country. Table 2.5 shows the regional distribution of micro hydropower potential of Ethiopia [7].

Table 2.5: Regional Estimation of Micro Hydropower Potential [7].

Region	Approximate Small Hydropower Potential
Oromia	35MW
Amhara	33MW
Benishangul-Gumuz	12MW
Gambella	2MW
SNNP	18MW

2.7. Small Hydro Power Potential in Arsi Negele

There are many Rivers flow in Arsi-Negele woreda. These include the *Gedamso, Lephis, Huluka, Awede Jitu, Awede Godu, and Dadaba Gudo*. The *Lephis* river stream, which flows from *Gara Duro* (*Duro* Mountain which is 3095 meter high) is about 15km distance from Arsi Negele town .Though there are many rivers in the area, the *Lephis* River is relatively close to the town and has high head. Based on the data obtained from site observation and the Ministry of Water and Energy, the flow rate of the river during dry season can be considered as $0.5m^3/s$ and it is greater than 2 m^3/s during rainy season. Based on the data measured using GPS during field survey, the head of 340 meter height can be obtained, since the GPS reading at the top of river stream is 2500 meter and at the bottom of the mountain is 2160.These values are used as input to HOMER simulator and the result is shown in Figure 4.4.

CHAPTER THREE

3. BIOGAS ENERGY SYSTEM AND BIOGAS RESOURCE

3.1. Biogas

Biogas typically refers to a gas produced by breakdown of organic matter in the absence of oxygen. Organic waste such as dead plant and animal material, animal feces, and kitchen waste can be converted into a gaseous fuel called biogas. Biogas originates from biogenic material and is a type of bio-fuel [12].Biogas is produced by the anaerobic digestion or fermentation of biodegradable materials such as biomass, manure, sewage, municipal waste, green waste, plant material, and crops. Biogas comprises primarily of methane (CH_4) and carbon dioxide (CO_2) and may have small amounts of hydrogen sulphide (H_2S), moisture and siloxanes [12].

The gases methane, hydrogen, and carbon monoxide (CO) can be combusted or oxidized with oxygen. This energy release allows biogas to be used as a fuel. Biogas can be used as a fuel in any country for any heating purpose, such as cooking. It can also be used in anaerobic digesters where it is typically used in a gas engine to convert the energy in the gas into electricity and heat. Biogas can be compressed, much like natural gas, and used to power motor vehicles. In the UK, for example, biogas is estimated to have the potential to replace around 17% of vehicle fuel. Biogas is a renewable fuel so it qualifies for renewable energy subsidies in some parts of the world. Biogas can also be cleaned and upgraded to natural gas standards when it becomes bio methane.

On a worldwide basis, the biogas process will still have its significance as a robust and easily to establish low-cost technology for the treatment of organic waster [13];Especially in developing countries like Africa. Municipal Solid Waste (MSW) contains a relatively large amount of organic matter, which decomposes by the actions of microorganisms under anaerobic conditions to produce biogas [13].

3.2. Composition of Biogas

The composition of biogas varies depending upon the origin of the anaerobic digestion process. Landfill gas typically has methane concentrations around 50%. Advanced waste treatment technologies can produce biogas with 55–75% methane, which for reactors with free liquids can be increased to 80-90% methane using in-situ gas purification techniques. As-produced, biogas also contains water vapor. The fractional volume of water vapor is a function of biogas temperature; correction of measured gas volume for both water vapor content and thermal expansion is easily done via a simple mathematics which yields the standardized volume of dry biogas [13].

Table 3.1: Composition of biogas [13]

S.n	Component	Concentration(By Volume)
1	Methane (CH_4)	55-65%
2	Carbon dioxide (CO_2)	35-40%
3	Water (H_2O)	2-7%
4	Hydrogen Sulphide (H_2S)	20-20,000ppm (2%)
5	Ammonia (NH_3)	0-0.05%
6	Nitrogen (N)	0.20%
7	Oxygen(O_2)	0.20%
8	Hydrogen (H)	0.10%

3.3. Biomass Combustion

Biomass resources come from plants or animal substances such as trees, waste products and animal by-products. Solar energy is stored as chemical form in biomass. Water from the earth combines with carbon dioxide from the atmosphere in the photosynthesis process that is driven by solar energy will produce carbohydrates (sugars) that form the building blocks of biomass. When biomass is combusted efficiently, stored energy that is formed in the chemical bonds of the structural components of biomass is released. Oxygen from the atmosphere combines with the carbon in the biomass to produce carbon dioxide and water. This cycling process shows that biomass is a renewable resource and carbon neutral when biomass is produced in sustainable way [14].

Biomass can be combusted to provide heat then subsequently converted into other forms of energy as well as electricity. Combustion is the most mature conversion technology utilized for biomass. However the efficiency of combustion is relatively low and mostly used for large-scale application.

3.4. Biomass Conversion Technologies

There are two types of conversion technologies for biomass utilization; Thermo chemical conversion and biochemical conversion [14].

3.4.1. Thermo Chemical Conversion

- **Gasification:** is a conversion process that partial oxidation of solid biomass particles into a producer gas which consists of CO, H2, CH4, and CO2 occurred [14].
- **Pyrolisis:** the conversion of solid or liquid biomass into a mixture of liquid, gaseous, and solid intermediate fuels in the absence of air [14].
- **Liquefaction:** whereas gasification and pyrolisis mainly produce the intermediate fuel with endothermic chemical reactions and require a certain temperature level, liquefaction tries to cleave the large biomass feedstock macromolecules by applying high pressure and only low levels of heat [14].

3.4.2. Biochemical Conversion

- **Anaerobic digestion:** the bacteria-driven conversion of biomass to biogas in the absence of oxygen results in the depletion of the biomass' oxygen content for the metabolisms .To achieve this, biomass is filled into a reactor and kept at the respective temperature level needed by the bacteria present [14].
- **Fermentation:** the processes that convert biomass into Ethanol and consist of two consecutive steps: first, biomass starch is converted to sugars using enzymes, afterwards the sugars are fermented to ethanol using yeast. The solid residues of fermentation, which still contain considerable amounts of biomass, can then be used for combustion or gasification [14].

3.5. Electric Power Generation Technologies Used In Biomass

There are two types of generation technologies using biomass:

3.5.1. Heat-Driven Generation

1. Stirling engines: are designed to use a cycle of heating and cooling a working gas; the gas is compressed, heated and expanded and then it is cooled. Due to the expansion it produces work at a piston. The network produced is thus the piston work minus the work needed to compress the gas. A generator unit then converts the piston motion into electricity [14].

2. Externally fired micro turbines: are gas turbines for a power range of less than 500 kWe. Although most turbines employ combustion chambers and expand the combustion air to generate shaft motion, some designs use heat exchanger technology similar to the Stirling heat exchangers to heat the turbine working gas. In this case, the process is called externally fired gas turbine (EFGT) and the engine can be operated based on all combustion fuels, similar to the Stirling technology [14].

3.5.2. Fuel-Driven Generation

1. Micro-turbines: are small, predominantly aero-derivative turbines using a comparably simple design and a generator directly mounted on the turbine shaft [14].

2. Gas engines and internal combustion engines: gas engines can be defined as Internal Combustion Engines (ICE) running on gases such as natural gas, producer gas or biogas. Most gas engines are spark ignition engines, whereas ICE can be either compression ignition or spark ignition engines. However, most ICE can also be converted to run on gas [14].

3.6. Biogas Production from Co-Digestion of Ethanol/ Brewery Wastes and Cattle Dung

Anaerobic co-digestion is a mature technology that takes advantage of complementary substrates to increase the methane yield of those substrates. The optimization of the carbon to nitrogen (C: N) ratio and the minimization of operational costs are between the most important advantages of this process. The study shows that co-digestion of brewery wastes (BW) with cattle dung (CD) in batch mode at mesophilic conditions, gives the maximum specific methane production of 0.287 m^3CH4/kg VS added (volatile solids) (46% of methane yield), with a mixing ratio of 70:30 (CD: BW) . The stable anaerobic co-digestion can be achieved using a mixture of brewery wastes and cattle dung in various proportions. The addition of BW increased the biogas yield from 0.41liter/day to 0.9liter/day. It was found that CD: BW of 70:30 is the optimum ratio from batch process. Moreover it was found that there was no clogging of the reactor on the maximum organic loading rate on 3.3kg VS/m^3/day in semi-continuous mode on 70:30 optimum ratios [15].

Table 3.2: Average biogas composition on steady state for brewery wastes and cattle dung [16]

Ratios CD:BW	CH_4%	CO_2%	Average Volatile fatty acids(VFA) Concentration During Starts of the Experiment	Average Volatile fatty acids (VFA) Concentration During End of the Experiment
90:10	67.0	30.5	3	1.9
80:20	67.5	30.0	3.3	1.6
70:30	69.0	29.7	3.7	1.4
60:40	66.0	31.5	3.4	1.7
40:60	63.2	32.8	2.9	2.0
20:80	59.6	33.9	2.7	2.1

3.7. Biogas Resource in Ethiopia

Over 88% of all citizens in Ethiopia rely on biomass fuel for cooking and lighting. And with 77% of agricultural families having cattle, many Ethiopia is eligible for biogas installation [17].

The agricultural waste potential in Ethiopia is 15-20 million tons and the wood potential is 1120 million tons. Among these resources about 30% of agricultural west and 50% of wood is exploited [11].

The most important thing of biomass combustion in this thesis is the availability of the biomass resources. Most of the inhabitants of Arsi Negele town participate in *Katikala* production and in parallel cattle fattening .So it is possible to get high amount of cattle manure and *Katikala* residues for biogas production. The table blow shows the biogas resource potential for three *kebeles* in Arsi Negele town.

Table 3.3: The biogas resource potential of three Kebeles in Arsi Negele [18]

List of HHs Activities	Kiltu Demma(01 kebele)	Melka shayit (02 kebele)	Meja kiltota (03 kebele)
Number of HHs involved in *katikala* production only	6	2	4
Number of HHs involved in both *Katikala* production and cattle fattening	23	25	21
Number of HHs involved in cattle fattening only	8	13	10
Number of HHs that do not involved in both activities	23	20	25
Number of cattle fattening per HHs average	2	2	2
Average cow dung produced per day per HHs	20-30 kg	20-30kg	20-30kg
Number HHs using cow dung for biogas	-	-	1
Number of HHs throwing Cow dung as waste	58	54	53
Number HHs using cow dung's for fuel	2	6	6

Arsi Negele town is mainly known by its traditional local *katikala (Areke)* production. The byproduct of *katikala* production is used as a main cattle fattening feed. *Arake* production and cattle fattening is the main income source for most of the town dwellers. The town has total 9,618 HHs [18]. From the assessments made by ANCEDA 62 % (5984 HHs) of town's dwellers have direct or indirect involvement in production and cattle fattening by using byproduct of *katikala*. Only 14 % of HHs that produce *katikala* is not involved in cattle fattening, this also due to absence of sufficient place for cattle fattening. From the total town population 38% (3655 HHs) of the town dwellers are directly involved in both a*rake* production and cattle fattening.

The average volume of *Katikala* produced per day is 55200 litters and average volume of *katikala* by product produced per day is 2692,100 liters [19]. About 96% of *Arake* producer carry out cattle fattening activities. Total of 14,500 cattle fattening (2 cattle per household) is carried out in the town at the same time. The total of 181250Kg or 181.250 ton of Cow dung is produced per day in Arsi Negele town [19].

Even though there is high potential for biogas plant operation there is only one biogas per 180 HHs under questionnaire assessment which is only converting 75kg of cow dung per day to its useful form (energy and organic compost). The huge remaining amount of cow dung is wasting and polluting the environment.

CHAPTER FOUR

4. DISTRIBUTED GENERATION SYSTEMS

4.1. Distributed Generation

Distributed Generation (DG), also called Distributed Energy (DE) systems, are energy systems located at or near the point of use. Typically ranging from 1 kW to 10 MW, they can provide both electricity and in some cases heat. There are a wide variety of potential benefits to DE systems both to the consumer and the electrical supplier that allow for both greater electrical flexibility and energy security [2].

For the customer, these benefits include: reduced price volatility, greater reliability, and improved power quality. There are many potential benefits for the energy supplier, such as released line capacity, reduced transmission and distribution congestion, grid investment deferment and improved grid asset utilization, and the ability of the DE system to provide ancillary services, such as voltage support and stability, volt–ampere reactive (VAR) support, and contingency reserves. Depending on economics, there are a wide variety of applications for DE systems: backup and emergency power, base load power, and peaking power in addition to offering a combined heat and power (CHP) option if the customer has a use for the thermal heat generated by the DE system [2].

Distributed generation (DG) is becoming an increasingly attractive approach to reduce greenhouse gas emissions, to improve power system efficiency and reliability, and to relieve today's stress on power transmission and distribution infrastructure [3].

In recent years, DG systems based on renewable energy source (RES) or micro-sources such as fuel cells, photovoltaic (PV) cells, wind turbines, and micro-turbines are experiencing a rapid development, due to their high efficiencies and low (or zero) emissions. The micro-source based DG also presents a challenge in terms of interaction to the grid, where the power electronic technology plays a vital role. The development of DG has led to a more recent concept called micro-grid, which is a systematic organization of DG systems. Compared to a single DG, a micro grid has more capacity and control flexibilities to fulfill system reliability and power quality requirements. The micro grid also offers opportunities for optimizing DG systems [3].Furthermore, the micro grid can operate in grid connected mode or autonomous islanding mode and benefit both the utility and the customers.

A customer-driven micro grid (CDM) is expected to fully embrace all these benefits that a micro grid and DG can provide. Since the micro-source based DGs are normally controlled and connected to the grid through power converters, by coordinating and controlling individual DG through the power electronics interface, the micro grid has significant control flexibility to fulfill system requirements in terms of efficiency, security, reliability, power quality, etc.

In addition, a micro grid with collective actions of DGs can provide many ancillary services to the upper-stream power system through proper control and communication. Proper operation of a micro grid requires advanced local voltage control and power flow/sharing control. Moreover, system protection has to be carefully coordinated with each DG and short circuit current has to be limited through the proper control of DG units in a micro-grid [3].

4.2. Interconnection Interfaces of Distributed Energy System

The electric output of DE systems can be connected to the electrical power system via three basic interconnection interfaces [2].

4.2.1. Synchronous Generator

Synchronous generators are rotating electric machines that convert mechanical power to electrical power. In a synchronous machine, a prime mover (like a turbine) turns the rotor that induces a voltage on the stator winding. A magnetic field is produced in the rotor by either a dc field current or by a permanent magnet. The electrical frequency of the induced voltage depends on the speed of rotation of the generator. When connected to an electric power system, the synchronous generator must run at a constant speed called “synchronous speed” and generate voltages corresponding to the supply frequency. Synchronous generators are used with most reciprocating engines and most high power turbines (gas, steam, and hydro).

4.2.2. Induction Generator

Like synchronous generators, an induction generator is a rotating electrical machine that converts mechanical power into electrical power [2]. Both machines have similar stator construction. The rotor in the induction generator, however, is different and no DC field current is needed for operation. There are two types of rotor designs available: cage rotor and wound rotor. Induction generators are typically only used in wind turbines and some low-head hydro applications. The advantage of the cage-rotor induction generator is the lower cost compared to asynchronous generator, but induction generators require a supply of VARs either from capacitors, from the electric power system, or from PE-based VAR generators to operate.

4.2.3. Power Electronics

The power electronics (PE) interface can be used to connect any type of DE system to an electric power system. PE-based inverters are used in micro-turbines, fuel cells, PV systems, some wind turbines, and energy storage systems [2].

Because of unique properties of PE interfaces, they can also be used to interconnect reciprocating engines that would normally be interconnected with only a synchronous or induction generator. When used with engines or wind turbines, the output of the electric generators is rectified to DC then converted to AC using an inverter.

4.3. Micro-Grid System Configurations and Features

In a broader and more futuristic view, a micro-grid is a tiny power system with a cluster of loads and distributed generators operating together through an energy manager and flexible ac transmission system (FACTS) control devices (such as power flow controllers, voltage regulators, etc.), and protection devices [2]. A micro-grid itself can be a DC grid or AC grid (or even a high frequency AC grid).

An AC micro-grid can be a single-phase or a three-phase system. It can be connected to low voltage or medium voltage power distribution networks.

The micro-grid is connected to the mains grid through a separation device (normally a static transfer switch, STS) at the point of common coupling (PCC), which ensures fast disconnection of the micro grid from the utility in case of a utility fault. More simply put, a micro-grid can be viewed as a distribution system with power generators and control devices. As shown in typical Figure 4.1, an energy manager serves as the control center for the micro-grid. This energy manager, together with the protection coordinator and power quality controller/monitor, maintain the reliable operation of the micro-grid and respond to the mains grid’s request.

Another main feature of a micro-grid, especially a CDM, is that the distribution network can be configured to a ring structure as shown in typical Figure 4.1 with added connections, thus the system reliability can be greatly enhanced.

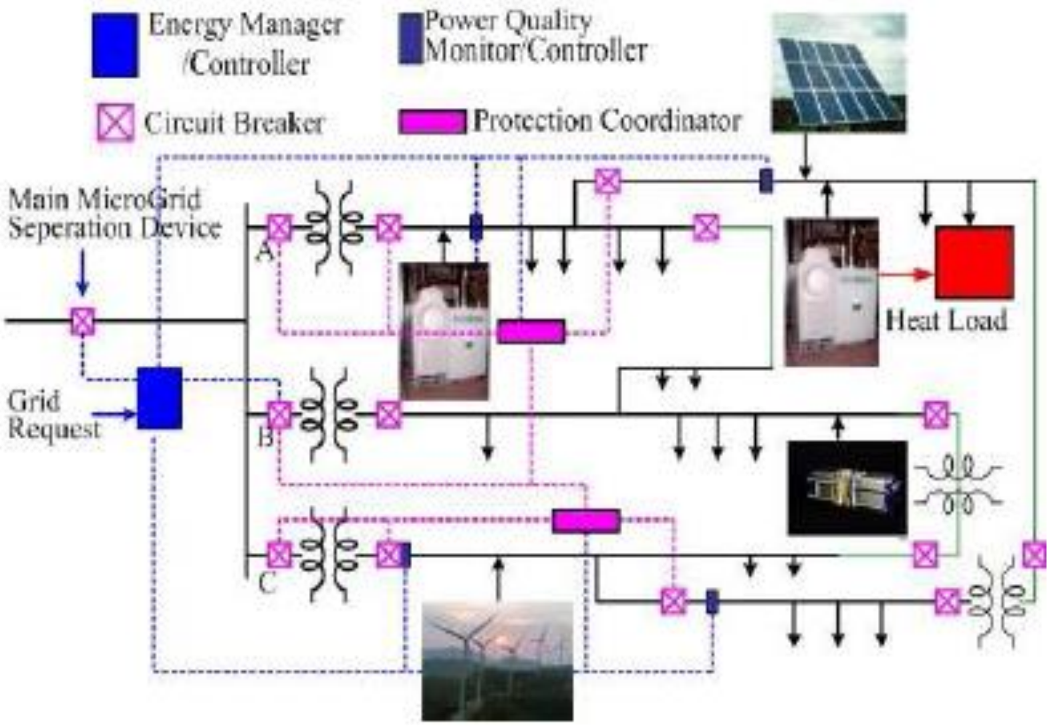


Figure 4.1: Typical Micro-grid system configuration and main features [3]

4.4. Micro-Grid Operation Modes

There are two operation modes for a micro-grid: grid-connected mode and islanding mode. When connected to the utility grid, the main function of the DG units is to generate power and provide local voltage and power support. With the interfacing power converters, controllable reactive power can also be produced by the DG units. As a result, the line loss can be reduced and the overall system efficiency can be greatly improved. The reference real and reactive power of each DG can be commanded by the micro-grid energy manager, or DGs can be commanded and controlled at their maximum power available through MPPT as in a PV or wind DG.

The other operation mode is the intentional islanding mode. This happens when the micro-grid is cut off from the main grid (e.g. during power outage of the main grid) and continues to operate to provide power to local loads. Islanding operation is a very important function of the CDM. For a reliable islanding operation, the DGs have to be controlled to meet the following three requirements.

First, the collective power generation from all the DGs in the micro-grid has to match the load demand. Therefore, accurate load sharing among the DG units according to each DG's power capacity is important to avoid possible damage to any DG.

Second, the DGs have to provide voltage control to ensure all feeders' voltages are within their normal ranges.

Third, all DGs have to be synchronized with each other and provide micro-grid frequency control. Due to different control objectives of the two operation modes, a fast and reliable islanding detection scheme is also important for each DG unit to ensure the proper operation of a micro-grid.

To ensure a smooth re-connection of the micro-grid back to the main grid when the grid recovers from a fault, a micro-grid re-synchronization method is also required. When the main is back on, the micro-grid has been operating in the islanding mode and has its own PCC terminal voltage magnitude, frequency and phase angle, which most likely are different from those at the main grid terminal. A re-synchronization scheme is thus needed before closing the separation switch. The resynchronization is to ensure the voltage magnitude, frequency and phase angle at the micro-grid end and main grid end match for a smooth reconnection of the two systems.

Finally, protection is another critical aspect of a micro-grid. New protection schemes and coordination methods are required for a micro-grid to respond immediately to the faults in the utility or within the micro-grid. This is because traditional distribution system protection methods may not work for micro-grids due to its radical change from the radial distribution system structure.

Moreover, with the presence of power electronics in the DG system, where the semiconductor device rating is typically 2-3 times of the rated current, the traditional over-current protection scheme is no longer suitable in a micro-grid. Furthermore, the conventional protection scheme at distribution network will be seriously affected because of the connection of DGs, as each DG will contribute to increase fault current of the system. Therefore, the micro-grid fault protection has to be re-coordinated and the fault current has to be re-evaluated and limited accordingly and preferably by DGs.

4.5. Proposed Distributed Generation System

There are many combinations of different alternative energy sources to build a DG system. In this thesis study, the proposed distributed generation system consists of small hydropower, biogas energy and grid. Small hydropower and grid are the primary power sources of the system to minimize operating cost of biogas as much as possible. In the proposed system, different energy sources are integrated through an AC link bus using HOMER. An overall power management controller is designed for the system to coordinate the power flows among the different energy sources using Matlab/Simulink.

4.5.1. Designing and Modeling of DG System with HOMER

4.5.1.1. HOMER

The Hybrid Optimization Model for Electric Renewable (HOMER), which is copyrighted by Midwest Research Institute (MRI) is a computer model developed by the U.S. National Renewable Energy Laboratory (NREL) to assist the design of power systems and facilitate the comparison of power generation technologies across a wide range of applications [20]. HOMER is used to model a power system physical behavior and its life-cycle cost, which is the total cost of installing and operating the system over its life time. HOMER allows the modeler to compare many different design options based on their technical and economic merits. It also assists in understanding and quantifying the effects of uncertainty or changes in the inputs.

HOMER performs three principal tasks: simulation, optimization, and sensitivity analysis based on the raw input data given by user. In the simulation process, the performance of a particular power system configuration for each hour of the year is modeled to determine its technical feasibility and life-cycle cost. In the optimization process, many different system configurations are simulated in search of the one that satisfies the technical constraints at the lowest life-cycle cost. In the sensitivity analysis process, multiple optimizations are performed under a range of input assumptions to judge the effects of uncertainty or changes in the model inputs. The quantity used to represent the life-cycle cost of the system is the total net present cost (NPC). This single value includes all costs and revenues that occur within the project lifetime, with future cash flows discounted to the present. The total net present cost includes the initial capital cost of the system components, the cost of any component replacements that occur within the project lifetime, the cost of maintenance and fuel.

4.5.1.2. Hybrid System Modeling

The general objective of this thesis is to design hybrid small hydro/biogas based distributed generation for Arsi Negele town to replace the energy used from firewood for *katikala* production and other electric cooking appliances. A schematic diagram of the grid-connected hybrid power supply system required is shown by HOMER as shown in Figure 4.2. The AC load considered is a primary load, which is an electric demand that must be served according to a particular schedule, whereas deferrable load is electric demand that can be served at certain period of time. The following subsections devoted to show how to model the loads that the system must serve, the components of the system and their associated resources, and how that collection of components operates together to serve the loads. The detail of load profile for Arsi Negele town is shown in Appendix B.

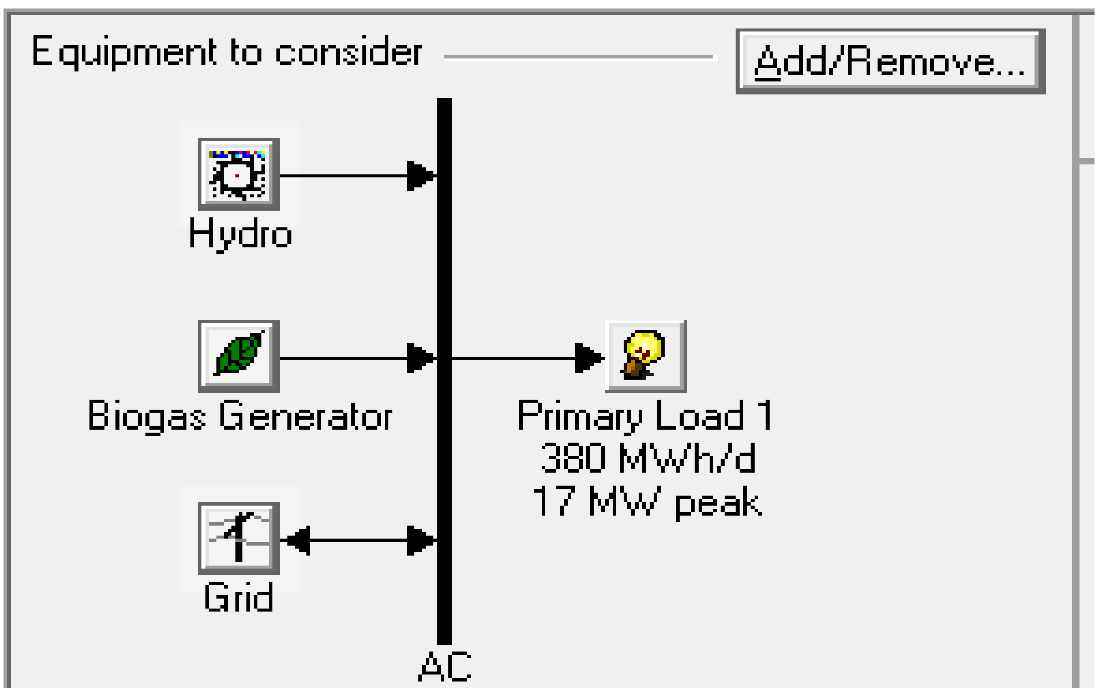


Figure 4.2: HOMER Schematic Diagram For Hybrid System Modeling

a) Electric Loads

The electric loads are usually the largest single influence on the size and cost of hybrid system components. So, deciding on the loads is one of the most important steps in the design of the DG system. The term loads refers to a demand for electric or thermal energy, if any. Three types of loads can be modeled using HOMER: primary load which is electric demand that must be served according to a particular schedule, deferrable load which is electric demand that can be served at certain period of time, the exact timing is not important and thermal load which is demand for heat.

Load Profile of Arsi-Negele Town

To provide electricity using renewable energy the load demand of households is determined. In addition to the existing load demand the load for *katikala* production is also considered [Appendix B].

Katikala producers make a distillation using ten pots at one run. If this pot is replaced by new designed electric input distillation still, five pots can replace the function of ten pots with one kilowatt electric heater as input each .In average five kilowatt (5KW) power can be considered for one HH.

Arsi Negele is a town which electricity grid has been already connected in low reliability so the capacity and continuity of electricity supply is limited. The town has total 9,618 HHs [18]. From the assessments made by ANCEDA, 62 % (5984 HHs) of town's dwellers have direct or indirect involvement in *Katikala* production. The total number of electric customers in Ethiopian Electric Utility of Arsi Negele district is 7406, among which **5544** is only in Arsi Negele town.

Based on literature reviewed and the existing conditions the following assumptions are considered. The Load demand in a day can be divided as follows [18, 19].

- **Domestic(Households):** Considering the 6000 households in Arsi Negele town,5544 are already electrified, and average load demand for each HHs, the following loads are considered: Lighting, TV, refrigerator, Oven/*InjeraMitad*, radio, and *katikala* producing still. The maximum power for each *katikala* producer is assumed to be five kilowatt (5 KW) and they can produce it in three shifts. The time duration for each shift is selected considering the time when other loads like cooking ,washing , and load of schools and public utilities become low .Considering 3000 *Katikala* producers in each shift, average load of total *katikala* producer is assumed to be 15000 KW.
    - The first shift is assumed to be from 11:00-17:00. At the afternoon cooking, washing and other activities are assumed to be come decreased; so that *Katikala* distillation can be takes place.

- The second shift is assumed to be from 20:00-24:00.At this time cooking, washing and other activities are assumed to be come decreased.
- The third shift is assumed to be from 00:00-06:00. During this time, since it is mid-night, most of the peoples sleep and other loads are very low. So *Katikala* producers can use this off-pick load time to produce *Katikala.*

❖ **Schools:** for schools the assumed loads are: Lighting, plasma TV for three high schools, computers, printers and radio.

❖ **Public Utilities:**

- Healthy center and clinics : refrigerator, lighting, printer and computer are considered
- Straight light: strait light for the town is also considered
- All office in the town,
- Water pump to the town,

The total electricity demand needed for the town in 24 hours is all shown in Figure 4.3 bellow**.**

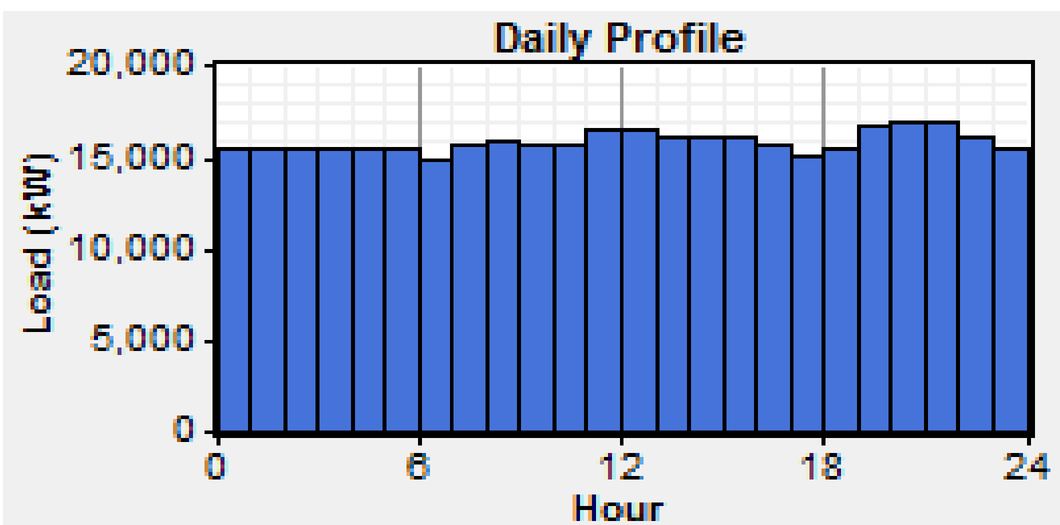


Figure 4.3: HOMER result of load profile of Arsi Negele town

b) Renewable Resource

Hydro Power Resource

Based on the data obtained from site observation and the Ministry of Water and Energy, the flow rate of the river during dry season can be considered as $0.5m^3/s$ and it is greater than $2\ m^3/s$ during rainy season. Based on the data measured using GPS during field survey, the head of 340 meter height can be obtained, since the GPS reading at the top of river stream is 2500 meter and at the bottom of the mountain is 2160.These values are used as input to HOMER simulator and the result is shown in Figure 4.4.

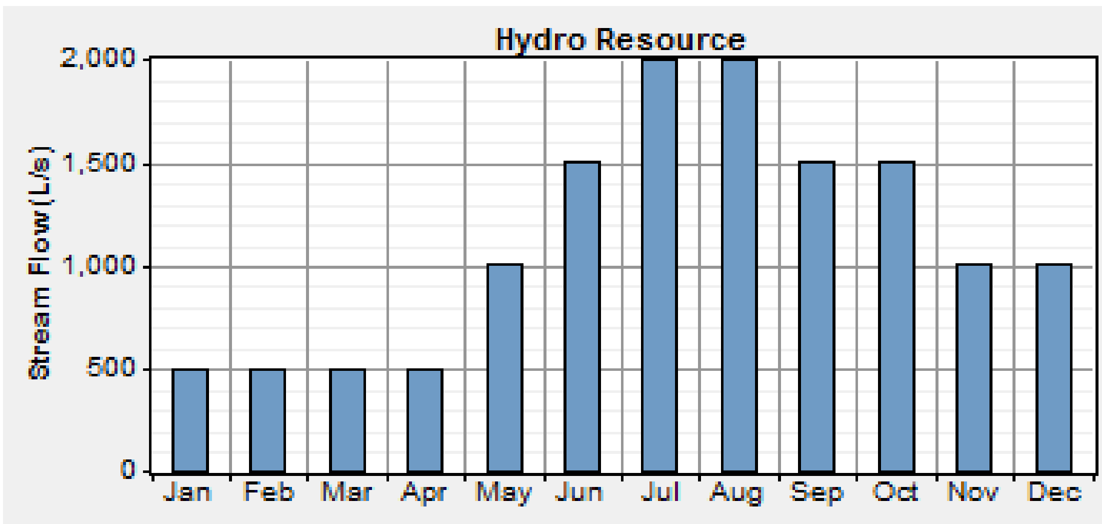


Figure 4.4: HOMER Simulation Result of Monthly Average Hydro Resource of Lephis River

Biogas Resource

Most of the inhabitants of the town participate in *Katikala* production and in parallel cattle fattening .It is possible to get high amount of cattle manure and *Katikala* residues for biogas production. The average volume of *Katikala* produced per day is 55200 litters and average volume of *Katikala* by product produced per day is 2692,100 liters [19]. Total of 14,500 cattle fattening (2 cattle per household) is carried out in the town at the same time [18]. In average 2 cattle per household fattening is taken and 181250 kg or 181.25 tons of cow dung is produced per day in Arsi Negele town. From this it is possible to get a biomass resource of greater than 300 tons per day in the town.

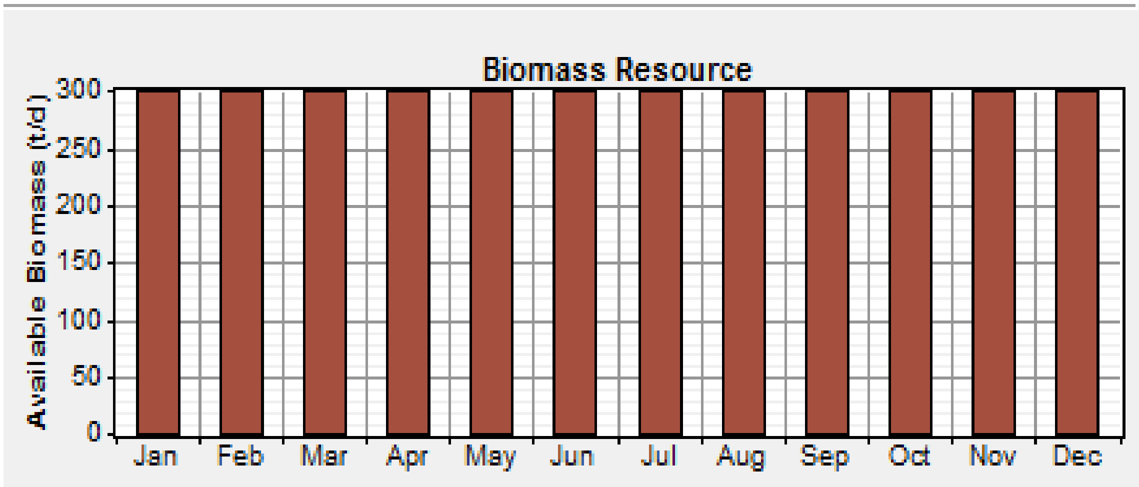


Figure 4.5: Biogas Resource of Arsi Negele

Existing Grid

Arsi Negele is a town which electricity grid has been already connected in low reliability so the capacity and continuity of electricity supply is limited. The total number of electric customers in the district is 7406, among which 5544 is only in Arsi Negele town. There are two medium voltage distribution lines from Shashamanne Substation, which supply power to Kuyera town, Arsi Negele town, and other small towns and villages with each capacity of 5MVA. There are 47 distribution transformers in the town and 9 in the small towns and rural villages. The peak load occurs in the evening from 6:30 pm to 8:00 pm. Power interruption occurs three times per week for total of 3 hours [21,22].

Additional information input into Homer is summarized in Table 4.1. The values given in this table are primarily chosen according to the size of the load for the assumed town.

Table 4.1: Additional Information Input Into HOMER [23].

S.N	Input Types	Small Hydro	Biogas	Grid
1	Size (kW)	1	1	1
2	Capital ($)	1500-3000	3000	7
3	O&M cost ($/yr)	15	100	-
4	Size considered(kW)	-	7000, 7500, 8000, 8500, 9000	8000
5	Lifetime	50	-	-

The costs are estimated according to the current local and global price of the components. Other inputs into the software, such as the range of sizes for the biogas generator, and grid demand rate are given so as to give flexibility to the software and optimize the output results.

For the analysis, biomass resource is considered for the generator fuels with prices of 30 US dollars per ton. The hydropower life time is 50 years, the biogas generator life time is 20000 hours and the interest rate is assumed to be the present rate of 6%.

The software generates the results which are a list of feasible power supply system sorted according to their net present cost. Furthermore, sensitivity variables, such as the range of biomass resource, range of water flow and grid power are supplied, and then the software is tuned for optimum results.

4.5.2. Control Schemes for Proposed Distributed Generation System Using Matlab/Simulink

Control schemes simulation system for the proposed distributed generation system has been developed in Matlab/Simulink. Figure 10 shows the overall diagram of the simulation model in Matlab/Simulink. The overall control strategy for power management among different energy sources in the system is discussed in this section. The system performance under different operating conditions is evaluated and discussed as well.

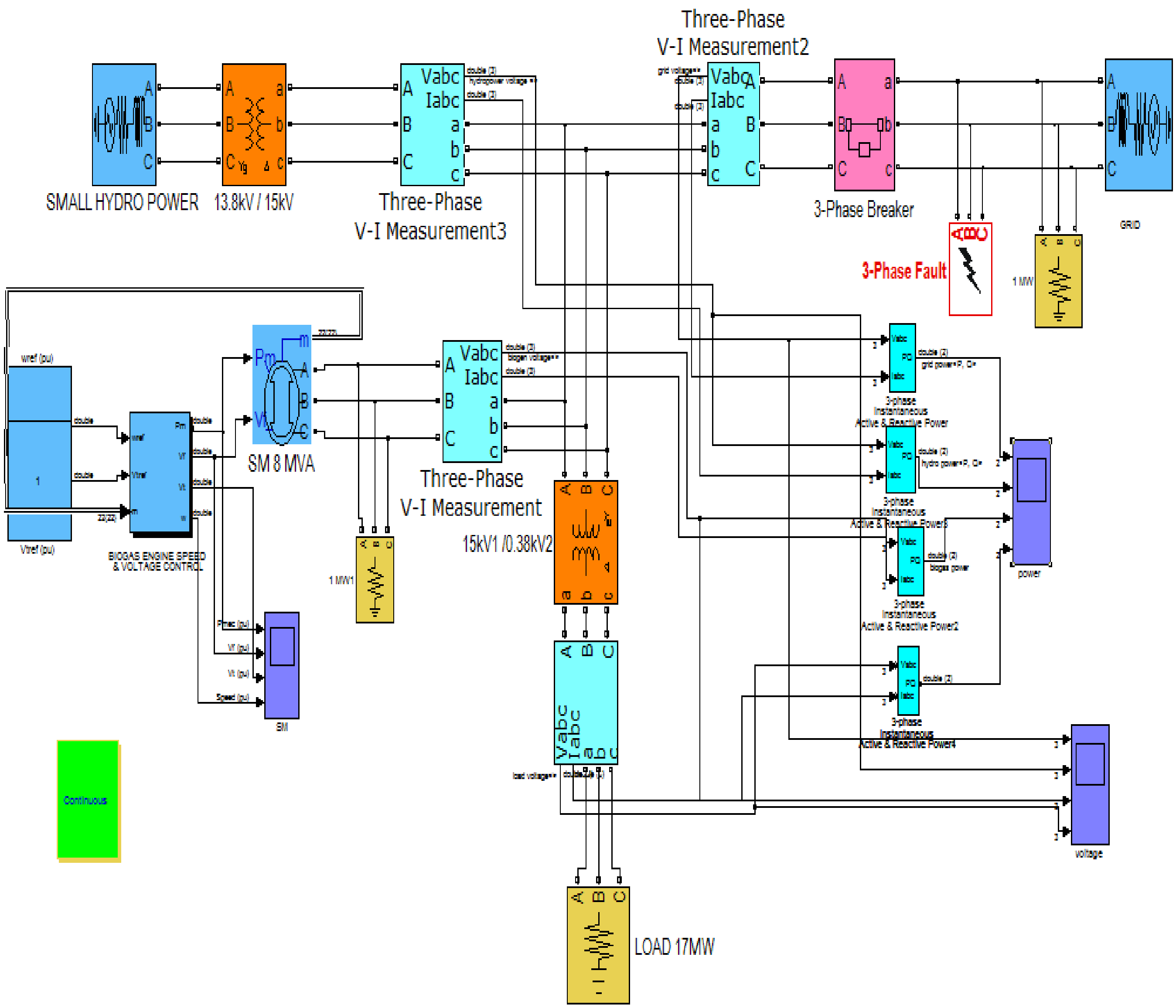


Figure 4.6: Simulation Model of Distributed Generation System

a) System Descriptions of the Distributed Generation

This system consists of a plant, simulated by a resistive load fed at 380 V through 15kv/380V transformer from a 15 kV distribution network. The 15 kV grid is modeled by a simple R-L equivalent source with short-circuit level 8 MVA (since grid sell capacity is 8KVA), assuming quality factor X/R = 10,and a 1 MW load. Hydropower generator is modeled by a simple R-L equivalent source short-circuit level 2.835MVA (since grid design power is 2.835KVA) ,and assuming quality factor X/R = 10) , the biogas generator/synchronous machine is rated 7.5 MVA (since the required maximum biogas power is 7.5KVA ,and 15 kV.

Initially, the load is 6 MW and the synchronous generator is in standby, delivering no active power. The synchronous machine therefore operates as a synchronous condenser generating only the reactive power required to regulate the 15KV bus voltages at 1.0 pu.

The Synchronous Machine (SM) block uses standard parameters; the other three-phase elements such as the inductive voltage source, the Y grounded/Delta transformer, and the loads are standard blocks from the Electrical Source and Elements libraries of powerlib. The Machine Measurement Demux block provided in the Machines library is used to demux the output signals of the SM and loads.

The SM voltage and speed outputs are used as feedback inputs to a Simulink control system that contains the biogas engine and governor block as well as an excitation block. The excitation system is the standard block provided in the Machines library.

b) Overall Power Management Strategy

The power difference between the generation sources and the load demand is calculated as:

P_{net}=P_{grid}+ P_{hydro}+ P_{load}…………………………………..…………………. (4.1)

Where,

P_{grid} = power from distribution network

P_{hydro} = power generated by the hydropower

P_{load} = load demand;

The governing control strategy is that: At any given time when the load is less than the power generated by hydropower and grid there is no active power generated by biogas generator (P_{net}> 0).When there is a deficit in power generation (P_{net}< 0), the biogas generator begins to produce Power for the load.

In the Load Flow study, A SM Bus Type should be initialized as P & V generator, indicating that the load flow is performed with the machine controlling its active power and terminal voltage. By default, the desired terminal Voltage UAB is initialized at the nominal machine voltage (15000 Vrms) and the Active Power is set to zero. The synchronous machine therefore absorbs or generates reactive power only to keep terminal voltage at 1 pu.

CHAPTER FIVE

5. SIMULATION RESULTS AND DISCUSSION

5.1. HOMER Simulation Result and Discussion

The design of hybrid DG system, which supplies electricity to model town, was introduced previously. As mentioned in the earlier sections in the design the system components that are locally available have been included without much concern to the efficiency. The results of the investigation will be presented in the following paragraphs.

After entering the hydro and biomass resource data into software, to find the optimum solutions, Homer is run repeatedly by varying parameters that have a controlling effect over the output. The parameters that have controlling effect on output are given in Table 4.1.The output of the simulation is a list of feasible combinations of hydro, biogas generator and grid. The optimization results are generated in either of two forms; an overall form in which the top-ranked system configurations are listed according to their net present cost (NPC) and in a categorized form where only the least-cost system configuration is considered for each system type. Table 5.1 shows a list of few possible combinations of system components in an overall form. The tables are generated based on a particular set of inputs selected from the input summary of Table 4.1 and the hydro, grid and biomass resource data for site.

Table 5.1: List of HOMER Optimization Result Output for Possible Combinations of System Components in an Overall Form

Hydro (kW)	Bio-g (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Biomass (t)	Bio-g (hrs)
2835	7000	8000	$ 26,720,000	2,556,770	$ 67,019,448	0.031	0.64	0.00	19,447	8,760
2835	7500	8000	$ 28,220,000	2,547,261	$ 68,369,568	0.031	0.68	0.00	20,836	8,760
2835	8000	8000	$ 29,720,000	2,533,870	$ 69,658,504	0.032	0.71	0.00	22,225	8,760
2835	8500	8000	$ 31,220,000	2,520,480	$ 70,947,456	0.032	0.74	0.00	23,614	8,760
2835	9000	8000	$ 32,720,000	2,507,090	$ 72,236,400	0.033	0.77	0.00	25,004	8,760

The biomass resource price is 30 $/ton and assumed it is available all seasons, and the biogas power generation plant cost is $3000/KW [23]. Hydropower capital cost is checked using different sources on the internet and the price ranged from $1500 to $3000/KW [23]. As the head of hydropower increase the capital cost per kilowatt decrease. The efficiency considered for hydropower is 85% and the hydro turbine is included in all simulation result. The assumed average grid price is $ 0.024 and the maximum grid purchase capacity is 8 MVA.

The following remarkable results can be noted from the simulation result. The most cost effective system, i.e. the system with the lowest net present cost, is the hydro-grid –biogas generator set-up. For this set-up, the total net present cost (NPC) is $67,019,448,the cost of energy (COE) is 0.031 $/kWh, contribution from biogas resources is 64 % and capacity shortage in kWh is 161,7020 or 0.00% .

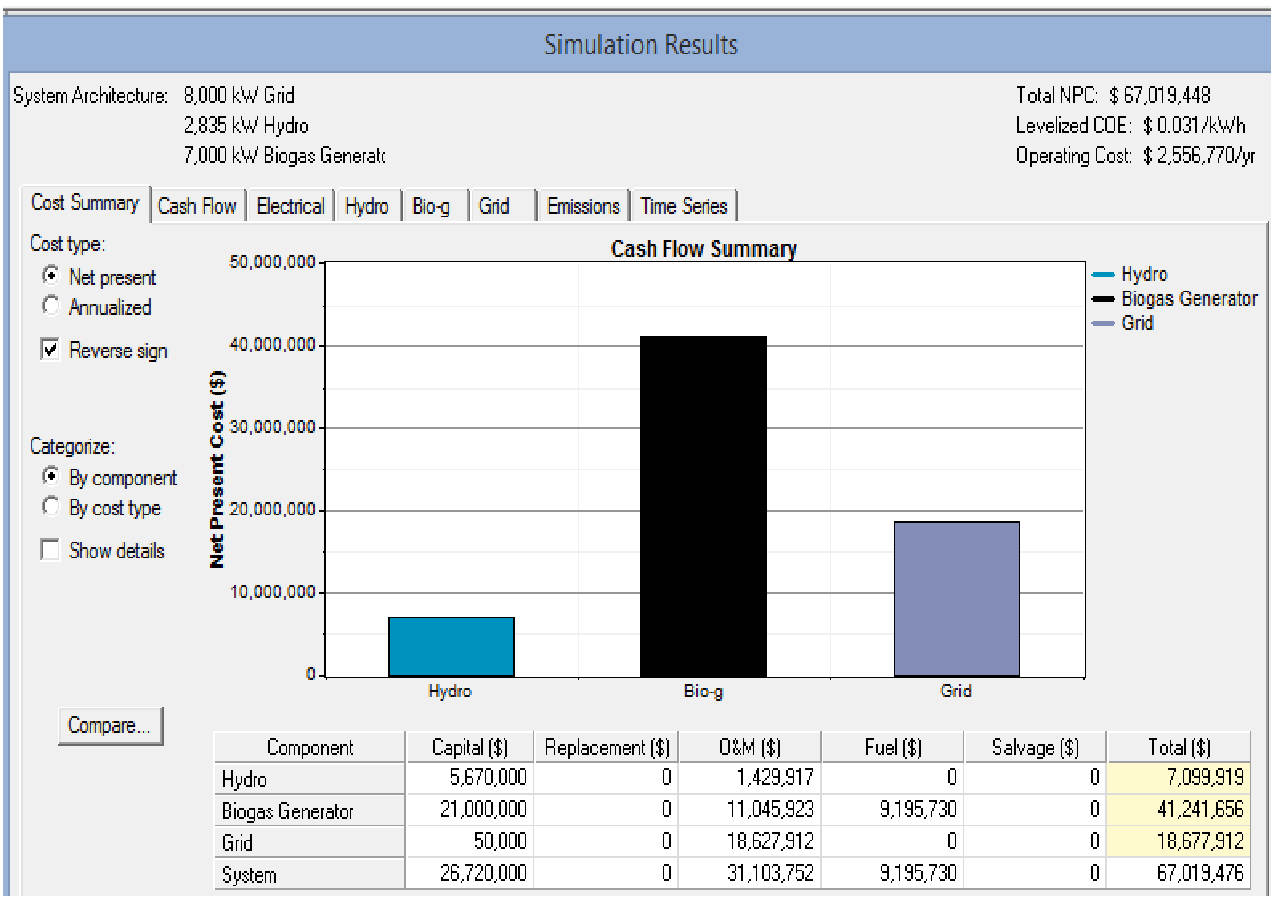
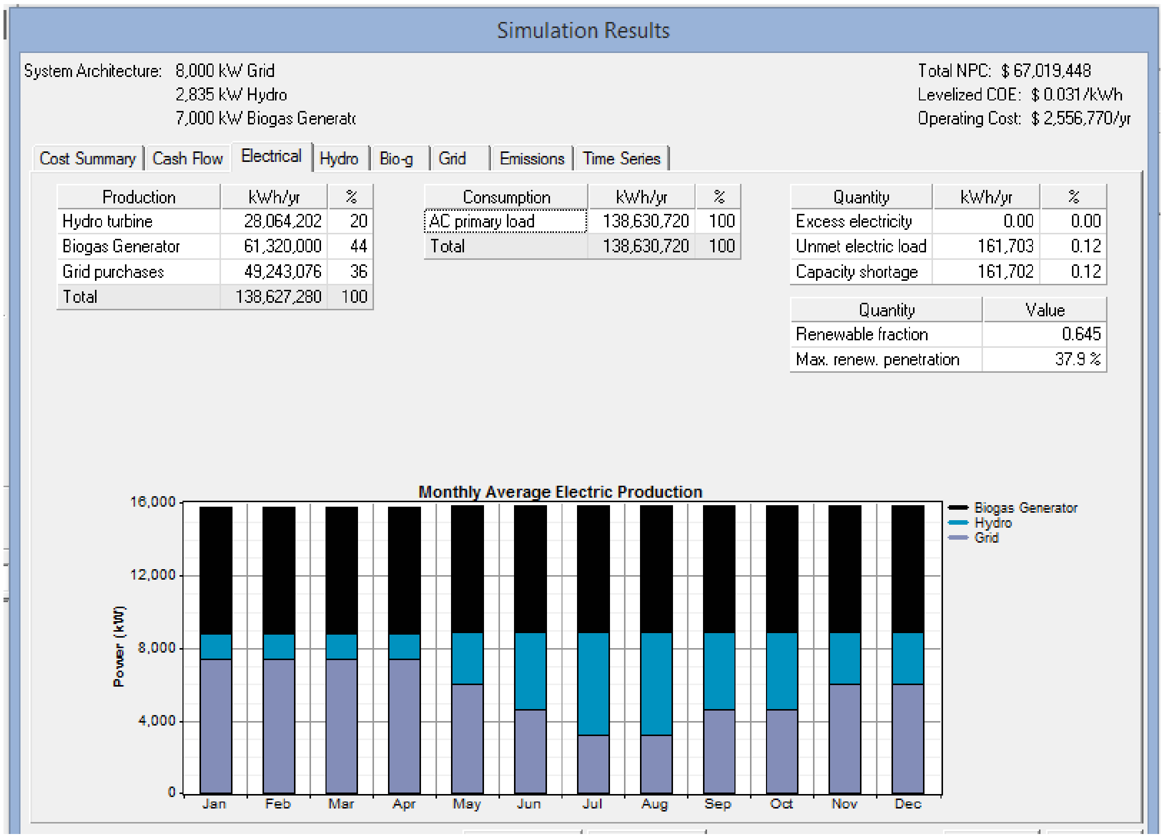


Figure 5.1: Cash Flow Summery for the Most Cost Effective System


Simulation Results

System Architecture: 8,000 kW Grid
2,835 kW Hydro
7,000 kW Biogas Generatc

Total NPC: $ 67,019,448
Levelized COE: $ 0.031/kWh
Operating Cost: $ 2,556,770/yr

Cost Summary | Cash Flow | Electrical | Hydro | Bio-g | Grid | Emissions | Time Series

Production	kWh/yr	%
Hydro turbine	28,064,202	20
Biogas Generator	61,320,000	44
Grid purchases	49,243,076	36
Total	138,627,280	100

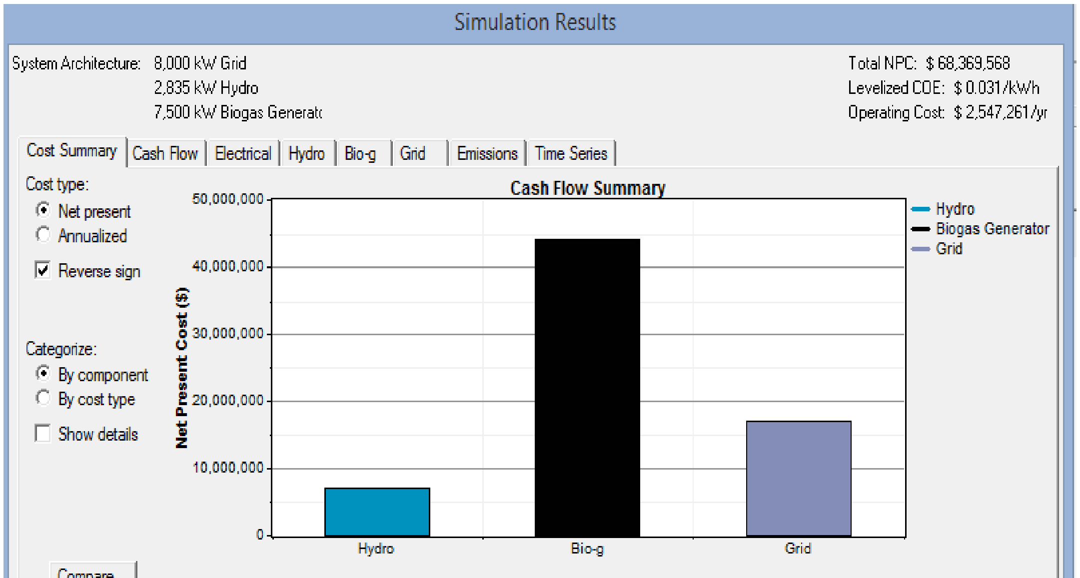
Consumption	kWh/yr	%
AC primary load	138,630,720	100
Total	138,630,720	100

Quantity	kWh/yr	%
Excess electricity	0.00	0.00
Unmet electric load	161,703	0.12
Capacity shortage	161,702	0.12

Quantity	Value
Renewable fraction	0.645
Max. renew. penetration	37.9 %

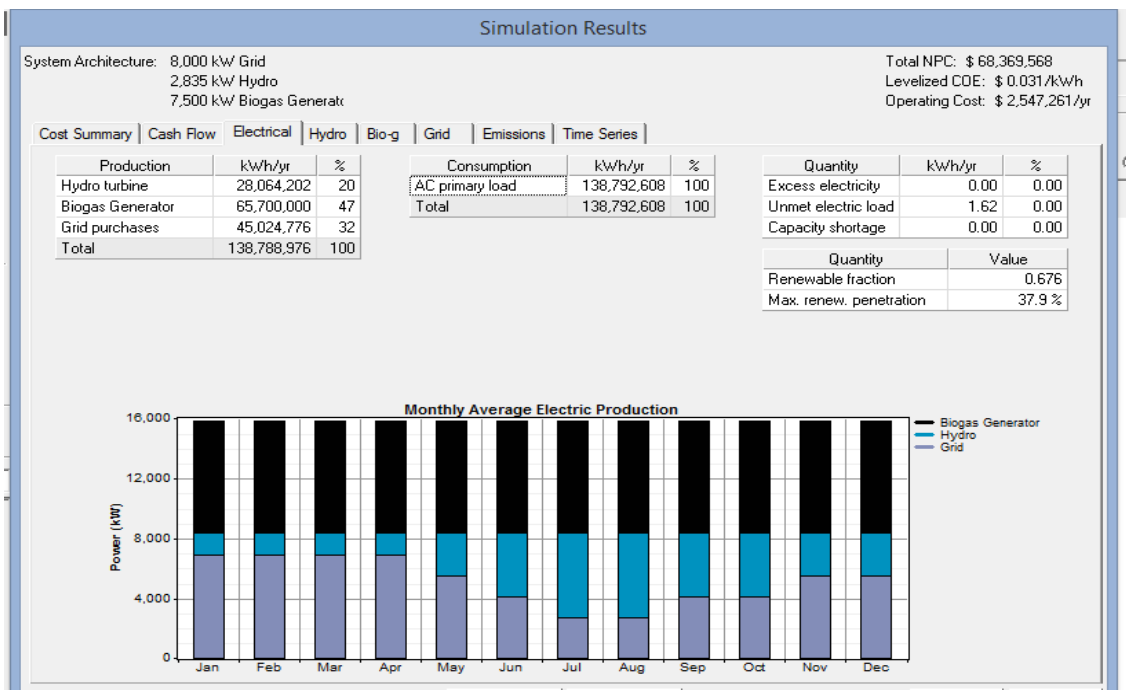
Figure 5.2: Monthly Average Electric Production of The Most Cost Effective

The second most cost effective system is one with NPC $68369568 and COE 0.031 $/KWH which is the same system type with that of biogas contribution of 7500 KW and so that capacity shortage in KWh is 0.00 or 0.00%.For this setup the part contributed by biogas resources is 68 %. Cash flow summery and monthly average electric production for this setup is shown in Figure 5.3 and Figure 5.4.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Hydro	5,670,000	0	1,429,917	0	0	7,099,919
Biogas Generator	22,500,000	0	11,834,916	9,852,565	0	44,187,488
Grid	50,000	0	17,032,194	0	0	17,082,194
System	28,220,000	0	30,297,028	9,852,565	0	68,369,584

Figure 5.3: Cash Flow Summery For The Second Most Cost Effective System



Production	kWh/yr	%
Hydro turbine	28,064,202	20
Biogas Generator	65,700,000	47
Grid purchases	45,024,776	32
Total	138,788,976	100

Consumption	kWh/yr	%
AC primary load	138,792,608	100
Total	138,792,608	100

Quantity	kWh/yr	%
Excess electricity	0.00	0.00
Unmet electric load	1.62	0.00
Capacity shortage	0.00	0.00

Quantity	Value
Renewable fraction	0.676
Max. renew. penetration	37.9 %

Figure 5.4: Monthly Average Electric Production For The Second Most Cost Effective System

5.2. Matlab/Simulink Simulation Result and Discussion

Steady state simulation shows how the generators coordinate each other due to control scheme. The fault condition is also proposed to investigate what would be happened to the system when the fault is occurred. The system load is assumed to be 6 MW, for simulation purpose, to show the effect of control system when load is less than power generated by hydropower and grid supply, and as well as to show how system react when fault occurs at the grid side.

a) The Steady State Scheme

The design power of hydro is 2.835 MW and for grid 8 MW. When the load demand is less than 10.835 MW, there is no active power generated by biogas generator. Figure 5.5 shows the grid supply power, hydropower generator power, and biogas generator and load whereas Figure 5.6.shows their terminal voltages respectively.

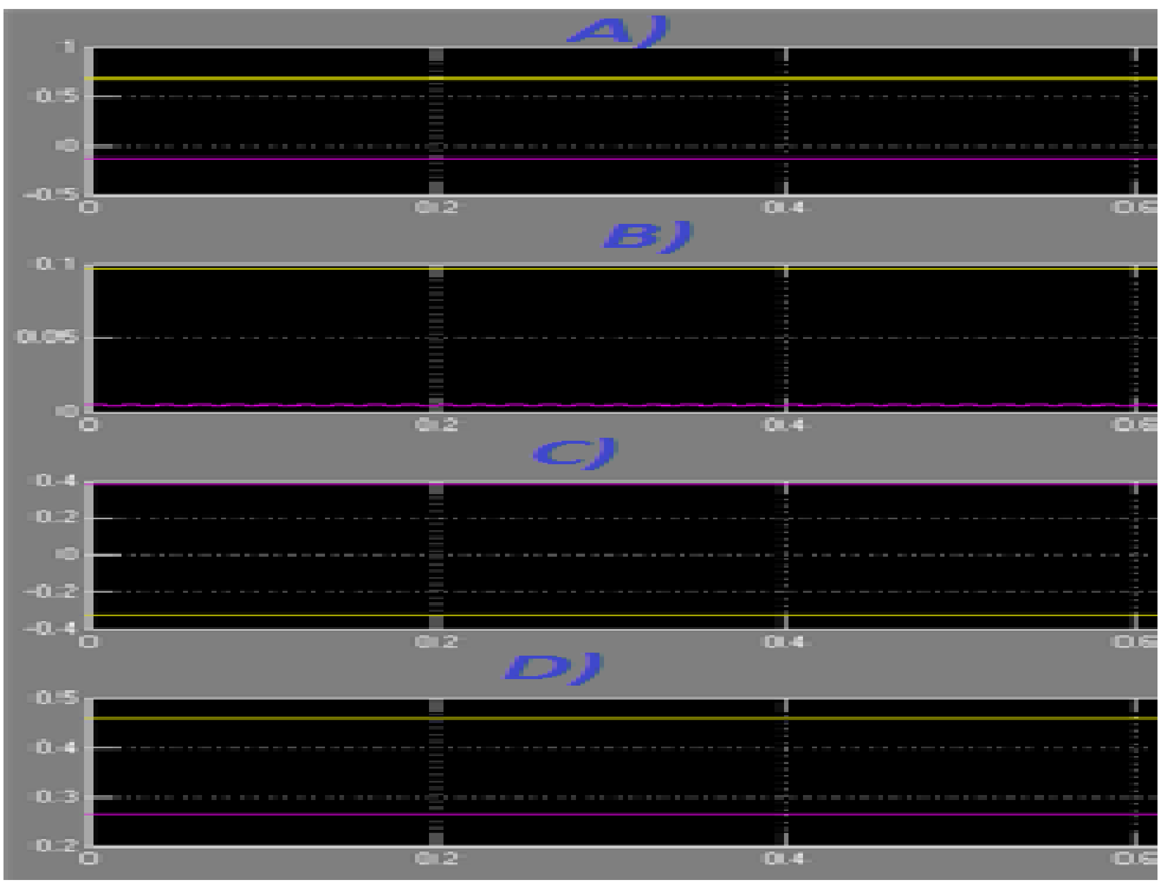


Figure 5.5: Active (Yellow Color) And Reactive (Violet Color) Steady State Power: A) Grid Power in pu ,B) Hydropower in pu C) SM Power in pu and D) Load pu

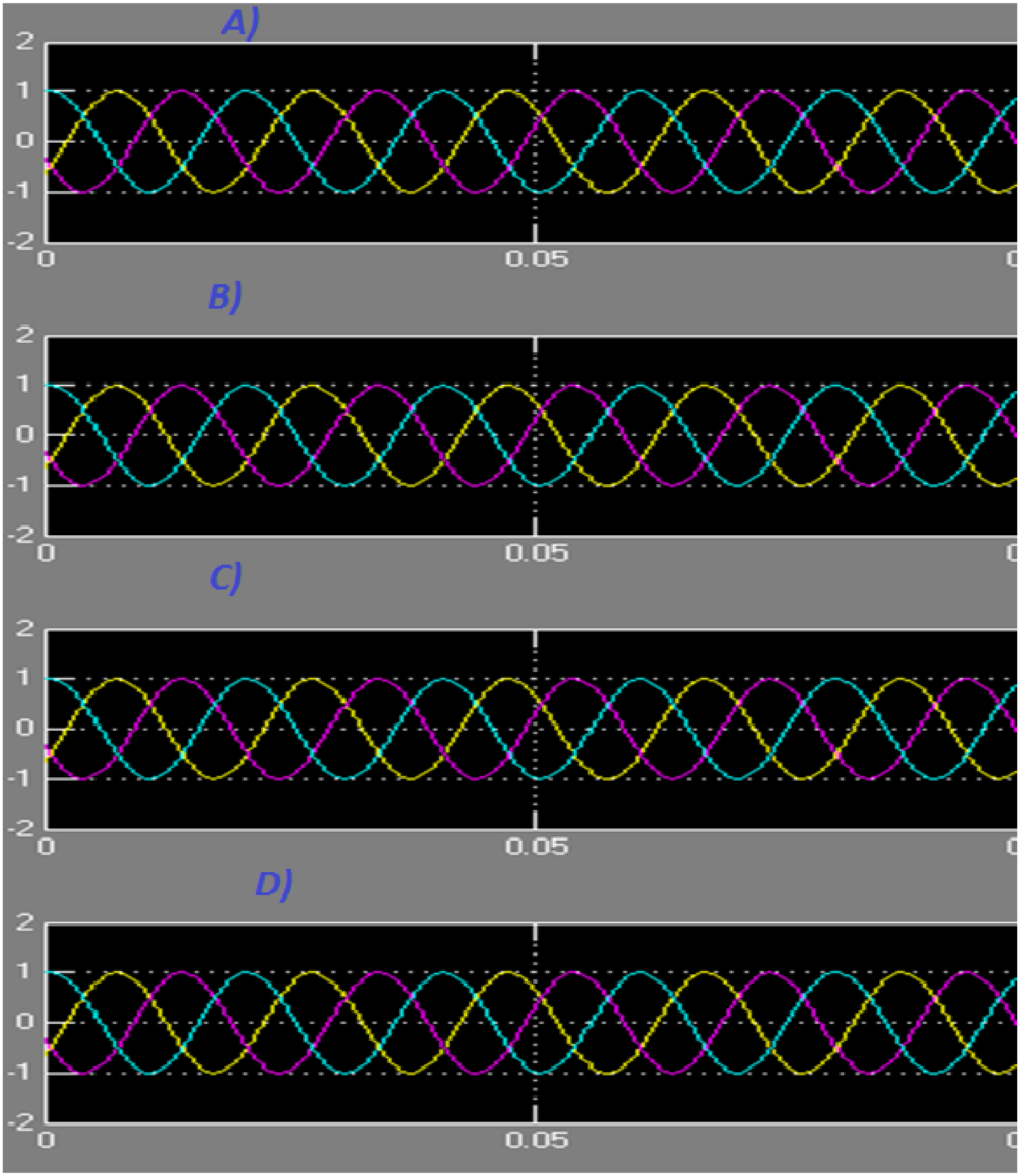


Figure 5.6: Three Phase voltage at steady state : A) Grid voltage in pu ,B) Hydropower voltage in pu C) SM terminal voltage in pu and D) Load voltage in pu.

b) When Three Phase Fault Occurs At Grid Side

At t = 0.1 s, a three-phase to ground fault occurs on the grid side 15 kV system, causing the opening of the 15 kV circuit breaker at t = 0.2 s, and a sudden increase of the generator loading. During the transient period following the fault and islanding of the DG system, the synchronous machine excitation system and the SM speed governor react to maintain the voltage and speed at a constant value. Figure 5.7 show the grid power, hydropower generator power, biogas generator and load whereas Figure5.8 shows their terminal voltages respectively.

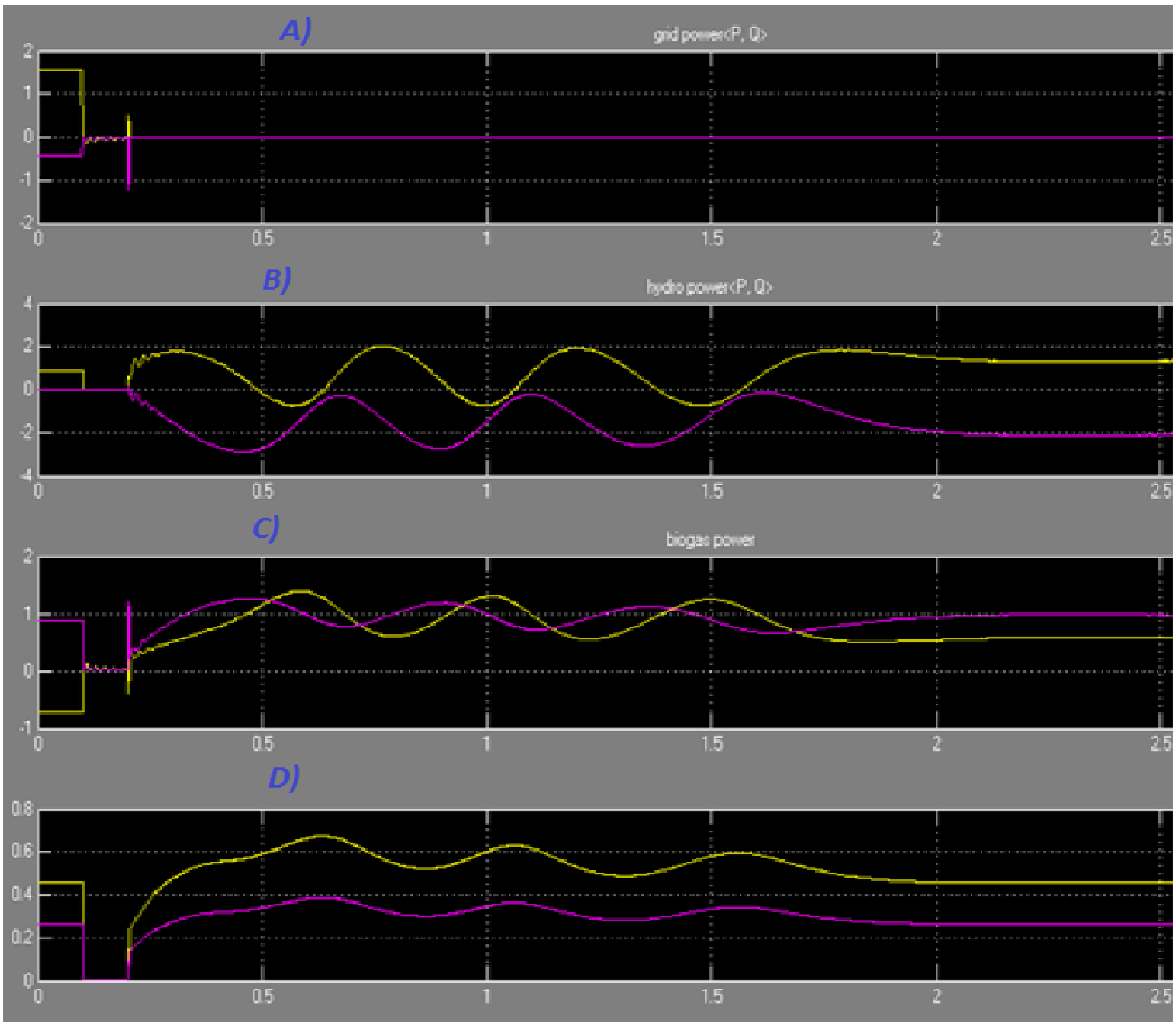


Figure 5.7: Active (Yellow Color) And Reactive (Violet Color) Power when three phase fault occurs: A) Grid Power in pu, B) Hydropower in pu C) SM Power in pu and D) Load pu.

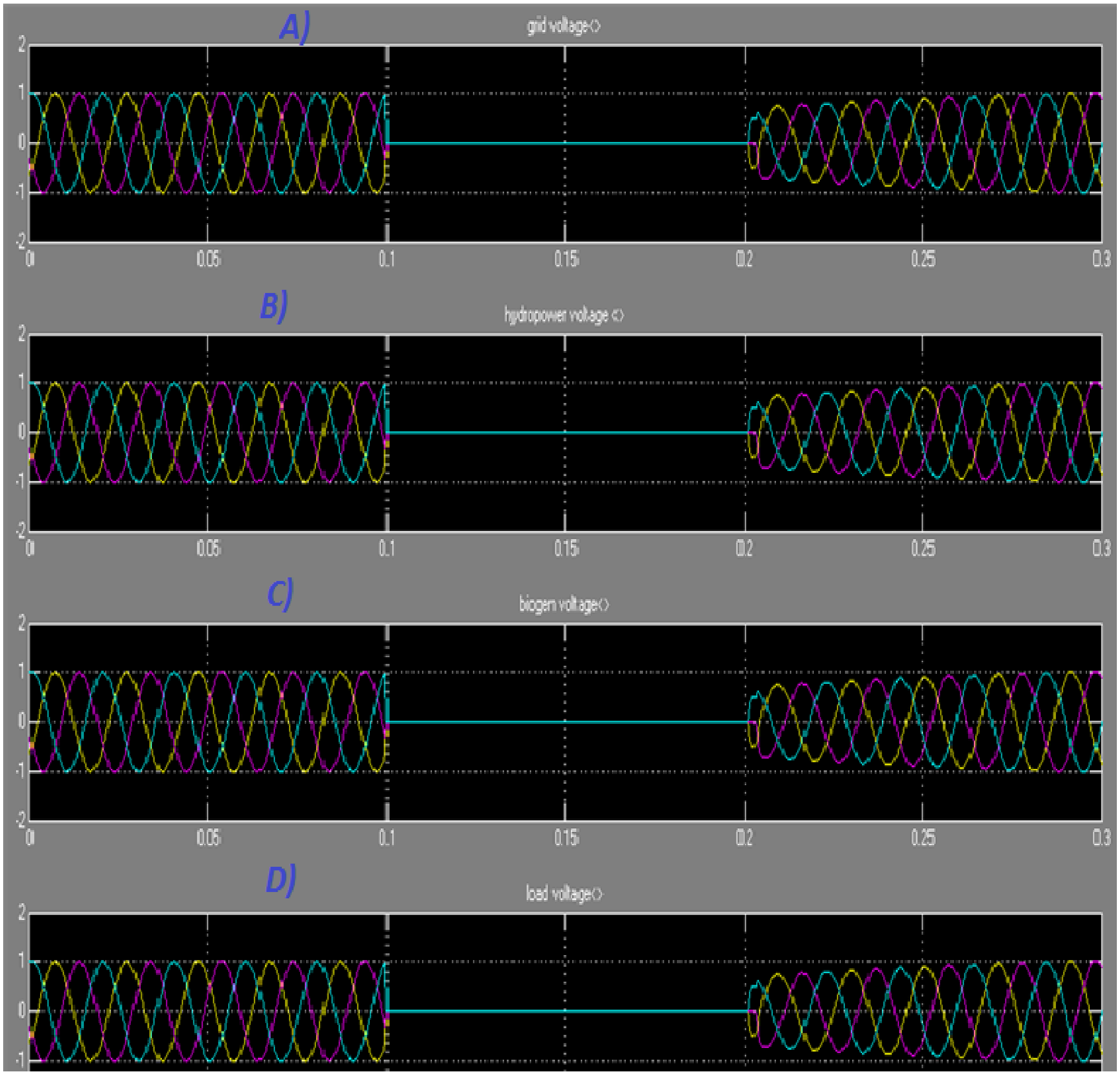


Figure 5.8: Three Phase voltage at fault condition at grid side : A) Grid voltage in pu ,B) Hydropower voltage in pu C) SM terminal voltage in pu and D) Load voltage in pu.

Matlab/Simulink Simulation Result shows that, at steady state condition, there is no active power generated by SM and the excess reactive power will flows-out to the grid, and the terminal voltage of the system is also constant. At fault condition, the terminal voltage drops to zero, and since terminal voltage is zero load power is also zero. After fault clearing and islanding, the SM mechanical power quickly increases from its initial value and its power output is the result of the difference power between load and hydropower generator output.

CHAPTER SIX

6. HOME ALCOHOL DISTILLATION AND STILL TECHNOLOGY

6.1. Distilled Beverage

A distilled beverage or liquor is an alcoholic beverage containing ethanol that is produced by distillation. Ethanol is produced by means of fermenting grain, fruit, or vegetables. This excludes un-distilled fermented beverages such as beer, wine, and cider. Vodka, gin, baijiu, tequila, rum, whisky, brandy, and soju are examples of distilled beverages. The term hard liquor is used in North America and India to distinguish distilled beverages from un-distilled ones (implicitly weaker) [24].

6.2. Fermentation

Fermentation is the conversion of sugar to ethanol and carbon dioxide by yeasts (wort to wash). Whilst doing this, it can create a range of flavours beyond what the wort started with. During fermentation yeast converts sugar into alcohol and carbon dioxide by feeding on a series of increasingly complex sugars, essentially breaking the sugar down into other compounds which enable it to grow. First on the menu is glucose, before moving onto maltose, then maltotriose. Depending on the strain of yeast, these sugars may be tackled at different rates, and not always strictly in sequence. Although sugars account for the majority of flavors, yeast works on various other compounds, including amino acids and fatty acids, which also contribute flavors [25].

$$\underset{\text{Glucose}}{C_6H_{12}O_6} \longrightarrow \underset{\text{Ethanol}}{2C_2H_5OH} + \underset{\text{Carbon Dioxide}}{2CO_2} + \text{Heat} \quad \ldots\ldots\ldots\ldots (6.1)$$

Theoretically 10 kg of sugar will produce 6.5 L (5.1 kg) of ethanol and 4.9 kg (4900L) of carbon dioxide. In doing so, some energy is released too (about 2.6 MJ/kg of ethanol). Yeasts are single-cell fungi organisms. The most important ones used for making ethanol are members of the Saccharomyces genus, bred to give uniform, rapid fermentation and high ethanol yields, and be tolerant to wide ranges of temperature, PH levels, and high ethanol concentrations. Yeasts are facultative organisms - which mean that they can live with or without oxygen.

In a normal fermentation cycle they use oxygen at the start, and then continue to thrive once it has all been used up. It is only during the anaerobic (without oxygen) period that they produce ethanol. The influence of the yeast depends on the sugar concentration in the wort, the pitching temperature and the rate of fermentation. There are three phases to fermentation once the yeast has been added: an initial lag phase, where little appears to be happening, but the yeast is adjusting to its new environment, and beginning to grow in size

After about 30 minutes, the yeast begins to reproduce rapidly and the number of yeast cells increases exponentially (thus known as the exponential growth phase). Carbon dioxide is released in large quantities, bubbling up through the liquor. As the fermentation proceeds, the yeast cells tend to cluster together (flocculate).

The last phase is a stationary phase during which nutrients are becoming scarce, and the growth rates slow down. The evolution of carbon dioxide slows down, and the yeast settles to the bottom of the fermentor.

Under optimal conditions, a yeast cell is able to split its own mass of glucose (i.e. about 200 million molecules) into alcohol and carbon dioxide every second.

6.3. Boiling Point and Distillation

6.3.1. Boiling Point

A liquid at any temperature exerts a pressure on its environment. This pressure, the vapor pressure, results from molecules leaving the surface of the liquid to become vapor and occurs because the molecules are in constant motion [26].

$$(\text{Molecules})_{\text{liquid}} \Leftrightarrow (\text{Molecules})_{\text{vapor}} \qquad (6.2)$$

As a liquid is heated, its kinetic energy increases; the equilibrium shifts to the right and more molecules move into the gaseous state, thereby increasing the vapor pressure. The boiling point of a pure liquid is defined as the temperature at which the vapor pressure of the liquid exactly equals the pressure exerted on it by the atmosphere. For example, at an external pressure of 1 ATM, the boiling point is reached when the vapor pressure equals 1 ATM. Every pure and stable organic compound has a characteristic boiling point at one atmosphere. The boiling point of an organic compound reflects its molecular structure, specifically the type of intermolecular interactions that bind the molecules together in the liquid state. The following table shows the boiling points of water, ethanol and methanol at 1 ATM.

Table 6.1: Boiling points of water, ethanol and methanol at 1 ATM[26]

Compound	Boiling Point(^{O}C)	Density(g/ml)
Methanol	64.7	0.79
Ethanol	78.5	0.79
Water	100.0	1.00

6.3.2. Distillation

Distillation is a method for separating two or more liquid compounds on the basis of boiling-point differences. The boiling point of a mixture is a function of the vapor pressures of the various components in the mixture. Consider, for example, the boiling characteristics of a mixture of water and ethanol. If water alone were present, the vapor pressure above the liquid would be due only to water. However, with water as only a fraction of the solution, the vapor pressure exerted by water (P_{water}) will correspondingly be equal to only a fraction of the vapor pressure of pure water at the same temperature ($P^{o}_{water}X_{water}$), where X is the fraction of molecules of water in solution, call the mole fraction of water. The same is also true for the ethanol component [26].

$$P_{water} = P^{o}_{water}X_{water} \quad (6.3)$$

$$P_{ethanol} = P^{o}_{ethanol}X_{ethanol} \quad (6.4)$$

The total pressure of the solution is the sum of the partial vapor pressure of the individual components. This is shown in Figure 5.1.

$$P_{total} = P_{water} + P_{ethanol} \quad (6.5)$$

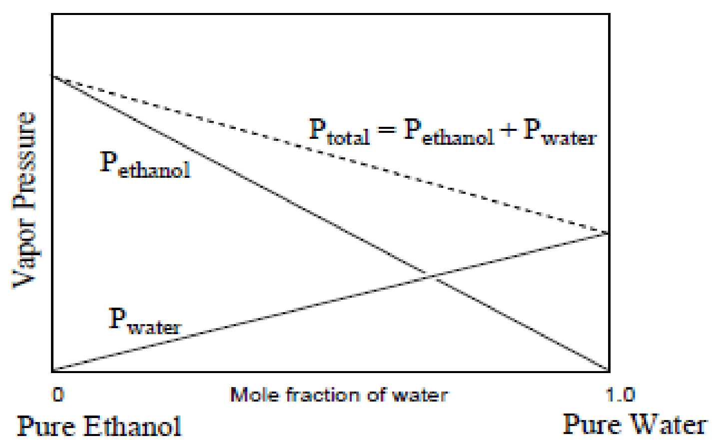


Figure 6.1: Vapor pressure-mole fraction diagram for ethanol-water solutions [27]

If Y stands for the fraction of ethanol molecules in the vapor above the solution:

$$Y_{ethanol} = P_{ethanol}/P_{total} \qquad (6.6)$$

A single expression for the total vapor pressure can be derived easily from equations 3-6 because,

$$X_{ethanol} + X_{water} = 1 \qquad (6.7)$$

$$Yethanol = \frac{Po\ ethanol\ X\ ethanol}{X\ ethanol\ (Po\ ethanol - Po\ water) + Po\ water} \qquad (6.8)$$

If the vapor pressures of pure water and ethanol at various temperatures and composition of the liquid are known, the fraction of ethanol in the vapor above the solution can be calculated. This calculation can be used to construct a temperature-composition diagram (sometimes called a phase diagram) like the one shown in Figure 5.2. Point L1 is the boiling point at atmospheric pressure for a solution with an initial 1:1 mole ratio of ethanol to water. To find the resulting molar composition of ethanol and water in the vapor phase follow the horizontal dotted line to point V.

The mole fraction of the component with the lower boiling point is greater in the vapor than in the liquid. If the vapor at V1 condenses, the liquid that collects will have the same composition as the vapor (V1). Now if the condensed liquid (L2) is re-vaporized, the new vapor will be even richer in ethanol. Repeating the boiling and condensing several more times allows us to obtain essentially pure ethanol.

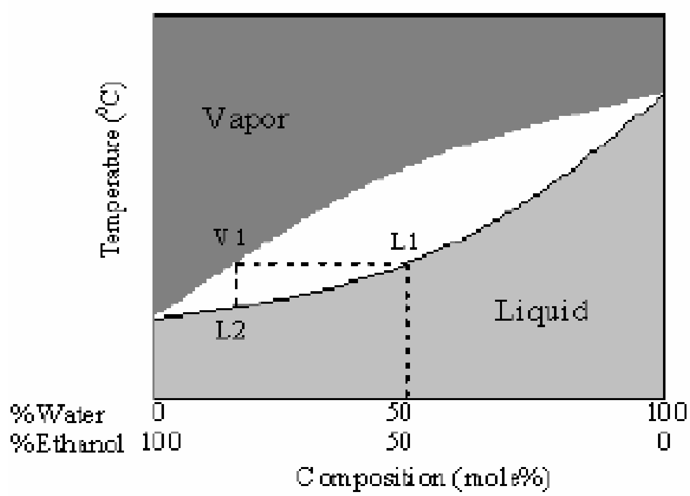


Figure 6.2: Temperature-Composition Diagram for ethanol/water solutions at 1.0 ATM [26]

In a simple distillation, only one vaporization and condensation occurs, corresponding to points L_1 and V_1 in Figure 5.2. The liquid collected is called the distillate. Simple distillation would not effectively separate a mixture whose boiling points differ by less than 60-70^{o}C.

6.3.3. Bubble Point and Dew Point

When heating a liquid consisting of two or more components, the bubble point is the temperature (at a given pressure) where the first bubble of vapor is formed [27] .Given that vapor will probably have a different composition than the liquid, the bubble point (along with the dew point) at different compositions are useful data when designing distillation systems. For a single component the bubble point and the dew point are the same and are referred to as the boiling point.

When a liquid mixture begins to boil, the vapor does not normally have the same composition as the liquid. The components with the lowest boiling point (i.e. the more volatile) will preferentially boil off. Thus, as the liquid continues to boil, the concentration of the least volatile component drops. This results in a rise in the boiling point. The temperatures over which boiling occurs set the bubble and dew points of the mixture [28].

6.4. Chemistry of Water-Ethanol Mixture

Ethanol is best known as alcohol since it contains hydroxyl group (-OH) attached to alkyl carbon [30]. Ethyl alcohol is a straight chain alcohol with molecular formula C_2H_5OH. It is mainly found in alcoholic beverages, as a pure organic solvent and as a alcohol fuel (power alcohol). Water (H_2O) and ethanol molecules mix or dissolve each other, since both the solvents are polar in nature. The hydrogen atom of the Hydroxyl (-OH) group on ethanol and water molecules are polar. The hydrogen bond is formed between the hydrogen of -OH group of ethanol and oxygen of water molecule.

Water-ethanol mixtures at different temperatures exhibit a wide range of dielectric constant, viscosity, density and a high degree of hydrogen bonding effects. Interaction between water and ethanol can be studied at different quantities by the measurement of conductivity over that composition range. Appropriate measurements provide useful indications of solvent-solvent interaction and solvent structure.

Mixed solvents of water-ethanol can be prepared by adding known amount of ethanol to water in volume ratio or mass ratio. Different percentage compositions of ethanol in water, like 10%, 20 %, 30%, 40 % etc can be prepared by mixing known volume of ethanol in water (10 % ethanol = 10 cm^3 ethanol + 90 cm^3 water). Volume fractions of ethanol in water is calculated as, Volume fraction = volume of ethanol / (volume of ethanol + water).

6.4.1. Boiling Points of Aqueous Solutions

Boiling points of aqueous solutions of ethanol depends on the concentration of the each component. Table 6.2 shows boiling point of aqueous solution of ethanol and water.

Table 6.2: Boiling point of aqueous solution of ethanol and water at different concentration [29]

BP °C	Weight % ethanol			BP °C	Weight % ethanol	
	Liquid	Vapor			liquid	vapor
78.1	95.5[‡]	95.5[‡]				
78.2	91	92		86.5	18	71
78.4	85	89		87	17	70
78.6	82	88		87.5	16	69
78.8	80	87		88	15	68
79	78	86		88.5	13	67
79.2	76	85		89	12	65
79.4	74	85		89.5	11	63
79.6	72	84		90	10	61
79.8	69	84		90.5	10	59
80	67	83		91	9	57
80.2	64	83		91.5	8	55
80.4	62	82		92	8	53
80.6	59	82		92.5	7	51
80.8	56	81		93	6	49
81	53	81		93.5	6	46
81.2	50	80		94	5	44
81.4	47	80		94.5	5	42
81.6	45	80		95	4	39
81.8	43	79		95.5	4	36
82	41	79		96	3	33

82.5	36	78		96.5	3	30
83	33	78		97	2	27
83.5	30	77		97.5	2	23
84	27	77		98	1	19
84.5	25	75		98.5	1	15
85	23	74		99	< 1	10
85.5	21	73		99.5	< 1	5
86	20	72		100	0	0

‡Azeotropic mixture

6.4.2. Flammability

These flaming cocktails illustrate that a distilled beverage will readily catch fire and burn [30]. Liquor that contains 40% ABV (80 US proof) will catch fire if heated to about 79 °F (26 °C) and if an ignition source is applied to it. (This is called its flash point. The flash point of pure alcohol is 61.88 °F (16.60 °C), less than average room temperature.)

The flash points of alcohol concentrations from 10% ABV to 96% ABV are

- 10% — 120 °F (49 °C) — ethanol-based water solution
- 12.5% — about 125 °F (52 °C) — wine
- 20% — 97 °F (36 °C) — fortified wine
- 30% — 84 °F (29 °C)
- 40% — 79 °F (26 °C) — typical whisky or brandy
- 50% — 75 °F (24 °C) — strong whisky
- 60% — 72 °F (22 °C)
- 70% — 70 °F (21 °C) — absinthe
- 80% — 68 °F (20 °C)
- 90% or more — 63 °F (17 °C) — neutral grain spirit

Beverages with low concentrations of alcohol will burn if sufficiently heated and an ignition source (such as an electric spark or a match) is applied to them. For example, the flash point of ordinary wine containing 12.5% alcohol is about 125 °F (52 °C).

6.5. Home Alcohol Distillation Equipment

Distillation is a method of separating mixtures based on differences in volatility of components in a boiling liquid mixture. Distillation is a unit operation, or a physical separation process, and not a reaction. The premises where distillation is carried out, especially distillation of alcohol are known as a distillery. Still is the apparatus used for distillation [30] .

6.5.1. Home Alcohol Distillation Still

There are different still types depending on the required alcohol content. These are: - pot still, reflux still and fractionating column [30].

Pot Stills

Pot stills can range in size from small stove top stills, to larger stills made from unwanted stainless still beer kegs. Some are hand crafted from copper sheet and riveted and soldered together.

A pot still simply collects and condenses the alcohol vapors that come off the boiling mash. This will result in an alcohol at about 40-60% purity, with plenty of flavor in it. If this distillate were put through the pot still again, it would increase in purity to around 70-85% purity, and lose a bit of its flavor [30].

Reflux Stills

A reflux still does these multiple distillations in one single go, by having some packing in a column between the condenser & the pot, and allowing some of the vapor to condense and trickle back down through the packing. This "reflux" of liquid helps clean the rising vapor and increase the % purity. The taller the packed column, and the more reflux liquid, the purer the product will be [30].

Fractionating Still

A Fractionating column is a pure form of the reflux still. It will condense all or most of the vapor at the top of the packing, and return about 9/10 back down the column. The column will be quite tall and packed with a material high in surface area, but which takes up little space (pot scrubbers are good for this). It will result in an alcohol 95%+ pure (the theoretical limit without using a vacuum is 95.6%), with no other tastes or impurities in it [30].

6.5.2. Thermometer

Two thermometers are needed, one for the fermentation and one for the still. The one on the fermentation doesn't need to be too accurate; it's only a guideline. It should show between about 10 ^{o}C and 40 ^{o}C . Using a thermometer with the fermentation helps to keep yeast in its ideal range. Reasonably good thermometer is needed for the head of the still (from 40 ^{o}C to 105 ^{o}C). The longer the thermometer, with the more space between the markings, the more accurate it will be. For pot stills the thermometer needs to be mounted in the head, whereas it should be at the top of the packed column in reflux still. In both cases, it's just prior to the final condenser [30].

6.5.3. Hydrometer

Two Hydrometers are required; one for the wort, and one for the spirit. These work by measuring the density of the liquid. If the liquid is dense (e.g. water with sugar in it), they will float up high in the liquid; if the density is low (e.g. half the liquid is alcohol), they will float lower in the liquid .The one for the wash is the standard hydrometer used by beer or wine-makers, good for specific gravities of 1.100 to about 0.970. It is used to work out how far the wash has fermented, and therefore how much alcohol is found in the wash. The one for the spirit is made for much lighter specific gravities. It is usually made with the scale reading between 0 and 100% alcohol, so it saves having to do any math [30].

6.5.4. Fermenter

This is just a clean bucket or tub or barrel. The fermenter has to be able to be easily cleaned and sterilized. It should have a good lid on it to keep out dust and bugs, and also an airlock. The airlock is an "S" shaped bit of tubing that holds some water in it - outgoing gases can bubble out through the liquid, but nothing tends to find its way in. A simple alternative is to just run a tube from the top of the fermenter, ending in a jar half filled with water. Once the yeast is off and running, there should no oxygen in the system, or else the yeast will forget about making alcohol, and just make more yeast [30].

6.5.5. Heating Element

Electric heater is preferably since it easy to regulate the power and no flame source to ignite stray vapors. Keeping the element within the vessel further reduces the risk; however it needs to be positioned such that it can be easy to clean around it. Internal also means that the minimum amount of liquid in the still have to kept, so that it will not boil dry. Some stills are mounted with two elements the second is used to speed up the pre-heating period, and the size of heat source matters the time of heating.

Gas for heating is perfectly safe as long as it doesn't come into contact with alcohol; the naked flame must not come into contact with alcohol either in the liquid or vapor forms. At a very low ABV % nothing will happen, in the middle range the alcohol will burn, and at a high ABV % it will detonate and explode [30].

6.6. Materials to Use for Still Construction

To make still, care must be taken to avoid using solder which contains lead or cadmium. Both of these are poisonous, and are bad for anyone who would consume the end product. Silver solder is best instead. Only food grade type materials (example, stainless steel, copper, glass, etc) are used [30].

Copper is an interesting case - high levels of it are known to be dubious to health, however it has been (and will continue to be) used for centuries in commercial stills (because of its excellent ability to transfer heat). This is because any dissolution is at such a low rate that we don't get exposed to enough of it. It is well known that the low wines produced in commercial stills can be a light green in color due to their copper pick-up; however they are still below limits prescribed for potable water by health authorities. It would also appear that the copper helps convert some of the esters and organic acids present (which affect taste and odor), so that they're reduced [30].

Materials to use for still construction are summarized as follows [30].

a. Both copper and stainless steel are safe to use. Stainless may be more durable. Copper helps remove sulfides from distillate product.
b. lead & cadmium free solder or brazing
c. Column packing material can be stainless steel scrubbers, pure copper scrubbers or mesh (with careful of copper plated iron), glass marbles, or commercial items like rushing rings.
d. Some of the safest (and also very good results) sealant material is simple flour paste. Certain types (rye flour), may work better than others
e. With a few exceptions (such as small sight glasses), using glass in a still for home hobby spirit distillation, should be usually be avoided, due to safety issues.

f. Glass for spirit collection/storage or aging containers is safe, with the one caveat that a flammable liquid is being stored in a container that can be broken.
g. When collecting into a glass container, this glass container should be placed inside a larger container (such as a stock pot), that is larger than the collection container. If there is any breakage, the entire contents should be held by this secondary container.
h. A glass thumper / slobber box is not safe.
i. There are almost no synthetic materials that can be shown to be safe to use in a home distillations device.
j. Silicone or plastic hoses may be adequate for coolant input and output lines, but should not come in contact with the vapor or product takeoff path.

6.7. Calculation of Condenser Size

To calculate the condenser size the study of heat transfer equipment is important. The transfer of heat to and from process fluids is an essential part of most chemical Processes. The most commonly used type of heat-transfer equipment is the ubiquitous shell and tube heat exchanger [31].The principal types of heat exchanger used in the chemical process and allied industries, are listed below:

1. Double-pipe exchanger: the simplest type, used for cooling and heating.
2. Shell and tube exchangers: used for all applications.
3. Plate and frame exchangers (plate heat exchangers): used for heating and cooling.
4. Plate-fin exchangers.
5. Spiral heat exchangers.
6. Air cooled: coolers and condensers.
7. Direct contact: cooling and quenching.
8. Agitated vessels.
9. Fired heaters.

The general equation for heat transfer across a surface is:

$$Q = UA\Delta T_m \quad \text{……………………………………………………… (5.9)}$$

Where,

Q = heat transferred per unit time, W

U = the overall heat transfer coefficient, $W/m^{2\,o}C$

A =heat-transfer area, m^2

ΔTm = the mean temperature difference, the temperature driving force, ^oC.

The prime objective in the design of an exchange is to determine the surface area required for the specified duty (rate of heat transfer) using the temperature differences available [31].

The overall coefficient is the reciprocal of the overall resistance to heat transfer, which is the sum of several individual resistances. For heat exchange across a typical heat exchanger tube the relationship between the overall coefficient and the individual coefficients, which are the reciprocals of the individual resistances, is given by:

$$\frac{1}{Uo} = \frac{1}{ho} + \frac{1}{hod} + \frac{do \ln\left(\frac{do}{di}\right)}{2kw} + \frac{do}{di} \times \frac{1}{hid} + \frac{do}{di} \times \frac{1}{hi} \quad \text{……..............(5.10)}$$

Where

U_o = the overall coefficient based on the outside area of the tube, $W/m^{2o}C$

h_o =outside fluid film coefficient, $W/m^{2o}C$

h_i = inside fluid film coefficient, $W/m^{2o}C$

h_{od} = outside dirt coefficient (fouling factor), $W/m^{2o}C$

h_{id} = inside dirt coefficient, $W/m^{2o}C$

kw =thermal conductivity of the tube wall material, $W/m^{2o}C$

d_i= tube inside diameter, m

d_o =tube outside diameter, m

The magnitude of the individual coefficients will depend on the nature of the heat transfer process (conduction, convection, condensation, boiling or radiation), on the physical properties of the fluids, on the fluid flow-rates, and on the physical arrangement of the heat-transfer surface. As the physical layout of the exchanger cannot be determined until the area is known the design of an exchange is of necessity a trial and error procedure.

6.8. *Katikala (*Arake*)* Distillation Still Design

6.8.1. Still Type Selection

There are different still types depending on the required alcohol content and cost of construction [30].These are pot still, reflux still and fractionating column. The pot still is appropriate for *Katikala* distillation since pot still simply collects and condenses the alcohol vapors that come off the boiling mash with an alcohol at about 40-60% purity. As it is discussed before, the average alcohol content of *'dagim araki'* is around 45%. If this distillate is put through the pot still again, it would increase in purity to around 70-85% purity, but lose a bit of its flavor [30].In addition, the cost of construction for pot still is also less than other still types. Thus, it is relativity affordable.

6.8.2. Pot Still Designs Concepts

There don't seem to be many instructions around for how to build pot stills. There are just so many ways, and it really depends on what material is available. One factor to consider is the angle of the lyne arm. Even with pot still we can get a little bit of vapor condensing on the head and arm, and running back down into the pot as a bit of reflux. Depending on how much internal reflux is going on, the flavor will vary. An upward sloping arm will cause much to run back into the pot, thus cleaning & lightening the vapor more, whereas a downward sloping arm will send the entire vapor towards the jar, and the heavier flavor will be collected. Downward slope arm is considered in this study [25].

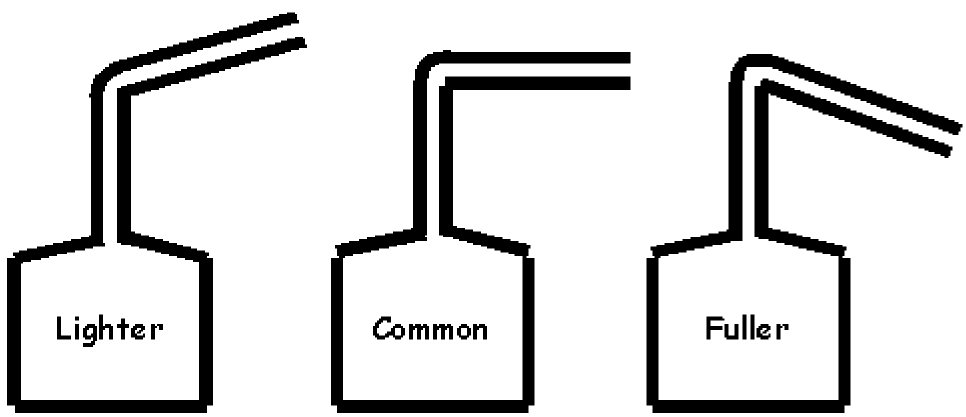


Figure 6.3: Layout of lyne arm for pot still [25].

The diameter of the tubing depends on the heat - for most stovetop models (typically built out of a pressure cooker) 1/4 to 1/2inch tubing is used for the lyne arm and the condenser. The narrower the tubing is, the lower the heat setting needed to use. The condenser running off of the pot still can be whatever diameter available (provided it's no smaller than 1/4"). Also, we don't have to have a coiled-tube condenser-we can use a jacketed model just as easily. With stovetop pot stills, there is a lot of room to adjust the materials dimensions, because the heat source is so easily adjusted [25].

Boiler/ Pot: Boiler pot can be made from a number of already available items. Old hot water cylinders, pressure cookers, Milk can, Converted Stainless steel Beer Keg, Copper water heater tanks. To hold 20 L at least another 1/4 spare for foam is required .Thus, something in the 25-30L range is good. The more surface area is easier for the vapor to come off. So wide is good rather than tall for the boiling pot.

Condenser: The amount of alcohol in the wash is determined by the boiling temperature not the amount of power supply. Extra power supply increase the amount of vapor produced; perhaps it can cause problems if the column diameter is too small. Thus, the power input should match to the column size. Some stills have two heating elements to give the extra boost while heating up to temperature, and then just switch back to one, to keep it simmering while doing the distilling.

Condenser size is calculated by considering the temperature and composition of vapor, temperature of cooling water, the desired temperature of the distillate, flow type of cooling water around the tube and also the shape of the tube (vertical or horizontal) [25].However, we can also use a few simplifying guesses to give an idea of what size it could be, for far less effort. The hardest bit is the “heat transfer coefficient". This describes what’s going on inside & outside the cooling coil or tube, as well as the heat transfer properties of the tube [31].

The heating element is more relevant than the size of the pot. If the outlet temperature of the water is kept law the length of the condenser is reduced. But then the flow rate of water needed increases. If we going for the "coil in a tub" approximately, the "cooling water outlet temperature" refers to how the tub would typically get to at the end of the run [25].

6.8.3. Proposed Pot Still Design

These sections discuss about the design of new *Katikala* distillation still to replace the traditional pot. These can be made from a number of readily available items. Appendix B shows the materials used for this research .This is relatively cheap and easy to make.

Boiler/Pot: Normal 10 litter pressure cooker that is made from stainless still was used. To avoid leakage it was sealed with gasket. Quarter of the boiler is required for the formed foam. The 6 L was filled in 10 litter boiler.

Outlet arm: 80 cm of 16mm (2/3in) soft copper tube, weld to form a "lyne arm", up 30cm vertically then 50cm long inclined downward. Then 25 cm, 16mm to 10mm reducer for coiled copper condenser part since 10mm soft copper tube is easily bent without flattening.

Heating element: 500 watt stove top electric heating element is considered because the wash used is small (6 litter) and stove for heating element is easy to use for this study purpose.

Thermometer: Mercury thermometer to measure pot vapor temperature at the top of vertical arm is used.

Condenser: 20 Littre plastic buckets with, coiled 150 cm, 10mm copper tubing is used.

Figure 6.4: New Designed Pot Still [by the author]

Figure 6.5: Material Used For Testing [by the author]

6.8.4. Distillation Test Result and Discussion

To check any leakage and for cleaning purpose the first run was made by water. It also used to check the required time to get to the required temperature. After that, the fermented wash which was bought from *katikala* producer was added to the boiler. The 3/5 of the still was left empty as head space for foam, bubbles, splashing and so on.

The first 10 mm^3 product was removed for the sake of purity. In the first run of the fermented wash the temperature was stabilized at 89 ^oC and the purity of the collected alcohol was 46 ABV. Then the temperature was rising gradually as the alcohol content in the wash decreases. There was corresponding change of purity of distillate/ ethanol as the head temperature change. Long time (1 hour) was required to reach the maximum temperature since the stove used was 500 watt. Perhaps the time required could have been lower if high power stove was used or the temperature controller was removed so that it heats up continuously.

The cooling water temperature was around 40 ^oC . It is shown that, as the cooling water temperature rises the collection of distillate slows down. The result of the distillation in terms of time, vapor temperature and alcohol content of vapor is summarizing in Table 6.3.

Table 6.3: Distillation test result of designed pot still [by the author].

S.no.	Time (Minutes)	Temperature	Total % of Alcohol	Remark
1	20	89	46	High % ABV
2	40	90	44	High % ABV
3	60	91	43	High % ABV
4	80	92	42	High % ABV
5	100	93	40	Low % ABV
6	120	94	38	Low % ABV
7	140	95	34	Low % ABV
8	160	96	30	Low % ABV

6.8.5. The Comparison between Newly Designed Pot Still and Traditional Still

To compare the newly designed pot still with the traditional one, 12 liter of fermented wash was taken to run two times with 6 litter in each run. Traditional *Katikala* producer expect only 40 liter katikala of unknown concentration from total 240 liter wash. The alcohol content of the wash is around 12 ABV.

They even do not know the factories which affect the quality of the product. They make distillation two times. The first run is to get high purity alcohol and the second run is to extract the remaining alcohol from the wash so that it has very law purity alcohol called '*Tera*'.

The run by using the newly designed pot was started by fixing the maximum temperature at 96 ^{o}C .The summarized distillation result of both new still and traditional still is shown on Table 6.4.

Table 6.4: Comparison of distillation result of both new still and traditional still [by the author].

S.n	Parameters		New still	Traditional still
1	% of Alcohol purity (ABV)	At first run to get high purity	Total collected ,42% ABV at temperature up to the end of 92 ^OC	35 ABV % with visible impurities
		At tail to extract All alcohol from wash	Total collected ,30 % ABV at temperature from end of 92 to 96 ^oC	About 10 % ABV with visible impurities
2	Total Yield from 12 litter wash		1.5 litter of 42 % ABV and 1 litter of 30 % ABV	1.3 litter of 35 ABV and 0.7 litter of 10 ABV
3	Heat up and Distillation time	For high % ABV	1 hour until required Temperature and 1.3 distillation times, total of 2.3 hrs at each run up to 42 % ABV	Minimum of 6 hours
		For low % of ABV	0.7 hours at each run	Minimum of 4 hours
5	Air pollution and CO^2 emission in the kitchen		No CO_2	High pollution and suffocation in the kitchen
6	Cost of energy used		0.5KW x 3 x 0.4277 =0.64 birr	9 birr

The quality of the best *Katikala* known as *"Arefa Areke"* was also compared with the produced one. The alcohol content was found to be 43 ABV which is lower than the newly produced *Katikala* at temperature less than 91 ^oC .

6.8.6. Advantages of New Still

- Low cost of energy used
- High purity of alcohol
- High product of alcohol
- Less time of distillation
- No CO_2 emission
- Small area of kitchen required
- Less man power to run distillation
- Less human health problem because of kitchen pollution
- High option to produce the required concentration of alcohol
- Long life of still
- Leakage controllability

CHAPTER SEVEN

7. CONCLUSION, RECOMMENDATIONS AND FUTURE WORK

7.1. Conclusion

A distributed power generation system which comprises of small hydro, biogas generator and grid has been discussed in this thesis ; to achieve a cost effective system configuration which is supposed to supply electricity to ArsiNegele town by considering the 6000 households, out of which 77% produce *katikala*; and average load demand for the HHS, Schools, Hospitals, Straight light, offices in the town and water pump to the town to improve the life of people where electricity from the main grid is not reliable .

Before the design of the distributed generation system was started, the hydropower and biogas energy potentials of the area under study were studied. Then, based on these potentials, a design of a grid connected DG electric power supply system for the town has been conducted.

The study of the renewable potentials of the site is based on site survey, the recently sampled data obtained from the ANCEDA, and from ministry of water and energy.

The analysis of the renewable energy resources data has been carried out by HOMER software. From the results, the hydro power potential of the site is found to be considerable, although it may not be sufficient for a large load.

The results also confirmed the availability of huge utilizable biomass energy at the site.

The COE of the feasible setups in this study, which is in the range of 0.031 $/kWh to 0.033 are comparable to the tariff in the country.

This system is grid-connected; when there is excess small hydro/grid power available (small electric load) biogas power turns off to minimize running cost. When there is a deficit in power generation from small hydro/grid, the biogas will begin to produce power which is equal to load demand. Hybrid hydro, grid and biogas offer greater reliability than any one of them alone because the energy supply does not depend entirely on any one source. In general the system works properly for both condition; when the load stepped-up and the grid-disconnected.

Steady state simulation shows how the generators coordinate each other due to control scheme.

At fault condition, the biogas generator power output is the result of the difference power between load demand and grid and hydro generator output.

The design of new distillation still started by first studying properties of katikala, the theoretical back ground about fermentation, boiling point and distillation, chemistry of water-ethanol mixture , i e. boiling points of aqueous solutions and Flammability, home alcohol distillation equipment's and materials to use for still construction. Industry visit at Nation alcohol and liquor gave me good understanding about alcohol distillation. Then the Proposed pot still was designed and made with available items. Then after cleaning, the fermented wash was added to the boiler and the distillation run. From the test of new distillation still, it was observed that there is corresponding change of purity of distillate/ ethanol as the head temperature changes. As the cooling water temperature raises the output distillate slows down. The boiling point of pure ethanol is 78.4 ^{o}C whereas the boiling point of water is 100 ^{o} C. The Boiling points of aqueous solutions of ethanol and water ranges somewhere between 78.4 ^{o}C and 100 ^{o} C depending on the concentration of both components. The temperature is stabilized at 89 ^{o}C fist which show that the alcohol content of the wash is around 12 ABV. In general using new still has many advantages over the traditional still, like low cost of energy used, controllability of alcohol purity, high product of alcohol from one run, less time of distillation, no carbon dioxide emission, small area of kitchen required, less human energy wasted to run distillation, less human health problem because of kitchen pollution, High option to produce the required concentration of alcohol, long life of still and leakage controllability.

7.2. Recommendations

The following recommendations are made out of this research; some of them are directed to the researchers while the others are directed to decision makers.

i. Ethiopia has a huge potential of renewable energy resources which can be used for electrification through the off-grid and grid-connected system. Thus, the author of this work recommends that the government, non-governmental Organizations and the private sectors should make combined efforts to minimize the prevailing problems of Katikala production and improve the existing benefits by providing improved distillation still to Katikala producers using more flexible approaches

ii. The implementation for this DGs and new distillation still technology as a pilot system in country can be done if a subsidy is available for this project, this will make it possible for more research, study and analysis.

iii. As far as the environmental aspects are concerned, this kind of DG systems have to be wide spread in order to cover the energy demands of the country, and in that way to help reduce the green house gases and the pollution of the environment.

7.3. Future Work

The following future works will be conducted:

- Study of biogas production from co-digestion of caw dung and *Katikala* by product
- Study of how to implement Hydro/Biogas based DG system for *Katikala* distillation
- Detailed design of biogas digester
- Detailed design of hydropower plant
- The study of solar heater application for *Katikala* distillation
- Study of biogas heater for *Katikala* distillation

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APPENDICES

Appendix A: Glossary

Areke: Araki is a distilled beverage. It is also called Katikala. Ground gesho leaves and water are kept for three to four days and after that a kita made up of teff or other cereals and germinated barley or wheat are added. The mixture is allowed to ferment for five to six days and then distilled. In the villages distillation is carried out with primitive equipment made of gourds and wood. The local beer tella can also be distilled to produce arake.

Dagim Areke: The araki can be redistilled and will then have higher alcohol content. The average alcohol content of dagim araki is around 45%."

Gesho: is common name of *Rhamnus prinoides* used in making local alcoholic beverage in Ethiopia.

Kita: Refers to baked bread made of whole-grain flour.

Teff: An annual grass cultivated for its seed, which is used as a grain and a common name of *Eragrostis tef.*

Appendix B: Load Profile of Arsi Negele

A. LOAD PROFILE FOR HOUSEHOLDS											
	LOADS	Flscent.	TV	Stove	Radio, Computer	Refrigerator	Oven/Enjera Metad	Katikala still	Washing Machine		
	Tn.equip	60,000	6000	12000	12000	6000	6000	30000	4000		
	T.watt.peak	660,000	420,000	14,400,000	600,000	600,000	14,400,000	15,000,000	2000000		
	no.HHSL	6000	6000	6000	6000	6000	6000	6000	4000		
	THO	4	6	3	13	24	4	17	3		
NO.	Hours/24									Total power (watt)	Total power (KW)
1	00:00 - 01:00	0	0	0	0	420000	0	15,000,000	0	15420000	15420
2	01:00 - 02:00	0	0	0	0	420000	0	15,000,000	0	15420000	15420
3	02:00 - 03:00	0	0	0	0	420000	0	15,000,000	0	15420000	15420
4	03:00 - 04:00	0	0	0	0	420000	0	15,000,000	0	15420000	15420
5	04:00 - 05:00	0	0	0	0	420000	0	15,000,000	0	15420000	15420
6	05:00 - 06:00	0	0	0	0	420000	0	15,000,000	0	15420000	15420
7	06:00 - 07:00	0	0	14400000	0	420000	0	0	0	14820000	14820
8	07:00 - 08:00	0	336000	0	600000	420000	14,400,000	0	1600000	15,756,000	15756
9	08:00 - 09:00	0	336000	0	600000	420000	14,400,000	0	1600000	15756000	15756
10	09:00 - 10:00	0		0	600000	420000	14,400,000	0	1600000	15420000	15420
11	10:00 - 11:00	0	0	14400000	600000	420000	0	0	0	15420000	15420
12	11:00 - 12:00	0	336000	0	600000	420000	0	15,000,000	0	16356000	16356

13	12:00 - 13:00	0	336000	0	600000	420000	0	15,000,000	0	16356000	16356
14	13:00 - 14:00	0	0	0	600000	420000	0	15,000,000	0	16020000	16020
15	14:00 - 15:00	0	0	0	600000	420000	0	15,000,000	0	16020000	16020
16	15:00 - 16:00	0	0	0	600000	420000	0	15,000,000	0	16020000	16020
17	16:00 - 17:00	0	0	0	0	420000	0	15,000,000	0	15420000	15420
18	17:00 - 18:00	0	0	14400000	0	420000	0	0	0	14820000	14820
19	18:00 - 19:00	528000	0	0	0	420000	14,400,000	0	0	15348000	15348
20	19:00 - 20:00	528000	0	0	600000	420000	0	15,000,000	0	16548000	16548
21	20:00 - 21:00	528000	336000	0	600000	420000	0	15,000,000	0	16884000	16884
22	21:00 - 22:00	528000	336000	0	600000	420000	0	15,000,000	0	16884000	16884
23	22:00 - 23:00	0	0	0	600000	420000	0	15,000,000	0	16020000	16020
24	23:00 - 00:00	0	0	0	0	420000	0	15,000,000	0	15420000	15420

Tnequip=total number of equipment

THO=total hour of opration

T.watt =total watt

no.HHSL=total number of HHs that have specified load

B. LOAD PROFILES FOR SCHOOLS							
NO.	**Hours**	**Lighting for schools**	**Plasma TV for 3 high schools**	**Computer**	**Printer**	**Total power (watt)**	**Total power (KW)**
1	00:00 - 01:00	0	0	0	0	0	0
2	01:00 - 02:00	0	0	0	0	0	0
3	02:00 - 03:00	0	0	0	0	0	0
4	03:00 - 04:00	0	0	0	0	0	0
5	04:00 - 05:00	0	0	0	0	0	0
6	05:00 - 06:00	0	0	0	0	0	0
7	06:00 - 07:00	0	0	0	0	0	0
8	07:00 - 08:00	0	0	0	0	0	0
9	08:00 - 09:00	0	8000	80000	0	88000	88
10	09:00 - 10:00	0	8000	80000	12100	100100	100.1
11	10:00 - 11:00	0	8000	80000	0	88000	88
12	11:00 - 12:00	0	8000	80000	0	88000	88
13	12:00 - 13:00	0	0	80000	0	80000	80
14	13:00 - 14:00	0	8000	80000	0	88000	88
15	14:00 - 15:00	0	8000	80000	0	88000	88
16	15:00 - 16:00	0	8000	80000	0	88000	88
17	16:00 - 17:00	0	0	80000	12100	92100	92.1
18	17:00 - 18:00	0	0	80000	0	80000	80
19	18:00 - 19:00	360	0	80000	0	80360	80.36

20	19:00 - 20:00	360	0	80000	0	80360	80.36
21	20:00 - 21:00	0	0	0	0	0	0
22	21:00 - 22:00	0	0	0	0	0	0
23	22:00 - 23:00	0	0	0	0	0	0
24	23:00 - 00:00	0	0	0	0	0	0

C.PUBLIC UTILITIES LOAD PROFLE								
NO.	**Hours/24**	**Lighting for offices**	**Computer s**	**Hospitals refrigerators**	**Printer**	**Straight light**	**Total power (watt)**	**Total power (KW)**
1	00:00 - 01:00	0	0	1000	0	6000	7000	7
2	01:00 - 02:00	0	0	1000	0	6000	7000	7
3	02:00 - 03:00	0	0	1000	0	6000	7000	7
4	03:00 - 04:00	0	0	1000	0	6000	7000	7
5	04:00 - 05:00	0	0	1000	0	6000	7000	7
6	05:00 - 06:00	0	0	1000	0	6000	7000	7
7	06:00 - 07:00	0	0	1000	0	0	1000	1
8	07:00 - 08:00	0	0	1000	0	0	1000	1
9	08:00 - 09:00	0	70000	3000	0	0	73000	73
10	09:00 - 10:00	0	70000	3000	12100	0	85100	85.1
11	10:00 - 11:00	0	70000	3000	0	0	73000	73
12	11:00 - 12:00	0	70000	3000	0	0	73000	73
13	12:00 - 13:00	0	70000	3000	0	0	73000	73
14	13:00 - 14:00	0	70000	3000	0	0	73000	73
15	14:00 - 15:00	0	70000	3000	0	0	73000	73
16	15:00 - 16:00	0	70000	3000	0	0	73000	73
17	16:00 - 17:00	0	70000	3000	12100	0	85100	85.1
18	17:00 - 18:00	0	70000	3000	0	0	73000	73

19	18:00 - 19:00	3300	70000	3000	0	6000	82300	82.3
20	19:00 - 20:00	3300	70000	3000	0	6000	82300	82.3
21	20:00 - 21:00	3300	0	3000	0	6000	12300	12.3
22	21:00 - 22:00	3300	0	1000	0	6000	10300	10.3
23	22:00 - 23:00	0	0	1000	0	6000	7000	7
24	23:00 - 00:00	0	0	1000	0	6000	7000	7

D.TOTAL LOADS PROFILE					
NO.	Hours/24	Domestic (Households)	Public Utilities	schools	Total Loads
1	00:00 - 01:00	15420	7	0	15,427.00
2	01:00 - 02:00	15420	7	0	15,427.00
3	02:00 - 03:00	15420	7	0	15,427.00
4	03:00 - 04:00	15420	7	0	15,427.00
5	04:00 - 05:00	15420	7	0	15,427.00
6	05:00 - 06:00	15420	7	0	15,427.00
7	06:00 - 07:00	14,820.00	1	0	14,821.00
8	07:00 - 08:00	15,756.00	1	0	15,757.00
9	08:00 - 09:00	15,756.00	73	88	15,917.00
10	09:00 - 10:00	15,420.00	85.1	100.1	15,605.20
11	10:00 - 11:00	15,420.00	73	88	15,581.00
12	11:00 - 12:00	16,356.00	73	88	16,517.00
13	12:00 - 13:00	16,356.00	73	80	16,509.00
14	13:00 - 14:00	16,020.00	73	88	16,181.00
15	14:00 - 15:00	16,020.00	73	88	16,181.00
16	15:00 - 16:00	16,020.00	73	88	16,181.00

17	16:00 - 17:00	15,420.00	85.1	92.1	15,597.20
18	17:00 - 18:00	14,820.00	73	80	14,973.00
19	18:00 - 19:00	15,348.00	82.3	80.36	15,510.66
20	19:00 - 20:00	16,548.00	82.3	80.36	16,710.66
21	20:00 - 21:00	16,884.00	12.3	0	16,896.30
22	21:00 - 22:00	16,884.00	10.3	0	16,894.30
23	22:00 - 23:00	16,020.00	7	0	16,027.00
24	23:00 - 00:00	15,420.00	7	0	15,427.00

Appendix C: HOMER Sensitivity Simulation Result

Hydro Capital ($)	Hydro Life (yr)	Bio-g Life (hrs)	Hydro (kW)	Bio-g (kW)	Grid (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Biomass (t)	Bio-g (hrs)
5670000	40	20000	2835	7000	8000	$ 26,720,000	2,556,770	$ 67,019,448	0.031	0.64	0.00	19,447	8,760
5670000	40	25000	2835	7000	8000	$ 26,720,000	2,556,770	$ 67,019,448	0.031	0.64	0.00	19,447	8,760
5670000	40	30000	2835	7000	8000	$ 26,720,000	2,556,770	$ 67,019,448	0.031	0.64	0.00	19,447	8,760
5670000	45	20000	2835	7000	8000	$ 26,720,000	2,556,770	$ 67,019,448	0.031	0.64	0.00	19,447	8,760
5670000	45	25000	2835	7000	8000	$ 26,720,000	2,556,770	$ 67,019,448	0.031	0.64	0.00	19,447	8,760
5670000	45	30000	2835	7000	8000	$ 26,720,000	2,556,770	$ 67,019,448	0.031	0.64	0.00	19,447	8,760
5670000	50	20000	2835	7000	8000	$ 26,720,000	2,556,770	$ 67,019,448	0.031	0.64	0.00	19,447	8,760
5670000	50	25000	2835	7000	8000	$ 26,720,000	2,556,770	$ 67,019,448	0.031	0.64	0.00	19,447	8,760
5670000	50	30000	2835	7000	8000	$ 26,720,000	2,556,770	$ 67,019,448	0.031	0.64	0.00	19,447	8,760
4252500	40	20000	2835	7000	8000	$ 25,302,500	2,556,770	$ 65,601,952	0.030	0.64	0.00	19,447	8,760
4252500	40	25000	2835	7000	8000	$ 25,302,500	2,556,770	$ 65,601,952	0.030	0.64	0.00	19,447	8,760
4252500	40	30000	2835	7000	8000	$ 25,302,500	2,556,770	$ 65,601,952	0.030	0.64	0.00	19,447	8,760
4252500	45	20000	2835	7000	8000	$ 25,302,500	2,556,770	$ 65,601,952	0.030	0.64	0.00	19,447	8,760
4252500	45	25000	2835	7000	8000	$ 25,302,500	2,556,770	$ 65,601,952	0.030	0.64	0.00	19,447	8,760
4252500	45	30000	2835	7000	8000	$ 25,302,500	2,556,770	$ 65,601,952	0.030	0.64	0.00	19,447	8,760
4252500	50	20000	2835	7000	8000	$ 25,302,500	2,556,770	$ 65,601,952	0.030	0.64	0.00	19,447	8,760
4252500	50	25000	2835	7000	8000	$ 25,302,500	2,556,770	$ 65,601,952	0.030	0.64	0.00	19,447	8,760
4252500	50	30000	2835	7000	8000	$ 25,302,500	2,556,770	$ 65,601,952	0.030	0.64	0.00	19,447	8,760
7087500	40	20000	2835	7000	8000	$ 28,137,500	2,556,770	$ 68,436,952	0.031	0.64	0.00	19,447	8,760
7087500	40	25000	2835	7000	8000	$ 28,137,500	2,556,770	$ 68,436,952	0.031	0.64	0.00	19,447	8,760
7087500	40	30000	2835	7000	8000	$ 28,137,500	2,556,770	$ 68,436,952	0.031	0.64	0.00	19,447	8,760
7087500	45	20000	2835	7000	8000	$ 28,137,500	2,556,770	$ 68,436,952	0.031	0.64	0.00	19,447	8,760
7087500	45	25000	2835	7000	8000	$ 28,137,500	2,556,770	$ 68,436,952	0.031	0.64	0.00	19,447	8,760
7087500	45	30000	2835	7000	8000	$ 28,137,500	2,556,770	$ 68,436,952	0.031	0.64	0.00	19,447	8,760
7087500	50	20000	2835	7000	8000	$ 28,137,500	2,556,770	$ 68,436,952	0.031	0.64	0.00	19,447	8,760
7087500	50	25000	2835	7000	8000	$ 28,137,500	2,556,770	$ 68,436,952	0.031	0.64	0.00	19,447	8,760

7087500	50	30000		2835	7000	8000	$ 28,137,500	2,556,770	$ 68,436,952	0.031	0.64	0.00	19,447	8,760
8505000	40	20000		2835	7000	8000	$ 29,555,000	2,556,770	$ 69,854,456	0.032	0.64	0.00	19,447	8,760
8505000	40	25000		2835	7000	8000	$ 29,555,000	2,556,770	$ 69,854,456	0.032	0.64	0.00	19,447	8,760
8505000	40	30000		2835	7000	8000	$ 29,555,000	2,556,770	$ 69,854,456	0.032	0.64	0.00	19,447	8,760
8505000	45	20000		2835	7000	8000	$ 29,555,000	2,556,770	$ 69,854,456	0.032	0.64	0.00	19,447	8,760
8505000	45	25000		2835	7000	8000	$ 29,555,000	2,556,770	$ 69,854,456	0.032	0.64	0.00	19,447	8,760
8505000	45	30000		2835	7000	8000	$ 29,555,000	2,556,770	$ 69,854,456	0.032	0.64	0.00	19,447	8,760
8505000	50	20000		2835	7000	8000	$ 29,555,000	2,556,770	$ 69,854,456	0.032	0.64	0.00	19,447	8,760
8505000	50	25000		2835	7000	8000	$ 29,555,000	2,556,770	$ 69,854,456	0.032	0.64	0.00	19,447	8,760
8505000	50	30000		2835	7000	8000	$ 29,555,000	2,556,770	$ 69,854,456	0.032	0.64	0.00	19,447	8,760

Appendix D: Some Practical Work Pictures

Figure D:0-1: New Designed Pot Still

Figure D:0-2: Material Used For Testing

Figure D:0-3: New Stove Top Stainless Pot Still

Figure D:0-4:16mm Copper Tube Arm

Figure D:0-5: Mercury Thermometer

Figure D:0-6: Plastic Bucket For Condensing Water

Figure D:0-7: 500 Watt Stove Top Electric Heating Element

Figure D:0-8: Fermented Wash Before Distillation

Figure D:0-9: Areke Residues After Distillation

Figure D:0-10: Alcoholmeter Test To Check The Alcohol Content