DESIGN OF A PHOTOVOLTAIC AND MINI HYDRO POWER GENERATION WITH ENERGY STORAGE TO BUILD ENERGY SUSTAINABILITY (THE CASE OF MERTI METEHARA)

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DEPARTMENT OF ELECTRICAL POWER AND CONTROL ENGINEERING

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Approval Sheet

We, the undersigned, members of the Board of Examiners of the final open defense by Daniel Eshetu Moges have read and evaluated his thesis entitled **"**Design of a Photovoltaic and Mini hydro power generation with Energy Storage to build Energy sustainability**"** and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Master of Science in Electrical Power and Control (Electrical Power) Engineering.

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DECLARATION

I hereby declare that this MSc Thesis is my original work and has not been presented for a degree in any other university, and all sources and materials used for the thesis have been acknowledged.

Signature: ________________ **Date:** July, 2020

This MSc Thesis has been submitted for examination with my approval as this thesis advisor.

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Date of submission 16/07/2020 G.C

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LIST OF ABBREVIATIONS

AC	Alternating Current
Ah	Ampere Hours
BMS	battery management systems
CAES	compressed air energy storage
DC	Direct Current
DGs	Distributed generators
D_{min}	Minimum duty ratio
DOA	Days of Autonomy
DOD	Depth of Discharge
ESS	Energy storage system
Hr	Hour
IEEE	Institute of Electrical and Electronics Engineers
IL	line current
ISH	shunt current
KM	kilo meter
KV	Kilo Volt
KVA	Kilo volt ampere
KVAR	Kilo Volt ampere reactive
KW	Kilo Watt
ms	Millisecond

MW	Mega watt
NA-S	Sodium sulfur
NASA	National Aeronautics and space administration
PCM	phase changing materials
PHS	pumped hydro storage
PV	Photovoltaic
RMS	Root Mean Square
RS	Series resistance
RSH	Shunt resistance
Si	Silicon
SLI	Starting lighting-ignition
SMES	Superconducting Magnetic Energy Storage
SOC	State of charge
VSI	Voltage source inverter

ABSTRACT

The work presented in this thesis concerns the dimensioning of Mini hydro, PV plant and Energy Storage System (ESS) which will be used as an energy buffer for merti metehara area. This ESS should help managing the metehara sugar factory company to inject electricity into their system in order to replace diesel turbine installed there. PV plant with rating of 400kw and mini hydro with rating of 400kw is designed. The capacity of ESS with rating of 400kw is chosen to satisfy peak hour power need for customer. The ESS is charged during peak off period (12:00 am to 6:00 am) from the grid.

Hence cost comparison of PV, mini hydro and ESS with diesel engine is performed. The conclusion of this work is that PV, mini hydro and ESS is cost beneficial and environmental friendly compared with diesel engine. The design of the ESS can be made within an acceptable budget. The capacity of ESS to link with the PV system and mini hydro depends on the priorities of the final output characteristics, and it also depends on which economic parameter that is chosen as a priority. In conclusion, a 1200kw power for 4 hours was produced and stored to satisfy the workers of the company without sustained power interruption. This design aspect increases the reliability and reduces the cost compared to Diesel engine used for backup usage. It is recommended the metehara sugar factory to install renewable energy (solar energy and hydro power energy) with ESS for additional power need.

Key words:-Energy, Environmental friendly, Peak off period, interruption, ESS

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the study

Power generation in the traditional power grid is highly centralized, with power and energy flowing unidirectional from large synchronous generators through a transmission/distribution network to end users. However, the technological issues associated with traditional electric utilities, as well as the environmental problems caused by the combustion of fossil fuels, have stimulated research and development into new power system technologies. With the emergence of distributed energy resource (DER) units, e.g., wind, photovoltaic (PV), battery, biomass, micro-turbine, fuel cell, etc., micro grid technologies have attracted increasing attention as an effective means of integrating such Distributed energy resource units into power systems[1].

Energy supplies from renewable (such as solar, l, photovoltaic, wind, hydro, wave, tidal, ocean and geothermal sources) are essential components of every nation's energy strategy, not least because of concerns for the environment and for sustainability. Sustainable development can be broadly defined as living, producing and consuming in a manner that meets the needs of the present without compromising the ability of future generations to meet their own needs. Reliable energy supply is essential in all economies for lighting, heating, communications, computers, industrial equipment, transport, etc. Almost all national energy plans include four vital factors for improving or maintaining social benefit from energy [4]:

1. Increased harnessing of renewable supplies

2. Increased efficiency of supply and end-use

3. Reduction in pollution

4. Consideration of lifestyle

Nowadays, distributed generation technology is becoming more and more mature, and is employed as key elements of active distribution network working cooperatively with conventional power grids. In addition, the issues of exhaustible natural resources, fluctuating fossil fuel prices and security of electricity have encouraged governments around the world to hold positive attitudes toward the development of emerging micro grids. Future micro grids will allow high renewable penetration and become building blocks of smart grids thanks to advanced communication and information technology. As the underlying scientific and engineering research questions are being answered, there is no doubt that micro grids will play an extremely important role in future electric power and energy systems.

In order to help meet these challenges, energy storage systems can play a significant role by enhancing the operating capabilities of the power system, ensuring its reliability, and lowering the cost while reducing future infrastructure investments. Moreover, energy storage systems, as backup power, can be essential for system stabilization services and emergency preparedness [6].

Thus, this paper work focus on design and model renewable energy (Solar, Mini hydro and ESS) for merti metehara to increase availability of energy for the community and replacing the diesel turbine installed there. The contribution of this thesis is to solve existing problem, i.e power outage happening in merti metehara and during the time when the community gets power from standalone generation the factory use the full power generated from the steam turbine for sugar production.

1.2. Statement of the problem

There is power fluctuation in the production of energy in Merti metehara. Reduction of power generation from the steam turbine leads power outage to community of merti metehara. Metehara sugar factory produce power around 9MW from steam turbine. But steam turbine output power is not constant due to resource of steam variation. Additionally, the company uses diesel engine to compensate the power shortage. But during operation of diesel engine release co_2 and makes the factory dependent on fossil fuel. Therefore fossil fuel must be replaced by renewable energy in order to reduce environment effect. The problem is compensated via integrating storage systems (ESSs) that address several challenges with renewable energy. In this thesis renewable energy integrated with energy storage technologies will be designed and modeled in Merti metehara for sustainable energy usage to that area.

1.3. Objectives

1.3.1. General objectives

The main objective of the thesis is designing and modeling photovoltaic, mini hydro and energy storage system for merti metehara community.

1.3.2. Specific objectives

i. Designing and modeling Photovoltaic and mini hydro power generation

ii. Designing and modeling ESS to Support photovoltaic and mini hydro power generation

iii. Evaluating overall cost of the systems and compare with cost of diesel engine installed in merti metehara.

1.4. Significance of the study

Improved reliability, continuous power supply and minimization of power outages could be achieved. The integration of renewable energy and storage system is used to mitigate supply fluctuations and improve power quality. Energy Storage System in a micro grid also provides benefits for voltage regulation, and operating reserves. Also ESS is useful for managing energy and improving the stability and economy of a micro grid system. Merti metehara is selected as case study because there is power fluctuation to that area. The design of this thesis makes merti metehara to be sustainable power and energy system user.

1.5. Methodology and tools

1.5.1. Methodology

The thesis in the specific topics was clearly studied by reviewing related works. The review done help for the problem intended to solve the problem. Then metrological data was collected from East oromia meteorological agency and Awash flow rate administration. Also from the internet manufacturing data sheet the cost of the equipment was collected and analyzed in detail. To verify performance of the proposed model of storage system, system was designed and modeled. The results of the simulation obtained from the simulating software were analyzed. Finally Conclusion of the thesis has been made.

1.5.2. Tools used

- Homer simulation
- Solar panel
- Mini hydro turbine
- Battery
- Inverter
- Rectifier

1.6. Description of the Study Area

Merti Metehara is Located in the East shewa zone of the oromia region at 200km distance from Addis Ababa. The location is found at latitude of 8.87^0 north and with longitude of 39.91^0 east. There is sugar factory started sugar production in 1970 G.C. It currently has more than 10,000 hectares of land covered with sugarcane. Its average production capacity is 136,692 tons of sugar a year. Through an expansion project conducted, it came up with an ethanol producing plant by the end of 2010.Currently the factory's ethanol plant has a capacity of producing 12,500 meter cube ethanol a year. The company has 10 transformers each rating of 1MVA for its consumption. Additionally the company feeds 12 transformer rating with 100kVA for the community living in merti metehara. The factory generates 9 mega watt electric powers from steam turbine. Recently additional power is taken from grid 1.5MW and 2 diesel turbine (450kw and 400kw).

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Theoretical Literature

Renewable energy resources (e.g., wind, PV) in micro grids can make maintaining grid stability and delivering reliable power challenging due to intermittency and fluctuation issues. Due to the variability and intermittency of renewable distributed generators (DGs), it is difficult to keep the micro grid operating smoothly all the time. Sustainable energy production and the efficient utilization of available energy resources, thereby reducing or eliminating our carbon footprint, is one of our greatest challenges in the 21st century. Thus, energy storage systems (ESS) are very important in renewable micro grids. An aggregated ESS may consist of several storage units. For example, a battery energy storage system (BESS) is composed of hundreds of battery packages [2].

2.1.1. General description about the thesis

Renewable resources like wind and solar are, by nature, variable depending on location and weather conditions. Cloud cover can cause massive voltage spikes in PV voltage outputs whereas wind speeds can vary dramatically over any given hour. These fluctuations bring about immense difficulties to grid planners in charge of dispatching renewable resources as well as to power generators as they try to meet their commitments to the grid.

Several demonstration projects are currently exploring ways in which storage technology can alleviate these problems and ensure quality, stable, power output, ultimately enabling higher penetration of renewable energy sources into the grid. PV and wind power fluctuations on an hourly, daily and annual time scale (and with a regional distribution) can be handled, employing a variety of flexibility technologies, such as demand side management, grid extension or energy storage [8].

The ESS is required to mitigate the dynamic mismatch between load and renewable power generation in the islanded micro grid. Energy storage has increasingly been recognized as a crucial technology to enable the global transformation towards low-carbon, resilient power systems. In addition to enabling more efficient up take of renewable resources, energy storage can directly service the power grid, enhancing grid operations and safety. ESS plays an extremely important role in improving the operating capabilities of micro grids. ESS can be divided into mechanical, electrochemical, chemical, electrical and thermal systems [1].

Table 2.1. Classification and characteristics of energy storage systems

	Technologies	characteristics
Physical storage	• Pumped hydro • Compressed air(supercritical CAES) • Flywheel	• Uses water/air as storage medium • No chemical change • Mechanical to Electrical
Chemical storage	• Lead- acid battery • Lead-ion battery • Flow battery(vanadium,Zn-Br) • Na-s Battery	• Use chemical as storage medium • Battery charges/discharges with chemical change/valence change
E/M storage	• Super capacitor	• Fast response, can release large amounts electric power in short times, high number of cycles
Other storage	• Fuel cell • Metal air battery	• Does not possess "charging" characteristics

There are several applications of ESS including aggregated and distributed ESS in renewable energy micro grids. The micro grid energy management system includes load leveling and peak shifting features, which are widely used to mitigate load fluctuations and improve power quality. ESS is typically used to suppress fluctuations in renewable sources, with methods such as constant power control, output filtering and ramp-rate control. ESS in a micro grid also provides benefits for power quality, voltage regulation, reactive power support, and operating reserves [1].

Interfacing circuits are needed for an ESS to connect to the micro grid. It is beneficial to provide an overview of structures and basic principles of several power converters such as DC-DC converters, AC-DC rectifiers, DC-AC inverters, AC-AC converters. The most important DC-DC converter for an ESS is the bidirectional buck-boost DC-DC converter, which is responsible for the charging and discharging of ESS. For DC-AC converters, the voltage source inverter (VSI) is the most widely used converter in practice [1].

An inverter can be used to integrate an ESS or solar photovoltaic into the micro grid. Within a BMS, cell balancing is important for reliable operation of the BESS. Compared with frequency regulation by wind generation system, a BESS is a better alternative for providing frequency regulation and inertial response in a faster, more accurate and flexible manner. So participation of BESS in an islanded micro grid frequency regulation can assist renewable DGs in operating at their maximum efficiency without excessive power curtailment [1].

Different ESS sizing technologies are evaluated. Cost-benefit analysis is a very common method to determine optimal storage sizing. The implementation of an expansion planning method for optimal storage sizing is included. The objective of this method is to minimize the operating cost, maintenance cost and investment cost of the entire micro grid system [1].

2.1.2. Power generation

Electrical power usually starts at power plants. In merti metehara sugar factory produces electrical energy through steam powered turbines. The waste of sugarcane are burned in order to make water boil and turn into steam which then enters the turbine and pushes against blades to turn the generator shaft to create electric current. Right after the turbine, the steam is usually cooled down and turned into liquid form again in order to increase efficiency.

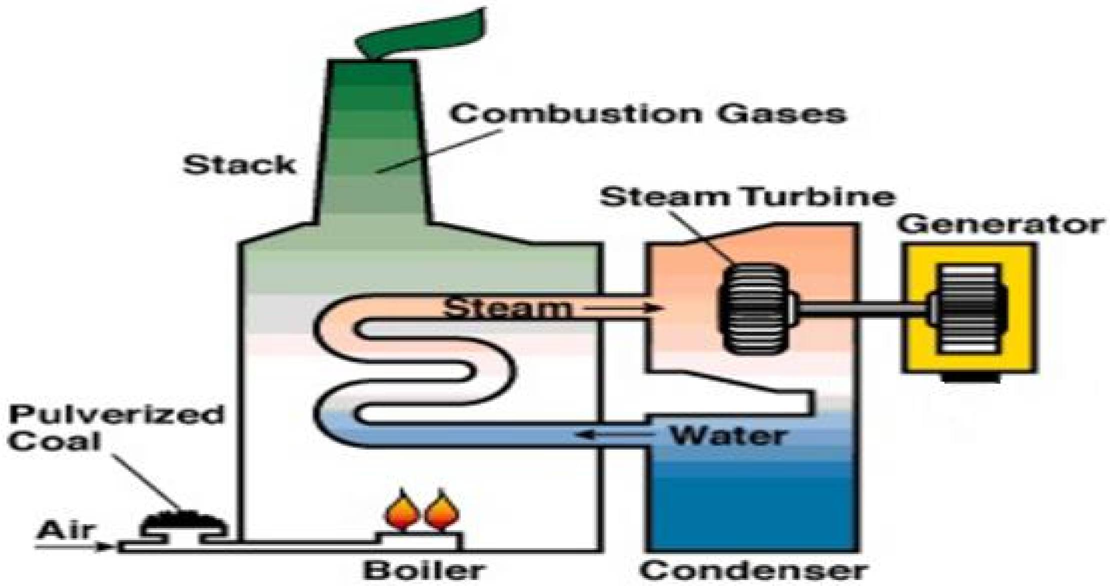


Figure 2. 1. Steam powered power plant [2]

The factory produces 9MW power from steam turbine. The factory use power of 10 transformers each rating of 1MVA and additionally power to customer surrounding the company which are the worker of the company and workers family. The power fed by customer is 12 transformers each rating of 100KVA.Since the power deficiency occurred to the factory uses additional power from diesel engine and from grid.

Solar Photovoltaic System

A PV system or a solar panel is one of the most used sources of renewable energies. There is good solar insolation for the production of energy from the sun in merti metehara. Thus it will be cost beneficial and pollution free power production to that area. Solar PV system includes different components that should be selected according to system type and applications. The major components for solar PV system are solar panels, solar charge controller, inverter, battery bank and loads (appliances).

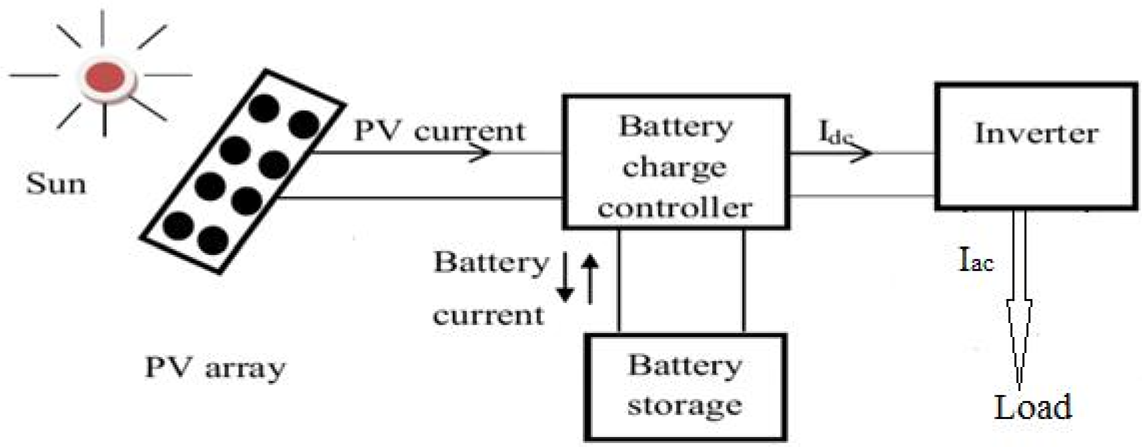


Figure 2. 2. PV system block diagram [9].

To understand the operation of a PV cell, both the nature of the material and the nature of sunlight need to be considered. Solar cells consist of two types of material, often P-type silicon and n-type silicon.

The amount of power available from a PV device is determined by

The type and area of the PV material

The intensity of the sunlight

The most prevalent bulk material for solar cells is crystalline silicon and categorized into.

1. Monocrystalline - silicon (c-Si): Single-crystal wafer cells tend to be expensive, and do not completely cover a square solar cell module without a substantial waste of refined silicon. Its efficiency reaches up to 15 per cent to 18 per cent.

2. Poly or multi crystalline silicon (poly-Si or mc-Si): Poly-Si cells are less expensive to produce than single crystal silicon cells, but they are less efficient. Its efficiency is 13 percent to 16 per cent. Ribbon silicon is a type of multi crystalline silicon.

3. Amorphous or thin-film Silicon: Amorphous (formless) silicon does not form a regular crystal structure, but an irregular network. Its efficiency is 5 per cent to 7 per cent module efficiency (stabilized condition).

Function of the System

The photovoltaic panel receives the sun’s rays (day light) and transforms them into electrical energy. By means of the charge regulator, the energy generated by the panel is conditioned and stored in the battery. The different systems are connected to the charge controller that manages the energy that comes. A photovoltaic system can supply direct current electricity and in different range of different voltages (12V, 24V, 48V, etc...) a 12 V voltage is often used for the rural electrification, is also possible to get alternative current of 110 or 220V.It is possible to convert direct current to alternative current of 220 V, using an inverter 12Vdc/220Vac which allows utilization of television, lighting [5].

Photovoltaic characteristics

As sun irradiance energy is captured by a PV module, the open-circuit voltage of the module increases.

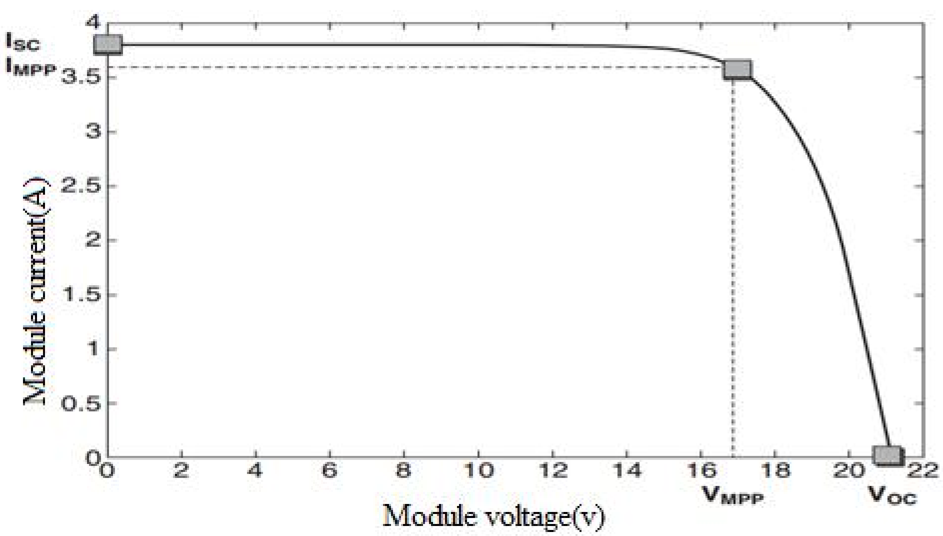


Figure 2. 3. Operating Characteristics of a Photovoltaic Module [9]

The PV fill factor (FF) is defined as a measure of how much solar energy is captured. This term is defined by PV module open circuit voltage (Voc) and PV module short - circuit current (Isc). This term is defined by PV module open circuit voltage (Voc), and PV module short - circuit current (Isc).

$$FF = \frac{VmppImpp}{VocIoc} \tag{2.1}$$

And

P_{max}=FF*V_{oc}*I_{SC} = V_{mpp} I_{mpp}

The maximum value for FF is unity. However, this value can never be attained. Some PV modules have a high fill factor. In the design of PV system a PV module with a high FF would be used. For high - quality PV modules, FFs can be over 0.85. For typical commercial PV modules, the value lies around 0.60.

Photovoltaic efficiency

The PV module efficiency, η is defined as:

$$\eta = \frac{VmppImpp}{Ps} \tag{2.2}$$

PS is the surface area of the module.

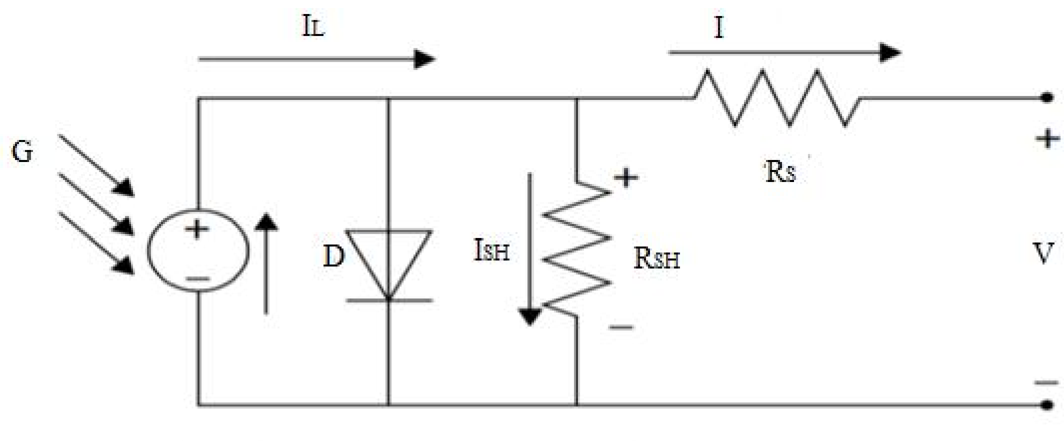


Figure 2. 4. Circuit of a PV cell [2]

Following the circuit and considering the solar cell to be an ideal one, we assume that RSH =∞ and RS = 0.

We get the net output current for the PV:

$$I = I_L - I_o(e^{\frac{q(V+IR_S)}{nKT}} - 1) - \frac{V + IRs}{R_{SH}} \tag{2.3}$$

Advantage of Photovoltaic Power Generation

i. PV system is long lasting sources of energy which can be used almost anywhere.

ii. PV systems can also be installed in a distributed fashion, i.e. they don't need large Scale installations it can be installed on roofs, which mean new space may not require and each user can quietly generate their own energy.

iii. PV systems have no moving parts and no noise or pollution is created from their Operation that makes them the safest method of power generation, and requires little maintenance and has a long lifetime.

iv. The environmental impact of a photovoltaic system is minimal, requiring no water for system cooling and generates no by-products.

2.1.3. Types of storage Technologies

2.1.3.1. Flywheels

Flywheel is a disk with a certain amount of mass that spins, holding kinetic energy. Modern high-tech flywheels are built with the disk attached to a rotor in upright position to prevent gravity influence. They are charged by a simple electric motor that simultaneously acts as a generator in the process of discharging. The spinning speed for a modern single flywheel reaches up to 16.000 rpm and offers a capacity up to 25kilowatt hours (kWh), which can be absorbed and injected almost instantly [1].

Advantages of flywheels

+ Low maintenance and long lifespan: up to 20 years

+ Almost no carbon emissions

+ Fast response times

+ No toxic components

Disadvantages of flywheels

- High acquisition costs

- Low storage capacity

- High self-discharge (3 –20 percent per hour)

2.1.3.2. Superconducting Magnetic Energy Storage (SMES)

The system consists of three major components: the coil, the power conditioning system (PCS) and a cooling system. The idea is to store energy in the form of an electromagnetic field surrounding the coil, which is made of a superconductor. At very low temperatures, some materials lose every electric resistance and thus become superconducting. The superconducting magnetic storage system (SMES) makes use of this phenomenon and in theory stores energy without almost any energy loss (practically 90 –95 percent efficiency).

However, since relevant superconducting materials are only known to work below -253° centigrade (C) (20º Kelvin [K]) (e.g. niobium-titanium -264º C [9º K], niobium-tin -255ºC [18 K]) a system to cool the components down to those temperatures is required. This can be accomplished by liquefying helium; but, it is very expensive and the process lowers the efficiency [2].

Advantages of Superconducting Magnetic Energy Storage

+ Fast respond times

+ Capable of partial and deep discharges

+ No environmental hazard

Disadvantage of Superconducting Magnetic Energy Storage

- High energy losses (~12 percent per day)

- Very expensive in production and maintenance

- Reduced efficiency due to the required cooling process

2.1.3.3. Batteries

A battery is a device that produces electrical energy from chemical reactions. There are different kinds of batteries with different chemicals. The idea behind them is that the two different chemicals within a battery cell have different loads and are connected with a negative (cathode) and the other with a positive electrode (anode). When connected to an appliance the negative electrode supplies a current of electrons that flow through the appliance and are accepted by the positive electrode [2].

A battery is a device that stores direct current (dc) electrical energy in electrochemical form for later use. The amount of energy that will be stored or delivered from the battery is managed by the battery charge controller. Electrical energy is stored in a battery in electrochemical form and is the most widely used device for energy store in a variety of application. The conversion efficiency of batteries is not perfect. Energy is lost as heat and in the chemical reaction, during charging or recharging. Because not all battery's can be recharged they are divided in two groups. The first group is the primary batteries which only converts chemical energy to electrical energy and cannot be recharged. The second group is rechargeable batteries. Rechargeable batteries are used in hybrid power generation system.

The internal component of a typical electrochemical cell has positive and negative electrodes plates with insulating separators and a chemical electrolyte in between. The cells store electrochemical energy at a low electrical potential, typically a few volts. The cell capacity, denoted by C, is measured in ampere-hours (Ah), meaning it can deliver C A for one hour or C*n A for n hours, [Luque and Hegedus, 2003].Many types of batteries are available today, such as Lead-acid, Nickel cadmium, Nickel-metal, Lithium-ion, Lithium-polymer and Zinc air. Lead-acid rechargeable batteries continue to be the most used in energy storage applications because of its maturity and high performance over cost ratio, even though it has the least energy density by weight and volume.

The deep-cycle version, on the other hand, is suitable for repeated full charge and discharge cycles. Most energy store applications require deep-cycle batteries [Patel, 2006].Depth of discharge is import factor for the battery. It refers to how much capacity will be used from the battery. Manufacturers generally rate their batteries at 25ºC. The battery's capacity will decrease at lower temperatures and increase at higher temperature. The battery's life increases at lower temperature and decreases at higher. It is recommended to keep the battery's storage system at 25 ºC.

Lead-Acid Batteries

The lead-acid battery is the oldest known type of rechargeable battery and was invented in 1859 by the French physicist Gaston Planté. Even though the concept is over 150 years old the lead-acid battery is still known for its cost-effectiveness today. A lead-acid battery usually has several in-series connected cells, each delivering 2 volts (V) and each consisting several spongy pure lead cathodes, positive loaded lead oxide anodes and a 20 –40 percent solution of sulfuric acid that acts as an electrolyte.

When discharged, both the anode and the cathode undergo a chemical reaction with the electrolyte that progressively changes them into lead sulfate that releases electrical energy in the process. This reaction can be almost completely reversed by supplying the electrodes with electricity, which is the reason a lead-acid battery can be recharged. The cycle life and the ability to tolerate deep discharges depend on the type. Starting lighting-ignition (SLI) batteries used in cars are not designed to be discharged to more than 50 percent as they have thinner lead plates. Doing so on a regular base will damage them and shorten their cycle life dramatically, whereas deep cycle batteries with thicker plates can handle this much better but are as a result heavier and bulkier.

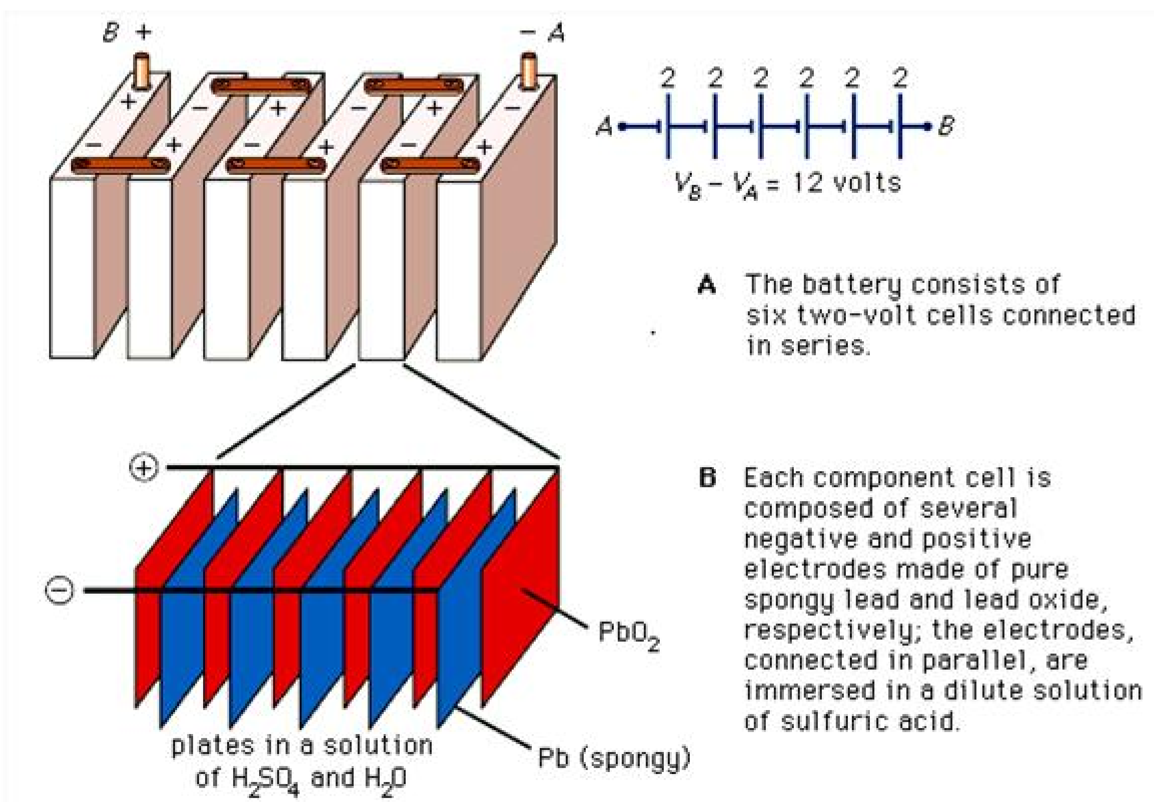


Figure 2. 5. The inside of a lead-acid battery [2]

Advantages of Lead acid battery

+ Easy and therefore cheap to produce

+ Mature technology, more than 150 years of experience and development

+ Very high surge-to-weight-ratio; capable of delivering a high volt of electricity at once, which is why they are so suitable as car starters

+ Easily recyclable

Disadvantages of Lead acid battery

- Very heavy and bulky

- Rather short lived

- Environmental concerns: although pretty safe, lead is very toxic and exposure can cause severe damage to people and animals

- Corrosion caused by the chemical reactions.

Lithium-Ion Batteries

Lithium is the lightest metal with the highest potential due to its very reactive behavior, which, in theory, makes it very fitting as a compound for batteries. Just as the lead-acid and most other batteries the Lithium-Ion battery by definition uses chemical reactions to release electricity. Although all are called lithium-ion batteries, there’s a variety of types with slightly different chemical compounds. The construction looks somehow similar to a capacitor, using three different layers curled up in order to minimize space. The first layer acts as the anode and is made of a lithium compound; the second one is the cathode and is usually made of graphite. Between anode and cathode is the third layer the separator as suggested by the name, separates them while allowing lithium-ions to pass through.

The separator can be made of various compounds allowing different characteristics and with that, different benefits and flaws. In addition, the three layers are submerged in an organic solvent – the electrolyte, allowing the ions to move between the anode and the cathode. In the charging process, the lithium ions pass through the micro porous separator into spaces between the graphite (though not compounded), receiving an electron from the external power source [2].

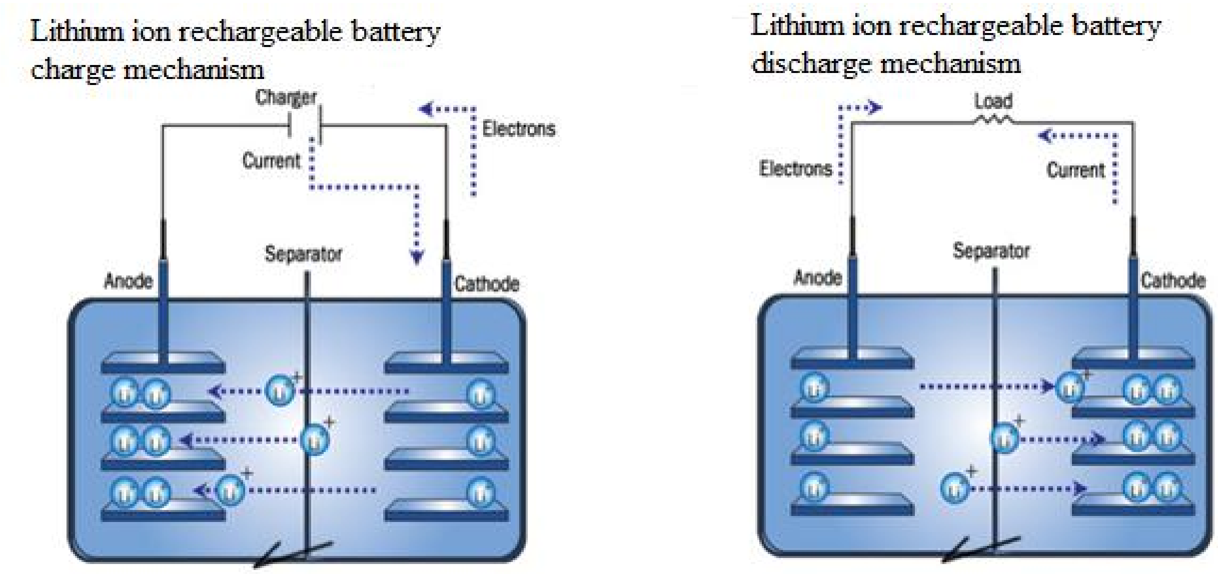


Figure 2. 6. Charge and discharge of Li ion batteries [2]

Circuit of a Battery

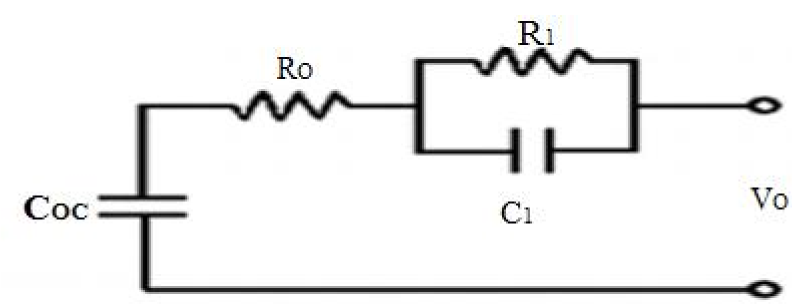


Figure 2. 7. Circuit of a Battery [15]

The following equation is used to calculate the SOC:

$$SOC = 100(1 - \frac{1}{Q}\int_0^t i(t).dt) \qquad (2.4)$$

SOC: the state of charge (%).

Q: the maximum battery capacity (Ah).

i: battery current.

For the discharge voltage:

$$V = E_o - R * i - k \frac{Q}{Q - it}(it + i^*) + Vo(t) \tag{2.5}$$

where E_0: battery constant voltage.

R: internal resistance.

i: battery nominal current.

K: polarization constant.

Q: battery capacity.

it: actual battery charge,

i*: filtered current.

For the charge voltage:

$$V = E_o - R * i - k \frac{Q}{it - 0.1Q} \times i^*) - k \frac{Q}{Q - it} \times it + Vo(t) \tag{2.6}$$

Advantages of Lithium ion battery

+ Highest energy density in commercial available batteries with huge potential

+ Provides higher voltages per cell (3.7V compared to 2.0V for lead-acid)

+ Low energy loss: only about 5 percent per month

+ Lithium and graphite as resources are available in large amounts

Disadvantages of Lithium ion battery

-Very expensive

- Complete discharge destroys the cells

- Deteriorates even if unused (Lifecycle of about 5 years)

- Lithium is flammable in contact with atmospheric moisture

Other Batteries in Development

i. Vanadium Redox-Flow Battery

The electrolytes of redox-flow batteries can be exchanged. This feature makes it very easy to charge electric cars simply by refueling. Other benefits of redox-flow battery include a long lifetime of about 40 years, and a capacity that can be easily increased by simply increasing the number of tanks and adding more electrolytes. However, the energy density of redox battery is very low, commonly 35 Wh/kg. Vanadium redox batteries possess quick responses, even faster than 0.001 s and they have cycle life in the range of 10,000 to over 16,000 cycles. They have a RTE of ~85% and can guarantee continuous power with discharge duration of over 24 h. They are suitable for enhancing power quality, uninterruptible power supply UPS, forestalling unscheduled power outages, and balancing the intermittent characteristics of renewable energies [16]. However, the major challenges with VRBs are low electrolyte stability and solubility, which results in low energy density, and relatively higher operating cost.

ii. Sodium Battery

The sodium-sulfur battery is another type of battery under development. The technological advantage of the sodium battery is its high power density, long battery lifetime (usually over 10 years) and high efficiency (up to 90%). But when this type of battery is operating, a high temperature (350^0C) is required to liquefy the sodium. This constraint increases the difficulty and operational cost of sodium-sulfur batteries. Another drawback is that the sodium battery is very dangerous if the liquid sodium comes into contact with water in the atmosphere [1].

iii. Zinc-air Battery

Just like the lithium-air battery, the zinc-air battery uses air as a second component. Zinc air has been a focus in development for a while because of its safety aspects and potential in density; but, was dropped due to the low efficiency and short life cycles. Zinc-air, just like lithium-air ,holds potential for grid storage due to its density and the fact that zinc is a commonly found metal, But as long as no data is presented and no field tests have been made it remains as an idea with theoretical potential.

2.1.3.4. Pumped Storage Hydroelectricity (PSH)

Hydropower engineering refers to the technology involved in converting the pressure energy and kinetic energy of water into more easily used electrical energy. The prime mover in the case of hydropower is a water wheel or hydraulic turbine which transforms the energy of the water into mechanical energy. Mechanical energy will be converted to electrical energy by using electrical generator.

Pumped hydro plants, so far, is considered to be the only possible way to store energy in a huge amount while maintaining a high efficiency and being economical as well and has about 98 percent share of total global storage predominant in today's grid.

Mini-hydro schemes are smaller still and usually do not supply electricity to the national grid at all and it is usually refers to hydraulic turbine systems which can be used for small factories and to supply an independent local mini-grid which is not part of the national grid. Small villages and isolated communities in developing nations are finding it beneficial and economical to use Mini-hydro power generation.

When you lift an object of a certain mass you overcome gravity. In order to do so you must supply a force over a height. The force required to lift is defined by the physical law (m for mass and a for acceleration), but in this case a is replaced by g for the gravitational acceleration (9.81 meters per square second [m/s2]). The work, meaning the energy supplied and therefore stored in the object is defined by w=F*d (in this example the term d for distance can be replaced by for height). This results in W=m*g*h, meaning the energy stored equals the mass multiplied by the gravity and the height [2].

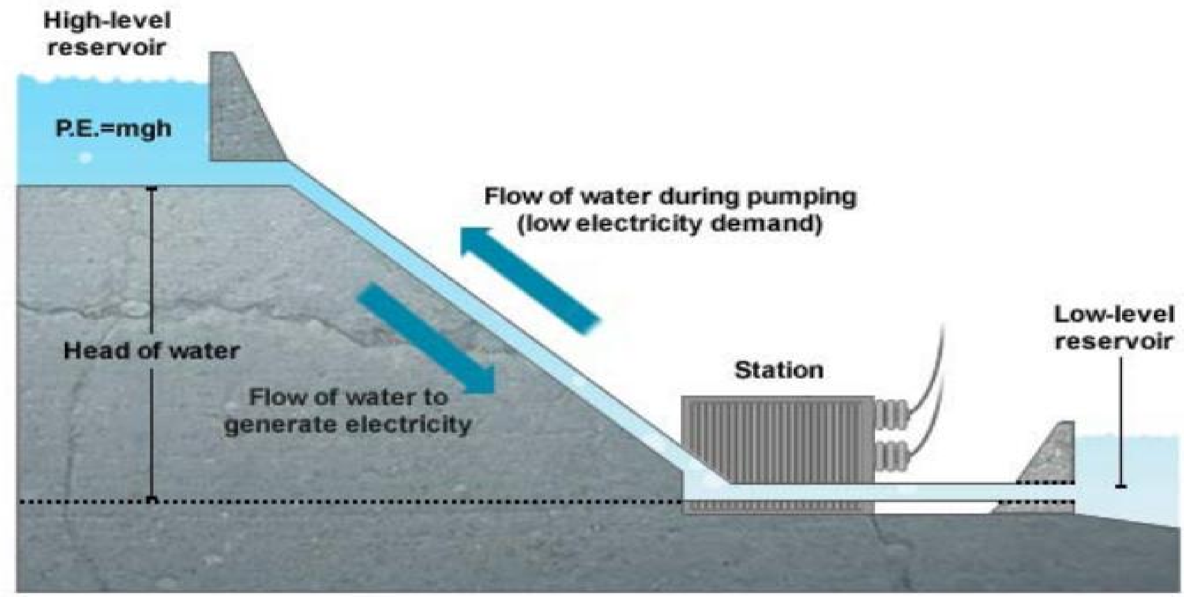


Figure 2. 8. Schematic of a Pumped-Storage Plant [21]

Advantages of Micro-Hydro Power Generation

i. It is renewable, non polluting, utilizes indigenous resource;

ii. Micro hydro schemes permit the energy to be generated near where it to be used, leading to reduced transmission costs;

iii. It can be easily integrated with irrigation and water supply projects in rural areas;

Table 2. 2. Classification of hydropower plants based on power capacity

Hydropower scheme	Power capacity
Large hydro	>100MW
Medium hydro	15-100MW
Small hydro	1-15MW
Mini hydro	100KW-1MW
Micro hydro	5kw-100kw
Pico hydro	<5KW

2.1.3.5. Compressed Air Energy Storage (CAES)

The basic idea is to use an electric compressor to compress air to a pressure of about 60 bars and store it in giant underground spaces like old salt caverns, aquifers or pore storage sites and to power a turbine to generate electricity again when demanded. These cavern storages are sealed airtight as proved by the existing two plants and have also been used to store natural gas for years now. However, the concept has two major problems when it comes to pressuring air. First, compressing the air leads to a very significant amount of heat generation and subsequent power loss if unused. In addition, the air will freeze the power turbine when decompressed. Therefore, both the existing plants in Huntorf and McIntosh use a hybrid concept with gas combustion as gas turbine power stations require compressed air to work efficiently anyway. Instead of using the combustion of the gas to compress the air like in a conventional gas turbine, the stored air in the caverns can be used, meaning that, technically, these CAES plants both store and produce electricity [2].

Advantages of Compressed Air Energy Storage

+ Capable of storing huge amounts of energy, similar to PSH

+ AA-CAES capable of efficiencies nearly as good as PSH (around 70 percent)

+ Fast response times

+ Inexpensive way to store energy

Disadvantages of Compressed Air Energy Storage

- Requires sealed storage caverns

- Economical only up to a day of storage (for AA-CAES)

- Competing against other storage needs (natural gas, hydrogen)

- Not yet fully developed

2.1.3.6 Thermal Storage

Thermal storage is the concept of storing energy in form of heat. There are different approaches to storing large amounts of heat; one of the most promising is the concept of phase changing materials (PCM). These materials are capable of holding large energy amounts when changing from one phase into another. We know this effect from a simple ice cube. If you heat the cube up it stays at 0° C (273° K) until completely molten. The amount of energy used to melt an ice cube is equivalent to the amount you need to heat water to 80° C (353°K). The same effect, but with a higher energy density, holds the molten salt storage concept, containing a combination of sodium and potassium, which is currently the first choice in several solar projects. However, research is being done to find other thermal storage concepts using materials that are cheaper and easier to handle.

Because heat is the lowest form of energy, it hasn't been really considered for storing energy because the most common way to produce electricity is to power steam turbines; it would be just too inefficient to transform already produced electricity through steam once again into heat just to power a steam turbine again. However, the concept is relevant for balancing solar thermal power plants, as they use the heat of the sun during the day to simultaneously produce electricity and "fill up" the thermal storage tanks, which allows them to generate electricity at night [11].

2.1.3.7. Hydraulic Hydro Energy Storage (HHS)

Basically, the idea is to cut out a large cylindrical body of rock and lift it hydraulically using hydro pumps to force water underneath it. The body would rise several hundred meters if completely charged and would sink into the ground again during discharge. Environmental impact would be minimal, the storage capacity incredibly huge and costs depending on the dimension even lower than PSH, once developed [5].

Table 2. 3. Theoretical energy capacity for different sizes for HHS

Radius [m]	62	125	250	500
Capacity [GWh]	0.5	8.0	125	2000

Energy storage systems have been instrumental in the modernization of our society. Energy storage systems have been essential for decoupling electricity generation from consumption since electrification began. Their use will grow yet more predominant in the future; the greatest amount of electricity is being generated by volatile renewable-energy sources, such as wind and solar power. This will entail the use of new solutions to optimally decouple the power generated by renewables from the power demanded. Multi-energy systems and virtual-power plants constitute the most promising solutions; both of them employ energy storage systems as well as demand-side and demand-response programs.

The main factors that influence the decision regarding the dimensions of the storage-battery system are as follows;

i. To stabilize power-output fluctuation (fluctuation data of demand and supply), and
ii. To increase the firm capacity or constant power (supply-demand match on a daily basis).

The most important services of EES can be summarized as follows:

Distribution infrastructure services:

i. Distribution upgrade deferral
ii. Voltage support

Customer energy-management services:

i. Power quality
ii. Power reliability
iii. Retail electric energy time-shift
iv. Demand charge management

Requirements for EES and Extension of Storage Usability

From the point of view of utilities:

i. Time shifting: Reducing the generation costs by storing in the off-peak time (mainly at night) and discharging at peak time (mainly in the daytime or noon peak hours).
ii. Power quality: EES can provide frequency control functionalities and, when located at the end of heavily loaded lines (especially in the distribution), may improve voltage drops by controlled charge/discharge operation.
iii. Emergency power supply for protection and control equipment: Batteries can be used for this important emergency activity in case of outage.

Characteristics of different types of energy storage

1. **Energy storage capacity**

For an energy storage system, the most fundamental characteristic in theory is its energetic capacity expressed in joules or kilowatt-hours. It is a heavily preponderant criterion for the dimensioning of energy storage systems.

2. Maximum power and time constant

The maximum charge or discharge power (which is sometimes asymmetric) represents another important characteristic, since it qualifies the maximum energy output of a system's performance. It has a very strong impact on dimensioning in power storage systems.
Storage technologies can also be characterized by the ratio of energetic capacity to maximum power; this ratio is sometimes called the time constant or the minimum charge/discharge time.

3. Energy losses and efficiency

The various energy transformations that occur during the conversion process are inevitably accompanied by losses, which depend greatly on the technology being considered.

4. **Aging**

Storage systems aging like any other object are subjected to stresses, particularly thermal stresses. Their complexity (numerous technologies within the system) multiplies the number of types of aging mechanisms, but some of these are often dominant and are used, once identified, in the development of macroscopic aging laws. Degradations related to aging are manifested by the deterioration of characteristics such as energetic capacity, which is reduced, or losses, which increase; this usually accelerates the degradation process late in the lifespan.

5. Costs

Cost of investment constitutes the most noteworthy part for buyers, but the systems with the lowest investment costs are generally the systems that degrade the most rapidly, particularly in terms of cycling, and/or in which the efficiency is poorest. Cost is often specified in €/kWh for accumulators with long time constants (energy storage) and in €/kW for those that are dimensioned in power, with short time constants (power storage).

6. **Response time**

Not all energy conversion phenomena have the same kinetics, and some technologies deliver maximum power more rapidly than others.

7. **State of energy**

Knowledge of the SOE is vital for the proper management of a storage system no matter whatever the application. The SOE is defined as follows:

SOE = E/Esto

where E is the quantity of energy stored at a given moment; that is the gross energy available if there were no losses at discharge (with the effectively restorable value necessarily being lower depending on the discharge efficiency), and Esto is the energy storage capacity. SOE value of 100%, therefore, corresponds to a full charge, and a value of 0% corresponds to a deep discharge (the maximum possible).

2.1.4. Interfacing circuits

Power converter interface devices are important for using energy storage systems (ESSs) in micro grids. With the development of power electronics technology, many different power converters have merged, which make the charging and discharging process of ESS controllable due to the bidirectional power flow ability of some converters. The converter may differ for different ESSs, for example, a battery energy storage system (BESS) needs DC-DC or DC-AC converters to connect to a micro grid and for a flywheel energy storage system (FESS), a back-to-back converter is needed to perform AC-AC conversion; or a rectifier can be used to convert AC output power from FESS to DC to connect to a DC link in a micro grid [1].

2.1.4.1. DC-DC Converter

DC-DC converters are used to change the voltage level at the DC source input to the desired DC output voltage level. There are several different types of DC-DC converters, namely step-down converter, step-up converter, and bidirectional DC-DC converter. A step-down converter converts a high voltage DC source into a low voltage output, while a step-up converter increases the DC source voltage to a higher output voltage. The bidirectional DC-DC converter can do both step-down and step-up conversions, and the power can flow in either direction between input and output.

Many ESSs are DC power sources, e.g., batteries and super capacitors. Also, the DC link appears in micro grids in between back-to-back converters. So, a DC-DC converter can connect DC ESSs to the DC link in a micro grid. In addition, for a photovoltaic (PV) micro grid, the ESS can work to mitigate the intermittency of the PV output through control of DC-DC converter [1].

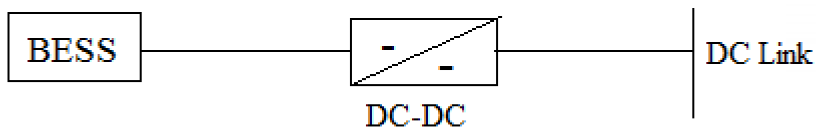


Figure 2. 9. Applications of converters for ESS [1]

2.1.4.2. AC-DC Converter

AC-DC converters are also called rectifiers, which is a device to convert AC power into DC output. In micro grids, the rectifier is useful to provide DC power to charge the ESS [1].

Single-Phase AC-DC Rectifier

In a single-phase rectifier, the input of the rectifier is one phase AC power. There are two major AC-DC rectifier types: half-wave rectifier and full-wave rectifier. The structures of these two types of rectifiers are very simple and no control signal is required.

Single-Phase Half-Wave Rectifier

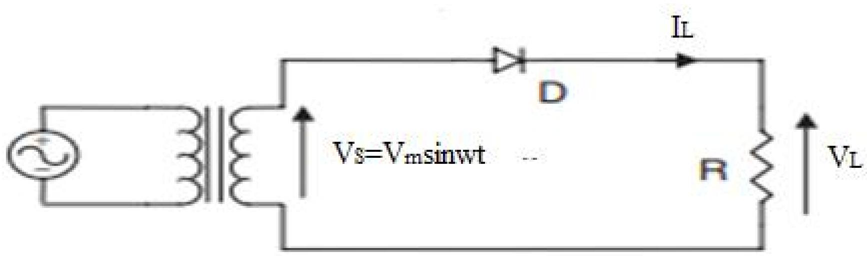


Figure 2. 10. Single-phase half-wave rectifier [1]

This half-wave rectifier can have the simplest structure among all the AC-DC converters. As shown in Figure below, only one diode D is needed in the half-wave rectifier. This diode limits the current flow in one direction. This means that only half of the AC waveform can pass through the diode. Thus the efficiency of the half-wave rectifier is very low.

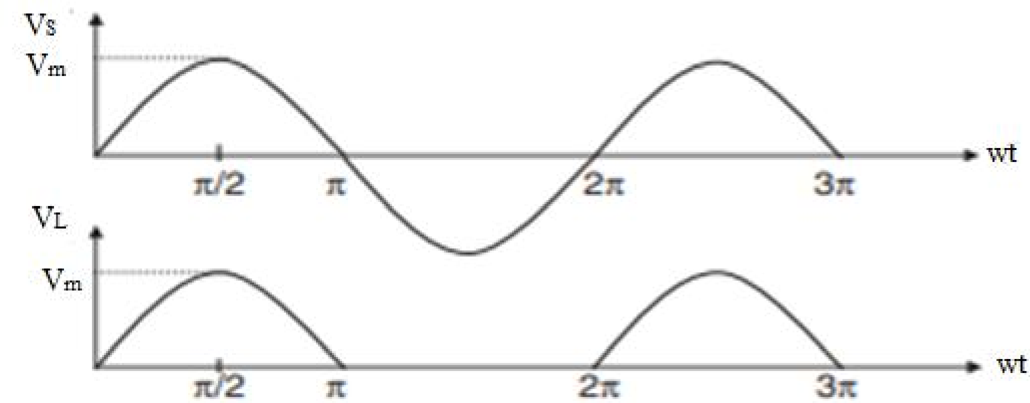


Figure 2. 11. Waveforms of the input and output of half-wave rectifier [25]

According to the waveform in Figure above, the voltage relationship of the input and output can be calculated. The average voltage on the load is:

$$V_{DC} = \frac{1}{2\pi}\int_0^{2\pi} V_m \sin wtd(wt) = \frac{1}{2\pi}\int_0^{\pi} V_m \sin wtd(wt) \tag{2.7}$$

$$V_{DC} = \frac{Vm}{\pi}$$

Where Vm denotes the amplitude of the input voltage

Single-Phase Full-Wave Rectifier

The full-wave rectifier allows the input AC source to complete its current flow circuit in both positive and negative half of an AC cycle. The structure of the full-wave rectifier is shown in Figure below.

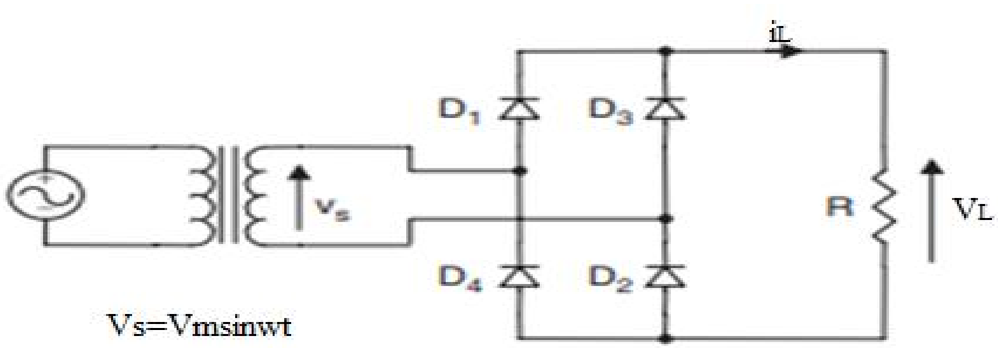


Figure 2. 12. Single phase full-wave rectifier

There are four diodes in the full-wave rectifier circuit. When the AC source voltage is positive, the current flows through D1 to the load and back to the AC source via D2. When the AC source voltage is negative, the current flows via D3-load-D4 path. Either way, the current always goes across the load from the positive to the negative pole.

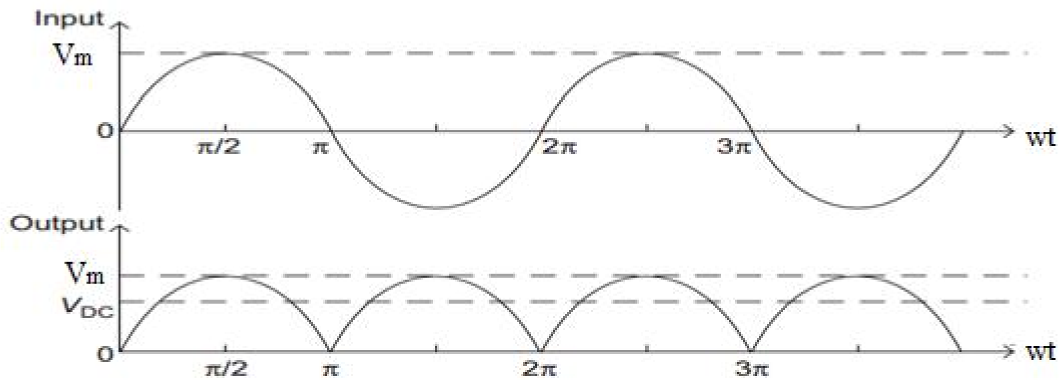


Figure 2. 13. Waveforms of the input and output of full-wave rectifier [1]

$$V_{DC} = \frac{1}{\pi}\int_{0}^{\pi} V_m \sin wt\, d(wt) = \frac{2V_m}{\pi}$$

Three-Phase AC-DC Rectifier

Three-Phase Half-Wave Rectifier

The star rectifier is a commonly used three-phase half-wave rectifier, which is like an aggregation of three single-phase half-wave rectifiers. For the three-phase half-wave rectifier, if the control signal is always on for the thyristors, the three thyristors will work as normal diodes. The diode's thyristors can be controlled to turn on or off at different times to produce different DC output voltages.

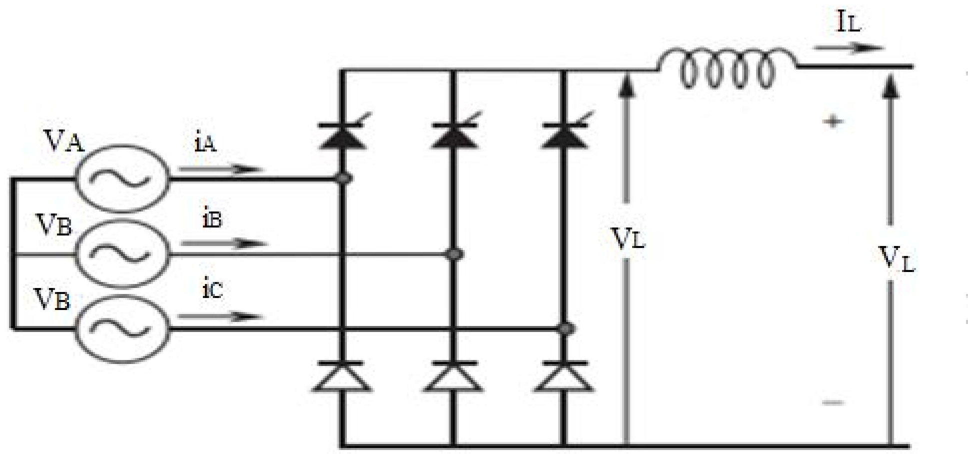


Figure 2. 14. Controllable three-phase half-wave rectifiers

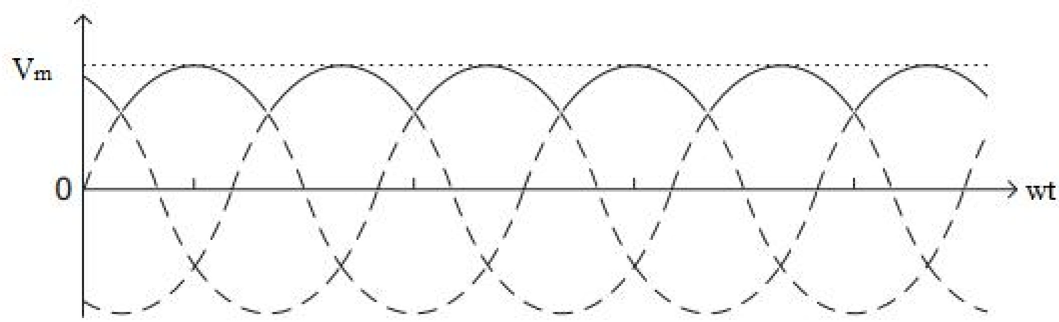


Figure 2. 15. 3 phase half-wave rectification with diodes [20]

$$V_{DC} = \frac{Vm}{2/3\pi} \int_{-\pi/3+\alpha}^{\pi/3+\alpha} coswt(dwt) = \frac{Vm}{\pi/3} \sin\pi/3\cos\alpha = \frac{3\sqrt{3}}{2\pi} Vm\cos\alpha \tag{2.8}$$

Three-Phase Full-Wave Rectifier

The three-phase full-wave rectifier has the bridge structure as shown in below. If all six thyristors are controllable, it is known as a fully controllable bridge converter. However, if the thyristors always conduct like diodes, the operation principle of the rectifier is similar to the single phase full-wave rectifier discussed in preceding sections. This means that the negative half cycle voltage of each phase will flip to the positive side.

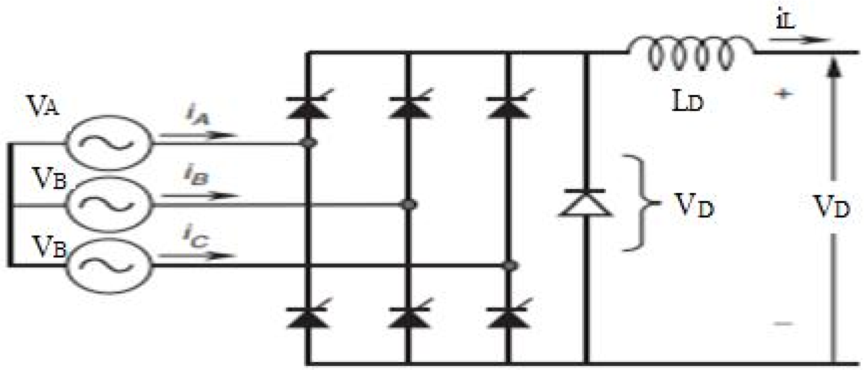


Figure 2.16. Fully controllable three-phase full-wave rectifier

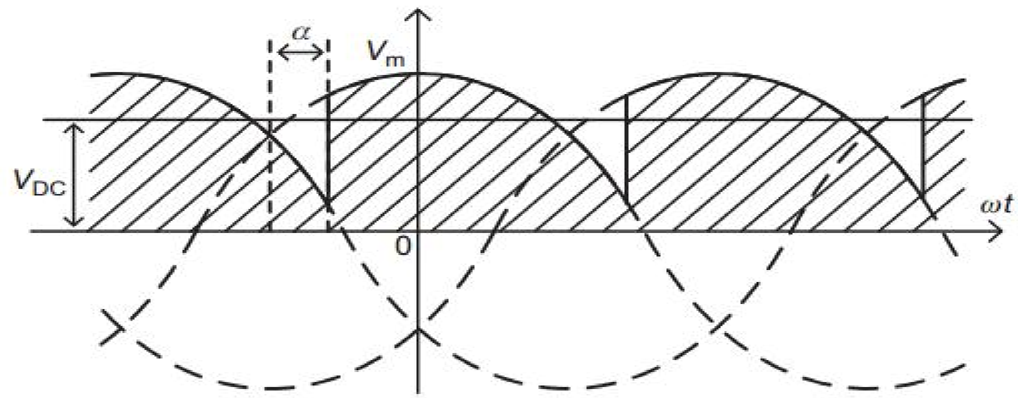


Figure 2.17. Waveform of the output of a controllable rectifier with delay α [18]

$$V_{DC} = \frac{2V_m}{2/3\pi} \int_{-\pi/3+\alpha}^{\pi/3+\alpha} \cos wt(dwt) = \frac{3\sqrt{3}}{\pi} V_m \cos\alpha \tag{2.9}$$

Since the diode is cheaper than thyristor, the half controlled bridge structure is cheaper.

2.1.4.3. DC-AC Converter

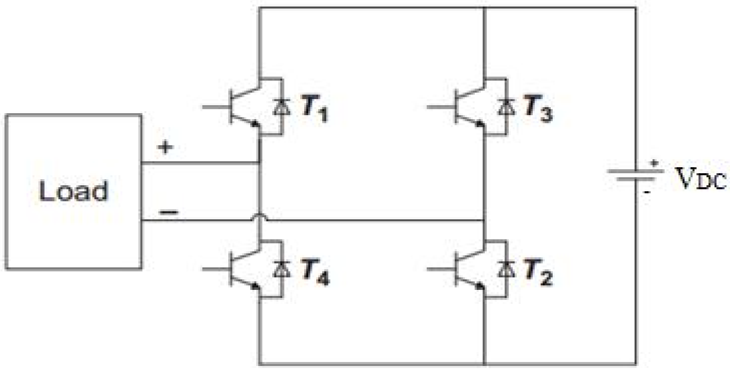


Figure 2. 18. Single-phase DC-AC inverter

A simple way to generate AC voltage on the load is called the bipolar pulse width modulation (PWM) Technique. In this method, the controller sends signal to turn on T1 andT2 during 0<t<T/2, which results in a positive current flow across the load. When T/2<t<T, the controller turns off T1 andT2 and switches on T3 and T4, so the current through the load becomes negative. By switching between these two modes continuously, an AC voltage (square wave) with period T can be obtained across the load. In order to obtain sinusoidal AC output voltage, a filter is needed to remove the harmonics.

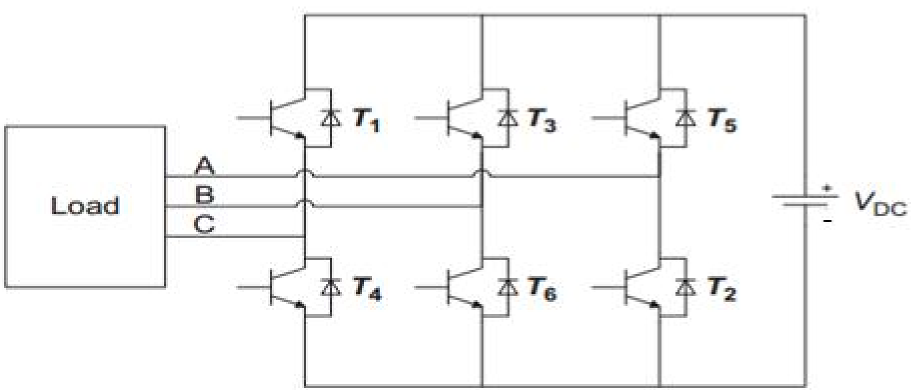


Figure 2. 19. Three Voltage source DC-AC inverter [1]

There are many applications of VSIs in micro grids. One of the most important applications is as a solar PV power inverter.

2.1.5. ESS Integration with Renewable

Renewable resources like solar are by nature variable depending on location and weather conditions. Cloud cover can cause massive voltage spikes in PV voltage outputs can vary dramatically over any given hour. These fluctuations bring about immense difficulties to grid planners in charge of dispatching renewable resources as well as to power generators as they try to meet their commitments to the grid. Several demonstration projects are currently exploring ways in which storage technology can alleviate these problems and ensure quality, stable, power output, ultimately enabling higher penetration of renewable energy sources into the grid.

An ESS can be added in many different places in the micro grid depending on its purpose. When acting as a load, the ESS can perform load leveling and peak shifting functions to flatten the load variation and support the peak demand. For renewable generators, the ESS can help suppress any fluctuations. Also, the ESS is able to improve the power quality of the micro grid by working as an Uninterruptible Power System (UPS) and enhance the low voltage ride through (LVRT) ability for solar photovoltaic generation.

Application of ESSs in renewable micro grids

Generator Side Distributed ESS

The major function of generator side distributed ESS is to smooth the output of renewables. A distributed ESS is usually connected to the DC link of the renewable generation unit. The distributed ESS outputs the desired power to compensate the fluctuation of renewable generation.

Load Side Distributed ESS

For the grid-connected micro grid, the load side distributed ESS can help users to save money. For example, the controller of distributed ESS can obtain the electricity price information from the power market. So, the distributed ESS can be charged from the main grid during the low electricity price period, and supply the loads from the stored energy when the price is high.

Load Management (Load leveling and peak shifting)

It is necessary to produce the almost exact amount of electricity that is demanded by customers. In order to maintain grid stability, a frequency of 50 or 60 hertz (Hz) (depending on the country's standard) must be generated. Higher deviations (±2.5 Hz) will result in causing damage to the generators.

The curve progression varies over the day; but, behavior is usually steady and pretty well known for each day and is used as a road map for production along general lines. For example, the need for electricity during the night is low whereas at noon, when everybody starts cooking, it is at its peak [9].

The concept of a load management which is separated into three different types:

Base Load: This is the amount of electricity that is demanded and produced at any time. Nuclear, hydroelectric power or brown coal plants are known and common to use as base load plants due to the long startup time and/or the low operating and fuel costs.

Intermediate Load: Power plants that are easier and faster to regulate are used for the task of middle load. These plants are capable of working within minutes to an hour and have moderate operating costs. Black coal or wind plants are typical of middle loads.

Peak Load: Peak load is the power demand outside of the daily "road map." Different events like unexpected hot and sunny days can lead to an extended use of air conditioners and therefore a higher electricity demand. Peak load plants have a fast response time, which means they're operational within seconds to a few minutes. A typical example would be gas turbine power plants or pumped-storage hydroelectricity.

Load Leveling

Load leveling is an important function of the ESS. It is useful to reduce the influence of the load variation and lower the cost of the microgrid. ESS in the microgrid can store energy when the load is low, and output the energy when the load is high. Hence the variation of load can be compensated by the ESS.

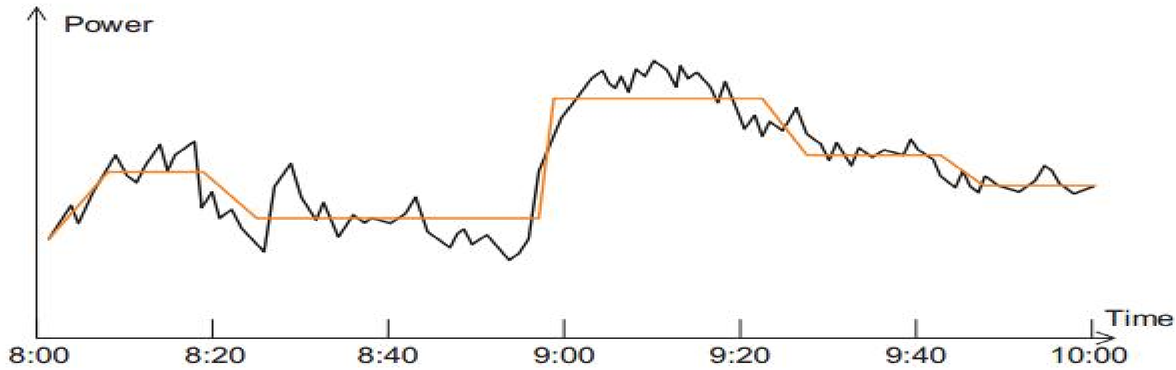


Figure 2. 20. The principle of load leveling [3]

Peak Shifting

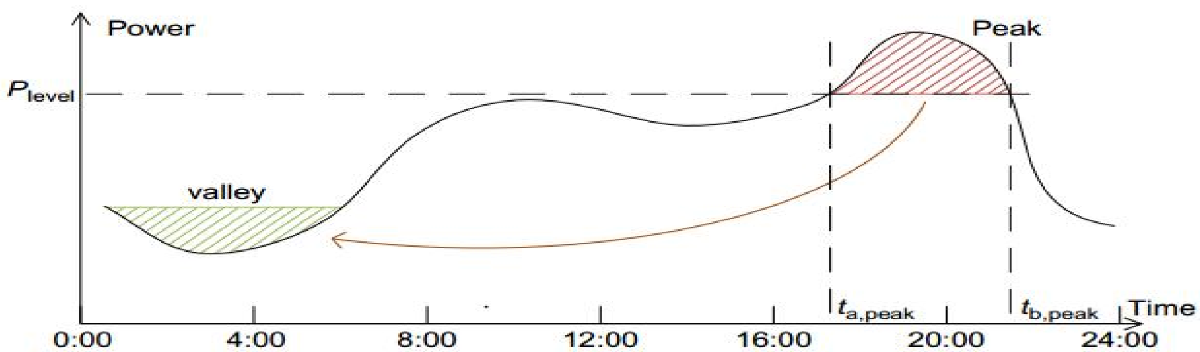


Figure 2. 21. The principle of peak shifting [3]

In a micro grid, the ESS can function either as a load (during charging period) or as a generator (when discharging). Therefore, it is able to perform peak shifting function to reduce or eliminate the peaks and valleys in the load profile, so the micro grid can satisfy the high demand during peak time. Also, this is useful to improve the economy of the micro grid operation.

Fluctuation suppression (intermittency mitigation)

The output of solar panels is intermittent due to weather variations such as clouds over the photovoltaic arrays. In addition, the micro grid is not as strong as the utility grid, so the fluctuation of generation may cause remarkable variations in network frequency and voltage, which makes the micro grid unstable. To solve this problem, ESS can be employed to mitigate the fluctuation. Three different fluctuation suppression techniques are constant power control, output filtering and ramp-rate control. The objective of constant power control is to keep the output of renewable generation constant. Output filtering aims to utilize the ESS to simulate a low-pass filter so that the high frequency terms can be eliminated. Finally, ramp-rate control aims to keep the change rate of renewable power generation within a desired range.

Uninterruptible power system (ups)

Renewable sources, such as solar panels may suddenly stop generating power due to clouds and shading. However, start-up of backup generators may take about 10 s. During this period, outages may occur in the micro grid. However, if there is ESS in the micro grid, the loads can be supplied by ESS to ride through the power shortage. There is a voltage detector installed at the output of the PV. The voltage detector senses the output voltage of the PV. If the solar panels stop generating power, the output voltage will drop to zero. Then, the voltage detector will send a command to the backup generator and ESS immediately. The switches S1and S2 will close, so the ESS can replace the PV as the power source to supply the micro grid.

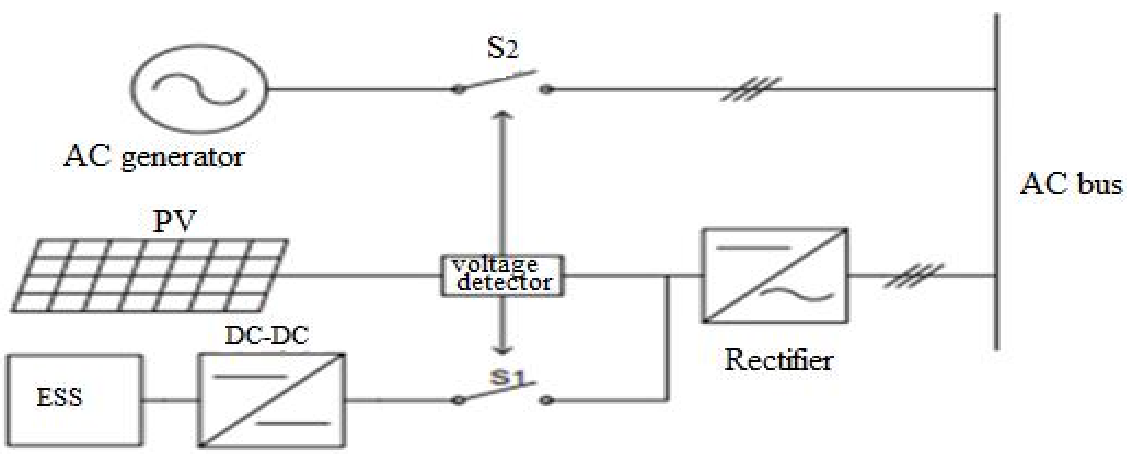


Figure 2.22. UPS for PV micro grid [1]

Low-voltage ride through

When some incidents happen in the micro grid or main grid, the voltage may suddenly drop and cause some DGs to disconnect and stop producing any power. If a certain DG in the micro grid is tripped because of the voltage drop, this may cause other DGs to disconnect from the grid and cascading power outage may result. Therefore, DGs, like wind turbines, are required to remain connected to the grid for a period during the voltage sag. This requires that wind turbines should have the capability to operate under low voltage conditions which are referred to as low-voltage ride-through (LVRT). By cooperating with ESS, the LVRT ability of wind generators can be improved.

Placement of the ESS to improve power quality

The high penetration of renewable energy presents a challenge for the stable operation of micro grids. Besides the control methods discussed above to solve the power intermittency issue, the placement of ESS in a micro grid is also important for power quality. The voltage stability and continuity of service are two important aspects of power quality .So, the placement of ESS should take into account these factors. Several power quality indices addressing the continuity of service should be considered when deciding the location of ESS. They are System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI) and Customer Average Interruption Duration Index (CAIDI). These indices are widely used to evaluate power quality in power systems.

SAIDI describes the average outage duration for each customer served

$$SAIDI = \frac{T_{in}}{N_{cs}} \tag{2.10}$$

Where Tint is total duration of customer interruptions, and Ncs is the total number of customers served.

SAIFI is the average number of interruptions that a customer would experience. It can be described as follows:

$$SAIFI = \frac{N_{\text{int}}}{N_{cs}} \tag{2.11}$$

Where Nint is the total number of customer interruptions.

CAIDI is calculated by:

$$SAIDI = \frac{SAIDI}{SAIFI} \tag{2.12}$$

The above indices provide useful information to construct micro grids containing an ESS. By simulating different micro grid configuration with the whole year's data, the optimal configuration of micro grid with ESS to gain the best power quality can be obtained [23].

ESS as spinning reserve

The spinning reserve is the amount of unused capacity in online energy assets which can compensate for power shortages or frequency drops within a given period of time. In spinning reserve technology, the most important problem is how much capacity should be reserved. Both the reliability and the economics of the micro grid should be considered when deciding on the amount of spinning reserve. It is necessary to set the reserve capacity at optimal value, so the operation of micro grid is most economical.

2.2. LITERATURE REVIEW

According to some research **[10, 11]**, an aggregated ESS is more capable of suppressing the power fluctuation in the micro grid than a distributed ESS. This is because the power output of the entire renewable farm is usually more stable than each individual unit. Besides the fluctuation suppression feature, aggregated ESSs also perform some energy management functions, such as load leveling and peak shifting. Moreover, in a PV micro grid, the aggregated ESS can store energy in the daytime and supply the micro grid in the night.

Gelma Boneya [9], Design of a hybrid electric power generation system utilizing both wind and solar energy for supplying model community living in Ethiopian remote area. He tries to electrify rural area studying the potential of the resource in the area. Hybridizing the available resource he design and model for specific area. Limitation of the project is when the wind is not blowing and sun is not shine at the same time there is no power generation.

Zheng JP [10], Hybrid power sources for pulsed current applications. IEEE Trans. Aerosp. Electron. He use Hybrid Energy storage System and fuel cell powered electric vehicles. The storage used is in small amount for vehicle application.

Carapellucci R, Giordano L [11], Hybrid Energy storage System-applications in renewable autonomous energy supply systems mainly based on a battery/hydrogen combination. The hydrogen storage is not matured to use for practical application.

The drawback of author No 1 is when sun is not shining and wind is not blowing at the same time no power generation. At author No 2 Energy storage used in this paper is for very low power rating not applicable for Residential load. Drawback of author No 3 is hydrogen storage technologies are not matured technologies for practical implementation.

Thus design, model and energy management strategies for energy system will play an important role and will unfold significant potentials for further improvements of cost, efficiency of renewable energy systems. This thesis focuses designing and modeling storage system with hydro, solar energy to make sustainable energy user of the community living in merti metehara.

CHAPTER THREE
3. MATERIALS AND METHODS

3.1. Data collection and analysis

Metehara sugar factory gets its electric power system from three sources. These are from Ethiopian electric power utility, from diesel generator and from steam turbine. The factory produces power around 9MW from steam turbine. Additionally, the company uses power from Grid (i.e. 1.5 MW) and 2 diesel engine (450kw and 400kw) turbine to compensate the power shortage and as a backup power. The Total load connected to generated power is as follows:

i. Ten transformers with rating of 1MVA which is consumed by the factory.

ii. Twelve transformers with rating of 100KVA which is consumed by the load of the workers of the company.

The interviews with some of the industry workers have clearly confirmed that frequent sustained interruptions are major challenges to their home. As per the information from the community, the power interruption lasts for 4 up to 8 hours in a week and the interruptions comes due to steam turbine fail or variation of steam resource. The factory gives priority to sugar production. So when steam resource varies, the community power may interrupt. The diesel generator is used as a backup power option but its running cost is very high. Therefore Photovoltaic, mini hydro and ESS energy production is important to satisfy community needs.

3.1.1. Load

A load is an end-use device that consumes electrical energy. Lights, mobile phone chargers, and appliances such as refrigerators, computers, televisions, pumps, heaters, and motors are examples of loads. Components whose primary function is to distribute, store, or convert electricity are generally not considered loads. A rectifier, which converts AC to DC, would be an example of such a component.

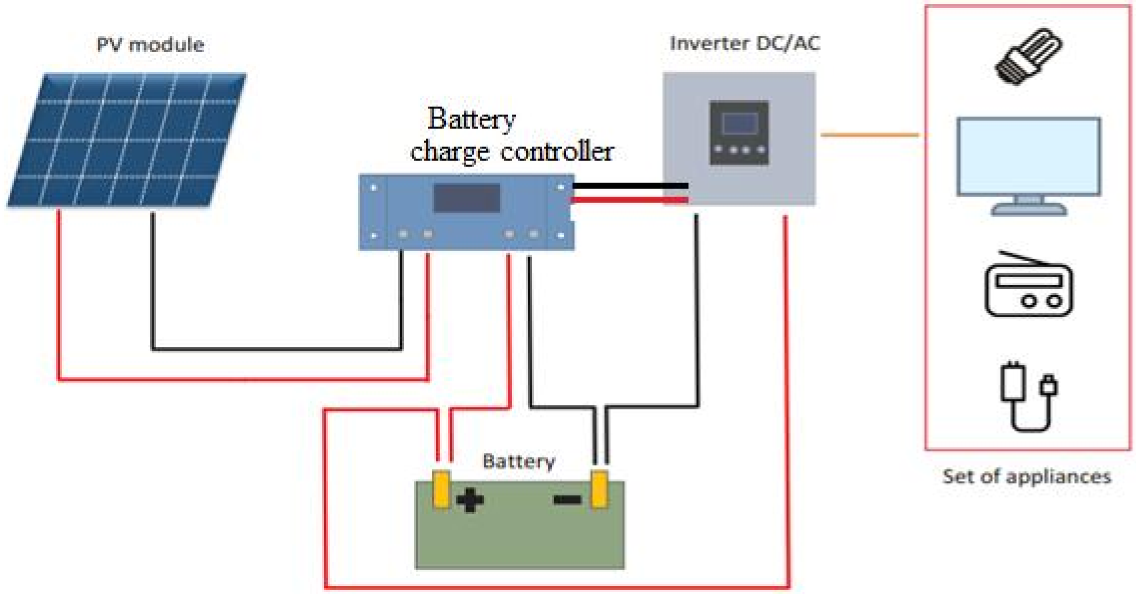


Figure 3. 1. Schematic diagram of off-grid PV-battery system

There are 3 villages where the metehara sugar factory workers live in. They get power from the factory power line. In order to satisfy the power for community additional source is needed. This is happen when the steam turbine fail there is power outage.

A data collection technique was made by interviewing concerned peoples and statistical method in obtaining the required data.

There is power interruption occur in merti metehara community. This interruption occurs due to steam turbine fail or reduction in steam resources. The factory gives priority to the sugar production if the power is decreased. When the steam turbine fails or reduces in resource the power shortage occurs to the factory. This makes the community not beneficial in using sustainable energy. Therefore to make the community sustainable energy user additional energy production is required.

Table 3. 1. Types of loads with power ratings

Appliance	Power rating per unit(w)	Daily hours(hr.)	Daily energy demand(wh)
Lamp(salon)	60x1	4	240
Lamp(bed room)	40 x1	2	80
TV	80x1	8	640

Toilet lamp	40x1	1	40
Refrigerator(not used by all peoples)	100x1	24	2400
Kitchen lamp	40x1	2	80
Stove	2000*1	3	6000
Mitad not used by all	3000*1	1	3000
Total			12,480

In one village there are 350 household.Taking all of the household use all load within 25 years.

Total energy consumed by all household per day =350*12480=4368kwh/day

If steam turbine fail or reduce in power the factory use diesel engine which has maximum capacity of 400kw*4hr=1600kwh/day.

This thesis focus replacing this diesel engine which give 1600kwh/day out of the total energy required for all household(i.e 4368kwh/day).The design also give benefit when standalone generation give power to community,the factory can use all energy generated from steam turbine. Generation of 400kw from photovoltaic give this opportunity.

For the second village 270 household. Taking all of the household use all load within 25 years.

Total energy consumed by all household per day =270*12480=3370kwh/day.

If steam turbine fail or reduce in power the factory use diesel engine which has maximum capacity of 400kw*4hr=1600kwh/day.

Replacing this diesel engine which give 1600kwh/day out of the total energy required for all household(i.e 3370kwh/day).The design also give benefit when standalone generation give power to community,the factory can use all energy generated from steam turbine. Generation of 400kw from minihydro give this opportunity.

For the third village 210 household. Taking all of the household use all load within 25 years.

Total energy consumed by all household per day =210*12480=2621kwh/day.

For this village if ESS is stored by charging at peak off period.Then it can be discharged at wanted time.Considering the total power derived at the factory 400kw ESS is selected to design.

The 400kw is selected for three purpose:

i. To replace diesel engine

ii. To use the network used in existing

iii. There is power capacity to charge at the peak off period

The stored energy is used at peak load.Most energy used by the community is at 18-22 o'clock.Therefore it is used at this time.The factory use the additional energy for its sugar production which is given to the community at that time.

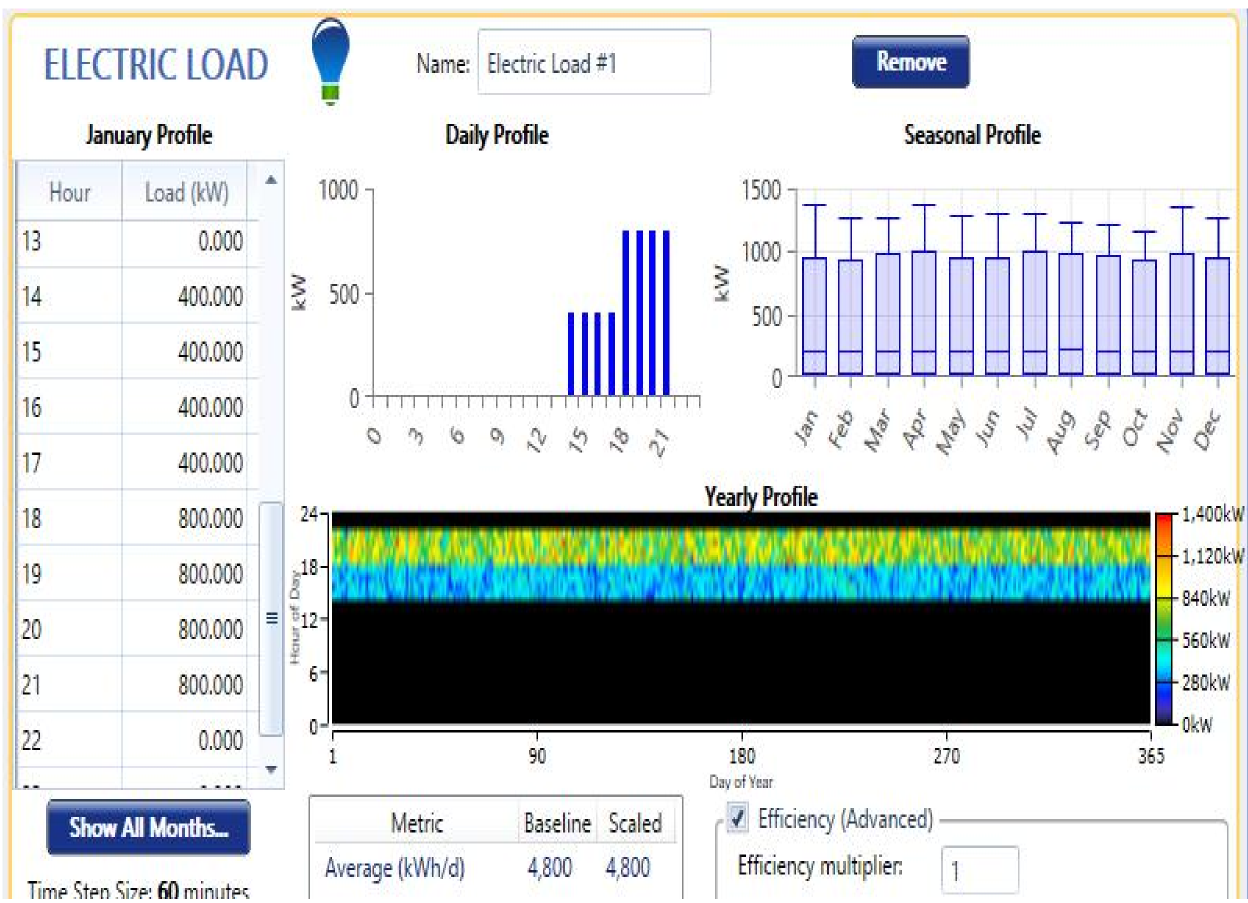


Figure 3. 2. Load profile data (14-22 o'clock)

3.1.2. Solar PV Array

A solar cell also called photovoltaic cell or photoelectric cell is a solid state electrical device that converts the energy of sunlight directly into electricity by using the photoelectric effect.

Table 3. 2.Sunshines hour data of metehara, source [East oromia meteorological agency(Adama)]

	The year sun shine hour data of 2019 G.C was recorded(Hrs)				
Month	2015	2016	2017	2018	Average
Jan	10.7	10.6	10.3	10.2	10.45
Feb	11.2	10.2	10.3	9.7	10.35
Mar	10.7	10.9	10	8.6	10.05
Apr	10.9	9.4	10.3	7.7	9.58
May	10.9	10.2	6.7	10.5	9.58
June	8.4	9.2	9.6	6.6	8.45
Jul	8.4	8.5	8.9	7.4	8.3
Aug	8.6	9.4	8.4	7.2	8.4
Sep	9.1	8.8	6.3	8.8	8.25
Oct	10.6	10.2	9.7	7.8	9.58
Nov	9.2	10.3	9.6	10.9	10
Dec	10.2	9.9	10.3	10.1	10.13

Conversion of sun shine hour to solar insolation is performed considering tilt angle .

Table 3. 3. Monthly average solar sunshine hour data and temperature of 2019 G.C

Month	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec
Average radiation in kwh/day	6.08	6.57	6.52	6.31	6.36	5.77	**5.23**	5.36	5.84	6.31	6.27	6.08
Temp Max	31.4	35	38	37.8	37.4	34.4	34.6	33.2	35.6	29	34.8	33.5
Temp min	12.5	17.2	15.5	21.4	-	23	23.6	19.6	23.4	20.2	11	16.2

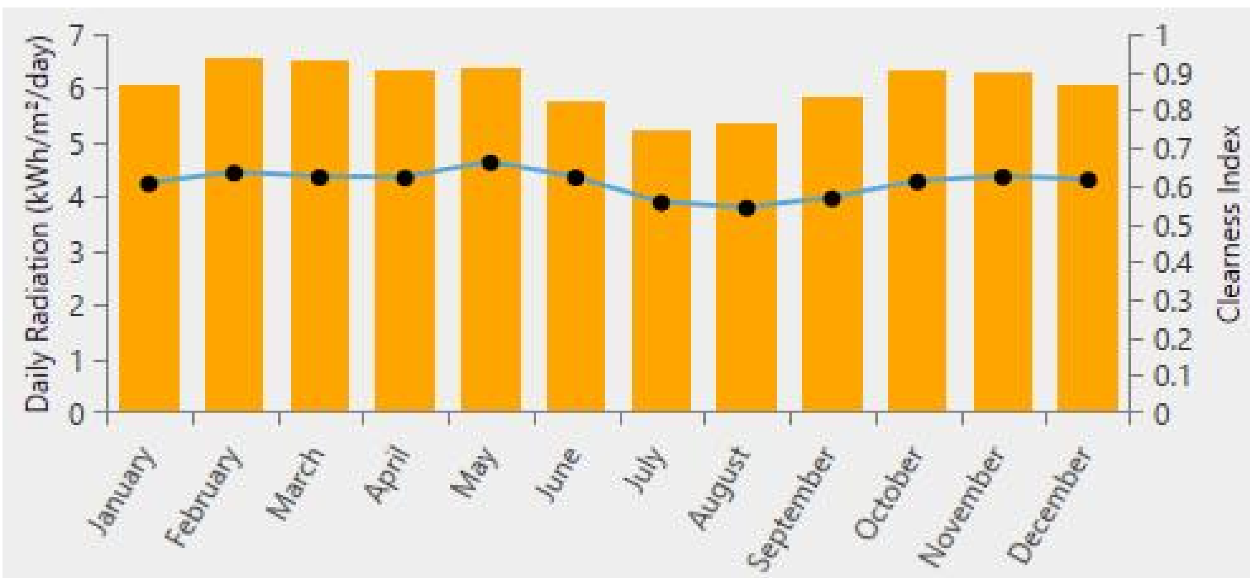


Figure 3. 3. Daily radiation curve (kwh/m^2/day) for merti metehara area

Assemblies of cells are used to make solar modules which are also known as solar panels. The energy generated from these solar modules is referred to as solar power or solar energy. Solar cells are also usually connected in series, creating an additive voltage. Connecting cells in parallel will yield a higher current. Modules are then interconnected, in series or parallel, or both, to create an array with the desired peak direct voltage and current [11].

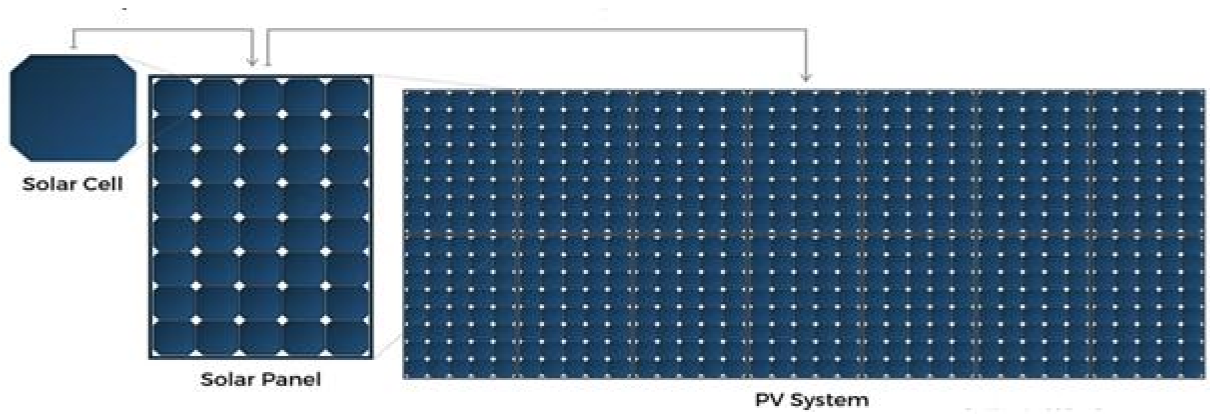


Figure 3. 4. Solar cell, solar panel and PV system [21]

The power output of a PV module is dependent on both the irradiance and the resistance of the load. Given that both can vary, the power rating of a PV module must correspond to a set of specific operating conditions. The power rating, or capacity, of a PV module is the maximum power that can be produced under “standard test conditions” (STC). Standard test conditions are defined as:[1]

• Irradiance of 1000 W/m^2

• Cell temperature of 25◦C

Availability of the panel from manufacturer and the size must be considered. For this thesis Blue sun longi **320w** is selected because it is available and medium in size:

Table 3. 4. Blue sun longi black mono solar panel 320w specification:

Module Type	BSM320M-60
Rated max power	320w
Open circuit voltage(v_{oc}/v)	40.9
Max power voltage(v_{mp}/v)	33.4
Short circuit current (I_{sc}/A)	10.15
Max power current (I_{mp}/A)	9.59
Module efficiency (%)	19.66%

Tilt Angle

The tilt angle represents the solar panel's angular displacement, from the horizontal axis, to achieve the most irradiance throughout the day. Most solar panels are tilted at an angle equal to the location's latitude. As Merti metehara is situated **+8.87° (8°52'12"N)** north latitude and **+39.91° (39°54'36"E)** east longitude. This location is taken from google satellite. Thus the panel inclination should be 8.87° degree facing south.

Peak Sun Hours

Solar irradiation or Insolation is a measure of solar radiation energy received on a given surface area and recorded during a given time. In regards to irradiance, irradiation is normally expressed in terms of peak sun hours - the amount of solar radiation energy expressed in hours of full sunlight per square meter. Peak sun hours represent the average amount of sun light available per day throughout the year and correspond to the length of time in hours at an irradiance level of $1KW/m^2$ needed to produce the daily irradiation.

$$Peak\ \text{sun hour} = \frac{\text{worst irradiance per day}}{\text{irradiation level at} 25\,^0\text{c}} \tag{3.1}$$

$$= \frac{5.23\ kwh/m^2/day}{1\ \text{kwh/m}^2}$$

$$\mathbf{= 5.23\ hr/day}$$

Worst irradiance per day is taken for reliable operation of solar system.

3.1.3. Rechargeable Batteries

Energy storage is required in most stand-alone systems, as energy generation and consumption do not generally coincide. Most stand-alone solar systems have batteries.

From blue sun longi manufacturer with a **12 volt and 250 amp-hours** battery capacity is selected. Putting batteries in series increase the voltage level. Four batteries connected in series gives **48 volt** and **250 amp-hours**.

3.1.4. Charge Controllers

In stand-alone systems, the system voltage of the PV array should be matched to that of the batteries; the usual system voltages are 12V, 24V and 48V. The charge controller voltage must be higher than the battery voltage. For example, with a 12V battery, it can be up to **14. 4 V**. The charge controller therefore measures the battery voltage and protects the battery against overcharging. Solar power systems available charge controller **48v, 30amp** is selected.

3.1.5. Inverter

Storage batteries use and store Direct Current and have an output usually in the range of 12-24 volts. Virtually all modern appliances operate on Alternating Current. An inverter is a device that takes the power from DC battery source and converts it to AC electricity. Available solar inverter Blue sun solar **100 kw** is selected from manufacturer.

3.1.6 Energy storage system

The importance of ESS sizing problems stems from both economical and operational reasons. The investment cost of the ESS is dependent on its power rating and energy rating. Oversized ESS introduces high capital cost to the micro grid whereas undersized ESS may not be able to provide the desired economic or operational benefits. Moreover, the integration of an improperly sized ESS will not be helpful for frequency regulation in islanded micro grids. Thus, it is crucial to determine the suitable size for the ESS.

Since the energy can be transferred to and from the main grid, the ESS can be used to perform energy arbitrage application in grid-connected micro grids. This is generally done by storing energy in low price periods and discharging this energy in high price periods to make a profit. Now in order to charge the ESS from the source of ac bus energy of 1600kwh/day is to be stored. So **400kw** rating must be used to charge ESS from the grid during off peak period (12 am-6 am) to satisfy the community need of energy.

Figure 3. 5. Energy storage systems [2]

Energy-Storage Performance Indicators

Round-trip efficiency is the most common one. It describes the losses measured during the charging; discharging. It is the ratio of the output energy to the input energy. High round-trip efficiency means low energy losses. The energy losses may be of different natures. Generally they are in form of heat and are released into the surrounding environment.

$$\eta = \frac{Eout}{Ein} \tag{3.2}$$

The state of charge (SOC) represents the amount of energy (E(t)) that can be withdrawn from or stored in an energy storage system over a specific time (t). The SOC is usually related to the maximum storable energy (E_{max}) and is specified as a percentage: A 100 % SOC is a fully- charged energy storage system, while a 0 % SOC is an empty one.

$$SOC(t) = \frac{E(t)}{E_{\max}} * 100 \tag{3.3}$$

The **depth of discharge (DoD)** is the ratio of the maximum amount of energy that could be discharged from an energy storage system to the maximum storable energy (E_{max}). It is usually specified as a percentage: A 100 % DOD indicates that the energy storage system can discharge all of the energy stored.

$$DOD = \frac{E_{\text{disch max}}}{E_{max}} * 100 \tag{3.4}$$

Comparison of different storage technologies

The best energy storage type should be chosen according to the practical microgrid application under consideration.

Efficiency

Table 3. 5. Comparison of the efficiency for different technologies [2]

	Flywheels	SMES	Lead acid battery	Lithium ion battery	PSH	AA-/CAES	Hydrogen /methane
Min efficiency	80%	90%	65%	90%	65%	45%	20%
Max efficiency	95%	95%	90%	95%	85%	60%	40%

Several technologies like flywheels or batteries are in favor for having very good efficiencies. The efficiency alone however is not an indicator for suitable technologies in grid systems as they can lack the required storage capacities; are just too expensive; or require large amounts of resources (landscapes for PSH are also considered as resources).

Energy losses

Table 3. 6. Comparison of the energy losses for different technologies [2]

Flywheel	SMES	Lead-acid	Lithium-ion	PSH	AA-/CAES	Hydrogen/ Methane
3-20% per hour	10-12% per day	5% per month	5% per year	0.5% per day	0-10% per day	0-1% per day

Like Flywheel, SMES are not favorable for storing energy for long period of hours. They loss energy before charging the load wanted to be charged.

System Power Rating

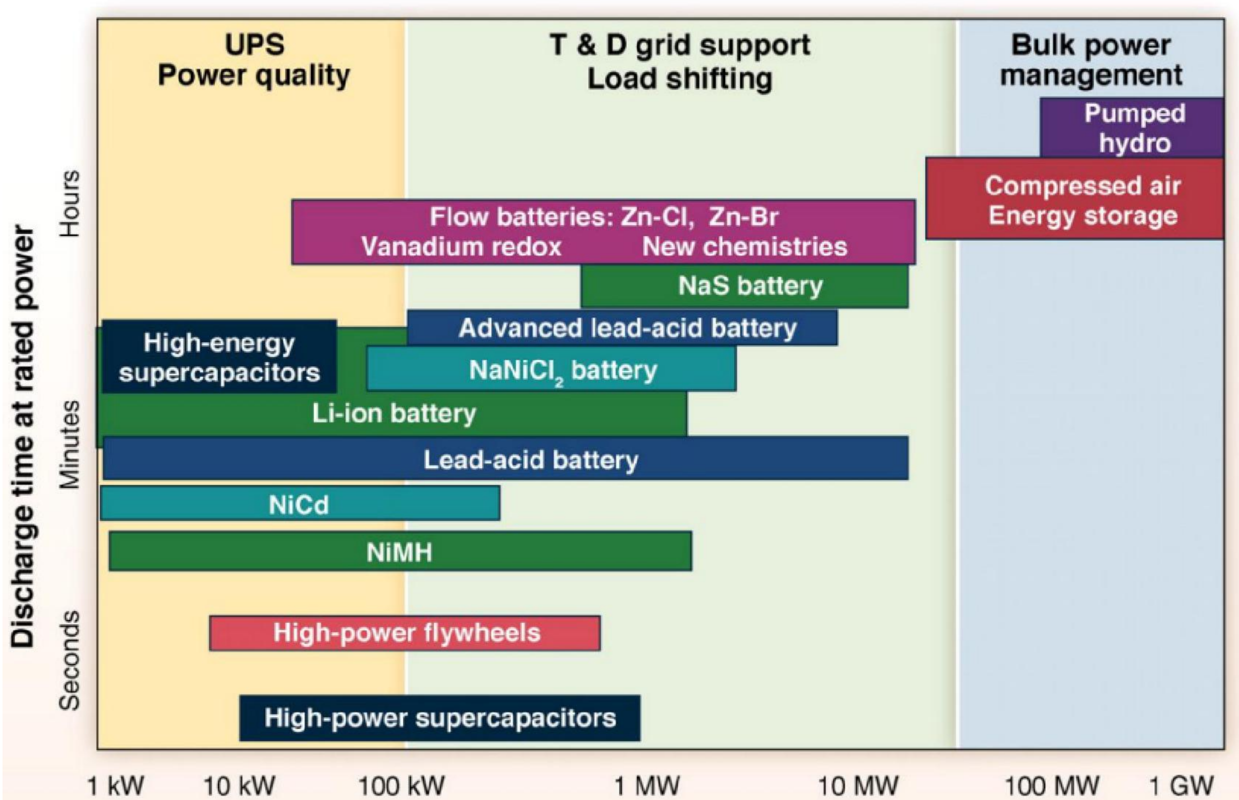


Figure 3. 6. System power rating for different technologies

For power rating of 10kw-1Mw with good discharge time, Batteries and High Energy capacitors are favorable.

Table 3. 7. Summary of characteristics of energy storage [1]

Comparison of characteristics for different types of energy storage					
Type	Energy density(wh/kg)	Power density(w/kg)	Response time	Continuous discharge time	Cycling times
Flywheel	5-30	400-1500	<1s	1s-15 min	Above 20,000 times
Compressed air	30-60	_	1-10 min	Above 1-24h	Above 100,000 times
Lead acid	30-50	75-300	<10s	1s-10h	2000 times
Lithium ion	75-200	150-300	<10s	1s-10h	<10000 times
Sodium sulfur	100-250	100-230	<10s	1s-10h	2500-6000 times
Super capacitor	5-10	5-10	<1s	1m-1h	100,000 times
Superconductin g	1-10	1-10	<5 ms	1ms-1h	100,000 times

Table 3. 8. Advantages and disadvantages of different types of energy storage [1]

The advantages and disadvantages of different types of energy storage		
Type	Advantages	Disadvantages
Flywheel	High power density, quick response	Low energy density
Compressed air	Large capacity, long continuous discharge time	Limited location, slow response
Lead acid	Large capacity, high energy density	Low power density, low cycling times
Lithium-ion	High energy density	Small capacity, hard for large scale application

Sodium-sulfur	High energy density	Needs high temperature in working process
Super capacitor	High power density, quick response	Low energy density, expensive
Superconducting magnetic	High power density, quick response, high cycling times	Low energy density, expensive, magnetic pollution to environment

3.1.7. Micro hydro storage

A hydraulic turbine is a rotating machine that converts the potential energy of the water to mechanical energy

Table 3. 9.Awash flow rate data, source [Awash flow rate administration, Adama]

month	2008	2010	2014	Average
Jan	76.345	-	31.425	53.885
Feb	64.704	36.38	26.497	42.527
Mar	60.769	39.386	60.708	53.621
Apr	69.453	35.7	56.75	53.967
May	81.76	105.824	56.834	81.472
Jun	54.678	25.872	56.637	45.729
July	134.098	156.324	76.699	122.373
Aug	202.085	242.23	108.412	184.242
Sep	321.858	336.361	160.169	272.796
Oct	98.583	-	152.568	125.575
Nov	117.23	-	-	117.23
Dec	71.677	-	28.681	50.179

Taking little amount of water by diverting from awash water to store in reseirvoir by considering not to affect the down stream community.Then through penstock taking flow rate

($2m^3/s$) for this thesis design.

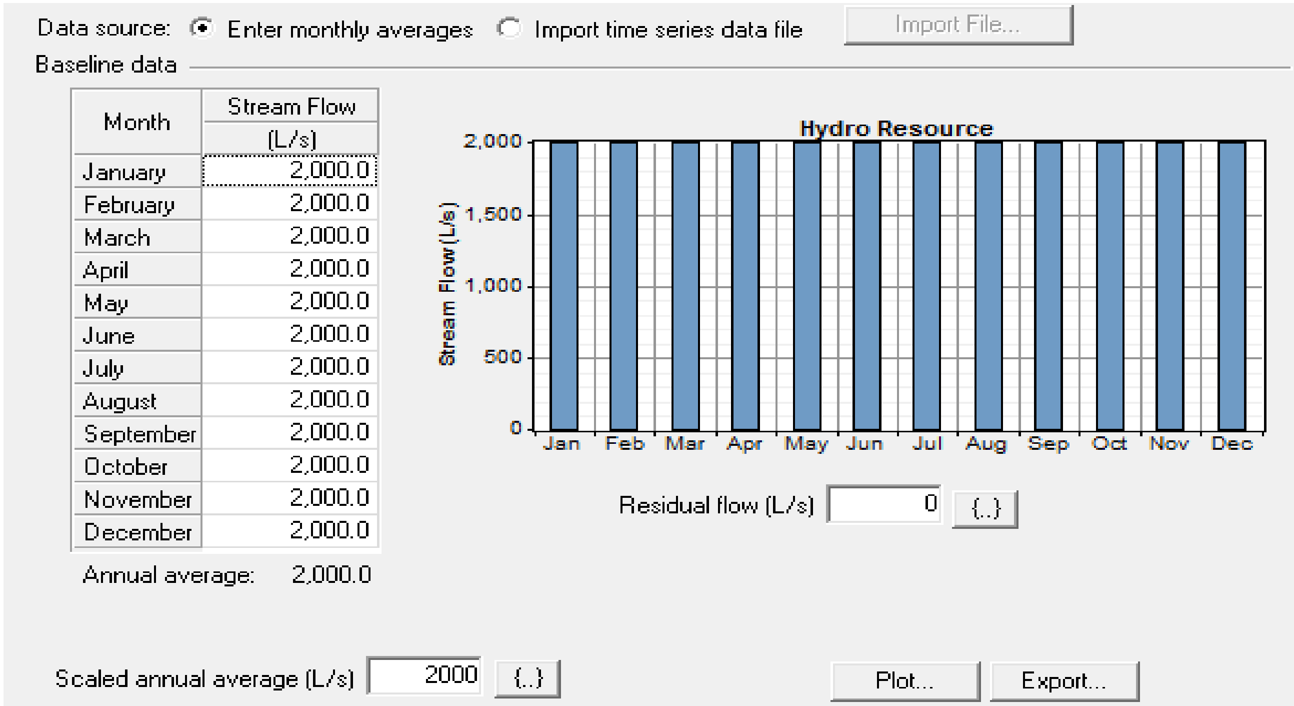


Figure 3. 7. Monthly hydro resource of 2019 taken for the design

There are two basic types of turbines, denoted as “impulse” and “reaction turbine”.

Table 3. 10. Classification of micro hydro turbines according to head, flow rate and power

Classification	Turbine name	Head range(m)	Flow range(m^3/s)	Power output(kw)
Impulse	Pelton	50-1000	0.2-3	50-15,000
	Turgo	30-200	0.5-3	20-5000
	Cross flow	2-50	0.01-2	0.1-600
Reaction	Kaplan	3-40	3-20	50-5000
	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

Impulse turbine is selected for power generation of this selected areas to take advantage of its efficiency.

Types of Generator used in Micro Hydro Power Generation

There are two types of generators suitable for use in a micro hydroelectricity supply scheme. These are synchronous generators (or 'alternators') and induction generators (in which induction motors used as a generator).Induction generator is simpler or more reliable machine than the synchronous generator. It contains fewer parts, is less expensive, and is more easily available from electrical suppliers, has no brush or other parts which require maintenance. These factors all make **induction generator** an attractive choice for mini hydro power generation than that of synchronous generator [5].

Since the power delivered from steam turbine does not sustain the power for the total connected load. Because of this the company uses additional power from grid and diesel engine turbine. The Diesel generator used running cost is very high. Additionally diesel engine is not environmental friendly. Therefore, another alternative power supply system should be designed.

In order to attain sustainability and free environment pollution using renewable energy (solar energy) integration with storage is best option. In merti metehara good solar sunshine availability motivates to focus on solar energy. Also there is Awash River passing through merti metehara. This makes advantageous to use mini hydro power generation.

> Medium discharge time (minutes to hours) is suitable for those applications whose energy to power ratio is between 1 and 10: flywheel energy storage, lead-acid batteries, lithium-ion batteries and sodium sulfur (NaS) batteries.

Discharge time is very important parameter for selecting of storage element or device.

3.2. System design and modeling

The importance of ESS sizing problems stems from both economical and operational reasons. The investment cost of the ESS is dependent on its power rating and energy rating. Oversized ESS introduces high capital cost to the micro grid whereas undersized ESS may not be able to provide the desired economic or operational benefits. Thus, it is crucial to determine the suitable size for the ESS. For grid-connected micro grids, however, the objective of the optimization problem mainly focuses on minimizing the total cost including the micro grid operation cost and the ESS investment cost. This is generally done by storing energy in low price periods and discharging this energy in high price periods to make a profit. Both energy rating and power rating should be considered while making the decision.

PV + mini hydro+ ESS is presented in this thesis. where the ESS uses grid energy for charging during the night as well as PV during the day.

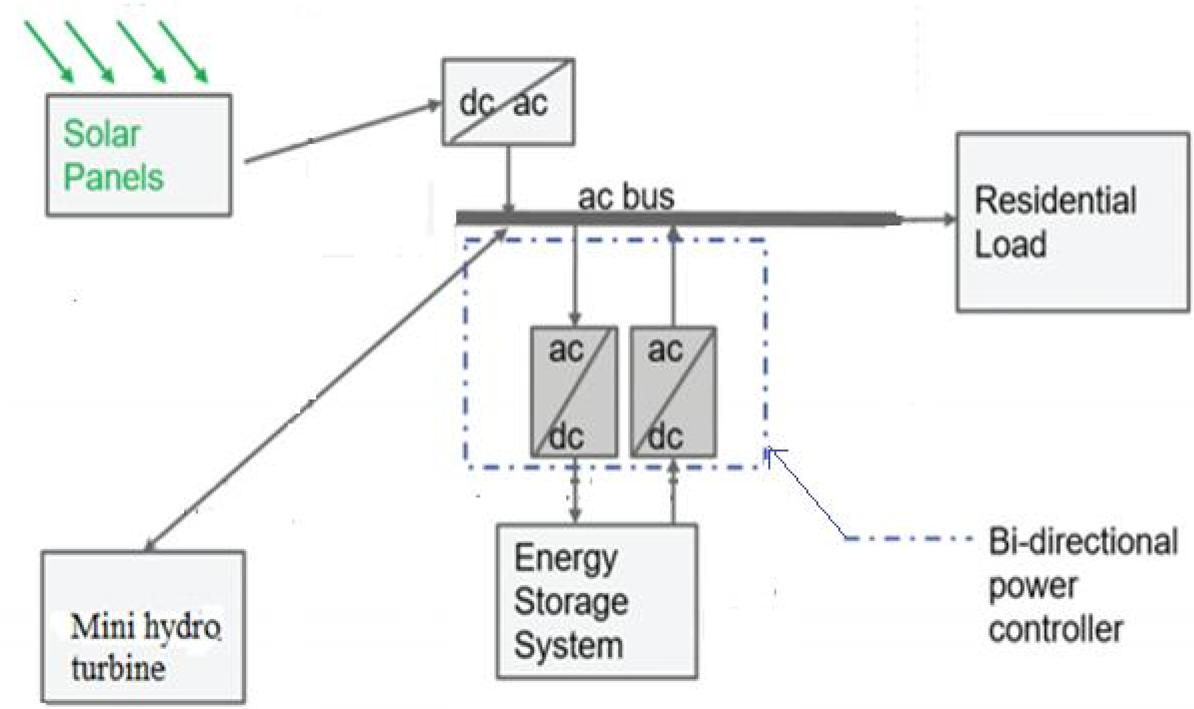


Figure 3. 8 Block diagram of the general model of this thesis

3.2.1. Photovoltaic System Design

The first step in designing a solar PV system is to find out the total power and energy consumption of all loads that need to be supplied by the solar PV system. The total installed power required from solar panel is 400kw. Therefore some portion of energy consumption of the community, i.e 1600kwh) is obtained from solar panel.

Selecting worst insolation of the area is good design consideration to generate electricity from solar continuously through the year. Minimum solar insolation @ merti metehara is 5.23Kwh/m^2/day on July. The first step in designing a solar PV system is to find out the total power and energy consumption of loads that need to be supplied by the solar PV system. Using peak power=400KW and 5.23 hours of operation.

3.2.1.1. PV array sizing:

Maximum Energy generated from connected modules power (P_{tot}) during worst time on july:

$$E_{gen} = P_{tot} * w \qquad 3.5$$

Where p=power of solar panel selected (mono Blue sun 320w peak per panel)

The actual usable energy production from a PV array will be less than E_{PV}. This is due to a number of factors:

i. Array shading; including dust
ii. Wire and connection resistive losses
iii. Module mismatch (caused by PV strings or modules having different maximum Power points)
iv. Array degradation over time (aging)

Due to the above factors safety factor (C_f=1.3) is considered.

$$P_{gen} = \frac{320}{1.3}$$

=246.15w

w=solar radiation for july in a case of merti metehara

=5.23 hrs

$$E_{gen} = p * w$$

=246.15*5.23

= 1287.36wh/day

$$N_m = \frac{E_{req} * 1.1}{E_{gen}} \qquad (3.6)$$

$$N_m = \frac{1600 * 1.1}{1287.36}$$

Nm= 1368 module

Where E_{req}=total energy required from pv module

P_{out}=output power from one module

Oversupply coefficient=1.1

w=worst solar insolation

Area of solar panels design (A_p)

$$A_p = \frac{\text{daily energy demand}}{G} \tag{3.7}$$

$$= \frac{1600 kwh/day}{5.23\ kwh/m2}$$

= **306m²**

The factors that affect the area of solar panels:

- Efficiency of the panel
- Safety factor
- Oversupply coefficient

Therefore total area covered by solar panels (A_{sp}) is:

$$A_{sp} = \frac{306 * 1.3 * 1.1}{0.1966} = \frac{437.58}{0.1966} = 2225.74 m^2$$

Total Area needed for all panel= **2225.74m²**

$$\text{Area needed for each panel} = \frac{2225.74}{1368} = 1.63 m^2$$

3. 2.1.2. Sizing of battery

Solar panels should be used in conjunction with deep cycle batteries. These batteries are designed to be charged and discharged over a long period of time. Deep cycle batteries are rated in Ampere Hours [Ah]. This rating specifies the amount of current in Amps that the battery can supply over a period specified in hours.

The state of charge (SOC) is the current value of the fraction of the maximum capacity that is still available to be supplied.

DOD – Depth of Discharge = 0.8

The following parameters are used for sizing:

1. Battery efficiency = 90%
2. Inverter AC voltage = 400V
3. Inverter efficiency = 85 %.

The storage capacity of the battery can be calculated according to the following formula.

$$\text{Battery storage needed} = \frac{E_o}{DOD * \eta_{out}} \tag{3.8}$$

$$= \frac{1600\ wkhr}{0.8 * 0.765}$$

Where $\eta out = \eta battery \times \eta inverter$

$= 0.9 \times 0.85 = 0.765$

=2614.38kwhr/day

$$\text{Battery rating in AH} = \frac{\text{storage capacity}}{V_{DC}} \tag{3.9}$$

$$= \frac{2614.38}{24}$$

=54.47KAh

Once the required battery capacity in Amp-Hours has been determined, battery cell can be therefore be selected by using manufacturers' catalogue. From blue sun logi manufacturer with a 12 volt and 250 amp-hours battery capacity is selected because of lithium ion battery makes beneficial having better life time and discharging time than lead acid battery.

$$N_{bs} = \frac{\text{system bus voltage}}{\text{Nominal battery voltage}} \tag{3.10}$$

=48V/12V

= 4 batteries

$$N_{bp} = \frac{\text{AH capacity}}{\text{Nominal AH capacity}} \tag{3.11}$$

$$N_{bs} = \frac{54.47}{250}$$

= **218**

So, the required numbers of batteries, Nb= **872**.

Size of the single battery is 520*268*220 mm

Area needed for single battery=.58*.268=0.16m^2

Total area needed for all battery=0.16 m^2*872

=140m^2

3.2.1.3. Charge Controller sizing

To give the battery longer lifetime it should be charged safely and the charge controller protects the battery from over charging and under charging. It has to be capable of carrying the short circuit current of the PV array.

$$\text{charge controller rating} = N_p \times I_{sc} \tag{3.12}$$

$$= 684*10.15$$

$$\mathbf{= 6943A}$$

Where N_p=Number of parallel solar panel

Isc=PV short circuit current

Charge controller with 48v**, 30amp** is available and selected from the manufacturer plate.

$$\text{Number of charge controller needed} = \frac{6943}{30} = 232$$

3.2.1 4. Inverter sizing

For reliable operation, the inverter capacity is increased by 20 – 25 %.

Maximum Ac load= 400kw, convertor constant= 1.2

$$\text{Converter rating} = \text{maximum ac load} \times 1.2 \tag{3.13}$$

$$= 480\text{kw}$$

Blue sun **5*100 kW, 48v** solar inverter is available and selected from manufacturer plate.

The module voltage is simply the cell voltage multiplied by the number of cells in series

$$\text{Module voltage} = N_{ser} V_{cell} \tag{3.14}$$

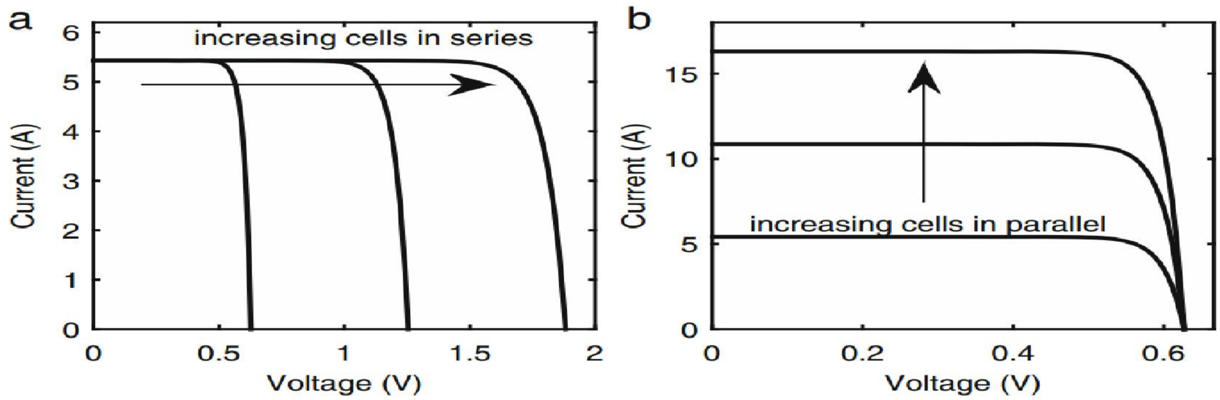


Figure 3. 9 (a) The I –V curve is changed as PV cells are connected in series and (b) parallel [2]

In a PV system consisting of a number of arrays, all arrays must have equal exposure to sunlight: the design should place the modules of a PV system such that some of them will not be shaded. Otherwise, unequal voltages will result in some strings with unequal circulating current and internal heating producing power loss and lower efficiency. Bypass diodes are usually used between modules to avoid damage. Most new modules have bypass diodes in them to ensure longer life. However, it is very difficult to replace built - in diodes if a diode fails in a panel.

For DC bus voltage (system nominal voltage) of 48 V, the number of modules to be connected in

Series, Ns will be

$$Ns = \frac{\text{System nominal voltage}(V_{DC})}{\text{Operating Voltage of a single module (Vm)}} \tag{3.15}$$

= 48/33.4

~ **2**

Ns=2 modules should be connected in series.

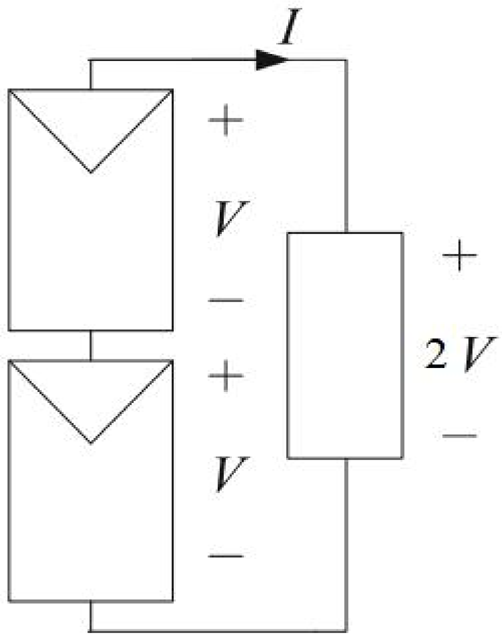


Figure 3. 10 A PV array consisting of one strings with two modules in each string [18]

Where V=24v

Then the number of solar modules connected in parallel which are called strings (N_p) can be calculated by dividing the total number of modules required to the number of series modules

$$N_p = \frac{N_t}{N_s} \tag{3.16}$$

= 1368/2

=**684 modules**

Therefore, 684 strings will be connected in parallel.

Battery Banks

In applications requiring more energy storage or greater voltage, the batteries are connected in series, parallel, or combination thereof to form a battery bank.

$$\text{Number of battery in string} = \frac{\text{Battery bank nominal voltage}}{\text{individual battery voltage}} \tag{3.17}$$

=48/12

=4 batteries in string

The battery bank has

=Total batteries/ batteries per string

=872/4

=**218 strings**

Each string has a capacity of 250 Ah, and so the battery bank has a total charge

Capacity of

Ah per string × strings = 250 × 218 = 54,500 Ah

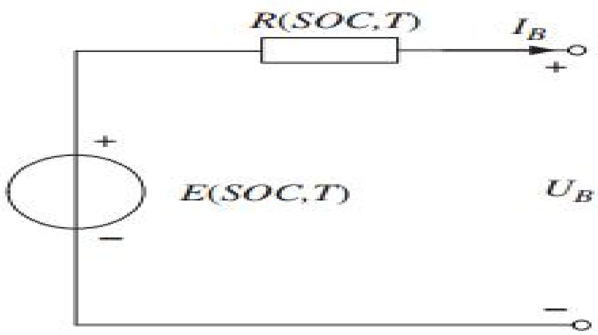


Figure 3. 11 The equivalent circuit model of battery

The SOC is obtained by the following equation,

$$SOC = \frac{\text{Used AH capacity}}{\text{Max AH capacity}} \tag{3.18}$$

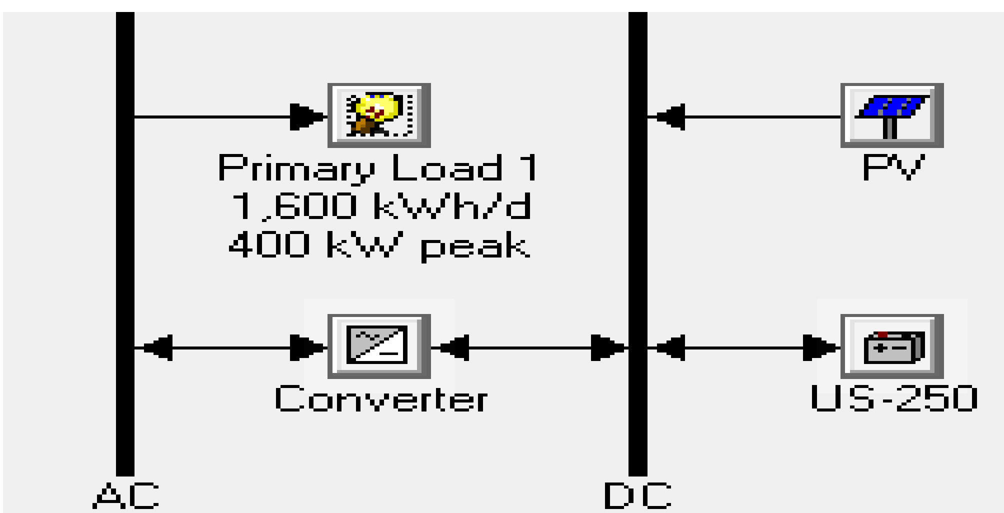


Figure 3. 12 Modeling Load demanded by photovoltaic system using homer software.

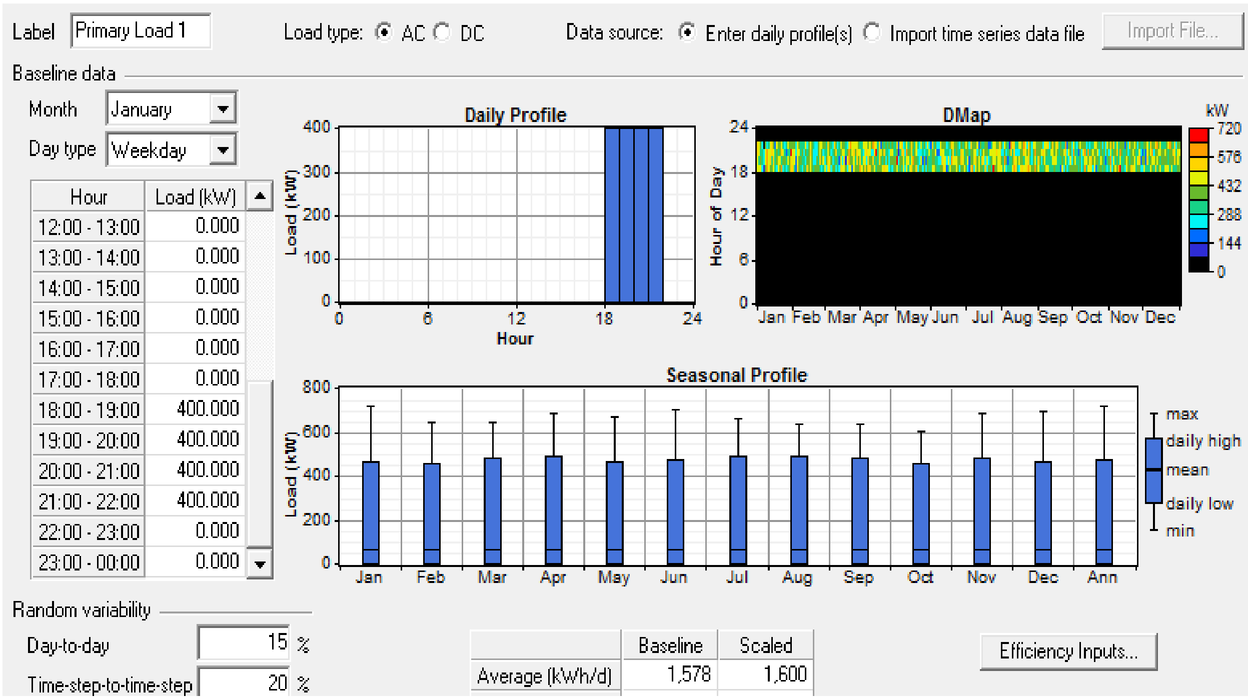


Figure 3. 13 Daily load curve wanted to be demanded by solar energy

Cost Analysis for PV System

The costs of a stand-alone PV system in the industry include initial costs, operating costs, maintenance costs, replacement costs, transportation costs and installation costs. The unit costs for PV module, battery, charge controller, and inverter are available and taken from manufacturer plate.

Table 3. 11. Cost summary of the PV system

Items(components)	Rating	Cost/rating	Total cost ($)
PV module	320w*1368	$0.22/w	96,307
Battery	250Ah*872	$185/unit	161,320
Charge controller	7 KA	$35.6/unit	8,322
Inverter	5*100kw	$9,600/unit	48,000
Total			**$ 313,949**

Replacement costs are mainly for batteries and its lifetime is considered to be 8 years so at least there should be a battery replacement two times. Thus, the batteries have to be purchased, after 8 years and 16 years.

2*161,320= **$322,640**

The maintenance cost is considered to be 10% of the total cost.

0.1*636,589= **$63,659**

Therefore, the total cost required for the solar PV system in Merti metehara which is expected to work for 25 years is

Total=$**313,949**+$**322,640**+$**63,659**

=**$700,248**

Cost benefit of PV System compared with diesel engine system.

Total Cost of solar PV system

Total=**$700,248**

Cost of diesel engine system per year

400kw full load diesel engine requires 29gal/hr (1gal=4.55 litres).

$2.576/gal*29gal/hr*4hr=$298.82/day

$298.82*365= **$109,069.3/year**

Total cost of engine in 25 years

$109,069.3*25=$2,726,733

Ratio of PV system cost to Diesel engine system cost is 0.256

In conclusion, the use of solar PV has cost benefits and environmental friendly. Renewable energy in addition, the problem of power interruption will not be a concern anymore.

3.2.2. Energy storage system design

Using peak power=400KW and 4 hours of operation. Charges during peak off period from grid connected of the company and discharge to the load during the power wanted.

ESS=400*4

=1600KWh/day energy to be discharged.

The factory receives 1.5 MW electrical power from the national power grid at 15kv; 3-phase 50Hz supply.

Now in order to charge the ESS from the source of ac bus energy of 1600kwh/day is to be stored.

So 400kw rating must be used to charge ESS from the grid during off peak period (12 am-4 am).

A 12 volt and 250 amp-hours battery capacity is selected for ESS from manufacturer.

Taking DOD=0.8

$\eta out = \eta battery \times \eta inverter$

$= 0.9 \times 0.85 = 0.765$

Energy storage per battery is

E_b=12*250*0.8*0.765

= 1.836kwh

Number of battery required to store 1600kwh/day

N_b = 1600/1.836

= **872 batteries**

$$P_D = \sum P_{Gi} + P_{ESS} \tag{3.19}$$

Where P_D is the real power demand of the loads; P_{DGi} is the real power generated by each DG in the micro grid;

PESS is the output of the ESS. If PESS>0, it means that the ESS is discharging.

On the Other hand, PESS<0 means that the ESS is being charged.

And the ESS charging and discharging condition is as follows:

Charging; $PD<P_{totalG}$

Discharging; $PD<P_{totalG}$

In this thesis to make the customer sustainable energy user the following design aspect is made.

PD=1200kw

PG1=400kw

PG2=400kw

PESS=400kw

Where PG1 is the power generated from photovoltaic system

PG2 is the power connected to the load from mini hydro

PESS is the power or energy stored using Energy storage system, storing energy during off peak period with the help of rectifier.

Rectifier

Hard chrome plating rectifier **12v, 0-10,000a** adjustable rectifier is selected.4 Hard chrome plating rectifier 12v, 0-10,000a is required.

Cost Analysis for ESS

ESS sizing problem in grid-connected micro grid objective is minimizing the total cost. The objective function is as follows:

Min(IC+MC+OC)

Where, IC=ESS investment cost

MC=ESS maintenance cost

OC=Micro grid operating cost

The following aspects should be considered to define system constraints:

1. The load should be satisfied for every hour; i.e., the power available from the main grid and the ESS should be sufficient.

2. The units should meet the reserve requirement.

3. The total amount of fuel that is to be consumed should be within the scheduling limits.

4. Emission by the units is also constrained to a certain limit

The ESS charging and discharging power are limited by the rated power.

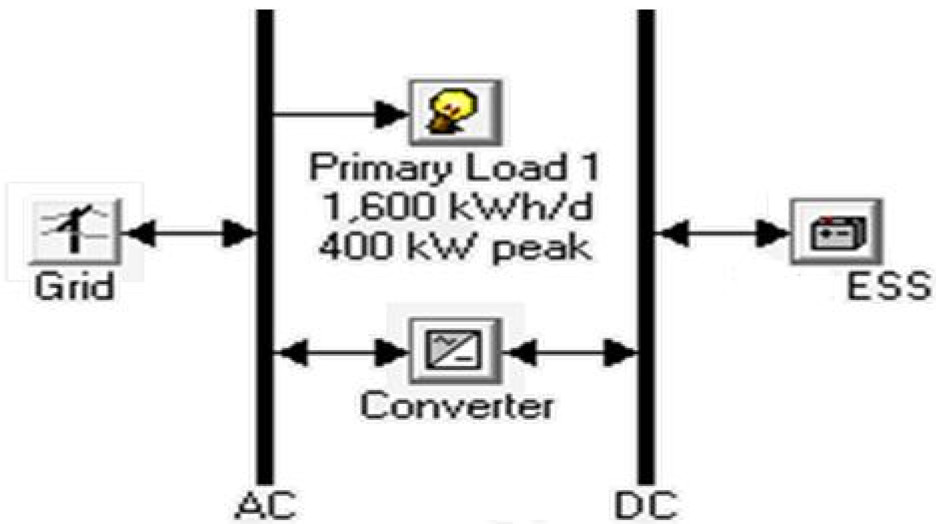


Figure 3. 14 Modeling Load demanded by ESS system using homer software.

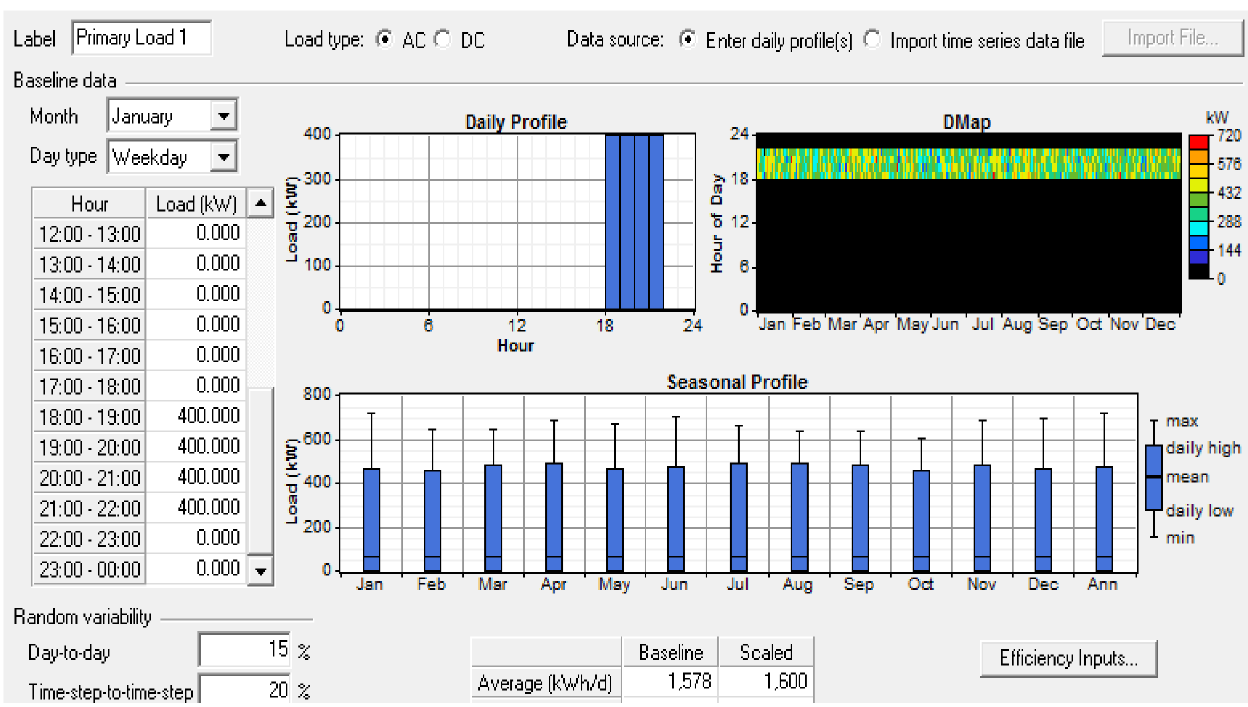


Figure 3. 15 Daily load curve wanted to be demanded ESS

Cost summary of the ESS system

Table 3. 12. Cost summary of the ESS system

Items(components)	Rating	Cost/rating	Total cost ($)
Battery	250Ah*872	$185/250ah	161,320
Rectifier	10,000a*4	10,000$/unit	40,000
Total			**201,320**

Replacement cost

2*161,320 =$322,640

The maintenance and operation cost is considered to be 10% of the ESS battery.

0.1*523,960=$52,396

Therefore, the total cost required for the ESS system in Merti metehara which is expected to work for 25 years is

$201,320+$322,640+$52,396=**$576,356**

ESS System cost compared to diesel system.

Total Cost of ESS system

Total=$576,356

Cost of diesel engine system per year

400kw full load diesel engine requires 29gal/hr(1gal=4.55 litres).

$2.576/gal*29gal/hr*4hr=$298.82/day

$298.82*365= $109,069.3/year

Total cost of engine in 25 years

$109,069.3*25=$2,726,733

Ratio of ESS cost to diesel system cost is 0.21.

In conclusion, the use of ESS has cost benefits with environmental friendly. in addition, the problem of power shortage will not be a concern anymore, this reduce power interruption.

3.2.3. Micro hydro turbine

Water at an elevated height in a reservoir inherits potential energy, and this energy is exploited in a hydropower plant. The different parts of a hydropower plant are shown in Figure below.

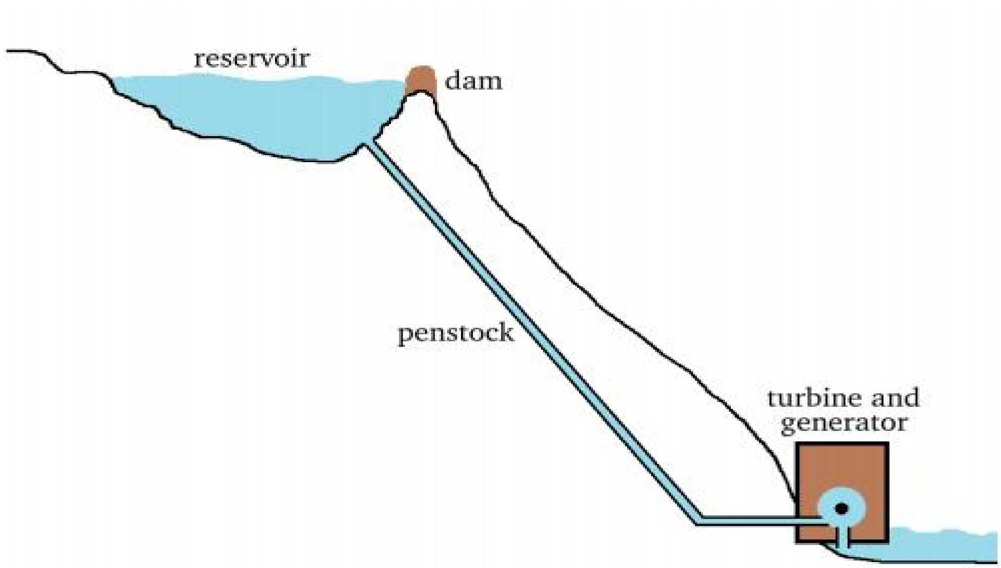


Figure 3. 16 Mini hydropower plant [5]

Taking some amount of water from Awash River and storing in reservoir, the following design procedure is made. This water does not affect the customer that live the downstream because this water is almost taken before for irrigation purpose to feed the sugarcane. But now the water used by hydro plant out can be used for feeding sugarcane.

$$P = \eta \times \rho \times g \times Q \times H \tag{3.20}$$

where η= efficiency of turbine generator, gearbox and turbine.

Taking=90%

ρ = density of water=1000kg/m^3

g= gravity of the earth=9.81 m/s^2

Q=flow rate used for design=2m^3/s

H=25m

P=ɳ*ρ*g*Q*H

=0.9*1000*9.81*1*25

=220kw

Using two turbines it can be produced 440kw (2*220kw) from few amount of awash water which is selected for the design.

Sizing of penstock

Step 1: Steel penstock diameter is calculated as follows

$$D = 3.55\left(\frac{Q^2}{2gH}\right)^{1/4} \tag{3.21}$$

where Q is flow rate = 1m^3/s

g=9.8m/s^2

h=height

$$D = 3.55\left(\frac{1^2}{2*9.81*25}\right)^{1/4}$$

$=3.55(0.0020)^{1/4}$

= 3.55*0.212

= 0.76m

Step 2: Determining the length of penstock

Assuming there is only head loss due to friction in penstock (applying the manning formula) then

$$\text{Head loss} = [10.29n^2Q^2/D_p^{5.33}]*L_p \tag{3.22}$$

Where n = manning coefficient = 0.012

In this thesis the head loss is assumed = 0.1(10%) x 25m= 2.5

$2.5=[10.29\times0.012^2\times1^2/0.76^{5.33}]\times Lp$

2.5 =[0.0015/0.23] × Lp

Lp= **383.34m**

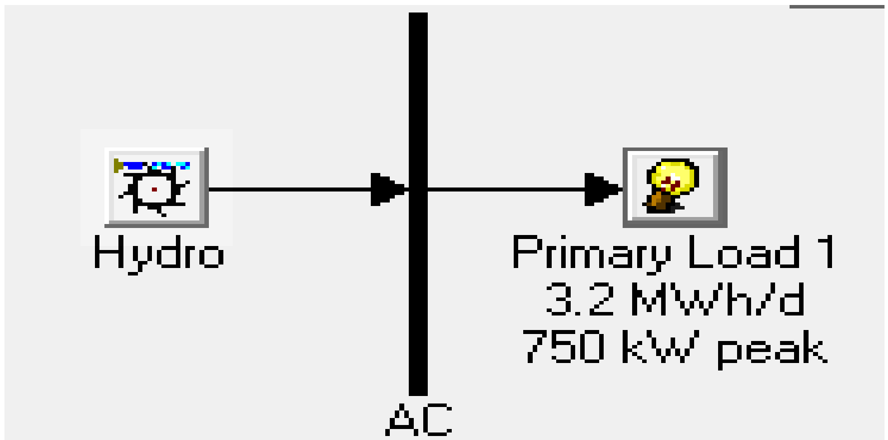


Figure 3. 17. Modeling Load demanded by hydro system using homer software

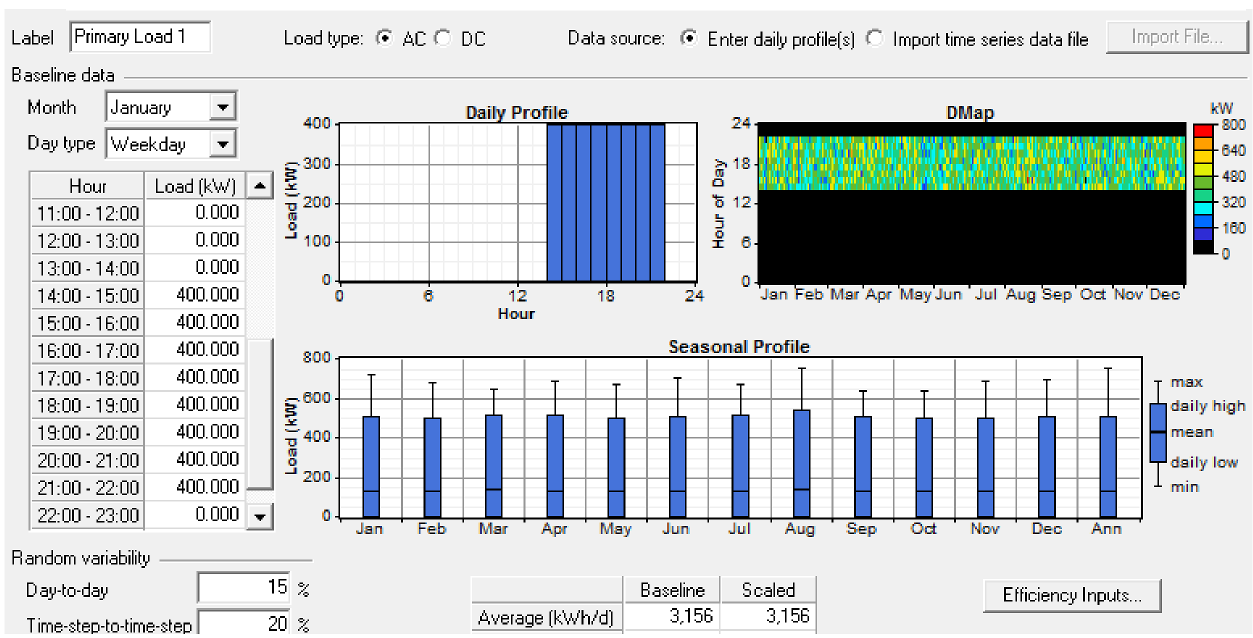


Figure 3. 18 .Daily load curve wanted to be demanded by hydro resource

Cost of micro hydro generation cost

Power stored obtained from the design is 400kw. **200kw Pelton Wheel for Micro** Hydro Generator is available and selected.**US $ 35200** / Set from supplier

Micro Hydro Turbine Generator 20kw 50kw 80kw 100kw **200kw** for Hydro Power Project **US $ 12000-45000** / Set from supplier.

The cost of mini hydro estimated at 0.85$/w.

Including civil work total cost estimated to produce 400kw is $340,000.

The model is used in order to run to 3 scenarios: The requirement is to generate 1200kw power for 4 hours to support steam turbine.

i. Standalone Diesel turbine set

This scenario is a classical standalone diesel generator powering a 1200kw load. Being standalone, the diesel supplies all the power required to be supplied. The cost required to fed the load for within 25 years is $**8,180,199**.

ii. PV only

In scenario the solar power plants supply power during the day and stores in a battery. It requires solar panel and battery for practical application to feed the 1200kw load. The total cost required to fed the load for 25 years is $**2,100,744.**

iii. PV, Mini hydro and ESS

There is 1.5MW power gained from grid. It can be used some fraction to store the energy at Peak off period using rectifier and stored in battery. This stored battery is combined with mini hydro and PV system to satisfy the power required. The total cost required to fed the load for 25 years is $**1,664,604**.

Cost-benefit analysis is a very common method to determine optimal storage sizing.

Best scenario from the 3 sceniorio is (iii) with the same energy consumption less cost benefited.

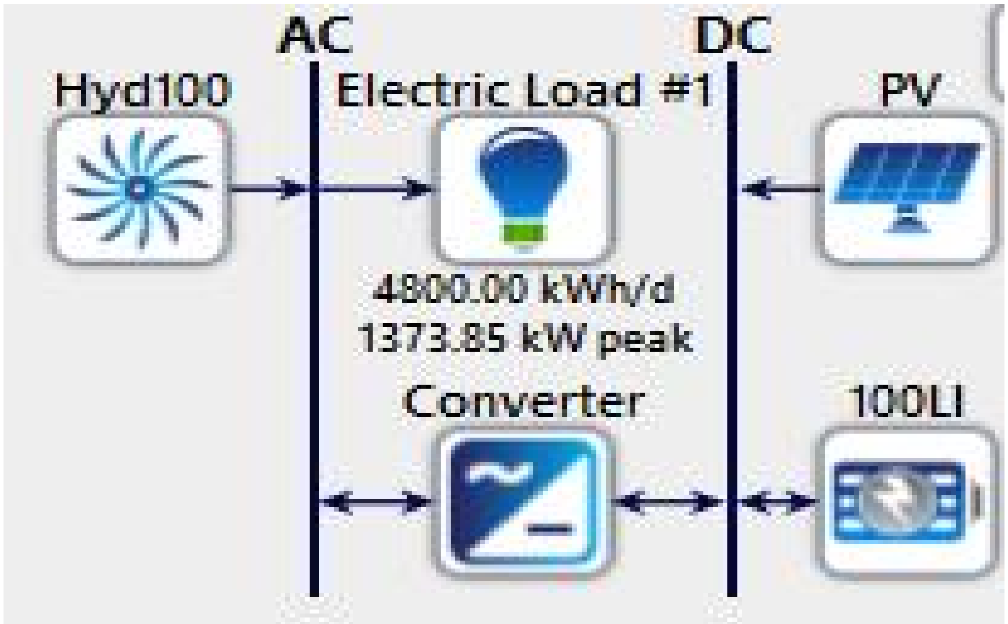


Figure 3. 19 General model of hydro and solar energy using homer software

Therefore 400kw power obtained from photovoltaic, 400kw obtained from ESS and 400kw from mini hydro can minimize the interruption of power to customer working in metehara sugar factory. Minimizing System Average interruption duration index, it is possible to make the community beneficial in getting sustainable Energy.

CHAPTER FOUR

4. RESULT AND DISCUSSIONS

HOMER Energy is the global standard for optimizing micro grid design in all sectors, from village power and island utilities to grid-connected campuses and military bases. HOMER (Hybrid Optimization of Multiple Electric Renewables), simplifies the task of evaluating designs for both off-grid and grid-connected power systems. When you design a power system, you must make many decisions about the configuration of the system, such as:

i. Which components are best for this system?

ii. How many and what size of each component are most efficient?

The large number of technology options, variation in costs, and availability of energy resources make these decisions difficult.

To use HOMER, you select and enter information under the Design button to provide the model with inputs, including components (e.g., generator, wind, and solar), component costs, and resource availability. You can also add new components, resources, and loads under the Library button.

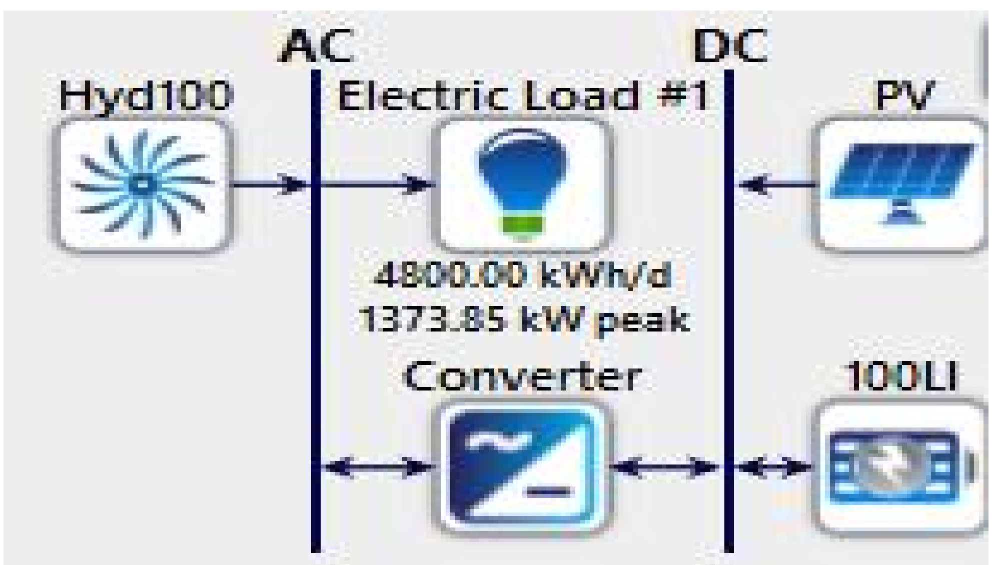
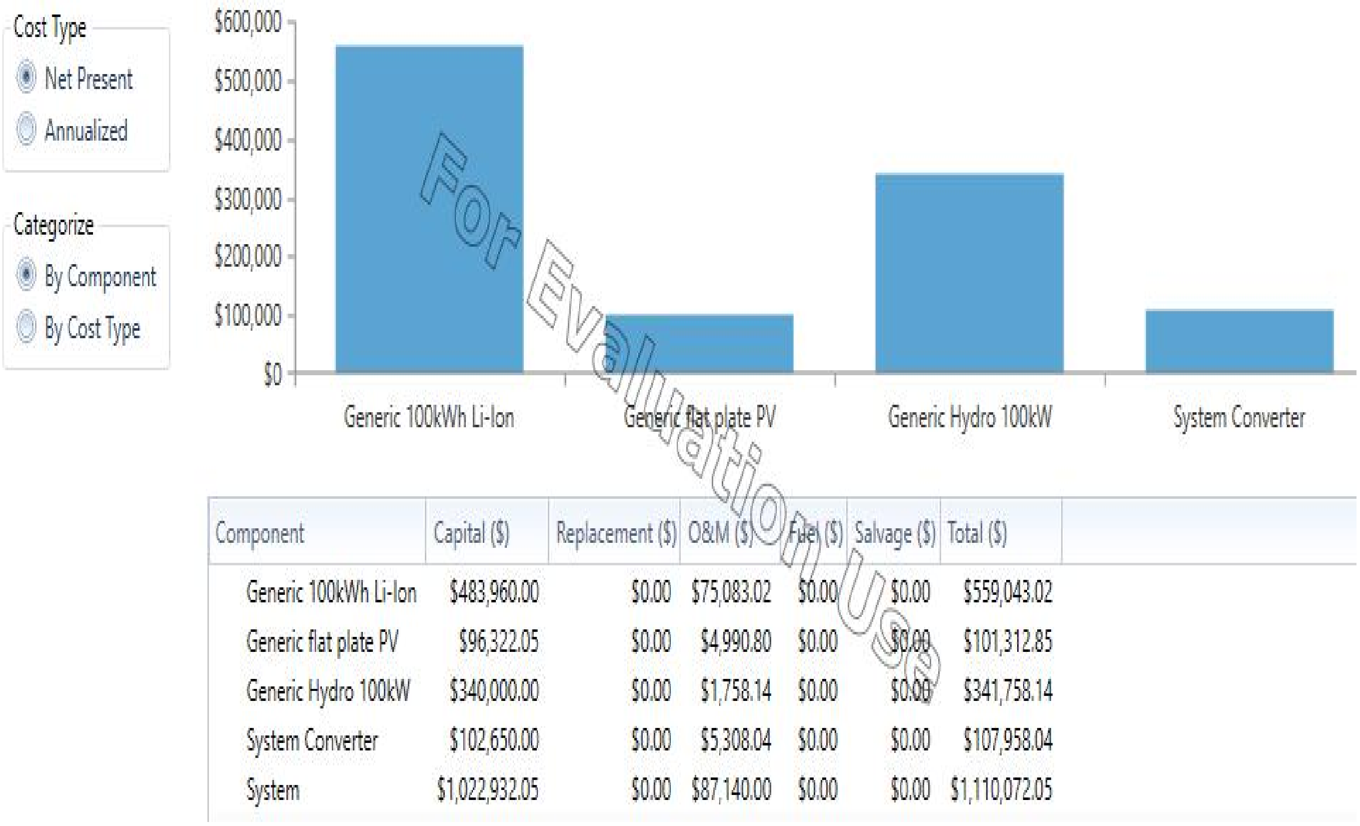


Figure 4. 1. Model of photovoltaic and hydro using homer software

Architecture				Cost			
PV (kW)	100LI	Hyd100 (kW)	Converter (kW)	NPC ($)	Initial capital ($)	O&M ($/yr)	Ren Frac (%)
400	78	417	1,026	$1.11M	$1.02M	$6,741	100
400	78	417	1,026	$1.11M	$1.02M	$6,741	100
400	78	417	1,026	$1.11M	$1.02M	$6,741	100
400	78	417	1,026	$1.11M	$1.02M	$6,741	100

Figure 4. 2. Optimization result of photovoltaic, battery and hydro usage for the thesis



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Generic 100kWh Li-Ion	$483,960.00	$0.00	$75,083.02	$0.00	$0.00	$559,043.02
Generic flat plate PV	$96,322.05	$0.00	$4,990.80	$0.00	$0.00	$101,312.85
Generic Hydro 100kW	$340,000.00	$0.00	$1,758.14	$0.00	$0.00	$341,758.14
System Converter	$102,650.00	$0.00	$5,308.04	$0.00	$0.00	$107,958.04
System	$1,022,932.05	$0.00	$87,140.00	$0.00	$0.00	$1,110,072.05

Figure 4. 3. Overall cost of the system

Production	kWh/yr	%
Generic flat plate PV	664,084	17.6
Hydro	3,104,424	82.4
Total	3,768,507	100

Consumption	kWh/yr	%
AC Primary Load	2,336,000	100
DC Primary Load	0	0
Total	2,336,000	100

Quantity	kWh/yr	%
Excess Electricity	1,268,650	33.7
Unmet Electric Load	0	0
Capacity Shortage	701	0.0300

Quantity	Value
Renewable Fraction	100
Max. Renew. Penetration	490

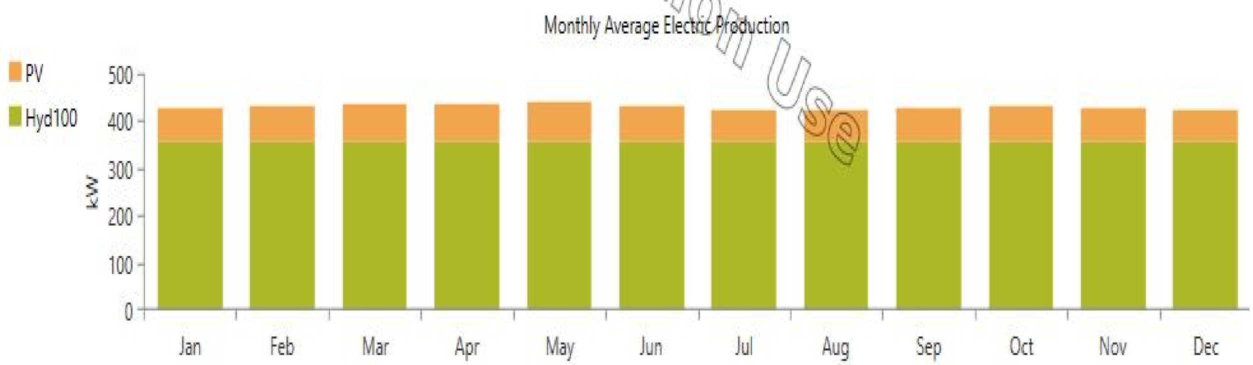


Figure 4. 4. Comparison of photovoltaic and mini hydro capacity in production of energy electrically

The design used so far can meet the demand of the customer from:

i. 400kw from mini hydro

ii. 400kw is produced by solar energy.

iii. 400kw is replaced by Energy storage system rectified from the grid or hydro during off peak hour.

ESS System cost to supply additional load of 400kw for 4 hours using rectifier from the grid at peak off period is $576,356.The total cost required to use PV, hydro and battery designed for this thesis is $1,686,428 to support the power used at merti metehara.

The software prove whether the design assumption made so far is applicable to recommend the metehara sugar factory installing solar energy,Mini hydro and Energy storage system.

Renewable energy integration with energy storage system makes benefit to the company sustainable energy production and environmental friendly with long range cost benefit.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

This thesis has shown that there is certainly a place in our future for grid-scale battery energy storage systems. The need of flexibility within the electricity system increases with the upcoming proportion of renewable energy generation. In order to avoid sustained power interruptions an alternative power supply system was designed by considering its initial investment cost of the system to be installed. A 1200kw power for 4 hours was produced and stored to satisfy the workers of the company without sustained power interruption. In conclusion to this thesis study, renewable energy integration with energy storage system makes benefit to the company sustainable energy production and environmental friendly with long range cost benefit.

5.2. Recommendation

From this project work, it has seen that Ethiopia has a huge potential for rural Electrification through the off grid system. I recommend metehara sugar factory to install renewable energy (solar energy and hydro power energy) with ESS for additional power need. This design aspect increases the reliability and reduces the cost compared to Diesel engine used for backup usage. I propose this design and recommend for Ing.Fitsum to check and apply this seniorio to their company to extend their power generation for the company consumption.

In Future students must work on Hybridizing different type of energy storage system and study their feasibility to use for grid support. They must also study in detail their drawback and improve their performance as much as possible.

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Appendix A

Equipment used for generation of photovoltaic, ESS and mini hydro energy.

Figure A.1 320w mono crystalline solar panel

Figure A.2 12v, 250Ah Rechargeable Lithium ion battery

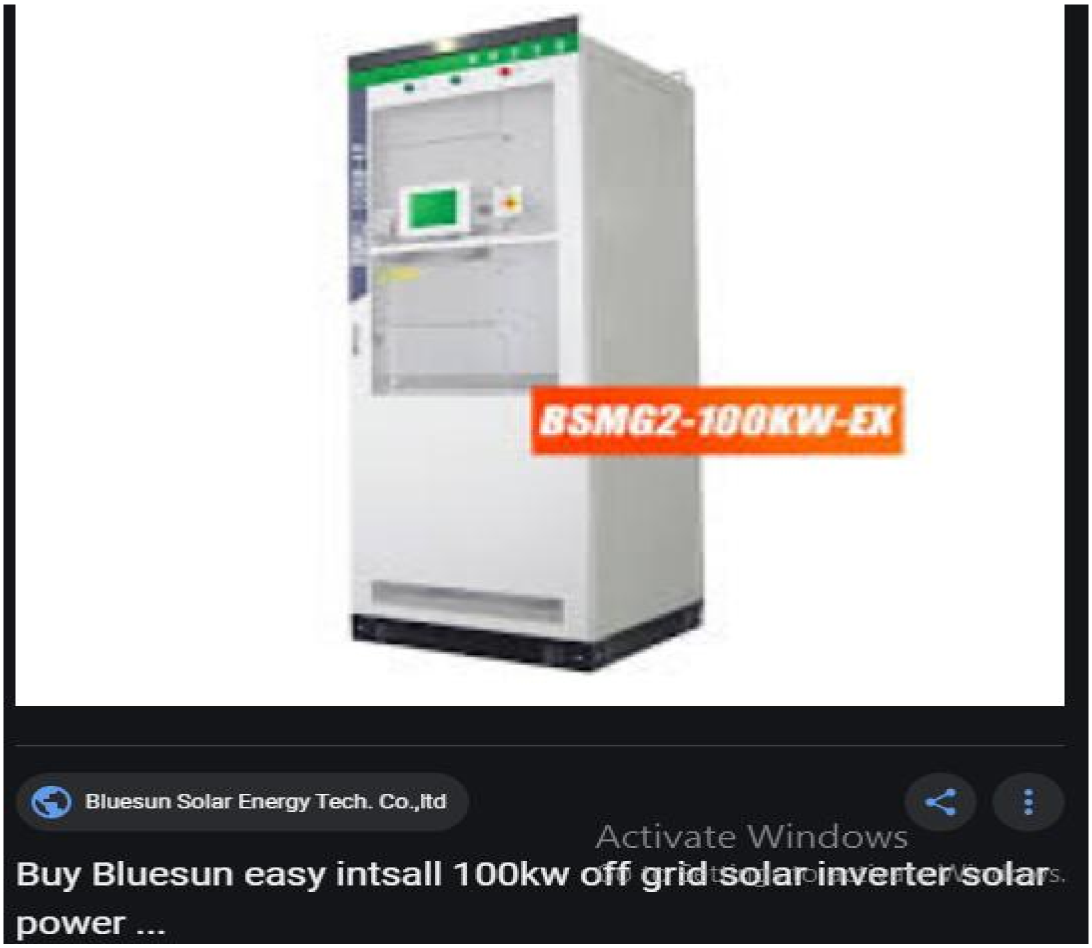

Figure A.3 100kw inverter

Figure A.4   30A solar charge controller

Figure A.5   200kw Pelton Wheel for Micro Hydro Generator