UNIVERSITY of RWANDA COLLEGE OF SCIENCE AND TECHNOLOGY ACE-ESD AFRICAN CENTER OF EXCELLENCE IN ENERGY FOR SUSTAINABLE DEVELOPMENT

TITLE: PV-DIESEL INTEGRATION TO REDUCE CARBON DIOXIDE EMISSION

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MASTERS OF SCIENCE IN RENEWABLE NERGY (REE)

Names of Supervisor: **Jean Marie Vianney BIKORIMANA**

October, 2020

DECLARATION

I, Vestine UMUHOZA, declare that this dissertation of "**PV-DIESEL INTEGRATION TO REDUCE CARBON DIOXIDE EMISSION**" is the result of my own work and have never been submitted or presented any way else for the similar award.

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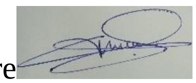
Signature

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CERTICICATE

This to certify that the project named "**PV-DIESEL INTEGRATION TO REDUCE CARBON DIOXIDE EMISSION**" with project number: **ACEESD/REE/20/02** is the record of the original work done by **Vestine UMUHOZA**, Registration number: 214000998. In partial fulfillment of the requirement for the award of Master of Science in Renewable Energy, under the African Center of Excellence in Energy and Sustainable Development (ACCE-ESD) of University of Rwanda, College of Science and Technology(UR-CST),during the academic year 2019-2020.

Supervisor:

Dr. JMV BIKORIMANA

Date 22 /10/2020

Signature

DEDICATION

Dedicated

To

Our Almighty God

My families

And

My close friends

ACKNOWLEDGEMENT

I deeply thank the Almighty God, who has guided me through the whole period of my studies.

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Nomenclature

η_i	Inverter efficiency
η_{gr}	Diesel efficiency
UR	University of Rwanda
CST	College of Science and Technology
ACE-ESD	African Center of excellence in Energy and Sustainable Development
I	Circuit current
I_{SC}	Short circuit current
V	Circuit Voltage
V_{OC}	Open voltage
R_L	Load resistance
AC	Alternating Current
DC	Direct Current
DG	Diesel generator
EMS	Energy Management System
ESS	Energy Storage System
HES	Hybrid Energy System
NASA	National Aeronautics and Space Administration
NRES	Non-Renewable Energy sources
RE	Renewable Energy
PV	Photovoltaic
P_{pv}	Photovoltaic power
P_{dg}	Power generated by diesel generator
P_L	Power demanded by load
P_{MAX}	P_{MAX} Maximum power of diesel generator
P_{MIN}	Minimum power of diesel generator
P_{NET}	Net load (P_L-P_{PV})
P_{OPT}	Optimum operation power
PRP	Primer power
Pr	Rate power
P_{out}	Actual operating power
P_{ng}	Nominal power of generator

P_{og}	Output power of diesel generator
P_{in}	Inverter power
P_{ch}	Hourly power demanded
N_{gr}	Number of diesel generator
FC	Fuel consumption of diesel rate
CO_2	Carbon dioxide emissions
GH	Greenhouse gas
GHG	Global greenhouse gas
AVR	Automatic voltage regulation
FF	Fill factor (dimensionless)

Abstract

Worldwide energy sector is essential for living and very important for development. For energy need, the world depends on different source of energy, among of them fossil fuels have played a big role, however, it has high contribution on Carbon dioxide (CO_2) emissions. Nowadays the population growth and industries are rapidly increasing consequently, there is high energy demand, which increase the amount of fossil fuels to be consumed. The studied cases of two different thermal power plant has indicated that there is a huge amount of 561.935 Kg of CO_2 per a day emitted due to full day operation. Nevertheless, the nations are moving in the direction of non-traditional energy assets, among which the sun powered fuel source is without contamination and limitless choice.

Accordingly photovoltaic-diesel power age framework is one of generally encouraging of its great presentation, because of its low CO_2 discharge considering to the independent diesel power age frameworks. The point of this research is to appraise the measure of carbon dioxide (CO_2) emanations that can be diminished once a photovoltaic framework is corporate customary electrical organization. The present thesis measures carbon impression discharged for diesel generator as far as carbon dioxide before being integrated with PV system by considering the quantity of fuels used during energy generation and also on the amount of energy demanded by the loads. Also it estimates the amount of CO_2 after being photovoltaic/diesel hybrid system. The research shows that there is a significate reduction of fuel consumed by diesel generator and with diesel working together with a solar photovoltaic, this fuel reduction resulting with a big amount of in CO_2 of 401,243 Kg per a day, due to high solar radiation in Rwanda which can reach to 6KWh/m^2/day, the research conclude that PV/diesel hybrid system is affordable in Rwanda and can be used as well of mitigating pollution, especial carbon dioxide emissions.

Chapter1.GENERAL INTRODUCTION

1.1 Background

Energy is fundamental to financial for social turn of events and improves personal satisfaction, it is significant for creating society. The absence of dependable power flexibly, the significant expense of AC matrix augmentation and the harsh geology are a portion of the serious difficulties looked in zap of enormous number of agricultural nations. Whereby a large portion of the cases, loads in those nations are controlled by diesel generators (DGs) with full time day operation [1]. Utilization of diesel power energy age framework require high utilization of petroleum derivatives bringing about the creation of carbon dioxide (CO_2) which is the essential "ozone harming substance" liable for an Earth-wide temperature boost , in extra to other nitrogen and sulfur oxides [2] . As the grouping of CO_2 has raised, the normal surface temperature of the earth has expanded by 0.74℃. In the event that we keep on emanating carbon without control, the temperatures are relied upon to ascend by an additional 3.4℃. Environmental difference in that extent would almost certainly have genuine ramifications for life on the earth.

Because of high running of diesel generators, their limited inconveniences and destructive substance for the climate have driven modern organizations and states are going to exchanging energy assets. Whereby, they are eager to move from utilizing these conventional generators to the Renewable energy advances. Sustainable power advances, (for example, sun oriented photovoltaic framework) can be decentralized not normal for the public power matrix. This permits end-clients to produce their own any place they are found. Additionally, these advances don't need any running cost, in contrast to the customary diesel generators. A total supplanting of diesel generators with sun oriented force is typically not plausible due the way that it's exclusively depending on sun based light (regardless of whether there is bounty and it is free) it isn't sure thing for an industrials purchasers as PV creation can be conflicting. This is the reason industrials are depending on PV-Diesel cross breed frameworks which have demonstrated to be entirely solid and practical. PV-Diesel Hybrid energy applications are of expanding interest and an all-around oversaw PV-Diesel framework can accomplish lifetime fuel reserve funds, while guaranteeing dependable power flexibly. To the extent that diesel fuel is decreased and such framework lessen CO_2 just as particulate discharges that are unsafe to wellbeing [3].

1.2 Problem statement

In same area over the world there is a significant some portion of populace doesn't approach power because of the way that the advancement in network remains more slow than populace development, this prompting a colossal hole between the interest and flexibly of power, what hinder truly their social, training and financial turn of events. Among the current flexibly of power have accomplished utilizing independent power system and comprehensively by diesel generator in any case, the unstable cost of petroleum products, combined with the ecological emanations like carbon dioxide, which is high dominant in the atmosphere. The world is worried about the amount of emissions emitted in the environment from the energy generation sector. Many meetings have been organized since 1970s, in order to decrease the environmental problems, by keeping energy generation full the load energy demanded, without increasing CO_2 in the atmosphere. It is hopefully that, this study of photovoltaic/diesel hybrid system is a good option to help the world for solving these mentioned issues of gap between demand and supply, climate change by reducing carbon dioxide, money saving due to reduction of fuels consumed by these diesel generators.

1.3 Objectives

The objectives of study contain with a major part called general objective which is the fundamental objectify of the research and specific objective which indicate the progress in which general objective can be achieved.

1.3.1 General objective

The principle target of this research is to assess the measure of carbon dioxide (CO_2) that can be diminished in electrical network generation by integrating solar photovoltaic system on diesel generator framework.

1.3.2 Specific objectives

The present research present the following objectives:

- To create a reliable and efficient PV/Diesel hybrid system
- To show haw CO_2 emissions can be reduce from working hours of diesel generator
- To reduce fossil fuel energy generation dependence
- To create PV/Diesel hybrid control system

1.4 Research methodology

This study of PV/Diesel hybrid system was carried through documentation which helped to model and optimize PV/diesel hybrid system. The site visit was conducted at Jabana I and Jabana II thermal power plants to collect some data for the case study. The data was analyzed and visualized using excel software.

1.5 Related works

Many scientists have been centered on the incorporation of environmentally friendly power with the customary fuel sources, particularly mix of sunlight based photovoltaic frameworks with the diesel generators for charge of far off and rustic zones that would help with extending the power access.

Different researchers have been made on the energy the executives by incorporating a brilliant network into a customary power framework including diesel generators, as the best approach to satisfy a specific force need of the buyers, the mixture framework was intended to conquer the issue of environmental change, to guarantee a solid flexibly without interference and to improve the general framework productivity.

A new methodology for optimal plan hybrid plan of sustainable power optimal activity procedure and financial examination of a photovoltaic-diesel cross breed, to meet the desirable electric burden with high inexhaustible division, low abundance and to diminish the fuel cost of diesel generator.

Present study come up with a solution of gap founded among these different research that have been done, without considering how PV-diesel integration can reduce a certain amount of carbon dioxide emissions is electrical conventional network.

1.6 Research hypothesis

The present study is based on the following hypothesis:

Integration of PV system into a network aiming at reducing of CO_2 emissions.

1.7 Scope of the study

This part of research shows the limitation by location to be carried on during the study.

Because of the means two sites have been conducted, Jabana I and Jabana II. The research might have been conducted all over the country, but the study was limited on these two thermal power plants. The study didn't put into consideration the optimization of cast due to the fact that it have be done by many other researchers, this study was based on optimization of CO2 emission reduction.

1.8 Organization of the research

This research is composed by four chapters which are as follows:

- Chapter 1: General introduction, where general objective of the study are clearly explained.
- Chapter 2: Literature review, through different readings, the interested study was done, on the demonstration of carbon dioxide (CO_2) emissions from non-renewable sources, CO_2 from photovoltaic system, working principle of solar photovoltaic and diesel system and its design.
- Chapter 3: Diesel optimum operation, this chapter shows the operating concept of diesel generators by showing some governing principals, their operating factors, controls and regulations on the perfect use diesel generators.
- Chapter 4: PV-Diesel hybrid optimization, this chapter explains clearly the functionality of PV/Diesel hybrid system its components and its control strategy. This chapter also contain, results and discussion, in this chapter also obtained result have presented and analyzed.
- Chapter 5: Conclusion and recommendations, this part is concerned by conclusion and recommendations of PV/diesel hybrid system integration and the carbon dioxide emissions reduction.

Chapter 2: LITERTURE RIVIEW

Reformist energy request development and quick consumption of petroleum derivatives have raised worries of future energy supplies [4]. In addition, the utilization of traditional fuel sources from petroleum derivatives has brought about high increments in Carbon dioxide discharges (CO_2), which are the main predominant reason for an unnatural weather change [5].

The energy area is answerable for 40% of the worldwide ozone harming substance (GHG) discharges [6]. Whereby Carbon dioxide (CO_2) emanations have expanded throughout the years because of ascend in worldwide energy request which increment the persistent consuming of petroleum derivatives, this has critical ramifications for the ecological and a significant supporter of the environmental change [7].

This issue can be overwhelmed by incorporating non-sustainable power sources (NRES) like coal, oil and gas with sustainable power sources (RES, for example, sun oriented, wind, hydropower, geothermal and biomass, which are known to be naturally inviting and e effectively recharged [8].

Among these inexhaustible sources, sun oriented energy transformation is a reasonable applicant as it permits direct change of sunlight based radiation energy to the electrical energy by utilizing photovoltaic (PV) framework [9]. Sun oriented energy is generally considered as one of the additionally encouraging environmentally friendly power advances which can possibly contribute altogether to a maintainable energy flexibly and which can be useful ozone harming substance discharges relief [10].

This study will analyze how photovoltaic-diesel hybrid power system will be a great interesting system to reduce greenhouse gas especially carbon dioxide emissions (CO_2) from diesel system grid generation, whereby the amount of carbon dioxide emissions from diesel generator depends on the measure of fuel devoured by the diesel generator [11].

The carbon substance of fills somewhat fluctuates, however normal the normal carbon content qualities to assess CO_2 emanations could be adjusted [12]. The utilization of 1 liter of diesel discharges 2.7Kg of CO_2. Nonetheless, the quantity of Kg of CO_2 created per liter of fuel devoured by the diesel generator relies on the attributes of the diesel generator and the qualities of the non-renewable energy sources, and it is typically fall in the scope of 2.4-2.8 kg/liter [13].

The present study puts into consideration the CO_2 emitted from solar photovoltaic by considering the life time of PV modules and the emission from their transport from manufacture up to the end users [14]. Integration of solar photovoltaic and diesel is more beneficial on the grounds that any individual force age framework isn't totally dependable where if any of every framework is closure the other can gracefully control which reduce some existing blackout, especially photovoltaic system will act as back-up system of diesel stem where the PV will generate electricity during the peak demand day time; Therefore, there will be a reduction of fuels to be used by diesel generator and also there will be no need of energy storage.

The PV-Diesel Hybrid framework must be finished with the control framework with the capacities to run the whole segment in a specific condition. And also there will be a need of some algorithm which allows this system to operate fluently depends on each critical condition; the energy source from photovoltaic clusters and generator has to be optimizing for providing the everyday load energy [15].

2.1 C02 emissions from traditional electrical network

The present study shows the historical consumption and the impact of the utilization of non-sustainable power sources. These non-sustainable power sources (NRES) are referred to as fossil fills, for example, coal, oil and petroleum gas.

Petroleum derivatives energy have assumed an unequivocally sure part in worldwide change; as it was a major driver of the Industrial Revolution which is known as the beginning of different technologies, social economic and development progress.

In any case, petroleum derivatives additionally have negative effect, being predominant wellsprings of nearby air contamination and producer of carbon dioxide (CO_2) and other ozone depleting substances, the figure (1) shows a correlation among GHG discharges from the different fuel sources, it shows how wind and sunlight based force radiate least outflows [16]. Basic counts could show that building a force plant of limit 1MW filled by gas-consolidated cycle would bring about 400 tons of carbon dioxide (CO_2) equal GHG outflows. Utilizing coal or oil would result somewhat more than twice that amount the comparing esteems for renewables are under 10% of the cleanest customary source [17].

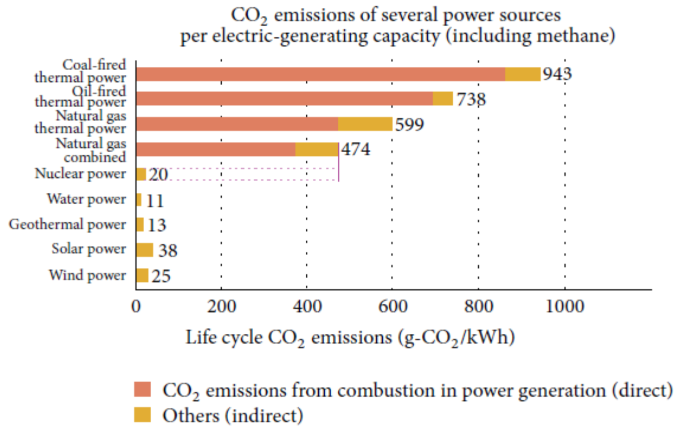

Figure 1: GHG emissions from different energy sources [18]

Non-renewable energy sources creation and utilization started with coal, it's originally revealed similarly as in China where cutting occurred out of dark lignite (one of the few types of coals). Be that as it may, huge – scale ignition of coal was normal connected with the period around the start of the Industrial Revolution [19].

The representation shows the worldwide utilization of non-renewable energy sources (coal, oil and gas) was from 1800 onwards. Generally speaking it has demonstrated that the worldwide utilization of petroleum derivatives has expanded from 1800-1860s where coal was the solitary petroleum product sources until the 1860s when the unrefined petroleum utilization start and the Natural gas creation start in the 1880-1890s.

The twentieth century saw an enormous expansion of fossil energy utilization, with coal declining from 96% of the complete creation in 1900 to under 30% in 2000 [5].

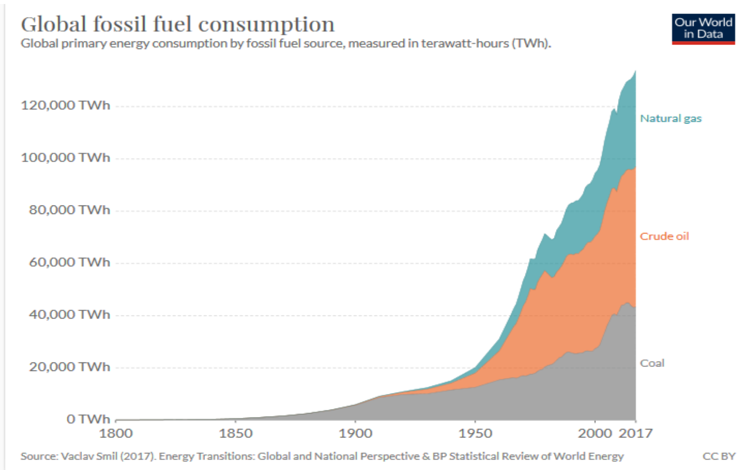

Figure 2: Global fossil fuel consumption

2.1.1: Fossil fuels consumption

Absolute utilization levels of petroleum products in higher-salary nations have regularly topped, and now declining as they change towards lower-carbon fuel sources as we have seen above the fossil fuel is the most dominant pollutant energy sources [5].

2.1.2 Coal consumption by regions

The overall provincial conveyance follows a fundamentally the same as example to that of coal creation.

Asia Pacific is the predominant coal purchaser, representing almost seventy five percent of worldwide utilization; this offer is somewhat bigger than a lot of coal creation.

The Africa accounts for 2.5%of the consumption; less than its 4% of production, while all things considered, Europe, Eurasia and North America represent short of what one fourth of coal utilization [20].

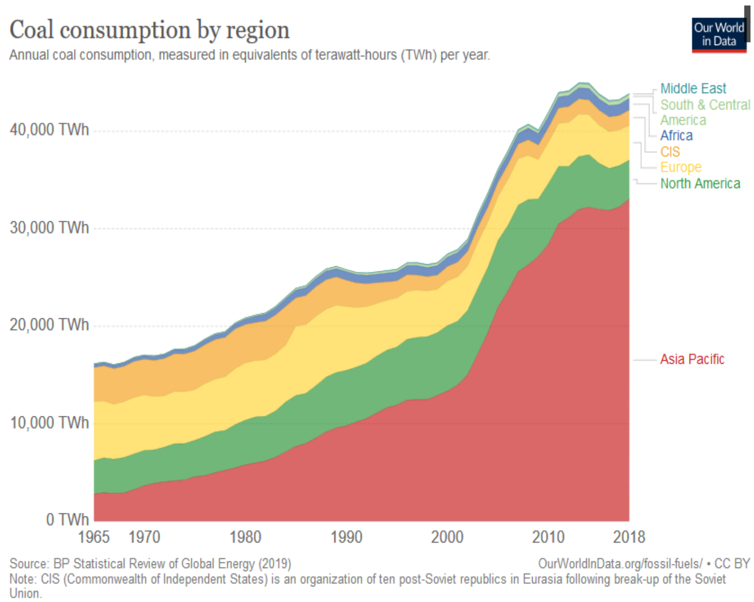

Figure 3: Oil utilization by area

2.1.3 Oil utilization by area

Absolute oil utilization by locale over this period, on relative standing we see a diminishing portion of worldwide utilization from Europe, Eurasia and North America as opposed to a rising offer in every single other district. Most remarkably Asia Pacific which has too much of worldwide oil utilization.

In correlations of oil utilization to creation by district, it has seen that Middle East is an a lot more modest customer than maker of oil where it was delivering 30% and burns-through 10% significance it is net buyer. Interestingly, Asia Pacific locale burns-through altogether much oil [20].

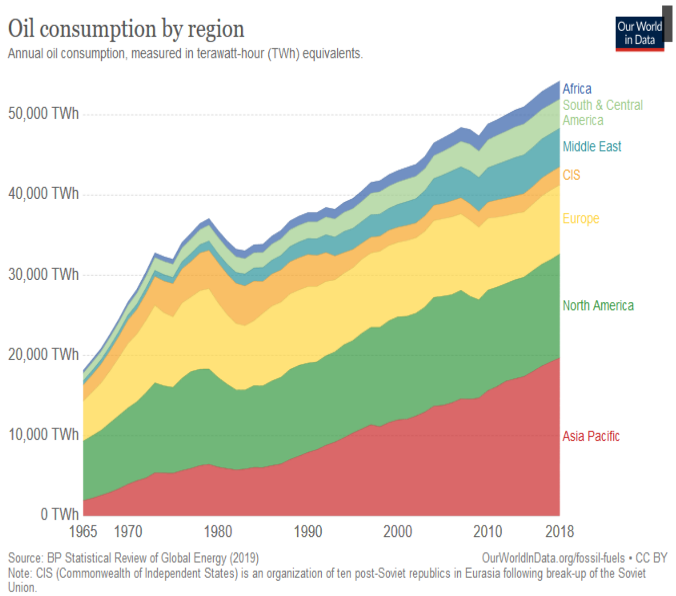

Figure 4: Flammable gas utilization by area

2.1.4. Flammable gas utilization by area

Territorial gas has strength in North America, Europe and Eurasia in the 1960-70s and the noteworthy local enhancement as utilization increments over the world comparative with the graph of gas utilization we see that the center East devours a more modest portion of the worldwide complete gas burned-through than it produces meaning it is a net gas exporter, while the Asia pacific district burn-through somewhat more than it produces meaning that it is a net gas exporter [20].

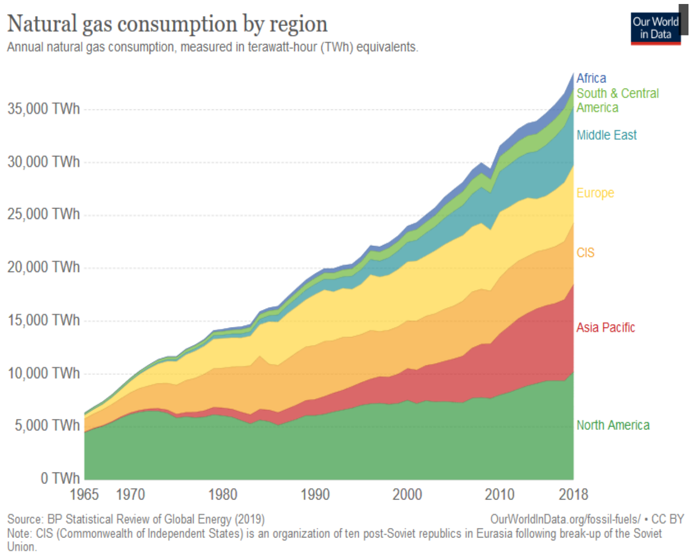

Figure 5: Gas consumption by region

2.2 Carbon dioxide emissions (CO_2) related to the electrical sector

Electrical grid Network comprise three major sectors: Generation, Transmission and distribution in this study the carbon dioxide (CO_2) emitted during transmission and distribution is negligible due to low ret, the study was interested in the carbon dioxide emitted during energy generation, where the world counts on fossil fuels as the most dominate energy sources.

Traditional electrical (thermal) strategies depend on utilization of non-sustainable power sources (NRES) for energy production which is mostly done by burning fossil fuels (coal, oil, and gas) to warm water in kettle to get steam, the steam drives a turbine that pivots transmitters inside an attractive field to create power [21]. Consuming of non-renewable energy sources in power plants discharge hurtful emission including Carbone dioxide (CO_2) which is the significant ozone depleting substance (GHG) causing an Earth-wide temperature boost, Sulfur oxide (SO_2) and Nitrogen oxides (NO_2) [22].

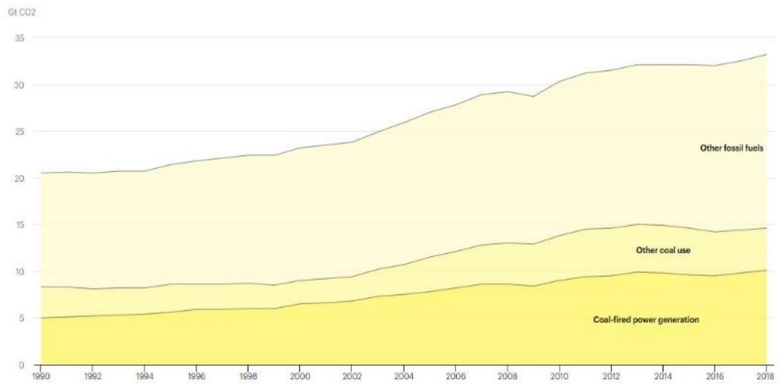

Figure 6: Global energy and related carbon dioxide emissions by sources

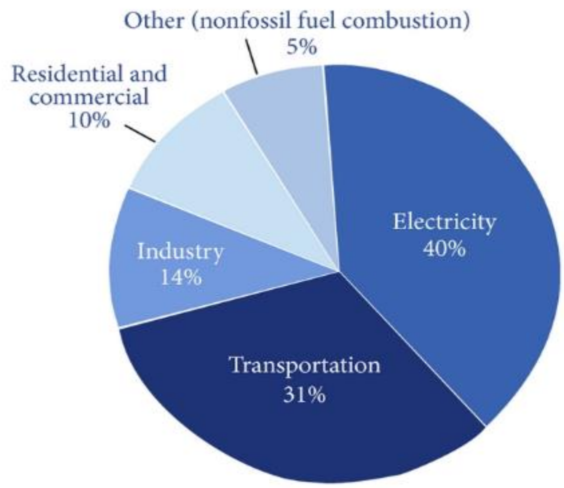

Figure 7: Global CO2 emissions by sector

Global Carbon dioxide (CO_2) emissions in 2019 was 33 Gig atones, [5] where approximately12 Gig tones (40%) are discharged from power age area through the burning of petroleum derivatives like coal, oil, and gas to produce the warmth expected to control steam-driven turbine.

2.3 Traditional electrical energy source and CO_2 emissions in Rwanda

Rwanda, is East African country, within 12,301,938 [23] populations, it has small territory of 26,338 Km^2 with 94.7% of the area is land and the rest 5.3% is involved by water. Its geology is inside scopes 1.05 and 2.840OS and longitudes 28.860 and 30.900oE [24] and has two blustery seasons in a year.

The power flexibly of Rwanda is made out of homegrown age and imported power from neighbor districts and the area shared force plants. The wellsprings of energy utilized in Rwanda are: hydropower plants, warm force plants (Diesel and Heavy fuel generator), methane gas, peat and sun oriented energy [25].

The installed power generation in Rwanda was 224.6MW by 2019, whereby 51% Rwandan family units admittance to power, associated with the public lattice and through off-network framework (14%) [26].

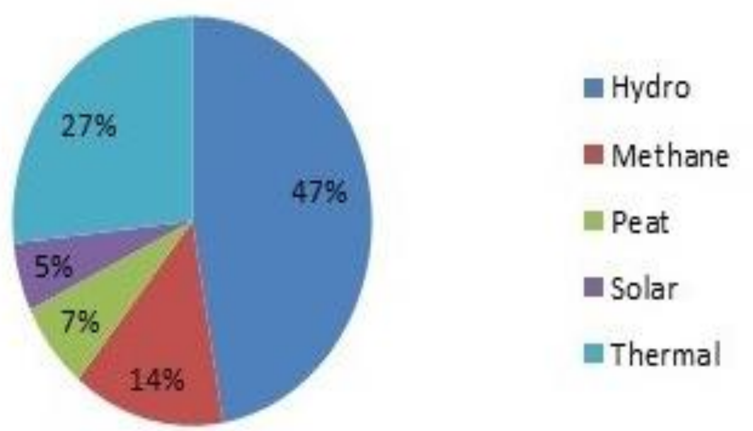

Figure 8: Rwanda energy sector in percentage (%)

Table 1 : Operational diesel power plant in Rwanda

Diesel power plant	Fuel type	Generation limit in (MW)	Operational mode
Jabana1	Fuel Oil/Heavy fuel oil	7.8	Peak
Jaban2	Heavy Fuel Oil/ Light Fuel	20	Peak
So Energy LTD(Mukungwa)	Light Fuel	10	Peak
So EnergyLTD (Birembo)	Light Fuel	15	Peak
Ndera So Energy LTD (Special Economic Zone)	Light Fuel	10	Peak
Kivuwatt	Methane gas	26.4	Base
Gishoma	Peat	15	Base

Due to high demand of electricity in Rwanda, there is still unbalance between energy demand and energy supply, so as to take care of this issue of intensity shortage, the legislature of Rwanda leased warm force plants as temporary [25].

2.3.1 Petroleum supply and demand in Rwanda

Rwanda right now depends on imports of oil fills from worldwide sources, official oil based good interest projections are contained in the downstream oil strategy (2012) which gauges yearly development 12% from 2012 to 2020. Nonetheless, current fuel utilization is around 38 million liters for every month, the key utilization for oil based commodities in Rwanda are street transportations, warm force age and flying [25].

Currently Rwanda oil stockpiling framework basically comprises of government and private area possessed fuel terminals equal to 72,000,000 liters as it has been appeared in table 2:

Table 2: petroleum products storage capacity [m^3]

product	Jabana (oilcom)	Rusororo (SP)	Gatsata (GoR)	Kabuye (ERP)	Rwabuye (GoR)	Bigigwe (GoR)	Kanombe (Airport)	Total
Petrol/Gasoline	7,000	8,000	6,600	3,000	1,800	3,000	-	29,400
Diesel/Gasoil	12,000	12,000	6,700	2,100	1,800	2,000	-	36,600
Kerosene	-	-	1,500	-	-	-	-	1,500
Heavy Fuel Oil (HFO)	-	-	-	600	-	-	-	600
Jet A1	-	2,000	-	-	-	-	2,000	4,000
Total	19,000	22,000	14,800	5,700	3,600	5,000	2,000	72,100

2.3.2 Fuel emission factor

The outflow factors are accommodated various kinds of fuel, as it is introduced in the table3. whereby, the kinds of energizes right now utilized in Rwanda are weighty fuel oil, light fuel oil (gas oil), methane gas (vaporous powers), biomass and peat which has been thought to be earthy colored coal with the end goal of the stock, and referenced emanation factors are NO_2, SO_X and CO [27].

Table 3: Emission factor per fuel type

Type of Fuel	Pollutant(g/GJ)		
	NO_2	SO_X	CO
Heavy fuel oil	300	1700	21.1
Gas oil	195	465	65
Gaseous fuels	185	0.393	60
Biomass	160	15.1	180
Brown coal	571	5000	60.5

2.3.3 Carbon dioxide emissions in Rwanda

Greenhouse gas emissions come from each sector of human activities, among then energy generation is one of the sector which emits GHG emissions with 23.1% for total emissions [25].

GHG emissions especial Carbon dioxide (CO_2) discharges originate from utilization of non-renewable energy sources burnt during energy generation process implies that due to the increase of energy there is an increase of fossil fuel consumption which increase carbon dioxide emissions in the environment [27].

Table 4: Carbon dioxide emissions in Rwanda from 2015 to 2019 [25]

Year	Amount of carbon dioxide emissions (CO_2 millions tons)
2010	1,162,354
2011	1,207,614
2012	1,275,636
2013	1,278,974
2014	1,335,621
2015	1,363,854
2016	1,403,087
2017	1,096000
2018	1,118,000
2019	1,118,000

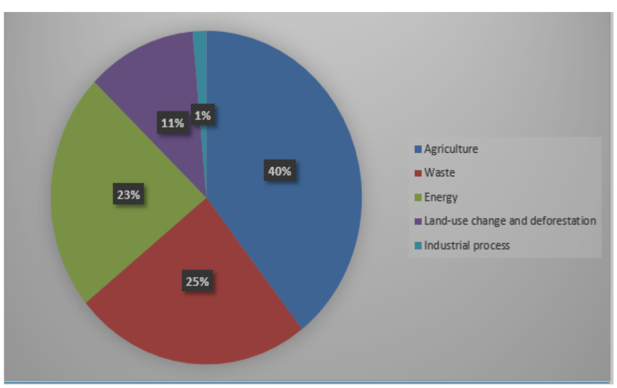

Figure 9: Rwanda emissions CO_2 by sector

2.4 Global impact of use of fossil fuels

Carbon dioxide does not only present negative effects on the society, but also they present positive effects on photosynthesis process. The present study was interested on demonstration of negative impact that can be caused by Carbon dioxide emissions from electrical network once, there is no measure taken for energy generation with the desire to meet the future energy demand. These effects can be categorized as follow:

2.4.1Carbon dioxide adds to air contamination in its function in the nursery impact

Carbon dioxide traps radiation at the ground level, making ground-level ozone

This air layer keeps the earth from the cooling around evening time, this think of the aftereffect of a worming of sea water. Seas retain Carbon dioxide from the climate.

2.4.2 Carbon dioxide contribute in environmental change

Environmental change in another impact of Carbon dioxide, where by the world's surface temperatures by catching sun oriented energy in the air, this reduction precipitation, this adjusts water supplies and climate designs, changing the developing season for food. Scientists accept that carbon dioxide is the essential offender which implies that its impacts are difficult, the proof shows that sea water levels have expanded, bringing about lost shoreline and waterfront wetland.

2.4.3 Carbon dioxide cause Acid Rain

Carbon dioxide is a supporter of the ecological impact known as corrosive downpour, whereby the discharges delivered from petroleum products copying energy plants consolidate with dampness noticeable all around, and afterward the outcome is the precipitation with high corrosive substance. Archived proof shows the physical harm some trees and other vegetation, which cause some kind of braid are at this point don't exist.

2.4.4 Impact of Carbon dioxide on Human Health

Carbon dioxide outflows sway human heath by supplanting oxygen in the climate, where by breathing become more troublesome as carbon dioxide levels rise.

The region whereby there is elevated level of Carbon dioxide cause some diseases like: respiratory sicknesses and heart maladies, cellular breakdown in the lungs, and cerebral pains [28].

2.4.5 Carbon dioxide has effect on atmospheric

There numerous motivations to be worried about the effects on atmospheric due to the temperature rising that probably going to bring about broad environmental change. Numerous creature and plant species are probably going to get terminated as environments conform to environmental change, while versatile species will endure, and different mitigates, the finally some biodiversity will be lost. Carbon dioxide perseveres in the environment for 50 to 200 years, so the emanations delivered now will keep on worming the atmosphere later on in the event that we continue to emit it without control. This circumstance of a dangerous effect of atmospheric is more genuine for the African locale on account of neediness, and all the more significantly over a portion of the populace relies upon atmosphere driven organizations, for example, smallholder cultivating, worker mining, farming and selling [29].

Chapter 3: DIESEL OPTIMUM OPERATION

A diesel generator is a gadget which utilizes diesel in its start pressure motor for transformation of mechanical force into electrical force for use in outer circuits. So a diesel genset is a mix of an electrical generator and a diesel motor likewise called the main player, mounted together to shape a solitary piece gear [30].

A diesel generator can be used as an emergency power supply in case of blackout, it can also be used in the place where there is no connection with the power grid and genset also can be can be utilized as a blend with sunlight based, to form a PV/Diesel hybrid as it is in this present study.

3.1 Selection contemplation

To settle on a choice on a kind of a motor, that is reasonable for a particular application, a few components are should have been thought of. The two most significant elements are force and speed of the motor.

A few principles that are utilized to make a decent choice, for the motor force is that the rating ought to be 10-20% more than the force requested by the end clients [31].

Whereas for speed stands, an engine must operate over the range of speed of (1300-3000 RPM) for diesel generators that run at low speed. There is an ideal speed at which eco-friendliness of diesel generator is most noteworthy. Motors ought to be run as intently as conceivable to their evaluated speed to maintain a strategic distance from helpless effectiveness and to forestall development of motor stores because of deficient ignition, which lead to higher support with high fuel consumption as result of high running cost and high pollutant emissions especially high carbon dioxide (CO_2) emissions [31].

For certain applications, the speed of motor isn't basic, however for different applications, for example, a generator, it is essential to get a decent speed coordinate. On the off chance that a decent match can be acquired, direct coupling of motor and generator is conceivable; in the event that not, at that point some type of intending will be essential for a gearbox or belt framework, which will add to the cost and diminish motor productivity [32]. There are different others factors that must be thought of, while picking a motor for an ideal application. These incorporate the accompanying: cooling framework, irregular ecological conditions (dust, earth, and so forth), fuel amount, speed administering (fixed or variable speed), helpless support, control framework, beginning hardware, drive type, surrounding temperature, elevation, moistness, and so on [33].

Table 5: Correlation among high and medium with moderate speed motors [31]

Type of engine	Engine (RPM)	Prime rating (KW)	Engine displacement(liter)	Footprint (m^2)	Weight (Kg)
Low speed	900	3,640	222	26	51,000
Medium speed	900	2,775	175	22	59,000
High speed	1,800	3,000	95	13.5	25,000

Correlation among high and medium motors are referenced in table 4 where, shows that a high engine generator operates at 1,8000 RPM with 95 liters of displacement is capable of delivering 3,000Kw of prime rating while a 900 RPM machine need to be about twice as larger to provide comparable 60Hz power output.

3.1.1 Diesel generator capacitive plants

Diesel motor power plants are most much of the time utilized for small power generation system. . The primary purpose behind their broad use is the high productivity of the diesel motor contrasted and gas turbines and little steam turbines in the yield range considered in applications requiring low hostage power, absent a lot of prerequisite of cycle steam, the ideal strategy for power age would be by introducing diesel generator plants [1].

3.1.2 Capacity blends

From the perspective of room, activity, upkeep and starting capital speculation, it is surely practical to go in for one huge diesel generator set than at least two diesel generator sets in equal. At least two diesel generator sets running in equal can be a preferred position as just the deficit in power – relying on the degree of intensity slice winning needs to top off. Additionally, adaptability of activity is expanded since one diesel generator set can be halted, while the other diesel generator set is creating in any event half of the force prerequisite. Another bit of leeway is that one diesel generator set can become 100% backup during lean and low force cut period.

3.2 Operational factors of diesel generator

All generator sets, whether diesel or gaseous petrol and paying little mind to application, load setting and activity, are intended to give power in the most proficient way conceivable. All things considered, each generator sets have an ideal outstanding burden to fuel utilization sweet spot, because of the way that various motors devour fuel at various rates, and higher remaining tasks at hand quite often consume fuel most effectively, diesel generator proficiency is typically accomplished at the higher finish of the heap setting the generator was intended to keep up. For instance a 15KW diesel generator, for example, may have lower fuel utilization when is working at 10KW instead of at 6KW [34].

To provide optimum fuel efficiency and machine life, the supplies shall provide several generators in series to match the load profile provided in each order, instead of one large generator which would run at high inefficiency. Additionally, should load grow beyond the capacity of the installed generator(s), it shall be possible increase of load capacity following a modular concept, adding multiple units to form combined source of electricity or min grid [35]. This operation concept also was considered for the current connection of solar photovoltaic modules as one of environmentally friendly power sources without storage consideration to form PV/diesel hybrid system as unit of energy generation.

3.2.1 Safety features

Running diesel motors beneath their planned burden limit is one of the most common issues

Coming about with marvel known as wet marking, which happens when unburned fuel is depleted because of low working temperature.

When unburned fuel is depleted from the burning chamber, it begins to develop in the fumes side of the motor, bringing about fouled injectors and development of carbon on the fumes valves.

Wet staking with others problems resulting from running level of diesel generator, can be avoided by running generator with its optimal range as possible [36]

3.2.2 Diesel generators sets capacity

The normal burden can be effectively evaluated by logging the current suffocate at the fundamental switchboard on a normal day. The over burden has an alternate significance when alluded to the diesel generator set. Over-burdens which seem immaterial and innocuous on power board gracefully, may get hindering to a diesel generator set, and subsequently over-burden on diesel generator set ought to be deliberately examined. Diesel motor are intended for 10% over-burden for 1hour in 12 hours of activity.

The A.C generators are intended to meet half over-burden for 15 seconds as explicit principles. The diesel generator set(s) choice ought to be to such an extent that the over-burdens are inside the above determined cutoff points [37].

Close by alternator stacking, the motor stacking regarding KW should be kept up above half. In a perfect world, the motor and alternator stacking conditions are both to be accomplished towards high productivity. Motor produces offer bends demonstrating rate (%) of motor stacking versus fuel utilization in grams. Ideal motor stacking comparing to best working point is wanted for energy productivity [38].

3.2.3 Sequencing of burdens

The hostage diesel producing set has certain cutoff points in taking care of the transient burdens. This applies to both KW and KVA. In this specific circumstance, the base burden that exits before the request of transient burden cuts down the transient dealing with limit, and on the off chance that A.C. generators, it builds the transient voltage plunge. Subsequently, incredible consideration is needed in sequencing the heap on diesel generator set(s). It is fitting to begin the heap with most elevated transient KVA originally followed by different burdens in the sliding request of the beginning KVA. This will prompt ideal measuring and better usage of transient burden taking care of limit of diesel generator set [39].

3.2.4 Load design

By and large, the heap won't be consistent for the duration of the day. In the event that there is generous variety in load, at that point thought ought to be given for equal activity of diesel generator sets. In such a circumstance, extra diesel generator set(s) are to be turned ON when burden increments. The run of the mill case might be a foundation requesting generously various power in first, second and third move. By equal activity, diesel generator sets can be run at ideal working focuses or close about, for ideal fuel utilization and also, adaptability is incorporated with the framework. This plan can likewise be applied where burdens can be isolated as basic and non-basic burdens to give backup capacity to basic burden in the hostage power framework [37].

3.2.5 Maximum single loads on diesel generator

The beginning current of squirrel confine enlistment engines is as much as multiple times the evaluated current for a couple of moments with direct – on-line starters. By and by, it has been discovered that the beginning current worth ought to be not surpass 200% of the full burden limit on the full burden limit of the alternator. The voltage and recurrence all through the engine turning over stretch recuperates and reaches evaluated values normally much before the engine the engine has gotten a move on [40].

3.2.6 Unbalanced burden impact

It is constantly prescribed to have the heap however much as could be expected, since unequal burden can cause warming of the alternator, which may bring about uneven yield voltages. The most extreme uneven burden between stages ought to be not surpass 10% of the limit of the creating set.

3.2.7 Neutral earthling

Unbiased ought to be given to give sufficient creation to the hardware to the earth deficiency, and furthermore to deplete away any spillage of potential from the gear to the earth for safe working.

3.3 Governing principles

The standards of the administering framework which controls the force yield by the motor. It is the electrical interest on the generator that sets the heap interest on the motor. The lead representative controls the fuel to the motor to build up the speed of the motor, and consequently the recurrence of the generator. The overseeing framework screens the speed and/or load on the unit and directs the fuel infusion framework to endeavor to hold the speed or burden on the unit steady [41].

3.3.1 Isochronous and Droop control

Each overseeing framework and lead representative sort needs to battle with an issue of the control when it is associated into an enormous framework with different generators or other energy resources.

3.3.1a. Isochronous control

Word "isochronous" can be broken into two sections, "iso" which means equivalent and ""chronous identifying with the time. As applied to a motor isochronous implies that every upheaval of the motor takes an equivalent time, or as such, the speed is steady.

3.3.1b. Droop control

Hang demonstrates that something is tumbling off or hanging. As applied to a generator set, it implies that as burden is applied the speed tumbles off or reduces.

In the event that the new unit's recurrence (speed) is even a modest quantity higher than the framework recurrence, the new unit will endeavor to convey the entire framework load. This would bring about the new unit being over-burden, and could harm the framework.

The main way the framework can do this, is to drive the new unit or at the end of the day, to mechanize the generator so as to bring the unit up to the framework recurrence.

To keep the unit from being either over-burden or mechanized, hang is brought into the administering framework. As the motor is stacked, the speed/recurrence will in general drop off (hang). Since the unit is secured in the lattice, it can't change speed, yet that is the thing that the hang in the lead representative would endeavor to do once the solidarity is on the framework and stacked to the longing load, the unit won't change load except if the administrator changes the speed reference input. Notwithstanding, if the framework recurrence were to change just barely, the heap would likewise change just barely.

With an abatement in load interest or potentially speed up, the control box raises the armature magnet and control valve. The oil under the force cylinder is currently depleted to the lead representative sump, and the spring pushes the force cylinder day break. This decreases the fuel conveyance and motor capacity to restore the motor to its consistent state condition [42].

3.3.2 Automatic voltage regulation (AVR)

Automatic voltage regulation shall be capable of maintaining voltage at $\pm 1\%$ of any value within 10% of the nominal voltage throughout the full range of rated load and power factor conditions. Droop, stability and voltage set point adjustments shall be by operator interface or programmable via laptop.

The automatic voltage regulation shall be capable of preventing sustained over voltage during over speed conditions following the loss of load. After a sudden load rejection at rated power factor, rated voltage shall be restored within 2 seconds. Force coordinating trademark will be movable for – off recurrence and rate, and be fit for being bend coordinated to the motor force bend with customizable in the field synchronizer [43].

Synchronization will not be require on all generator sets but will be subject to separate order. However, each generator set supplied under this contract shall be capable for synchronization with other diesel genset or renewable energy sources.

A fully featured synchronizer shall be included either as part of the automatic voltage regulation (AVR) or as a separate unit. The synchronizer shall be controlled by the alternator start-up system and interface directly to the governor and AVR. Clean contacts for close/open of the main breaker shall be included as well as interface to any other indications required [44].

3.4 Maximum power transfer

Likewise with most force age gadgets, diesel gensets will be associated with a heap. The heap might be the network, a discretionary gadget, a battery, sustainable power sources, or any blend of them. The principle objective when planning a genset is to augment the force move to the heap. There are a couple of approaches to examine this issue, with the fundamental subjects of examination being the most extreme force move hypothesis and force factor revision [38].

The most extreme power transfer hypothesis expresses that for a given circuit, maximum power transferred to the load happens when load resistance (DC circuit) or impedance of load (AC circuit) is equivalent to the opposition or impedance of the source

This theorem can be clarified utilizing a basic two resister as observed

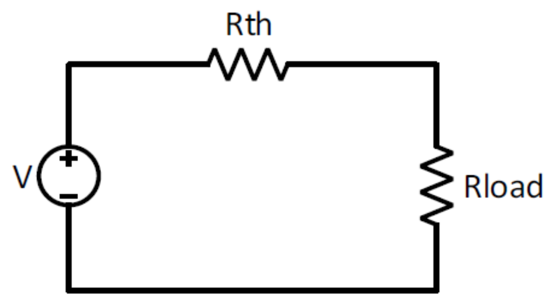

Figure 10 : A simple circuit resister

Ohm's low equation has been utilized to determine the current of the framework using the known source voltage and resister values.

$$I = \frac{V}{R_t + R_L} \quad (1)$$

Where I, is the circuit current, V is the voltage, Rt is the thèvenin equal obstruction and RL is the heap opposition.

This current will be the equivalent through the source obstruction and the heap.

The force in the heap, PL, can be spoken to as:

$$P_L = V \times I = I^2 \times R_L = \frac{V^2 \times R_L}{(R_t + R_L)^2} \quad (2)$$

To decide the greatest force, the subordinate is taken regarding the heap opposition and set equivalent to zero:

$$\frac{dp_L}{dR_L} = \frac{V^2 (R_t + R_L)^2 - 2V^2 \times R_L (R_t + R_L)}{(R_t + R_L)^4} = 0 \quad (3)$$

Through equation 3 with respect of resistance load, it is discovered that resistance of load (RL) is equivalent to the resistance source (Rt) for maximum power transfer.

At the point when load resistance is higher than the resistance of the source , equation 6 shows that the general current will be higher, yet brings about lower power over the resistance of the load, as appeared in equation 5.

At the point when the resistance of the load is less to the resistance of the source, the general current will be lower, which brings about lower power transfer [45].

3.5 Operating concept and specific values of a typical diesel generator

Diesel generators are estimated so that higher working effectiveness is gotten when they are running at high burden factor and near their appraised power; this has been considered as one requirement forced to the diesel generator's activity [46].

A diesel generator running under this condition is required to diminish its particular fuel utilization which will bring about lower activity cost and high contamination level.

Fig 12 shows RKD-224GF diesel generator of the following data record, common power of 280KVA, exhaust volume of 201 litter, fuel consumption 3000×1335×1880, shape size 2795 m^3, cylinder Number 6 and the cylinder diameter 105 mm, it can operates on 50 HZ, rated voltage 400/230 V, power factor of 0.8, connection mode is 3-phase [47].

Figure 11: Diesel generator

3.6 Efficiency of diesel generator

The diesel generator is a gadget of framework which is generally used to flexibly a heap when power age by PV module is lacking. Diesel generator model is planned so that, it is continually working somewhere in the range of 30 and 100% of their ostensible force.

Energy produced by diesel generator is characterized in Eq.4.

$$P_{og} = P_{ng} \times N_{dg} \times \eta_{gr} \tag{4}$$

Where; P_{ng} (KW) is the ostensible intensity of generator, N_{dg} is the quantity of the diesel generators, P_{og} (KW) is the yield power from the diesel generator and η_{gr} the proficiency of diesel generators [48].

3.7 Fuel consumption Model of diesel generators

The fuel devoured by the diesel generator changes relying upon the nature of motor its yield power and on its connected force. Notwithstanding, a straight model of diesel fuel utilization rate Fc represented as:

$$FC = A_d \times P_{out} + B_d \times P_r \qquad (5)$$

Where: A_d and B_d are the consumption curve coefficients, these fuel incline coefficients are 0.24 L/KWh and 0.08145 L/KWh individually. These values of A_d and $B_d$are adopted from the manufacture's data sheet [49].

FC is the fuel utilization rate (liter/hour)), P_{out} is the real working yield power (KW) and P_r is the evaluated power diesel generator (KW) [50].

3.7.2 Single diesel generator operation

The single genset is likewise estimated to coordinate the pinnacle load interest and it is allowed to work from minimum power (P_{MIN}) toward maximum power (P_{MAX} On the off chance that base force is non-zero and a heap power is lower than the base force, some restorative activities ought to be applied by following details of genset maker. Except if in any case expressed, the activities considered in the reenactment device are either allowing genset activity underneath least force or associating a dump burden to guarantee the genset works at least force.

Henceforth, a variable dump power equivalent $P_{DUMP} = P_{MIN} - P_L$ is connected whenever load power must be greater than minimum power of diesel generator, implies $P_L < P_{MIN}$.

All in all, constant activity with heaps of under half of its most extreme rater power is unadvisable, particularly at low speeds, working in this "taboo zone" or low force at low speeds can't be continued because of deficient ignition, which can prompt a diminished motor life expectancy and high fuel consumption with high pollutant emissions especially carbon dioxide (CO_2) emission as dominant level [43].

3.7.3 Multiple diesel generator operation

The activity of various diesel generator in equal are controlled utilizing two normal techniques called "ON/OFF" and "Ideal". The two procedures permit the detachment and reconnection of individual diesel generator to satisfy the heap need and into thought the necessary turning save [34].

The turning save, which is determined as a level of the current burden interest, shows the overflow of intensity that could be provided promptly by the generators if there should be an occurrence of an abrupt increment of load needed.

Thusly, the disengagement of diesel generators are possibly allowed if the amassed evaluated intensity of those that stay in activity is equivalent of higher than the necessary turning hold. In the ON/OFF methodology, diesel generators in activity share a similar bit of the load [46].

The ideal system attempts to guarantee that all the diesel generators, except for one, work at much as conceivable at their ideal force working point, POPT, where the fuel utilization in insignificant. The ideal point is around 80% of the appraised power [51].

Chapter 4: PV/DIESEL HYBRID OPTIMAZATION

4.1 Photovoltaic diesel hybrid system

A hybrid power system is a network made by combining two or more energy resources that can produce the same or similar results; PV-diesel integration comprises of solar photovoltaic framework, and diesel generator managed by intelligent controller to guarantee that the system is matched with loads.

4.2 Components of PV Diesel Hybrid System

Photovoltaic and diesel hybrid system contains many different components, however key components are as follows:

4.2.1 Photovoltaic system

Sun powered PV modules are comprised of PV cells, which are most ordinarily fabricated from silicon. Cells can be founded on either wafers (fabricated by cutting wafers from a strong ingot square of material) or flimsy film testimony of material over ease [52].

Figure 12 shows photovoltaic modules connected to DC-DC converter, DC to AC inverter and the loads.

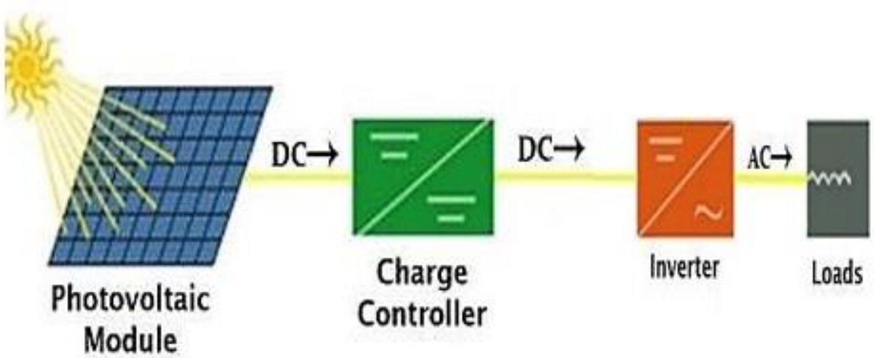

Figure 12: PV system

Sun based PV boards have a long life expectancy (over 25 years), yet their yield gets marginally decrease after some time. PV board fabricates for the most part ensure 90% of the underlying presentation.

4.2.1.1 Power output of PV module

The photovoltaic module execution is profoundly influenced by sun oriented irradiance and the PV module temperature. Present study, an improved recreation model will be utilized to gauge the PV module execution. To appraise PV module yield, most extreme force point following (MPPT), the sun based radiation accessible on the module surface, the encompassing temperature and the production information for the module will be considered as module input.

The figuring technique is given by Eq.6

$$P_{pv} = V_{oc} \times I_{sc} \times FF \qquad (\mathbf{6})$$

Where: I_{sc}(A) and V_{oc}(V) are the short out current and open voltage of a sun oriented photovoltaic module,FF (dimensionless) is the fill factor, it is the proportion between the ostensible and greatest force standard [53]

4.2.1.2 CO2 emission after connecting solar photovoltaic into a diesel grid connected

CO_2 emission reduction after integrating a PV system into a diesel grid connected system can be calculated using eq.7. Implies that hence there is high penetration of PV power generation into photovoltaic and diesel hybrid system there will be huge reduction of CO_2 emission.

$$ER_{Y,1} = EGPJ,_{Y,1} \times EF_{Y} \qquad (7)$$

Where: $ER_{Y,1}$ is CO_2 emissions diminished in year by solar power generating system [t CO_2/y] and $EGPL,_{Y,1}$ is the net amount of electricity generation utilizing the PV/Diesel hybrid system only generated by solar power generation system in year [MWh/year]

EF_Y CO_2 is emissions factor of electricity in year [t CO_2/MWh]

4.2.2 PV inverter

DC to CD converters are broadly utilized in photovoltaic framework producing frameworks as a connection between photovoltaic boards and the heap, this permit the stream up of the most extreme force point (MPP), suggests that converter are intended to associate photovoltaic board and perform activity to look through the greatest force point.

DC to DC converter is on the charge of controlling yield voltage from close planetary system which can be higher or lower than the information voltage because of working conditions, dc to dc converter upgrades the match between the sun based cluster and the utility framework, and the other incorporated fuel source.

Inverters assumes huge job, more than just transforming the electrical flow of a sun powered energy framework, yet additionally to keep up key ascribes for sunlight based energy system(reliable, effectiveness and others highlights, for example, information observing, consistency of yield and conveyed age) so as to drive more PV entrance. PV inverter's life expectancy can arrive at over 10 years.

The figure 14 shows the operational graph of the PV inverter [52].

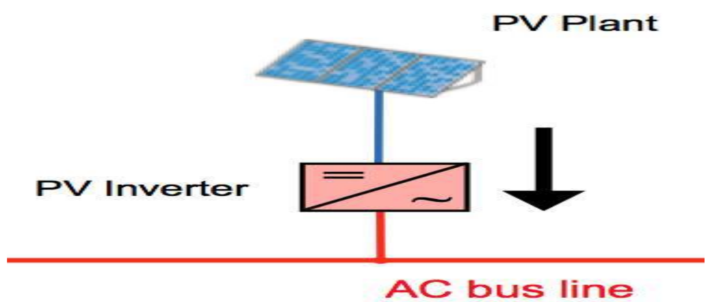

Figure 13: Photovoltaic inverter

4.2.2.1 Efficiency of inverter

The inverter is a gadget of intensity hardware which permits changing over the DC current from DC transport bar to the AC current for AC loads. The power traveling the inverter to serve the interest is given by Eq.8.

$$P_{in} = \frac{P_{ch}}{\eta_i} \qquad (8)$$

Where P_{in} is the invertor power, η_i is the efficiency specified efficiency of the inverter in (%), P_{ch} is the hourly demanded (W) [48].

4.2.3 PV converter

The converter is a force electronic gadget, used to change DC over to AC circuit. These gadgets use exchanging gadgets. These DC to AC change should be possible among 12V, 24V, 48V to 110V, 120 V, 220V, 230V, 240V with flexibly recurrence 50Hz/60Hz. DC to AC converter is basically intended for changing a DC power flexibly to an AC power gracefully. Figure 14 show a DC to AC solar photovoltaic [54].

Figure 14: PV DC to AC converter

4.3 PV and diesel hybrid system and its functionality

PV and diesel hybrid system is made of PV system coupled with diesel generators,

this system can operate as off grid known as isolated system with energy storage system for rural area far from the main grid, it can also operate as grid connected system where PV and diesel generators are connected to the grid for constant energy supply without energy storage system, this is known as bidirectional system where PV system supply energy at its highest penetration in order to reduce diesel working hours. For the case of surplus energy is transmitted to the grid and the grid supply the system for high load this functionality allow the system to operate without energy storage. These energy resources are utilized to finish each other, regardless of whether the objective is to avoid the energy mismatch between demand and supply and to meet the load on time, and to reduce the overall yearly fuel consumption which minimize CO_2 emissions from diesel generators. This system of PV and diesel hybrid is connected into the grid in synchronous way though synchronous machine.

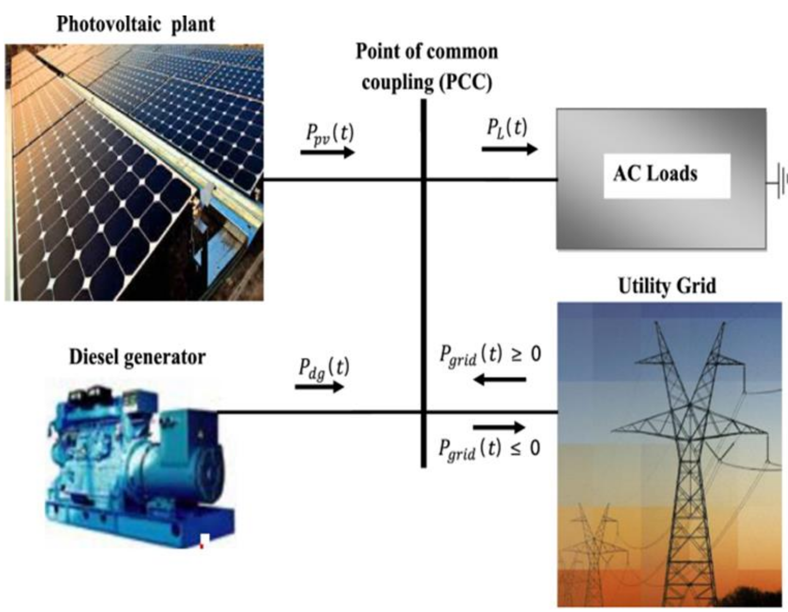

Figure 15: PV-Diesel hybrid

4.3.1 Energy control strategy for PV and diesel hybrid system

The PV/Diesel energy framework concentrated in this work requires the choice of a control technique to ensure the dependability and nature of the energy administration, limiting the fuel utilization and boosting the lifetime of framework parts. There is a typical procedures called "ON/OFF control" is the best control with intends to control PV/Diesel framework by turning ON or OFF the inverter or diesel generator as per atmosphere conditions and burden varieties, this algorithm also help the grid to supply the PV/Diesel hybrid system, with $P_{grid} < 0$ in the event of abrupt increment of burden interest or PV/Diesel system to supply the grid in case there is energy surplus, where $P_{grid} > 0$.

Figure below, shows the flowchart of the control strategy [55].

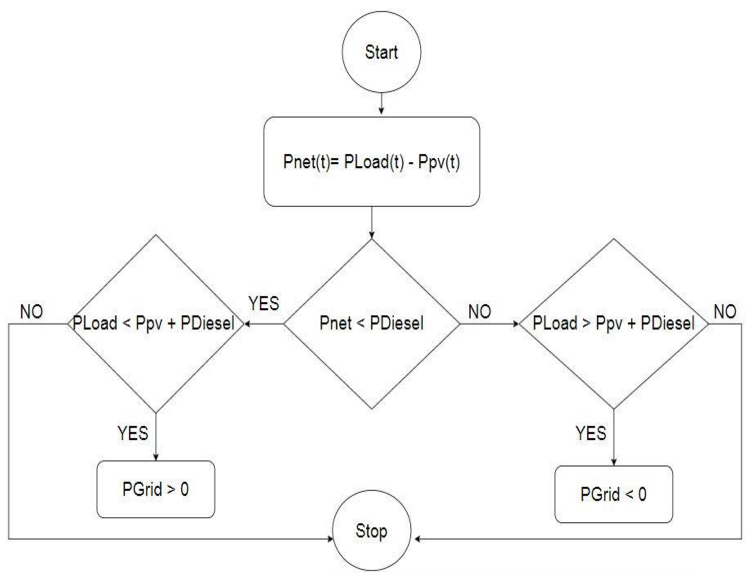

Figure 16: Flowchart of energy control strategy for PV/diesel hybrid system

The Fig 16, indicate the control strategy of PV and diesel hybrid system in order to maintain reliable energy needed by the load. This strategy consider net power as reference, because it indicate the difference energy needed by the load to the PV power system generation and it does not put into consideration on the energy saving system. The net power indicate whether the power load is greater or less that the diesel generator system power and then controller provide condition to follow:

If the net power is greater than diesel generator power generation, this implies that load power needed is less than PV and diesel hybrid system power generation, then grid starts consuming the surplus from the system, or the system continue to operate on its normal condition.

Else if the net power is less than diesel power generation , this implies that the power load power is greater than PV and diesel system power , then grid starts supplying the system in order to meet load demanded, or the system continue to operate on its normal condition.

4.4 Mathematical model of PV and Diesel generator hybrid system

Diesel generator ought to work over the base force PMIN which commonly goes 30-40% of appraised limit. Working the motor beneath this level reductions the change proficiency, yet additionally this may short motor's lifetime, builds upkeep cost and increment contamination level because of high fuel utilization. All things considered a greatest eco-friendliness of around 3 KWh/l when run above 80% of its appraised limit [56].

The diesel generator must flexibly the net burden, which is characterized as the contrast between the heap interest and the created PV power. The equation 9 shows that:

$$P_{NET} = P_L - P_{PV} \tag{9}$$

Clearly, the produced PV power decreases the fuel utilization and the power level at which diesel generator works. There are two recognize control cases relaying upon demanded load to ensure that diesel generator is operating at its maximum operation.

First, if load power P_L is lower than P_{Max} the diesel generator cuts-off to avoid genset operation below its maximum point, PV power will supply the load and the grid used to supply the load in case $P_L<P_{PV}$. The grid power has obtained through equation 10:

$$P_{Grid} = P_L - P_{PV} \tag{10}$$

Second, if load power P_L is more than P_{Max} the equation provides that $P_{NET} \geq P_{Max}$, means that diesel generator is supplying the load and surplus from PV power system is taken by the grid.

The optimal strategy tries to ensure that the genset operates at much as conceivable at their optimal operating power point, P_{OPT} , where the fuel utilization is negligible and at this point the rated power is around 80% [51].

The figure18, indicates PV/diesel hybrid power generation, where blue-color presents load power, red color presents diesel generator system power and yellow color present power generated by solar photovoltaic system.

The figure 17 indicates also the limitation of solar PV/diesel generator hybrid, where the load power level is small than PV power generation and it is under minimal power of diesel generator, the present study shows that grid connected PV/diesel hybrid is a good solution to that limitation, where grid must supplies the load in order to avoid minimum operation of diesel generator and to allow high penetration of PV system on the grid [57].

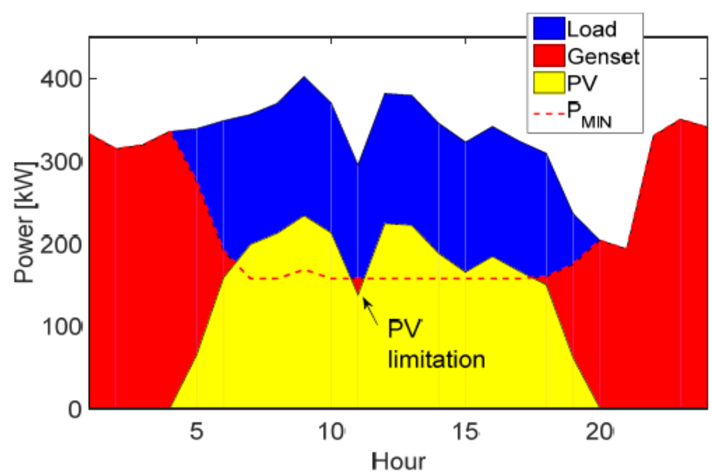

Figure 17: PV/ Diesel hybrid power generation with time

4.5 Mathematical model of CO_2 emission from PV-diesel hybrid system

In order to compute grid emanation from the studied case, it is important to talk about reference emission which is gotten by estimating of burning of petroleum products of power station multiplied by the emission factor (default value). Whereby project emission is given by estimating of burning of diesel oil in the diesel motor that is a segment by hybrid system and the total generated electricity by the hybrid system.

It is necessary to put into consideration the following default values, when you to get the carbon dioxide ($C0_2$) emissions reduced as a result of this combination of PV-Diesel system:

$C0_2$ emanation factor of electricity in year [tCO_2/MWh], net quantity calorific value of the diesel oil used for diesel engine [GJ/t], emissions factor of utilizes oil for diesel engine [tCO_2/GJ],

Net quantity of calorific value of fossil fuel [GJ/mass or volume unit] and emanation factor of the utilized fossil fuel grid connected power in year [tCO_2/GJ].

Reference emission in emanation of fossil fuel in power station grid connected before being integrated with solar photovoltaic, by considering the quantity diesel fuel consumed by the grid which indicates the amount of injected power to the grid from diesel generator [MWh/year].

A diesel grid connected system has high CO_2 emission, whereby 2.7 Kg of CO^2 is the emitted emission from diesel consumption of one liter [58]. A constant load demand of 25 MW with 12 hours dairy diesel generators operation can approximately emit 16,655.76 Kg of CO^2 by taking into consideration the typical values from Fig 11 of diesel generator. This means that 116,590.32 Kg of CO2 emission a week. Therefore, an integration of solar photovoltaic system as a green energy is required.

4.5.1 Calculation of Reference CO_2 emissions

The reference emissions is given by the product of net electricity generated utilizing PV and diesel hybrid system that is produced and injected into the grid to the CO2 emission factor of electricity in year. The reference CO2 emission is shown in equation 11:

$$RE_Y = EGPJ_Y \times EF_Y \tag{11}$$

Where: RE_Y The Reference CO_2 emissions in year [tCO_2/y]

$EGPJ_Y$: The net electricity generated and injected to the grid by hybrid system [MWh/y]

EF_Y : The CO_2 electricity emanations factor in year [tCO_2 /MWh]

4.5.2 Calculation of emission factor for electricity

The electricity emission factor is driven mathematical by the ratio of the product of quantity of fossil fuel consumed in year by a diesel generator, net quantity of calorific value for utilized petroleum and the CO_2 emanation factor from diesel generator to the quantity of net electricity generated and fed to the grid in year. The electricity emission factor is shown in equation 12:

$$EF_Y = \frac{\left(\sum_i FC_{i,y} \times NCV_{i,y} \times EF_{CO2\ i,y}\right)}{EG_Y} \tag{12}$$

Where: EF_Y , The CO_2 emanations factor of electricity in year [tCO_2/MWh], $FC_{i,Y}$ is the quantity of utilized oil in year [mass or volume], $NCV_{i,y}$ is the net calorific value of fossil fuel [GJ/mass or volume],EG_Y is the net quantity of electricity that is produced and injected to the grid in year [MWh/y].

4.5.3 Calculation of CO_2 emissions from the project

The emission emitted from the project is obtained from the product quantity fossil fuel consumed diesel generator, net calorific value utilized oil and the emanations factor of utilized fossil fuel.

CO2 emission from the project is shown in equation 13:

$$PE_Y = PDO_Y \times NCVDO,_Y \times EFDO,_Y \tag{13}$$

Where: PE_Y Project CO_2 discharged in year [t CO_2/y]

PDO_Y: Quantity of devoured diesel oil for diesel generator in year [t/y]

$NCVDO,_Y$: Net calorific estimation of diesel oil utilized for diesel motor [GJ/t]

$EFDO,_Y$: Emissions factor of the diesel oil utilized for diesel motor [tCO_2/GJ]

4.5.4 CO_2 emissions reduced from diesel generator

Carbon dioxide (CO_2) emissions reduced from diesel generator is gotten from the difference between the CO_2 emissions reduced from PV/Diesel hybrid system and the CO_2 emissions reduced from solar power system.

$$ER_{Y,2} = ER_Y - ER_{Y,1} \tag{14}$$

Where: $ER_{Y,2}$ CO_2 discharges diminished in year by diesel connected with PV [tCO_2/y], ER_Y CO_2 emanations decreased in year by PV/Diesel [tCO_2/y], $ER_{Y,1}$ CO_2 emissions reduction in year due to by solar power generating system [tCO_2/y]

Therefore, CO_2 emissions factors of electricity in year for the power generation using diesel engine under the project ($EF_{Y,2}$) can be compared with CO_2 emissions factor of electricity under the reference (EF_Y)

$$EF_{Y,2} = \frac{PDO_Y}{0.86} \div \frac{EGD_{J,Y,2}}{2.71} \qquad (15)$$

Where:$EF_{Y,2}$ CO_2 emissions factor of electricity in year by diesel engine power generating system [tCO_2/MWh], PDO_Y Quantity of consumed diesel oil for diesel engine in year [t/y], $EGPJ_{Y,2}$ Quantity of net electricity generated using the hybrid system that is produced by diesel engine power generating system [MWh/y].

4.5.5 CO_2 emissions reduced by PV-Diesel hybrid system

The Carbon dioxide emissions reduced from this system is calculated by:

$$ER_Y = RE_Y - PE_Y \qquad (16)$$

Where: ER_Y CO_2 outflows diminished in year [tCO_2/y]

RE_Y Reference CO2 outflows in year [t CO_2/y],

PE_Y Project CO2 emanations in year [tCO_2/y]

4.6 Model of optimization

4.6.1 Introduction

They are many techniques used to optimize for example, hybrid optimization model for electrical renewable energy (HOMER) software, Genetic Algorithm (GA), Sisifo software, fuzzy Logic, Stochastic program, Mixed Integer Programming, however, linear programing has been approved as a strong tool for optimization. Therefore, the present thesis has opted to employ the linear programming for optimization of fuel consumed by diesel generator and CO_2 emissions reduced from electrical network.

4.6.1.1 Description of Linear programing

Linear programming comprises of a linear equations formulation of system and mathematical improvement method which competes the maximum or minimum value for a given linear function, known as objective function. This program has been developed on 1947 by George B.Dantzig how was commonly credited with being the father of linear programming [59] .

Linear programing was helpful in the present study by indicating the feasible area in which there is a feasible amount of carbon dioxide emissions (CO_2) that can be generated by PV and diesel hybrid system for generation of load demand by indicating the minimum utilized fuel and maximum PV power penetration in the PV and diesel hybrid system.

4.6.1.2 The procedure of model

The used model during the study has two main procedures, the first was formulation of linear programming problem (objective function and its rated constraints), and the second was linear programming solving. As the result, the target was to compute the most suitable amount of CO2 emission that can be emitted for generation of electrical power demanded within its corresponding PV power production.

4.6.2 Objective functions formation of PV-diesel hybrid integration

The optimization of the system has the objective functions of minimizing fuel consumption for diesel generator targeting less amount of pollutant carbon dioxide emissions (kg CO_2) which is the main dominant greenhouse, by reducing working hour of diesel generator, and also reduction of cost of diesel generator.

Equation 17 shows objective function of diesel generator consumed fuel reduction

$$\text{Min} \sum_{t=1}^{24} \left(P_d(t) \times C_f \times C_p \right) \qquad (17)$$

Where P_d (t) is the diesel output power during the period; t is the operating time of diesel generator per a day; C_f is the oil consumed by diesel to generate unit of power and C_p is the cost of each unit of the diesel oil.

Minimization the fuel cost of diesel generator is important for improving the utilization of sustainable energy which is green energy source through increases of renewable energy penetration, especial PV penetration which increase the whole power system.

Present study did not went in deep of fuel cost reduction of diesel generator but it have been focused on carbon dioxide emissions reduction which is in another way of reducing fuel consumption of diesel generator in the same time diesel fuel cost decreases.

The output power of diesel generator decreases proportionally to the diesel fuel reduction.

The equation 18 shows first objective function of minimizing CO2 emission:

$$\text{Min} \sum_{i=1}^{n} \gamma_i \; P_{PVi} + \sum_{i=1}^{m} \beta_i \, \text{Pd}_i \qquad (18)$$

Where, n: is the number of operating PV modules, γ: is the expected power production from PV modules, m: is the number of diesel generator and β is the expected power generated by diesel generator.

Objective function minimization is subject to the constraints that the grid power balance and operating time. Implies that power produced by the system must be greater or equal to load power at time t and the operating time for diesel need to be minimize up to 6 hour, targeting reducing working hours of diesel generator.

$$k_1 x_i + k_2 y_1 \;\leq\; P_L \qquad (19)$$

$$c_1 x_1 + c_2 y_{21} \leq 24h \qquad (20)$$

$$0 \leq c_1 \leq 10 \,, 0 \leq c_2 \leq 6 \qquad (21)$$

Where: x_1, y_1 and P_L are PV system production, diesel generator power production and power consumed at a load level individually.

c_1 is PV system operating time and c_2 is diesel generator operating time, which must be equal to the 6 hours with the purpose of reducing its working hours targeting low amount of fuel consumption and less carbon dioxide emissions (CO_2).

Equation 19 gives maximum values for x_1 and y_1 that reflect the energy production from a PV system and a diesel generator respectively. Equation 22 gives the respective values.

$$\binom{x_1}{y_1} = \begin{pmatrix} \frac{P_L}{k_1} \\ \frac{P_L}{k_2} \end{pmatrix} \tag{22}$$

Equation 20 gives maximum values for x_1 and y_1 referring on working time for PV a system and a diesel generator respectively. Those values are given by the following equation:

$$\binom{x_1}{y_1} = \begin{pmatrix} \frac{24}{c_1} \\ \frac{6}{c_2} \end{pmatrix} \tag{23}$$

Equation 22 and 23 clearly show that minimizing the use of diesel generator can reduce CO_2 emission. A cost analysis could be done to confirm the optimum use of both systems. However, researchers have proved that. Researcher in paper [60] showed reduce of a diesel generator maximizes the benefit.

The figure18 can be used to analyze different situations. The following section gives the case study related to two thermal power plant that are operating in Rwanda

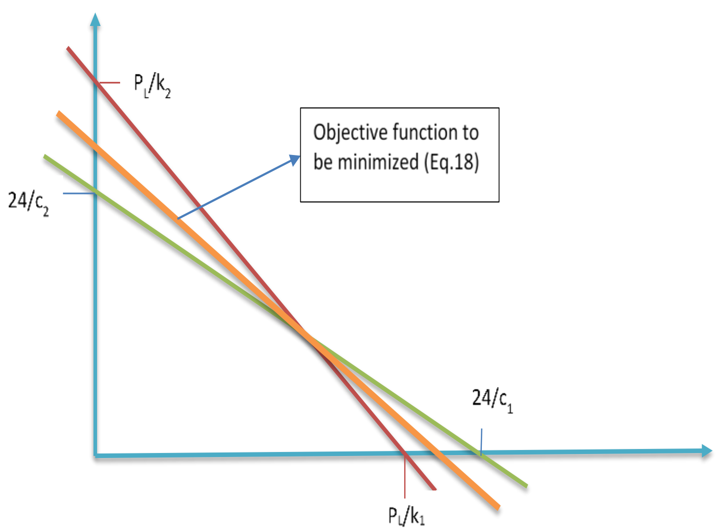

Figure 18: Objective function minimization using graphic method.

4.7 Case study thermal power plant: Jabana (I&II)

The researcher has considered Jabana I and Jabana II thermal plants as a case study of the present study, these thermal plants both have similarity of consuming the same type of fuel, which is Heavy Fuel Oil (HFO), there are located in Gasabo district in Kigali city.

The operating time of these thermal plant depends on season, means that in the summer time they can operate 24 hours, whereby in the rain season the operating rate reduces 3 hours or less

4.7a. Time step-up

There are various ways of time step-up for hybrid system, among them the net electricity production from solar photovoltaic has considered during the present study.

4.7b. Solar radiation

To ensure solar photovoltaic power production, it is necessary to consider the availability of solar radiation which is the most important element during PV power production, hence Rwanda is equatorial country, there abundant of solar radiation whereby 6KWh/m^2/day of solar radiation can be reached as maximum, this make possible and reliable on production of PV power generation system in Rwanda. PV power output increases proportionally to the increase of solar radiation in whereby CO_2 emission reduce according to the increase of solar radiation. While carbon dioxide emissions reduce with respect to the increases of PV power production to mean that once there is high solar radiation resulting with a high energy produced from solar photovoltaic system and this cause a huge amount of reduced power produced by diesel generator. Though, there is a reduction of fuel oil consumed as well CO_2 emissions reduction.

4.7.1 Jabana I thermal power plant

Jabana I is a small thermal power plant among the existing ones in Rwanda. Its rated power is 7.8 MW and it is made by six combined diesel generators with 1.3 MW of rated power for each. Its general operating power varies according to the load, this variation causes some diesel generators to work under their rated power, whereby the minimum range of operating power is between 6MWand 6.6 MW, this under-rated power brings high emissions due to low efficiency. The researchers' purpose was to examine the amount of carbon dioxide emissions that can be reduced by combining Jabana thermal power plant with a solar photovoltaic system.

The table 6 shows the impact of time step-up on Jabana I thermal power plant as from the equation 5 and 16, the utilized fuel and C02 emissions generated have been calculated with respect to output power, rated power of the generator and time step.

Table 6: Jabana I thermal power plant with the impact of Time step-up

Diesel Power (KW)	Diesel fuel consumption (Kg)	CO2 emissions (Kg)	PV Power generation (KW)	CO2 reduced (Kg)	Time Step (min)
7800	54720	147744	0	0	5
5850	41488.2	112018.1	1950	35725.9	15
3900	31533.1	85139.2	3900	62604.8	30
2600	19650.9	53057.6	5200	94686.4	45
1950	15813.3	42696	5950	105048	60

The figure 18 shows the impact of time step on CO_2 emission and PV power production.
The observation shows that solar photovoltaic generation is proportionally increasing with the time step up. Therefore, the higher PV power generated, the lower power generated from diesel generators which implies a small amount of diesel fuel consumption as well as CO_2 emissions reduction.

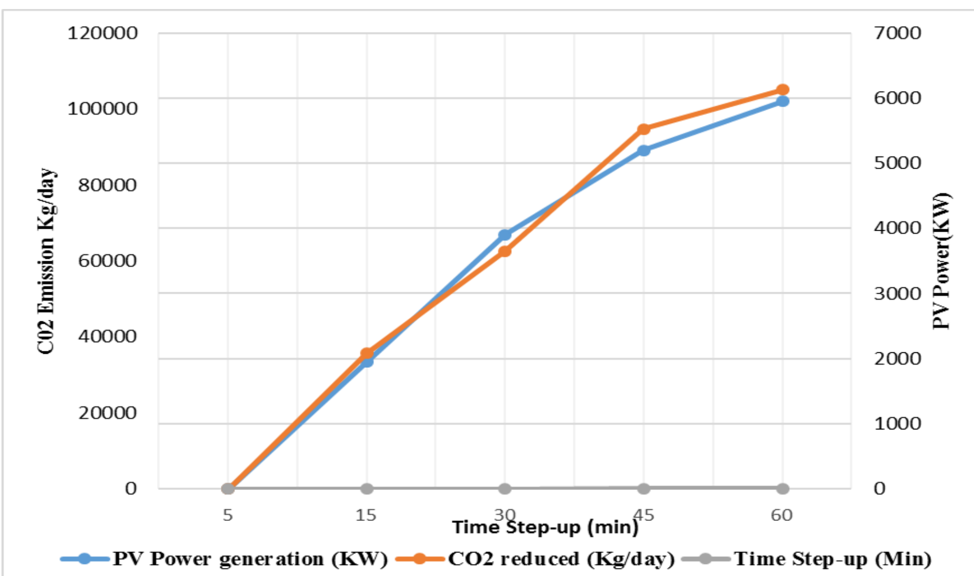

Figure 19: Jabana I within the impact of time step-up on CO2 emissions and PV power

Table 7: Jabana I thermal power plant with the impact of solar radiation

Diesel Power (KW)	Diesel fuel consumption (Kg)	CO2 emissions (Kg)	PV Power generation (KW)	CO2 reduced (Kg)	Solar radiation (KWh/m2/day)
7800	54720	147744	0	0	4.5
5850	41488.2	112018.1	1950	35725.9	4.8
3900	31533.1	85139.2	3900	62604.8	5.2
2600	19650.9	53057.6	5200	94686.4	5.5
1950	15813.3	42696	5950	105048	6

The table 7 and figure 19 show the impact of solar radiation on CO_2 emission and PV power production. They show that solar photovoltaic generation is proportionally increasing with the solar radiation. When PV power generated in the system is big, there is low power generated from diesel generators which implies a small amount of diesel fuel consumption as well as CO_2 emissions reduction.

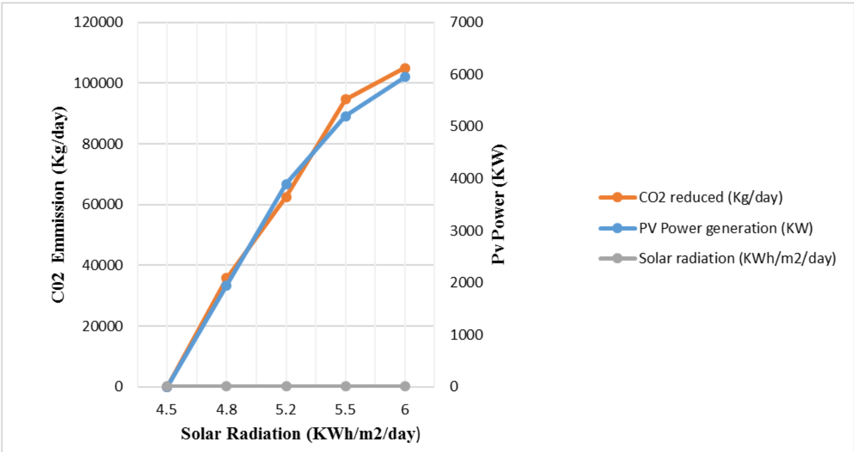

Figure 20: Jabana I within the impact of solar radiation on CO2 emissions and PV power

4.7.2 Jabana II thermal power plant

Jabana II is large thermal power plant, within generating capacity of 21MW as rated power. It is made by combination three diesel generators within 7MW of rated power for each diesel generator. The operating power of whole plant varies according to the load demanded where it can reach to 19.5 MW.

Table 8: Jabana II thermal power plant with the impact of Time step-up

Diesel power (KW)	Diesel fuel consumption (Kg)	CO_2 emissions (Kg)	PV Power generation (KW)	CO_2 reduced (Kg)	Time step (min)
21000	153370.8	414191	0	0	5
15750	134038.8	361905	5250	52286	15
10500	87404.4	235992	10500	178199	30
7000	66740.4	180199	14000	233992	45
5250	43702.2	117996	15750	296195	60

The data from table 7 describes and generates the figure 19 as the impact of time step-up on Jabana II thermal power plant. The equation 5 and equation 16 have been used where consumed fuel and C02 emissions emitted have calculated with respect to the output power, rated power of the generator and time step. The observation shows that the more time step increases the more amount of PV power generation increases and this result to the reduction of diesel generation within less fuel consumption as well C02 emissions reduced in the system.

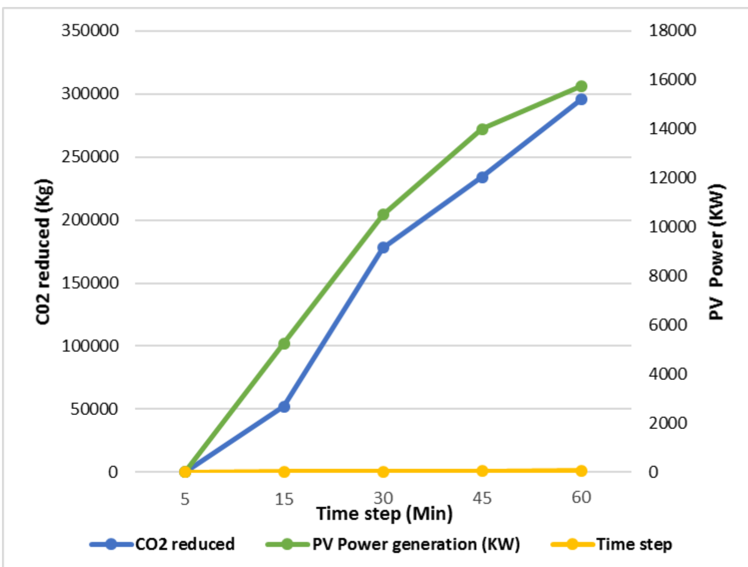

Figure 21: Jabana II within the impact of time step-up on CO2 emissions and PV power

Table 9: Jabana II thermal power plant within the impact of solar radiation

Diesel power (KW)	Diesel fuel consumption (Kg)	CO_2 emissions (Kg)	PV Power generation (KW)	CO_2 reduced (Kg)	Solar radiation (KWh/m²/day)
21000	153370.8	414191	0	0	4.5
15750	134038.8	361905	5250	52286	4.8
10500	87404.4	235992	10500	178199	5.2
7000	66740.4	180199	14000	233992	5.5
5250	43702.2	117996	15750	296195	6

The table 9 and figure 21 shows the impact of solar radiation on PV power production and carbon dioxide emissions, with the help of equation 5 and 16, the fuel consumption and CO_2 emissions have been calculated. Once, solar photovoltaic is not connected, the load will supplied by diesel generator, therefore there is a high amount of fuel consumed, resulting to a big amount CO_2 emissions. When a PV is connected on the system within the presence of solar radiations there is load sharing between PV and diesel generators, most of the case number of operating diesel generators reduce in order to meet load. When there is an increase in solar radiation, the PV power generation will increase resulting with a small amount of diesel power whereby low fuel is consumed with a continuous decrease in CO_2 emissions.

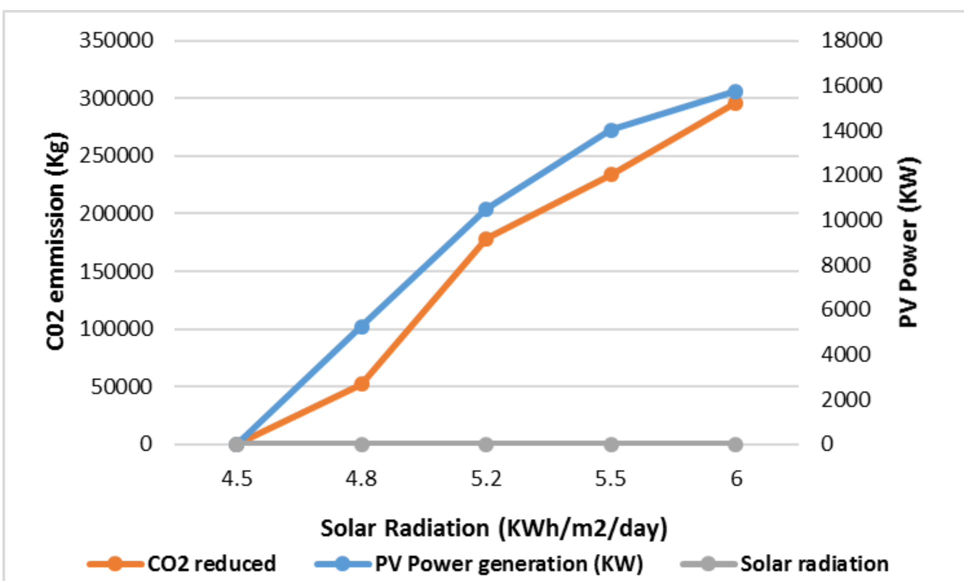

Figure 22: Jabana II within the impact of solar radiation on CO2 emissions and PV power

Chapter 5. Conclusion and recommendation

5.1 Conclusion

Study's aim was to analyze on the amount of carbon dioxide that can be reduced from a diesel generator generation system once it is integrated with a PV power system, during the study, it has been noticed that the considered thermal power plants operate full time a day in the dry season, which can be considered as a disaster in nature, due to the fact that when diesel generators get long operational time consume high fuel and start emitting higher amount pollutions, especially CO_2 emissions. The study has been demonstrated diesel power generation only are responsible of emitting 561,935 Kg of CO_2 per a day. The study shows that if an existing thermal power generation are operating together with a solar photovoltaic there is a significate reduction amount of CO_2 401,243 Kg per a day, this encourage the researchers to conclude that PV and diesel hybrid is preferred over the diesel generators because it minimizes the diesel operational hours thus reducing fuel consumption, which significantly reduce CO_2 emissions and other pollutions.

5.2 Recommendation

Due to COVID-19 pandemic it was not possible to collect all data from different districts of Rwanda, so new researchers are recommended to consider the significance of the present research and extend it on other Rwandan thermal plants in order to meet the Rwandan government target of reducing of CO_2 emission. This can be achieved once published research can be disseminated and implemented. Therefore, African Center of Excellence in Energy and Sustainable Development (ACEESD) is recommended to follow the student's thesis implementation for helping them to achieve theirs dreams.

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