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

IMPACT OF DISTRIBUTED GENERATION ON VOLTAGE REGULATION IN THE DISTRIBUTION SYSTEM (Case study: Rwanda)

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By

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DECLARATION

I, the undersigned, declare that this Project proposal is my original work and has not previously been submitted for a degree at the University of Rwanda or any other university. All sources of materials used for the thesis work will be fully acknowledged.

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APPROVAL

Submission date: 05/11/2021

This project has been submitted for examination with my confirmation as a university supervisor.

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Abstract

Distributed Generation (DG) is the energy generating from a variety of small sources of energy source, such as small hydropower plant, solar and wind, those are located close to the user. On-site generation is a type of DG in which a customer owns the generation and it is installed on its premises. The inserting of distributed generation on a distribution network can have an effect on voltage adjuster. A Distributed Generation may in some cases provide voltage support but it may as well as cause a grid challenge depending on several variables such as intermittent distributed generation, atmospheric conditions, solar irradiance, DG location, and voltage regulation method. The impact of DG was studied by analysis of data collected at Rwanda National Control Center and using Power World simulator.

Keywords: Distributed generation, Voltage regulation, distribution system.

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List of abbreviations

DG	Distributed Generation
MW	Megawatt
GW	Gigawatt
IPPs	Independent Power Producers
PV	Photovoltaic
DC	Direct Current
AC	Alternating Current
DFIG	Double Fed Induction Generator
HAWT	Horizontal Axis Wind Turbine
VAWT	Vertical Axis Wind Turbine
LTC	Load Tap Changer
LDC	Line Drop Compensation
CH4	Methane gas
CO2	Carbon dioxide
KP1	Kibuye power
KV	Kilovolt
KVAR	Kilovolt Ampere
MVAR	Megavolt Ampere
VAR	Volt Ampere
KW	Kilowatt
ANSI	American National Standards Institute
CSP	Concentrating Solar Power
HV	High voltage (HV)
LV	Low voltage (LV)
MV	Medium voltage (MV)

CHAPTER 1. INTRODUCTION

1.1. General introduction

Generally, Distributed Generation is defined as small generators, based on output power and physical size, that are linked to the current power distribution grid joined. The difference between power plants working in the current transmission network and DG is tolerable to some extent [1]. Power plants on transmission networks generally are situated distant through the loads are served and are operated by utilities, while DG typically are situated side near in relation to the loads are served and Instead of a utility company, it could be worked independently by a customer or an independent power producer. Currently, power systems generate electricity which require three stages to be passed through before reaching to the end users such are: Generation, Transmission and Distribution network. Electricity is dispatched to the customers by using three levels of voltage which are high voltage 110 KV and 220KV (HV), medium voltage 15KV and 30KV (MV), low voltage0.4KV (LV)[2]. The distribution networks are designed to function in radial manner with energy flowing in one direction only, from the higher levels of the feeder to the users located along the feeder.

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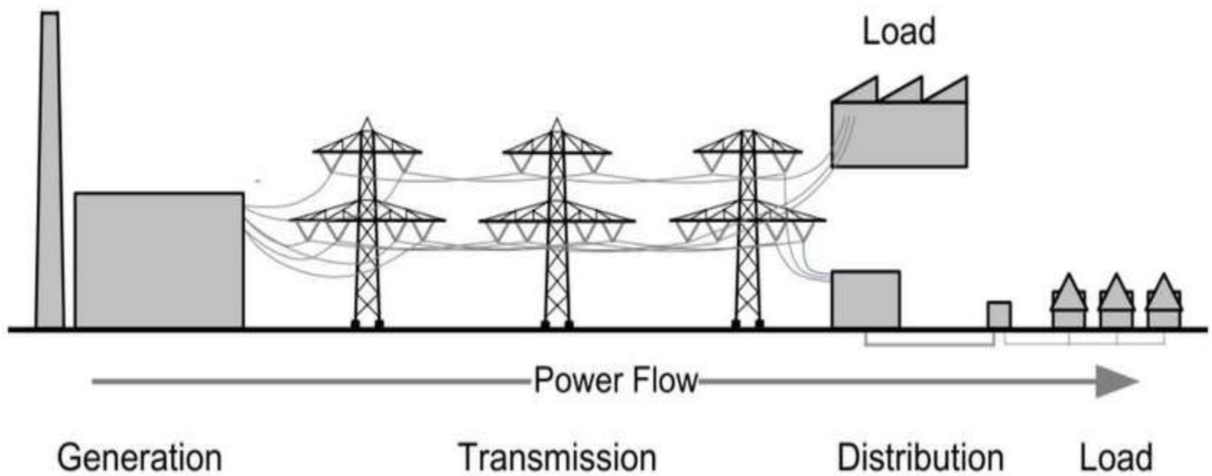

Figure 1. 1: Traditional view of power flow[3]

Because of economic and population growth, global demand for electricity is rapidly increasing. Large power plants are required to meet the increased demand for electricity. However, with advanced technology, both renewable and non-renewable energy are now being used as generation of electricity within the distribution network or on the side of the customer in the network, which is known as Distributed Generation (DG), a portion of the energy demand is met by centralization of production, while the remainder is met with DG in that order to meet the rising demand for load , electricity will be produced close to the user[4]. Because of their ability to be near to ending users also connected to distribution networks of lower voltage,distributed generation technologies are an important component of energy development.

Distributed generatins(DGs) are equivalent to central power plants that are large in terms of electricity generation. The term "DG" has frequently been described as a small-scale model electric power generation units linked to low-voltage distribution systems. This is a definition takes distributed generation into account in the context of its installation location, goal and also area served. By terms of position , distributed generation is expected to be closer to the consumer side regarding of purpose, units of distributed generation are positioned like a source of electricity, similar to what is anticipated of massive power plants [5]. The spread of technologies for distributed generation, primarily renewable energy sources like wind and PV, may have an effect on the process of electricity distribution networks. Voltage profile changes can occur resulting via changes in electricity demand and consumption and fault in circuits my happen frequently at high level. Power flows, along with load loss, become increasingly bi-directional as generation and load levels increase[6].

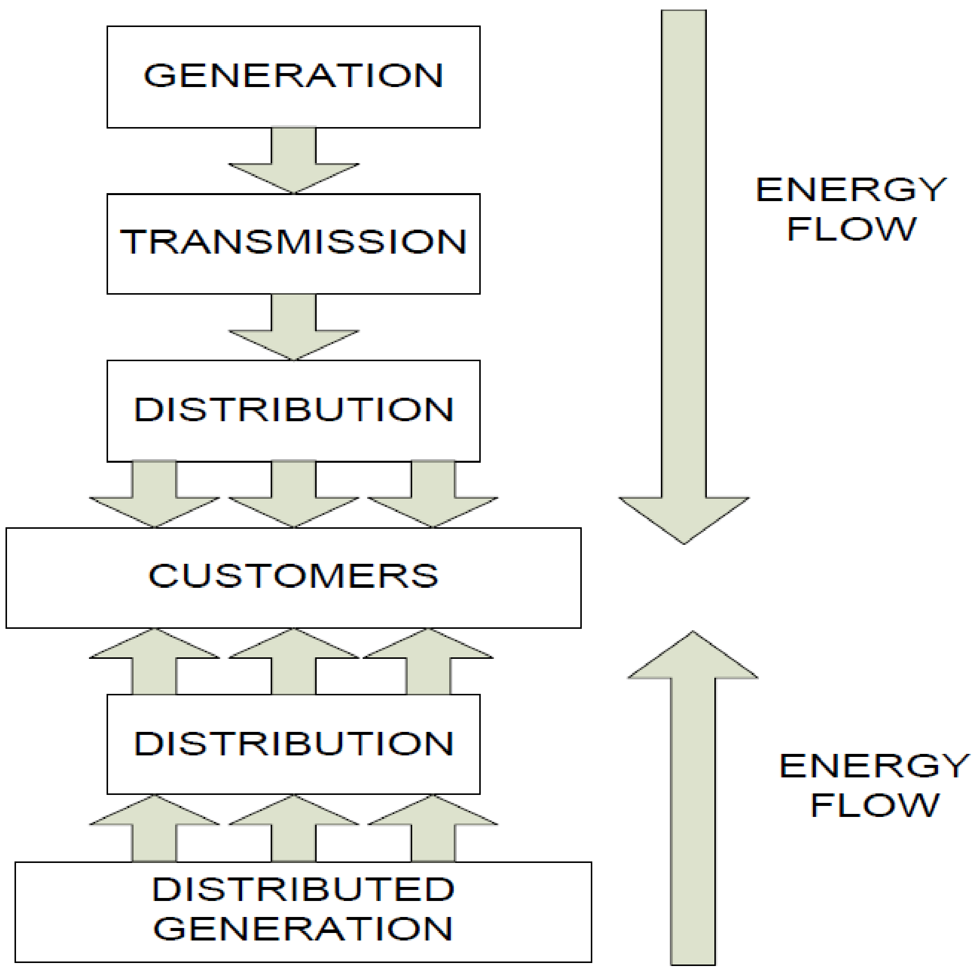

Figure 1. 2: New industrial electrical energy supply concept [7]

1.2Background

The word "distributed generation" refers to any type of power from electricity generation integrated technological innovation into a distribution network closer up until the point of consumption. Distributed Generation (DG) is linked via a low voltage (LV) or medium voltage (MV) grid. They are typically below 30MW in size and are not centrally planned in the network. The distributed generation principle differs from conventional centralized energy generation in which electricity is generated in large power plants and distributed to end users via transmission and distribution lines. Central power is made up of large power plants that generate, transmit and distribute electricity to the grid [8]. Small and micro generators are directly connected to the lower side of voltage distribution networks in a distributed electricity system.

Electricity that is not required by customers directly connected to the grid demand is delivered into the active distribution network abroad. The acceleration of DG contributes in reduction of greenhouse gas emissions and reduced utilization of fossil fuels, both of which benefit the environment. According to the International Renewable Energy Agency, global solar capacity was 580 Gigawatts at the end of 2019, 3.4 Gigawatts off grid, and 743 Gigawatts of onshore wind power in 2020 [9]. The distributed generation provided by companies of energy service and independent generators of power is altering how users perceive energy.

The total installed capacity of DG predicts 520MW globally by 2030.The total installed capacity, according to the Rwanda Energy Group (REG) energy Rwanda's power generation capacity was 238.368 Megawatt in 2019 from various generating stations, primarily hydro power plant in our country[10]. Only Imports account for 11% of available capacity with remainder produced homely. With the Combination of technologies 50.6 percent comes via hydropower plants, 27 percent from diesel, 14 percent from methane gas, 7 percent from peat, and 6 percent from solar, which was accomplished via including personal shareholders independent power producers in the energy sector (IPPs) [10]. There were 37 hydro power plants connected to the grid, totaling 120.7MW, including national power plants and shared regional power plants.

In Rwanda, renewable energy sources accounted for approximately 113.14 Megawatts of total energy consumption [10]. Rwanda's solar power plant contributed approximately 12.2MW. The

National Grid is served by four solar PV plants: GIGAWATT solar power (8.5MW), Nasho solar power (3.3MW), Jali solar power (0.25MW) and Nyamata solar power (0.03MW)[10].

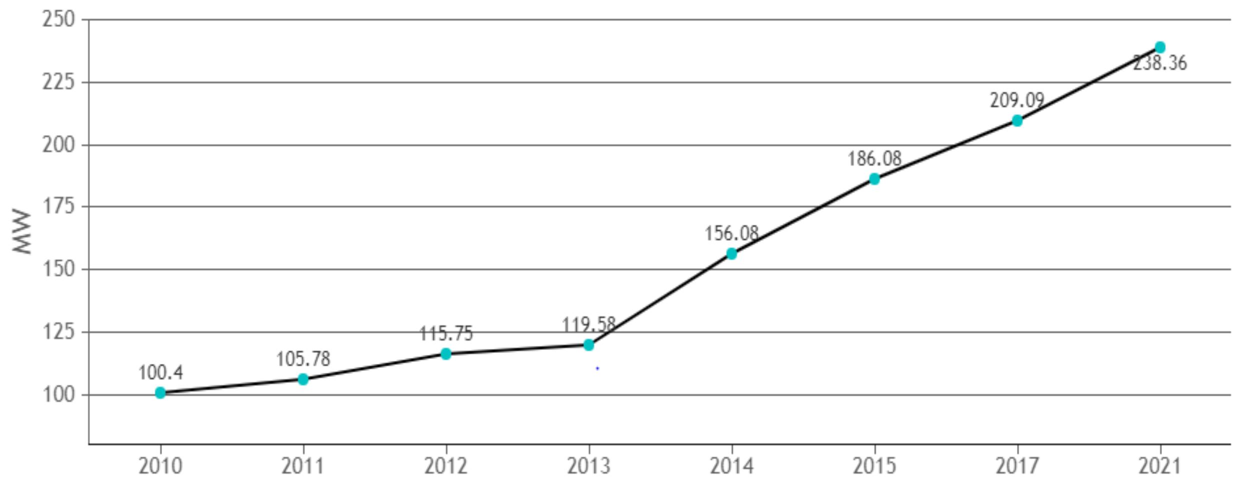

Figure 1. 3: Evolution installed capacity in Rwanda[10]

Furthermore, the PV solar capacity does not remain constant because its accessibility varies from low via high during peak evening hours. Furthermore, Transmission line losses and distribution line losses of about two percent of total installed power must be considered.

1.3 Statement of the Problem

In general, electricity demand is steadily increasing, and researchers' primary task is to investigate how to generate electricity from renewable energy sources in order to meet rising load demand for electricity while also reducing the environmental impact on generation of electricity. The incorporation of distributed generation into distribution networks results in numerous changes to the power system, including voltage profile, voltage fluctuation, power flow, power quality, stability, and dependability and power system protection. Rwanda has a couple of distributed generation systems are all factors to consider. Among these distributed generation sources is photovoltaic solar energy, which is connected to the grid at the Musha substation in the Eastern province. DGs obviously have an impact on the distribution system in both positive and negative ways. This thesis work will specifically investigate the impact of Photovoltaic in the system of distribution on Rubona feeder.

1.4 The objectives

1.4.1 Major of objective

Primary goal of this study is to investigate the potential influence of distributed generation on voltage regulation in Rwanda's distribution system (DS).

1.4.2 The Specific Objectives

The specific goals of this work are as follows:

- Collect and analyze data of the Distributed Generation
- To simulate both with DG and without DG on the feeder
- To compare the result between with and without DG in order to see the different.
- To perform the analysis of impact of both on voltage regulation in the distribution system
- Drawing conclusion and recommendation for implementation

1.4 The study of Scope

This work will look into comparison of experimental results with also without Distributed Generation. Both performances will be analyzed and compared, and the results will be discussed in order to determine the best solution to the problem.

1.6 Limitation of the study

As with many researches, deficiencies and limitations are unavoidable; therefore, because this research was conducted using software, it was severely limited by how the software was structured. This includes limited data, components and other manufacturing performance characteristics.

1.7 Hypothesis and significance of the study

1.7.1 Hypothesis

This dissertation is proposed to look into the impact of Distributed Generation regarding voltage regulation in a distributed system (DS), and the findings will be used by customers before connecting their energy sources, as well as standard for future study.

1.7.2 Significance of the Study

Because of increasing load demand for electricity, having a thorough understanding of the influence of distributed generation performance about both the negative and positive sides is critical as part of system optimization. This research aims to benefit a thorough comprehension of influence of distributed generation on voltage regulation and will provide guidance on how to avoid negative effects on voltage regulation in the system caused by various causes, particularly those caused by distributed generation when connected to existing power.

1.8 Thesis outline

The outline of this thesis consists of six chapters.

- Chapter 1 is Introduction which provides a brief overview of the back ground and motivation for the study, problem statement, objectives, limitation, expected outcomes and outline of the thesis.
- Chapter 2 gives a brief overview of DG technologies, the literature review which contains the related work done by other researches on this topic and the impacts of DG into the grid are also presented in this thesis.
- Chapter 3 is the research methodology that describes methods, tools used in this thesis.
- Chapter 4 is the simulation that represents and explains simulation parameters and scenarios.
- Chapter 5 is the results and discussions that represents the results of the project objectives.
- Chapter 6 is the conclusion and recommendation based on the research results.

CHAPTER2. REVIEW OF LITERATURE

2.1 Introduction

Distributed Generation (dg) was modern concept in electrical systems that is being utilized to meet increased demand for energy. Distributed generation was available in the form of solar (PV), wind, small hydro, fuel cell, and other small scale rating systems. Distributed generation is referred to as "on-site generation," "distributed generation," "decentralized generation" and "distributed energy." Distributed generation relates to generators of electricity designed to produce electricity also deliver it to clients near theirs location; It could also be linked to the power grids [11]. Distributed generation feasible applied to supply Customers' access to electricity during peak hours; it can also provide a consumer with complete demand enabling them to function independently of the network. To define the distributed generation concept, the table below presents some classifications for defining the size of the generation unit:

Table 2. 1**:** Range of Distributed generation[11]

Sort of Distributed Generation	**Range**
Micro Distributed Generation (McDG)	1W <5Kilowatt
Small Distributed Generation (SDG)	5Kilowatt<5Megawatt
Medium Distributed Generation (MeDG)	5Megawatt<50 Megawatt
Large Distributed Generation (LDG)	50Megawatt<300 Megawatt

In this chapter types of Distributed Generation(dg), different Distributed Generation technologies. Distributed Generation in case of Rwanda, influences of Distributed Generation on voltage regulation are presented in this review of literature.

2.2 Types of Distributed Generation

DG powered by inverters and DG rotating machine are the two major types of distributed generation. Usually, inverters are typically utilized after the generation process in DG systems, because the generated voltage can be either Direct Current form or Alternating Current , but it must be converted in Direct Current and after that back in Alternating Current via the rectifier with the nominal parameters [12]. Couple active power (P) and reactive power(Q) delivered in relation to the distribution network feasible used to categorize distributed generation (DG). PV and fuel cells are the only types of distributed generation utilizing active power injection that operate at unit power factor and are linked to the distribution system via a suitable electronic interface. Only gas turbines supply reactive power in the distribution system and operate at zero power factor in distributed generation with reactive power injection. This sort of power generation provides both active and reactive power are based on synchronous machines such as gas turbines, combined heat and power. Wind farms and double fed induction generators are examples of distributed generation with active power injection and reactive power absorption (DFIG)[12],[4].

2.3 Distributed Generation technologies

Photovoltaic (PV)systems, small hydropower plants, fuel cells, gas turbines, wind turbines, and other distributed generation technologies are examples.

2.3.1. Photovoltaic (PV) system

A photovoltaic (PV) system light conversion energy out of the sun electrical power. Semiconductive materials are used to build solar cells, which exposed to sunlight, converts the self-contained energy of photos into electricity. Their cells are arranged in either a fixed or a moving array in order to track the light and produce the most energy [13]. Photovoltaic system (PVs) is one of the most encouraging ways to maintain our energy-intensive standard of living because they do not contribute to global warming or pollution of the environment, are simple to use and do not necessitate any other fuel than sunlight. Alternatively, they require big spaces and have a high cost of initial. Photovoltaic (PV) system generates direct current (DC) and after convert it to alternating current (AC) voltage using an inverter. With and without battery storages are two general designs that are typically used.

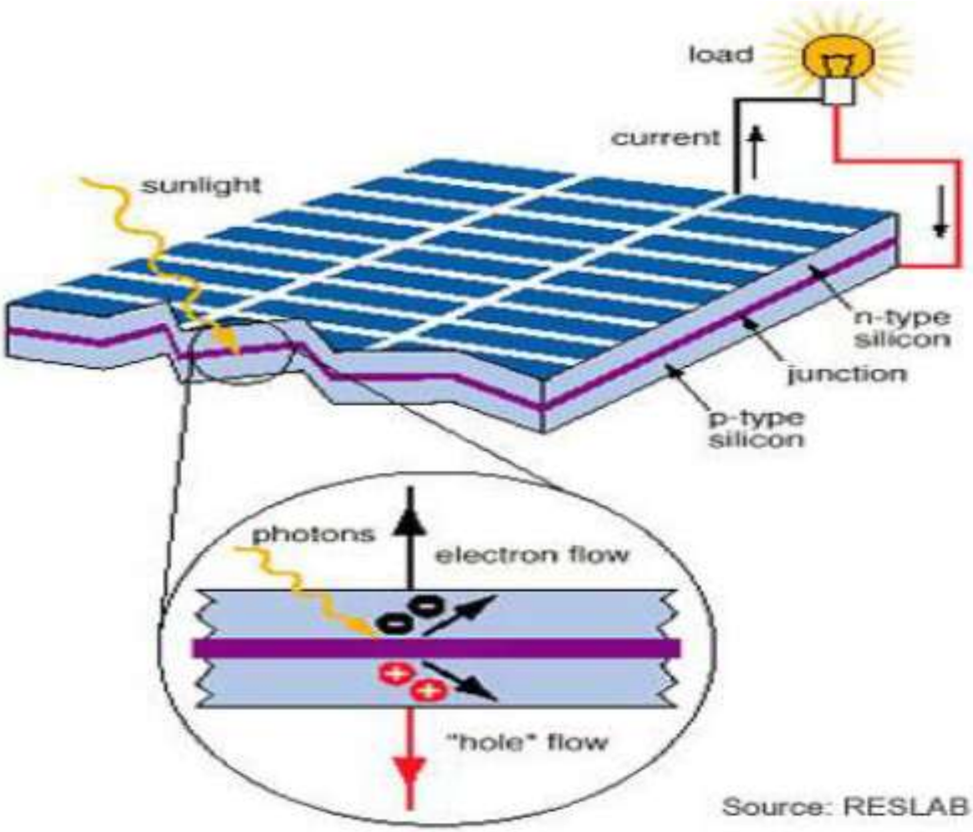

Figure 2. 1: Schematic diagram of photovoltaic system[14]

2.3.2 Fuel cells

The Fuel cells working like the battery which is constantly transferred with a high hydrogen content fuel gas; the duty of fuel cell works by passing hydrogen through the anode of a fuel cell and oxygen through the cathode. It utilizes the reaction of H_2 and O_2 with the aid of an ion conducting electrolyte to generate an induced DC voltage. Inverters are used to convert DC voltage to AC voltage, which is then delivered to the grid. A fuel cell is made up of two electrodes connected by a conducting electrolyte. It emits no harmful emissions and is extremely quiet. However, it has a high operating cost. The benefits of a fuel cell include: no moving parts, increased reliability and no noise[15].

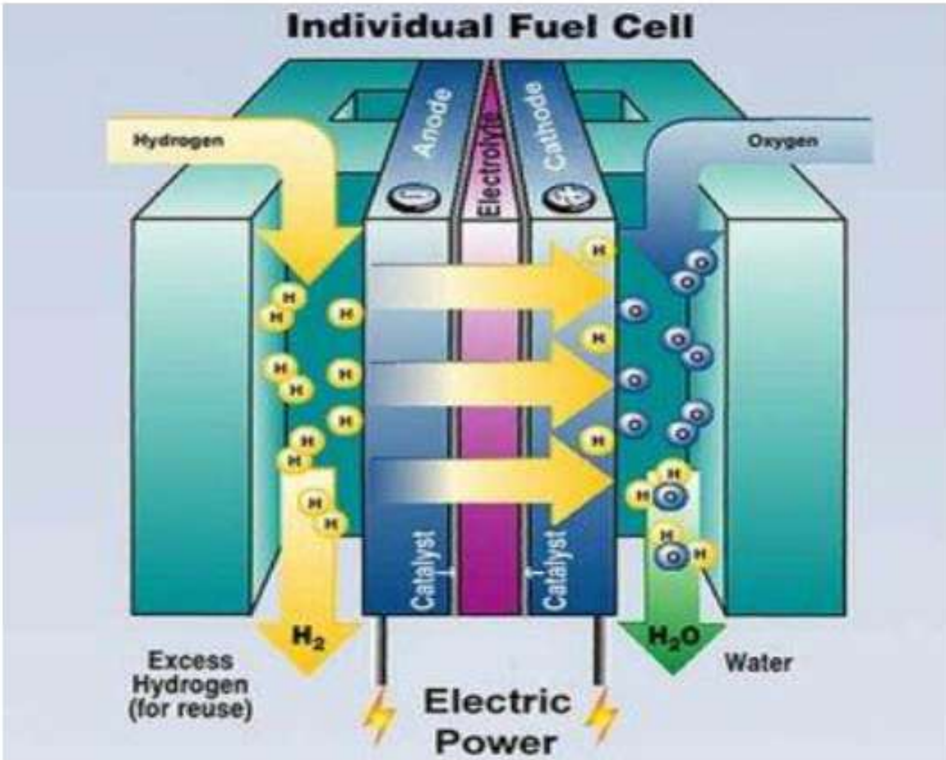

Figure 2. 2: Schematic diagram of fuel cell[14],[15]

2.3.3 Wind turbines

Wind turbines use the wind as an input to convert to useful electricity as the system's output. Wind turbines convert the motive power of the wind energy into electricity energy. Wind turbine generation has been identified as the fastest growing technology because it is one of most affordable also environmentally kindly methods of generating electricity generated via renewable sources. The amount of wind power that can be generated depends on the wind speed and the area swept by the turbine blades. There are two types of turbines: vertical axis (VA) and horizontal axis (HA) (HA). Horizontal axis wind turbines (HAWTS) have rotating blades that are parallel to the ground and horizontal on an axis[16].

Figure 2. 3: Horizontal axis wind turbine (HAWT)[17]

Vertical axis wind turbines (VAWTS) have perpendicular to the ground rotating blades around the vertical axis.

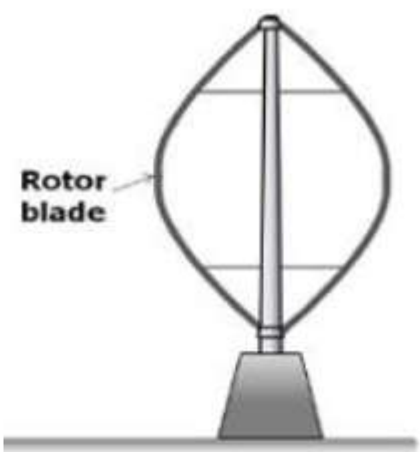

Figure 2. 4: Vertical axis wind turbine darrieus type (VAWT)[17]

The operation of a wind turbine is divided into two stages: The rotor first extracts motive power from the wind and it is converted into mechanical torque in the shaft.; the power generation system then this torque is converted into electricity. The generator system is the most common system produces an alternating current, voltage output which is proportional to speed of wind. Because the wind speed of wind is not constant and generated voltage varies, inverters are used to convert DC to AC. A wind farm is a collection of wind turbines that are linked together to generate power ranging from 200 to 50MW. Fixed-speed wind turbines, on the other hand, are directly connected to the grid).

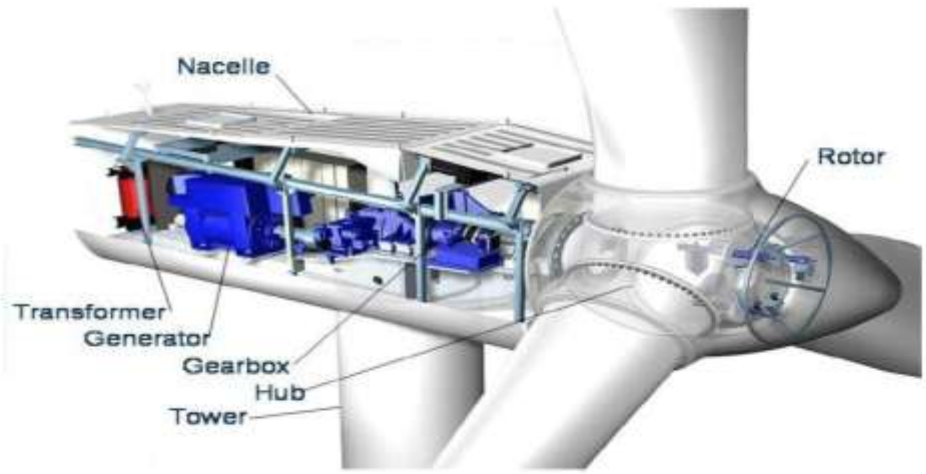

Figure 2. 5: Schematic conduct diagram of wind turbine[18]

2.3.4 Microturbines

Microturbine technology is based on very high-speed rotating turbines combined with a generator to produce a high frequency output. Natural gas is typically used to power micro turbines.

The primary benefit of a microturbine its clean and low-emission operation; however, in their drawbacks include elevated level of noise produced and a low efficiency. A micro-turbine is a mechanism that converts thermal energy into mechanical energy by utilizing the movement of gas[19]. They are single shaft machines with a turbine compressor and generator mounted on a single shaft. The combustible is mixed with air pumped by the compressor in the combustor chamber to turn turbine. Most microturbines are made up of four major parts: a compressor, a combustion chamber, turbine blades and a drive shaft. Because the output voltage from microturbines is DC, it not possible directly linked to the power grid or a utility, instead that must be converted to DC and then to AC in order to complete the utility's nominal voltage and frequency condition.

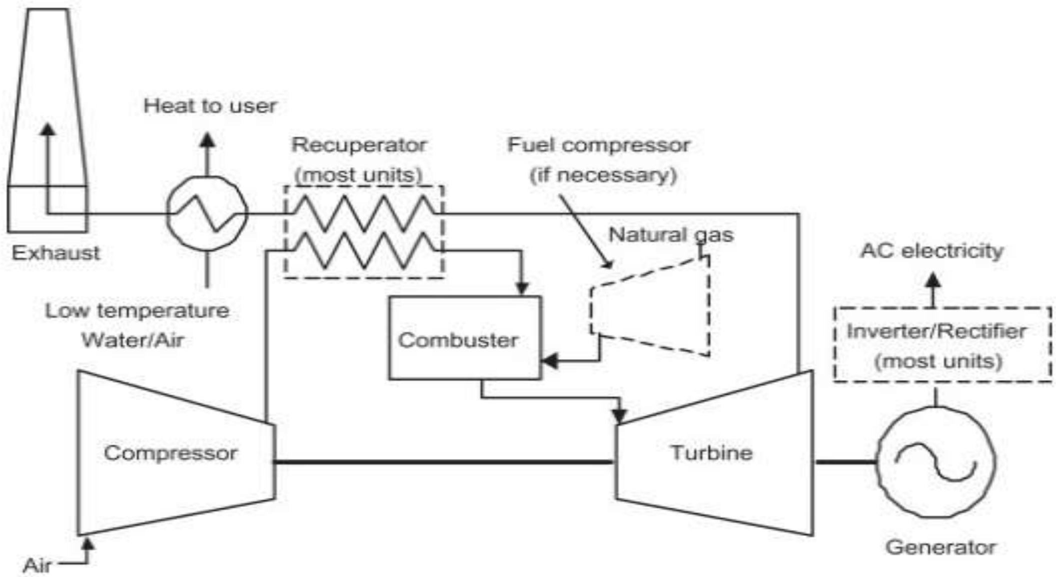

Figure 2. 6: Microturbine Schematic Diagram[19]

2.3.5 Hydropower

To generate electricity, a hydropower plant makes use of the flow of water toward the sea or a lake. The most visible form is the construction of large dams to create reservoirs. Because of the difference in water levels upstream and downstream of the dam, the potential energy in water can be used effectively. The size of comparable installations ranging via a few megawatts to hundreds of megawatts (MW), with some very large installations running. By definition, the location of hydropower based on large reservoirs in remote locations. Large-scale hydropower plant is always an option necessitating robust system of transmission. To increase the quantity of hydropower plant, the transmission system must be strengthened further. Hydropower, in particular exhibits long-term variation at timescales ranging from days to years. This makes hydropower very appealing in terms of market for electricity with operation of transmission system. Timescales that are longer than a couple of days are typically unimportant in all the market of electricity with transmission system work. Small hydropower schemes could be used to strengthen the distribution grid in such mountainous areas where Small hydropower and flow or river are located closer to the client than large hydropower[20].

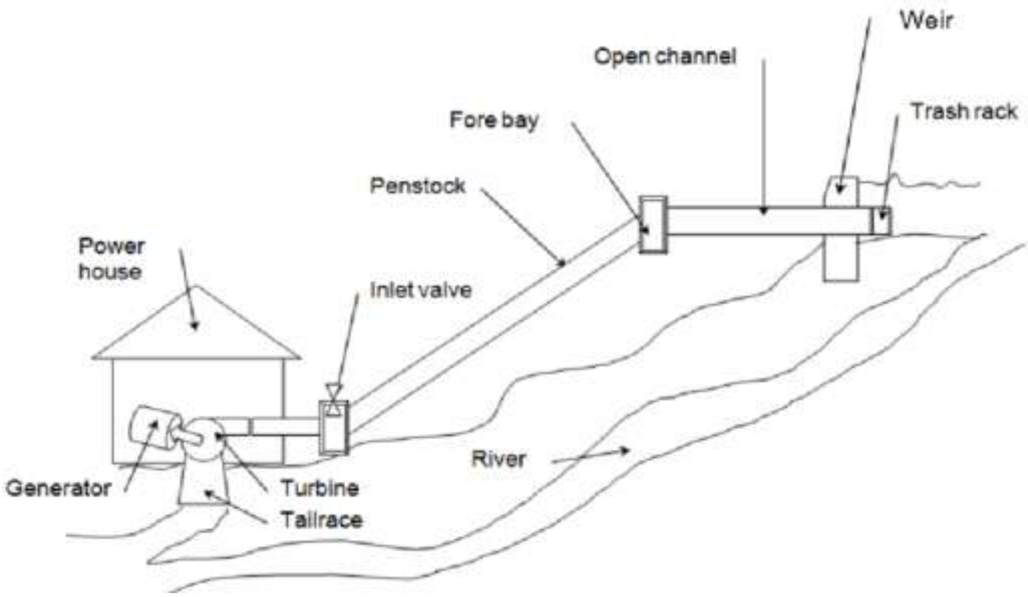

Figure 2. 7: Schematic diagram of small hydro power plant[20]

2.4 The influence of distributed generation on power system Grids

Inserting generation dispersed into systems that were originally designed to function without the use of any new distribution system generation have a significant influence on flow of power and voltage levels at both customer and utility apparatus. Relying on the distributed generation characteristics of distribution system operation, these impacts can have a positive or negative impact. The primary goal of this dissertation is to look into the technical influence that distributed generation has about voltage regulation in distribution network. One approach to addressing influence is to look into the action of an electric system without also with distributed generation. The outcomes of these two operations states provide critical details about electric firms and customers [21].

2.4.1. Impact of distributed generation regarding voltage regulation

Distribution voltage regulation networks are primarily based on the flow of radial power from the substation to the load. This is frequently accomplished at the substation using Load-Tap-Changing (LTC) transformers. Switched capacitor banks installed along the feeder improve voltage regulation as well [22]. The voltage is regulated by the radial distribution system using load tap changing transformers (LTC) at substations and line regulators on distribution feeders. Voltage regulation is based on one-way power flow and regulators include line drop compensation. By changing the direction and magnitude of real and reactive power flows, the connection of distributed generation may result in changes in voltage profile along a feeder.

Nonetheless, depending on the distribution system with distributed generator distributed generator attributes as well as the site of distributed generation impact via distributed generation regarding voltage regulation feasible negative or positive.

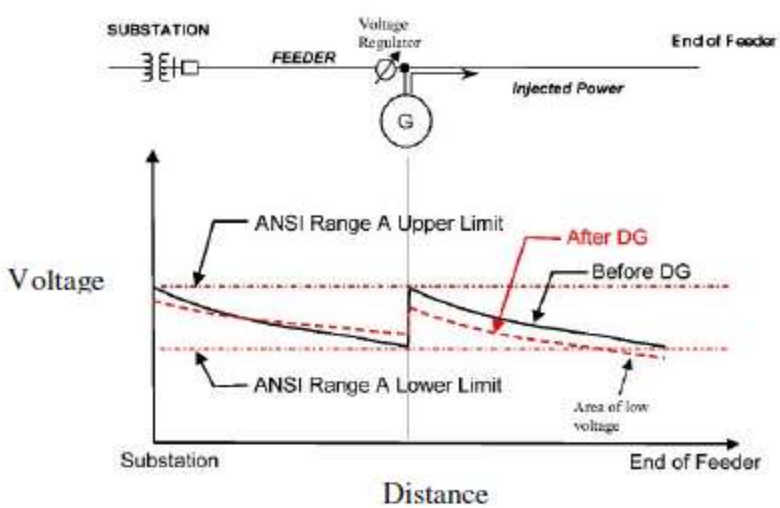

Figure 2. 8: Distributed Generation unit interfering with voltage regulation on distribution system[22]

The distributed generation system is installed further down of the Load-Tap-Changer transformer, which has capacitor bank. The voltage on the feeder is observed to be lower with distributed generation than without distributed generation incorporated into the network. The voltage adjuster will be disrupted, and determining a voltage in the normal range will necessitate a sufficient facility.

The distributed generation diminished the load observed via the load compensation on control side, causing the adjuster to put a lower voltage at the feeder's ending.

This phenomenon has opposite effect that was anticipated with the implementation of distributed generation. There were two potential answers to this issue: The first answer is to relocate distributed generation in relation to the regulator's the upstream side, while the flowing answer is to add adjuster control for compensating generation dispersed output. The placement Distributed Generation (DG) units equipped along power division feeders may result in undervoltage or overvoltage due to an excessive or insufficient injection of reactive and active power. When a small Distribute Generation (DG) system shares a distribution transformer with multiple loads, the voltage on the second level can rise levels sufficient to cause a surge in voltage at these clients.

It can occur if the distribution transformer is located at the point where the primary voltage on the feeder is close to or above the fixed limits. On a 120-volt base, the American National Standards Institute upper limit was 126V. Under normal circumstances with no DG, the load voltage terminal is less than the voltage at the transformer's primary[22]. Inserting Distributed Generation can result in a reversal of flow of power, possibly even increasing the voltage, and the voltage received at the customer's location may be higher than on the distribution feeder's first side.

2.4.2 Regulation in distribution system

The primary operation and accountability of a company that provides electricity is keep the distribution system's voltage stable. Voltages which are outside within its normal operating range can cause destitute system and client load operation, utility apparatus and customer loads are damaged in extreme cases and security problem. In general, utilities work hard to adhere to standard voltage limits; however, while some clients may not always located this range of 230 volt-base, the standard requires that the service entrance voltage be between 220 and 230 volts in Rwanda [23]. Even so, due to significant variations load also the lengths in distribution circuits that take place as a result of disturbance this is not an easy task for all customers. To achieve voltage conditions, it is necessary to carefully place and coordinate voltage regulating equipment, to be active in controlling a rise in system load and to perform studies of periodic load flow. Voltage regulation practices for spiral power systems use a single power source and power travels only one path via the substation to all system charges. As a result of this condition, it is assumed that as one's distance via the substation grows, the voltage on the primary feeder will always decrease. The only time these givens are violated when there is excessive compensatory reactivity. Utilities take precautions to ensure that this condition does not occur in the system. The presence of radial flow implies that the voltage drop across each distribution system will have an effect on both of these fundamental voltage regulation assumptions. Voltage regulation in the network is typically accomplished entirely through substation load tap changing transformers, with no additional voltage control equipment on the main feeders or on the network's end [23].

Because the network is in urban environment the main feeder lengths are relatively short and the secondary grid was electrically tightly interconnected in such a way that voltage drop was minimal. In general, thermally limited systems characterized urban networks which means as fill increases long before voltage drop becomes an issue, the transformer and cables reach their thermal limits.

Longer spiral distribution systems, on the other hand are typically voltage drop limited, which means that the voltage drop exceeds any thermal limits well before any thermal limits are reached[24]. It explains how a large amount of power injected is required to a large extent change voltage in system. Although low voltage urban networks are less sensitive to DG's influence on distribution system voltage control , they are much more complicated to deal with as well as more sensible than spiral distribution systems in terms of other issues such as fault coordination and protection [24].

2.5 Distributed generation in case of Rwanda

In Rwanda, technologies for renewable energy such as biomass, solar, peat, geothermal with small hydropower plants were on the rise. Biomass dominates and is widely used on all the supply and demand perspectives of Rwanda economy. With numerous areas having sample rainfall most streams and rivers remaining untapped, small hydropower represents a considerable potential for rural power supply. Solar irradiation is high via 4-6 kWh/m^2/day but diffusion is hampered by high initial costs with restrictions on high load usage[25]. Biogas has the potential to meet the thermal energy requirements of farms and small businesses given the large number of houses owning cows and other farm animals.

The geological expedition in Rwanda still at the geoscientific surface exploration stage. Bugarama and Gisenyi were prioritized when it came to locating sites for exploratory professional work[25].Presently, the total installed capacity for electricity generation is 238.6 Megawatts via various sources of power, the majority of which are hydro power plants. Hydropower plants contributed approximately 120.728 MW in Rwanda in 2020[26] .

An assessment of Rwanda's solar energy potential included on-grid, off-grid, and concentrating solar power. In Rwanda, the solar power plant generates approximately 12.2 MW. Many Rwandans live in rural areas in which traditional biomass Rwandans live in rural areas where traditional biomass such as wood is the primary source of cooking energy and heating water. According to the data biomass particularly wood fuel accounts for 83 percent of total consumption of energy. Off-grid energy systems are not connected to the National power also provide energy services to various households.

2.5.1 Hydropower Plant

The hydropower plant is Rwanda's most important energy resource for power generation. The hydropower plant has identified 70 hydro sites in the country with a total capacity of 15 MW from outside the country. Rwanda’s hydropower plant sector has made enormous progress. The hydropower plant is Rwanda's most important energy resource for power generation, with a total installed power is about 368MW, accounts for 50.63 percent of total installed capacity. The National and shared regional power plants are among the 37 grid-connected hydropower plants with a combined capacity of 120.728 Megawatts. The hydropower plants are either publicly owned and operated, leased to private companies or owned and operated by a private company[26]. Rwanda currently has 11 isolated networks are supplied by off-grid micro hydropower plants with a total capacity of 1.311 Megawatts supplying isolated networks.

2.5.2 Solar Energy Technology

Solar energy is the electricity generated by the sun. It is also a type of renewable energy that has no environmental impact and will never run out. These are various types of radiant energy emitted by the sun. Light ultraviolet rays, infrared rays and X-rays are the most dangerous. Currently, satellite data show that Rwanda's territory is in the overall zone with a daily global emission of about 4.6KWh/m^2/day. The current average solar radiation for most of the country is about 4.5KWh/m2/day and the sunshine time per day is 5hours making solar energy economically feasible in Rwanda. The Rwandan government intends to achieve 100 percent access to electricity by 2024 by promoting the use of renewable energy, primarily on-grid also off-grid solar PV systems. Rwanda has a total installed power of 12.2 Megawatts of on-grid solar power[10],[26] . The current average solar radiation for most of the country is about 4.5Kwh/m2/day and the sunshine time per day is 8 hours which making solar energy economically viable in Rwanda.

2.5.3Biomass Energy Technology

Biomass energy is the oldest source of energy used by humans. Organic matter produced by plants, both terrestrial and aquatic, is used to generate biomass energy. It includes forest crops as well as residues, as well as crops raised on forest land "energy farms" specifically for their energy content as well as animal manure content. Biomass fuel can be used to heat homes, cook food and even generate of electricity [26]. The most common source of biomass energy is the combustion of wood, but energy can also be produced by the combustion of herbaceous plant material, animal manure and peat. Biomass energy can also be used to produce a liquid biofuel such as ethanol or methanol. Biomass energy is also widely used in food preparation, with wood used by rural households and charcoal used by urban households. Utilization of the promotion of institutional and domestic biogas technology was the starting point for modern bio-energy systems in Rwanda. As of June 2016, 10,216 households and 81 institutions were connected to biogas systems, which provided cooking energy, lighting energy, quality fertilizer and job opportunities. The installation of biogas systems in schools and prisons has reduced firewood consumption by nearly 60% and 40%, respectively, while also significantly improving hygienic conditions and saving money. Currently, biogas is used for cooking in 11 of 14 prisons. In comparison to using electricity, this has cut the cost of cooking in prisons by half[26].

2.5.4 Methane gas

In the Eastern African Rift Zone, Methane Gas Resources is based in Lake Kivu. The lake contains high concentrations of naturally occurring carbon dioxide (CO2) and methane gas (CH4), with the highest concentrations at depths ranging via 270 meters and covering an area of approximately 2400 square kilometers. The lake's biology is supported by the oxygenated upper layer of the lake, which extends from the surface to a depth of 60 meters. Rwanda and the Democratic Republic of the Congo share resource equally. Until 2004, the gas was extracted on a small scale, with the extracted gas being used to power a boiler at a brewery in Gisenyi. Since then, Rwanda's government has prioritized the production of electricity from this one-of-a-kind resource in order to deal with the country's growing electrical energy shortfall [26].

Methane -to-power projects that have been completed or are currently in progress

a) KivuWatt projects

A subsidiary of contour Global has been in commercial operation since December 31, 2015, with a nominal gross capacity of 26MW.

b) Kibuye power plant (KPT1)

The Rubavu district pilot project has been producing approximately 3 Megawatts of electrical power with a design capacity of 3.6Megawatts**,** Symbion power acquired the KP1 barge as well as onshore facility in 2016. Symbion has completed the liquidation process and is now raising funds to resurrect and scale up the plant to 25Megawatts.

2.5.5 Rwanda's Peat to Power

According to a Rwanda peat study, Rwanda’s peat bogs contain up to 155 million tonnes of dry peat spread across 5000 hectares. The Akanyaru, Nyabarongo rivers as well as the Rwabusoro plains are home to nearly 77 percent of peat reserves. The study estimates a potential for electricity generation from exploitable peat reserves of about 150MW for sod application and 177MW for milled peat application based on 30 years of operation.

Gishoma 15 MW Peat Power Plant

Since 2021 in Gishoma, the governments have been working on a 15MW peat power plant, Ruzizi District reduce the country's electricity shortfall and to coincide with a significant increase in electricity demand in the region as a result of the local cement factory and country development. In 2012, Shengli Energy Group

CO, Ltd/Shandong run power plant engineering technology CO Ltd was awarded a contract to construct a 15MW peat-fired power plant in Gishoma, Ruzizi district and Western Province. The plant was tested and successfully connected to the grid because it was the first of its kind in Rwanda and Africa in general. In 2017 project was completed as well as all testing and commissioning went smoothly [26].This thesis was based on the GIGAWATT Global in Rwamagana district, Eastern Province has a solar power plant. Its generation capacity is approximately 8.5MW and it is connected to the grid at the Musha substation.

2.6 Related works

Seyed-Ehson Razavi et al,[4] In their study on the "Impact of DG on protection and voltage regulation of distribution systems," they discovered that while using DG was important for secure power generation and reducing power losses, widespread use of such technologies introduces new challenges to power systems such as optimal location, protection device settings, voltage regulation, and power quality issues. Their goals were to provide a complete revision of various sort of Distributed Generation also to investigate new challenges that have emerged associated with the presence of Distributed Generation in power grids. DG were classified into the following groups during their research based on the reactive and active power delivered to distribution system.

Distributed Generation (DG) with active power injection only

Distributed Generation (DG) with reactive power injection only

Distributed Generation (DG)with active power injection and reactive power absorption

DG with active and reactive power injection

Based on voltage control in the presence of DG, they discovered that incorporating DG into existing power networks as a result in a variety of issues because conventional electrical grids were designed to supply load demand via the generation side. Such networks are expected to have unidirectional power flow. When DG is connected to the system, the power flow is bidirectional because the extra power produced by DG is fed back to the generation side. They discovered that bidirectional power flow had a significant influence on distribution system in relation to voltage control, system safeguarding and operation. They demonstrated that in order to have bidirectional power flow, the voltage control on the system would necessitate the use of modern techniques.

They demonstrated that high penetration of DG, such as PV units, can cause overvoltage in distribution systems, which should be effectively threatened. They stated that the proposed solution to mitigate the negative impact of DG had been thoroughly investigated. Overall, a thorough examination of the influence on the distribution system has been conducted, all in terms of protection and voltage regulation.

LjubomirKojovic et al[7] When DG is integrated into a typical distribution system, it has a technical impact on voltage regulation as it was demonstrated in their research on "Influence of DG on Voltage Regulation." In their research, they discovered that computer models for the integration of Distributed Generation (DG) with voltage adjuster and capacitors were created. Where control systems were simulated and put into action. During their research, they discovered that the effect of DG on voltage regulation is determined by its delivered power as well as its feeder loading. The influence on voltage was less when DG delivered only active power than when Distributed Generation delivered both active power(P) and reactive power(Q). They discovered that a DG can adjust reactive power generation and voltage by reducing (or absorbing, if needed) output of reactive power. If voltage is increased by rising reactive energy, lowering reactive power(Q) causes voltage on the line to fall. The reactive power setting can be used to regulate the DG output voltage. This adjustor, however may not be sufficient to control excessive voltages, in this instance, regulator of voltage may be used. They concluded that when a DG sized to closely match the local load is located near the load, it can provide a significantly reduce losses.

C.P. Lawrence et al [17] They studied changes in voltage profile and voltage regulation operation in their research on "studying the effects of DG on voltage regulation." In their research, they created a distribution system model with line drop compensation and integrated it into the PSCAD/EMTDCTM simulation environment. The simulation now includes Distributed Generation to investigate its effects on the traditional voltage regulation scheme. They have used PSCAD/EMTDCTM to model and operate DG based on reactive and active power. A 3phase controlled voltage source with two PI control loops was used in their DG implementation with fixed active power of DG and reactive power DG. In their study of DG effects, they discovered a number of changes in the voltage profile of the feeder that indicate what happens within the distribution system when the real power of DG is increased. They concluded by demonstrating the modeling and simulation of a typical radial distribution system with DG attached to one of the feeders. The simulation results showed that large DG power injection can disrupt voltage regulation in a distribution system, potentially resulting in voltage violations.

Carmen L.T. Barges et al[23] In their study titled "Impact of DG Allocation and sizing on Reliability, Losses and voltage profile, "they used the methodology for evaluating the impact of DG unit installation on electric losses, reliability and voltage profile evaluation of distribution networks. The losses and voltage profiles were calculated using a power flow method in which generators were represented as in PV buses. Indexes of dependability were evaluated using analytic methods that had been modified to handle multiple generation. The methodology can be used to evaluate the impact of installation location and DG capacity on these system performance characteristics for various generation expansion planning options. The results of the proposed methodology for systems extracted via the literature proved its applicability. They found that DG had influence on system reliability, losses and voltage profile. They carried out their research on two test systems, the results for the two system and various allocation alternatives are presented the demonstrating the method' connection.

2.7 Literature gaps

Like many places in world, Distributed Generation energy utilization is fastly growing in Rwanda. Therefore, people need to have enough knowledge in order to positively its use as well as development of future related projects while taking into consideration the related problems. Regarding to related literatures, Distributed Generation impacts have been discussed by different researchers. Such studies were done throughout the world, unfortunately many Rwandans have not yet effectively informed so that they can deal with those conditions.

This research work will contribute in terms of helping Rwandans to be aware of the effects of DG on their systems. Being informed on this will help them to avoid those consequences where applicable and apply the technical mitigation techniques for those that are unavoidable.

CHAPTER 3: RESEARCH METHODOLOGY

3.1Introduction

Following some basic information about DG that will aid in comprehension, this section will demonstrate the method used and the steps that were taken to achieve the desired results. This method is made up of a literature review, data analysis via site visits to the Rwanda National Electricity Control Centre (RNECC) and simulation software. These allowed me to assess the dg's influence on voltage regulation in the distribution (case study: Rubona feeder).

3.2 Data collection

In this thesis data used were collected on Musha substation. Musha substation there is a feeder which is called Rubona feeder where Gigawatts (Rwamagana solar power plant) was connected. To obtain data I visited National Electricity Control Centre and I talked with employers, give me data of that feeder. After getting data, I analyzed those data in order to see that if those parameters can have impact on voltage regulation in the distribution system.

3.2.1 Rubona Feeder Case Study

3.2.2 Characteristic of Rubona feeder

Rubona feeder is located at Rwamagana district, Eastern province at Musha substation. Musha substation receives 110KV and step dawn this voltage to 15KV.As it is shown in figure 3.1, There are 5 feeders on this busbar where one of them is Rubona solar PV. On this feeder there are no customers connected to it. At this substation there is on load tap changer transformer used in regulating of voltage to be maintained on the limit. So, data collected of this feeder are composed by Voltage, frequency, active power, power factor and reactive power are all factors to consider. Those data are for rain season and sun shine season in order to see if there is positive or negative impact of Gigawatts on this feeder of Rubona when it is ON or OFF.

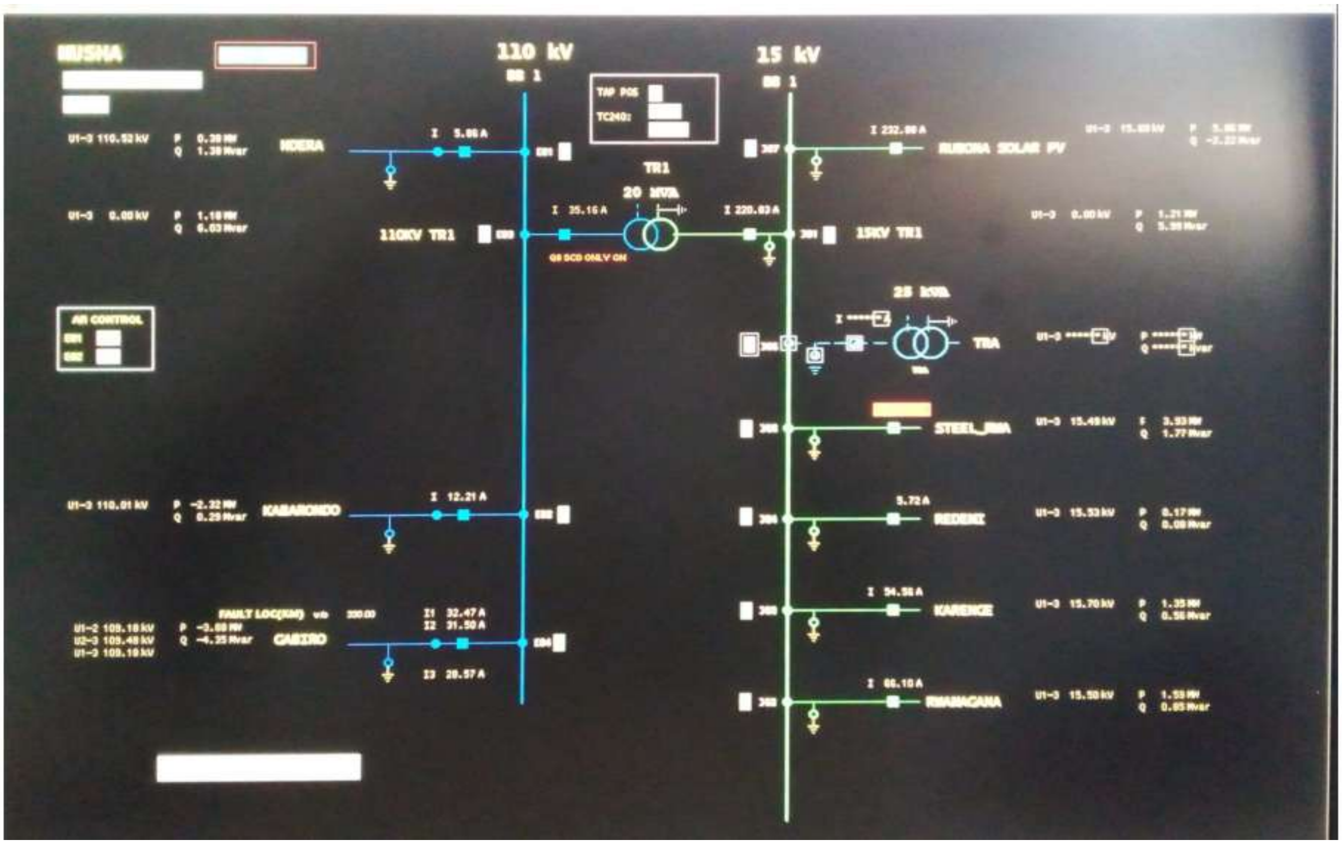

Figure 3. 1: overview of case study

Rubona feeder is where Gigawatt PV plant is connected. To generate electricity, solar PV modules are used. In Rwanda's Southern and Eastern provinces, daily solar irradiation ranges from 4 kWh/m2 north of the city of Ruhengeri to 5.4 kWh/m2 south of the capital, Kigali. Conditions, however vary via season to season with daily average irradiation levels in the cloud reaching on it. Rwanda benefits greatly from solar energy even while the rainy season there is daily and sufficient sunlight particularly in the Eastern province, which is known for its high levels of irradiance. The Gigawatt power plant is located on leased land, approximately 58 kilometers by road at the campus of Agahozo shalom youth village (ASYV), Rwamagana District in Eastern province of Rwanda. This solar power plant covered an area of 17 hectares used 28,360 photovoltaic panels, string 1418,20 panels in series, four stations each had transformer and produced 8.5 Megawatts of power is attached to the grid. The inverter input voltage was 700VDC with an output voltage of 415VAC between lines. The step-up transformer was connected between the national grid lines and the inverter, and steps up voltage from 0.415KV to 15KV. The Gigawatts project was the second large-scale solar project in East Africa, accounting for 6% of the country's total electrical supply.

Figure 3. 2: Location of Rwamagana Solar Power Plant[10]

As already indicated in the title, this case study is chosen with a purpose of testing and demonstrating the impact of PV as DG in this feeder. The PV system is connected to Musha substation at busbar of 15KV in order to support the energy demand in the system. So, the goal of this project is to determine what effect the PV might have on voltage control of the local distribution system (DS) when it is switched ON or OFF.

3.3.3 Arrangement of Data collection

The data was collected in rainy season and dry season so that it would be possible to see how the various season affect the performance of Rubona feeder when a particular DG is connected to it.

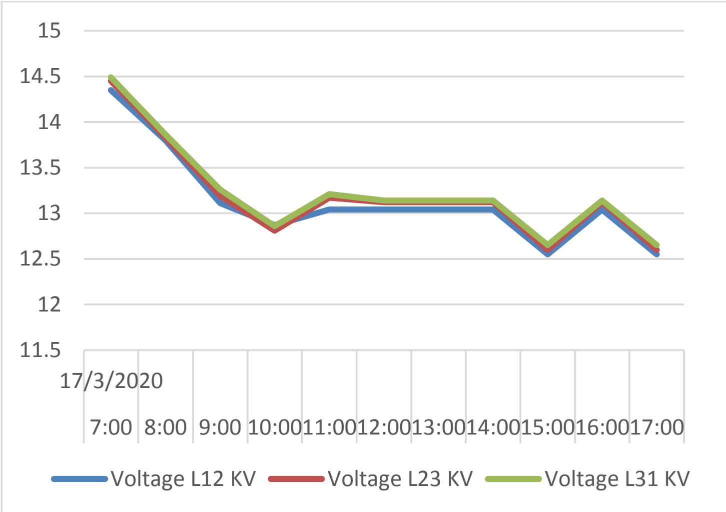

Figure 3. 3: Voltage variation without solar

Figure 3.3 depicted the voltage variation during the rainy season when solar was turned off, due to the intermittent nature of solar irradiation. When PV was disconnected from that feeder, the voltage dropped from 15KV to 12.5KV, as shown in the graph.

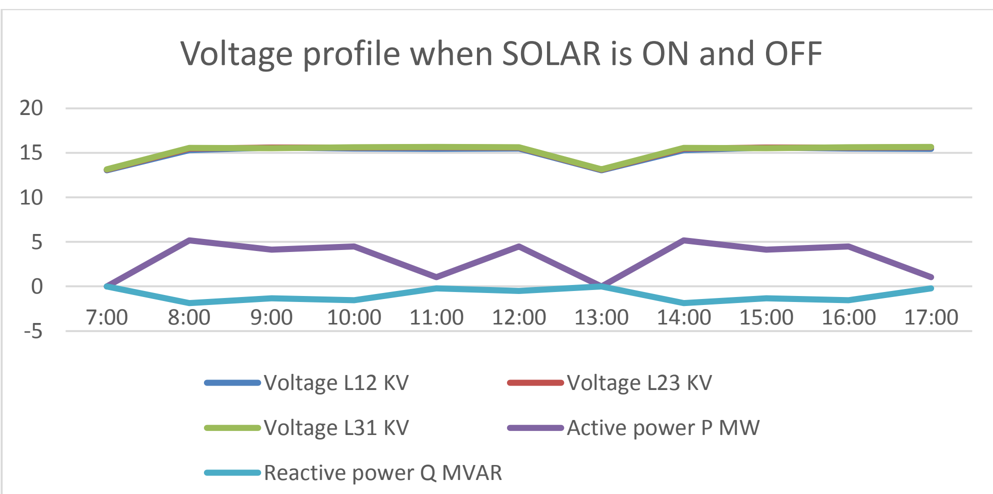

Figure 3. 4**:** Voltage variation when solar is ON and OFF

Figure 3.4 showed how voltage changes when solar is ON and OFF. On this feeder, when solar was off voltage reduce and when solar was on voltage increase. Those variation between ON and OFF cause voltage fluctuation on this feeder**.** This changes between voltage when solar was ON and OFF occur in the rain season, in this rain season there was intermittent solar irradiation, fluctuation power generated relatively quickly as a result of the passage of clouds above the panels as well as other projected shadows occurred in the rain season. Climate changes rapidly, it is rains every few times. With the variation of voltage caused by climate change, also active and reactive power varies depending of climate change.

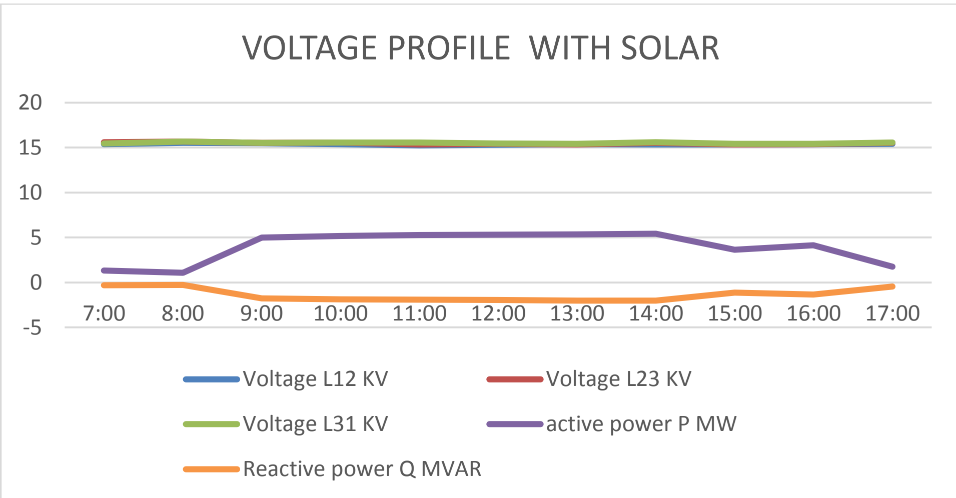

Figure 3. 5**:** Voltage profile in dry season

The figure above showed how voltage at Rubona feeder was stable during the summer. During the summer because there were no rains of every time, at Rubona feeder there was no variation of voltage.

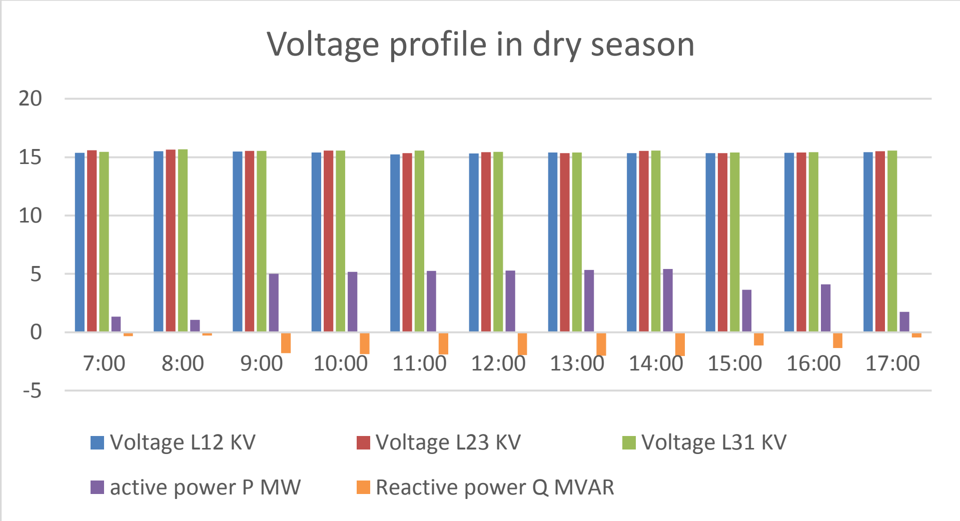

Figure 3. 6: Voltage profile in dry season

Figure 3.6 showed how voltage was constant in dry season. In dry season Rubona feeder was stable because in that season solar shine regularly without disturbance of climate**.**

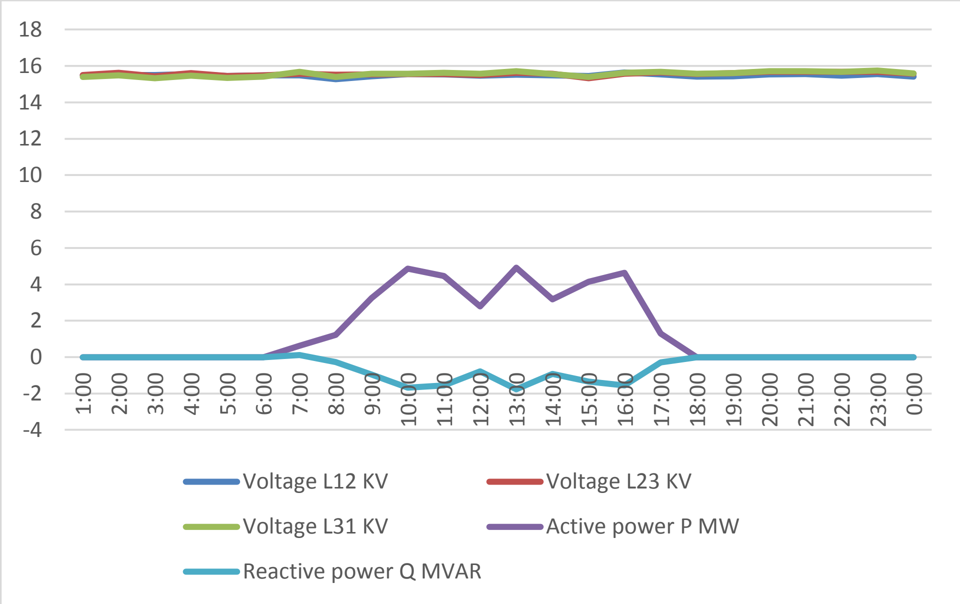

Figure 3. 7**:** Variation of active and reactive power with time

Active power varies with time. With this figure we see that at the starting active power is low, and increase with time and then starts to reduce at the evening even reactive power.

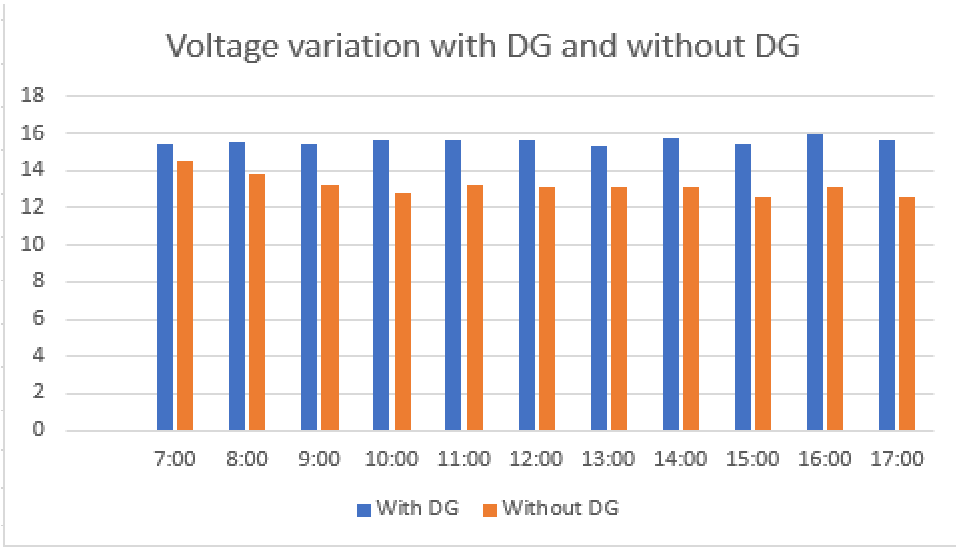

Figure 3. 8: Voltage variation without DG and with DG

Figure 3.8 showed how voltage look like with DG and without DG. With DG there was no variation of voltage it was like constant means no disturbance of voltage regulation in the system but without DG figure showed how voltage changed irregularly which cause voltage fluctuation in the system. This change of voltage occurred in the rain season led to confuse the voltage regulation on that feeder.

3.4 Power world simulator software

Power WorldTM is a cutting-edge a software package for simulating the operation about extremely massive power system in great detail. Power World takes the amount power that is extracted or injected at all network junction (or "bus") as input also calculates the voltage at all of these buses by solving the power flow equations. This can be done once for a snapshot of the system's conditions ,or it can be done repeatedly to track the system's evolution over time [27].

The Power World Icon

When you double-click the Power World icon, the software begins to run and the welcome screen appears.

Figure 3. 9: Welcome to the homepage of World power [27]

There is a ribbon interface at the top of this welcome page. It incorporates all menus. Our subsequent experiments will show how to use these menus in detail. It's important to note that there were two modes of operation: Run and Edit mode. New power flow cases can be created in the Edition mode, and existing cases can be altered. In Run mode, the power flow cases can be simulated and a variety of power flow tools can be used.

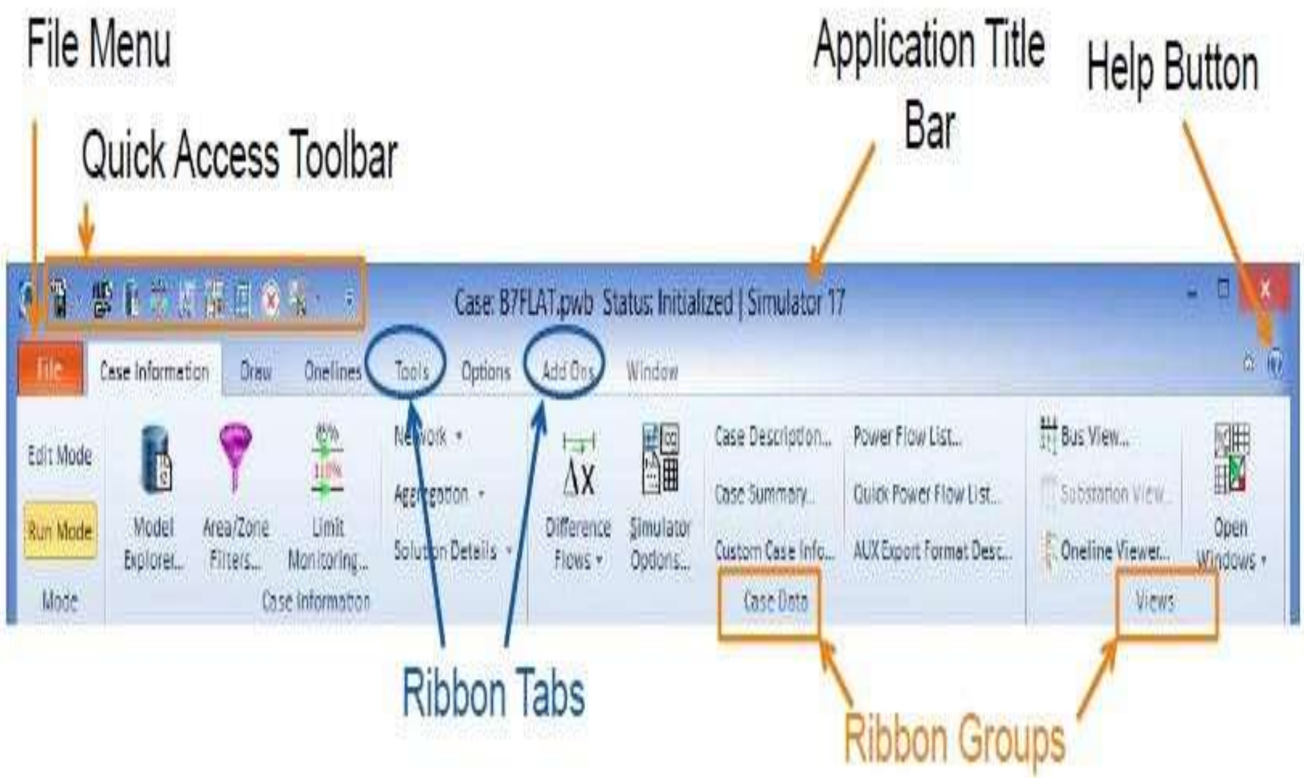

Figure 3. 10: The ribbon user interface [27].

The power world simulator was primarily used in this work for load flow analysis of PV grid connected in order to ascertain the influence of PV on voltage when it was ON and OFF.

3.5 Description of methods

The followed steps for the analysis of DG impacts in distribution system was shown below

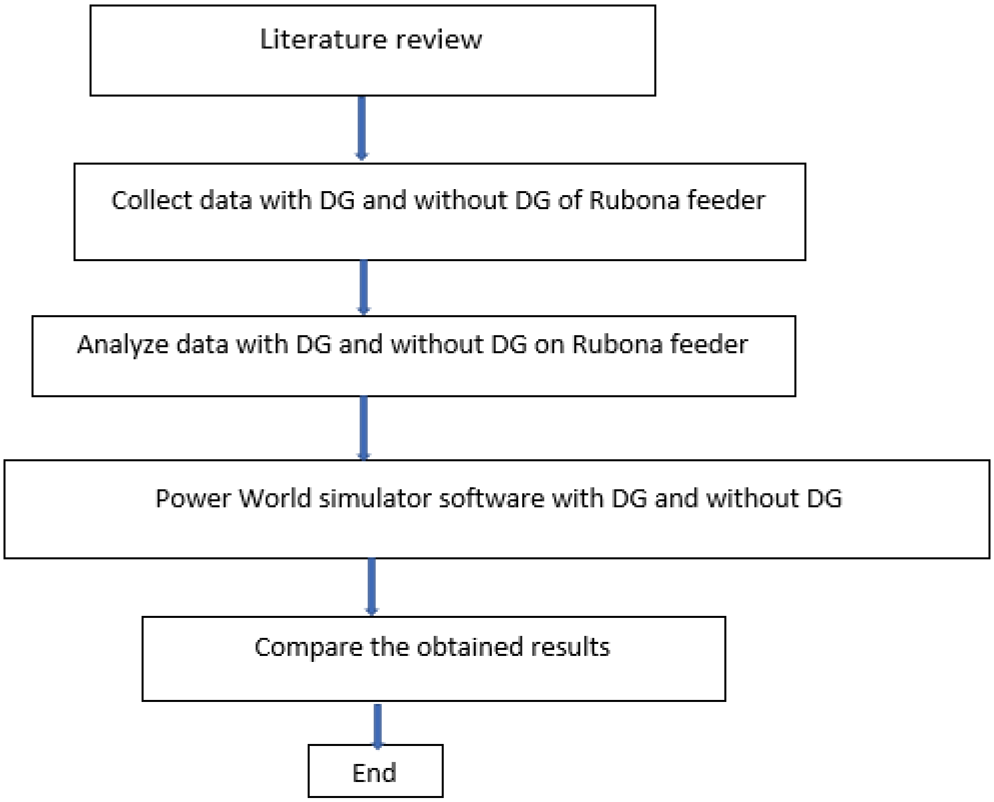

Figure 3. 11**: Research steps**

In this thesis, a studied system was simulated using the Power World simulator software under two conditions: one without DG and one with it. In this study, the general working principle of the Power World simulator was explained, and the various steps to flow were illustrated in detail.

CHAPTER 4. MODELING AND SIMULATION

4.1. An overview to Voltage regulation

Voltage regulation is an important feature of a power system in a distribution network. Every electric appliance is made to work with a specific limit; if voltage is too high or too low, the appliances will be damaged. As a result, it is critical to keep the voltage within the allowable range. In most cases, the voltage is measured in terms of nominal voltage per unit (pu). The utility is responsible for maintaining this voltage within 5% of its nominal value, i.e., between 1.05 and 0.95 pu. Electrical power is divided into two components: active and reactive power. Active power represents the rate at which energy is consumed, which is measured in Watts (KW or MW). However, in alternating current (AC) systems, some voltages are measured in (VAR, KVAR or MVAR). Reactive power has no effect on energy production or consumption and loads are distributed along the feeder.

A current flow as a result of the active and reactive power they draw from the feeder. This current's combination and the impedance of the feeder causes a voltage fall. Because impedance increases with length, voltage falls are greater for buses located further away via slack bus power which oscillates between sources and sinks; this power is known as reactive power(Q) and is active power (P). Furthermore, the voltage drop is greater for larger electrical power transmission. Small-scale PV system installations are rapidly increasing. Distribution network voltages are extremely sensitive to changes in the active power generated by distributed PV systems. As a result, PV-enabled distribution networks are likely to encounter a number of voltage quality issues:

• Overvoltage occurs when PV generation overtake local load and power flow is reversed.

• Fast voltage fluctuations are caused by abrupt changes in terms solar irradiance.

• Significant voltage differences between nodes occur as a result of uneven PV generation capacity distribution.

4.2 MODELING OF GIGAWATT

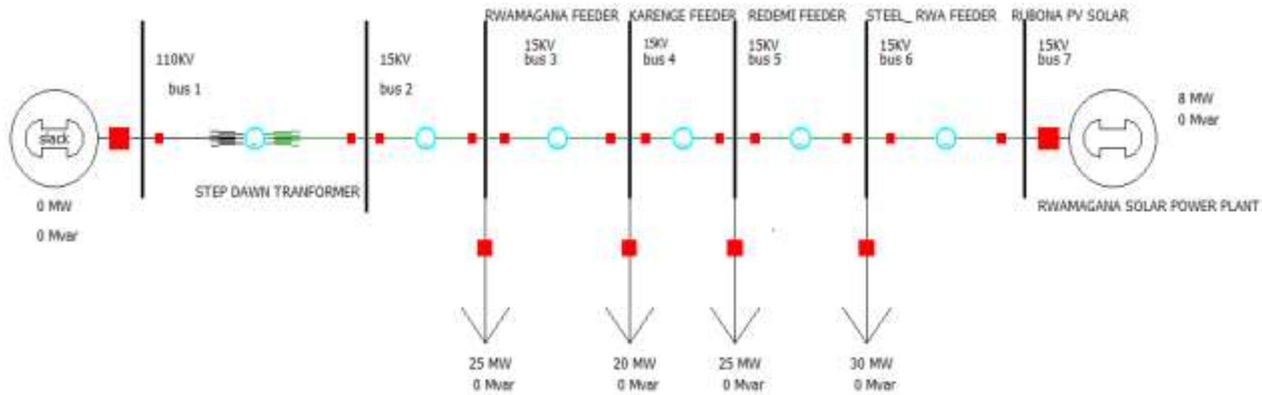

Figure 4. 1: Modeling of Rwamagana solar power plant connected at Rubona feeder

Figure 4.1 shows the steps followed in power world simulator to demonstrate where PV connected on Musha substation at Rubona feeder without load. Musha substation receives 110KV and stepdown it to 15KV as it is shown on the above circuit, on 15KV is where all five feeders are connected. Those feeders are (RUBONA PV SOLAR, STEEL_RWA FEEDER, REDEMI FEEDER, KARENGE FEEDER, and RWAMAGANA FEEDER). The loads are connected at all feeders except Rubona feeder.

4.3 STEPS TO CARRY OUT SIMULATION USING POWERWORLD SIMULATOR

The following steps are carried out to model the test system in the power world simulator**:**

- Draw the buses and enter the data
- Draw the transmission lines and enter the data as given in the case study
- Draw the generator and enter the data
- Draw the load and enter the data
- Now run the model and observe the voltage at all the buses in the system with DG
- Remove DG
- Run the model and observe the voltage at all the buses in the system without DG
- Stop the simulation

4.4 Experiments

In this work two experiments were performed in order to examine how PV connected on buses does impacts on the system voltage.

- Effect of PV generation on voltage profile at the different buses
  - When PV was ON at the bus
  - When PV was OFF at the bus

1stExperiment with PV

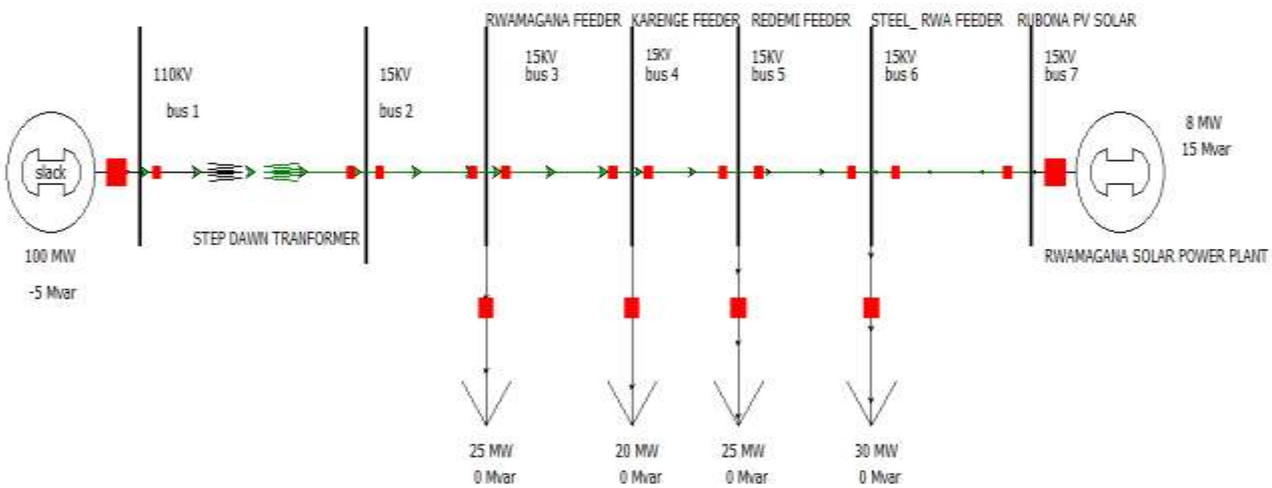

Figure 4. 2: Running model with DG

After connecting the model with DG, then run it in order to see the changes of voltage at all feeders. The flowing table shows the variation of voltage at all feeders when PV is connected on Rubona feeder.

Buses

	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar
1	bus 1	1	110.00	1.05000	115.500	0.00			99.69	-4.62
2	bus 2	1	15.00	1.03350	15.503	-2.15				
3	bus 3	1	15.00	1.02581	15.387	-3.26	25.00	0.00		
4	bus 4	1	15.00	1.00340	15.051	-5.48	20.00	0.00		
5	bus 5	1	15.00	0.98318	14.748	-7.95	25.00	0.00		
6	bus 6	1	15.00	0.97789	14.668	-9.89	30.00	0.00		
7	bus 7	1	15.00	1.00001	15.000	-10.27			7.50	15.39

Figure 4. 3: Voltage variation with DG

Table 4. 1**:** Voltage variation with DG

Buses	Pu volt
1	1.05
2	1.03
3	1.02
4	1.003
5	0.98
6	0.977
7	1

2nd Experiment without DG

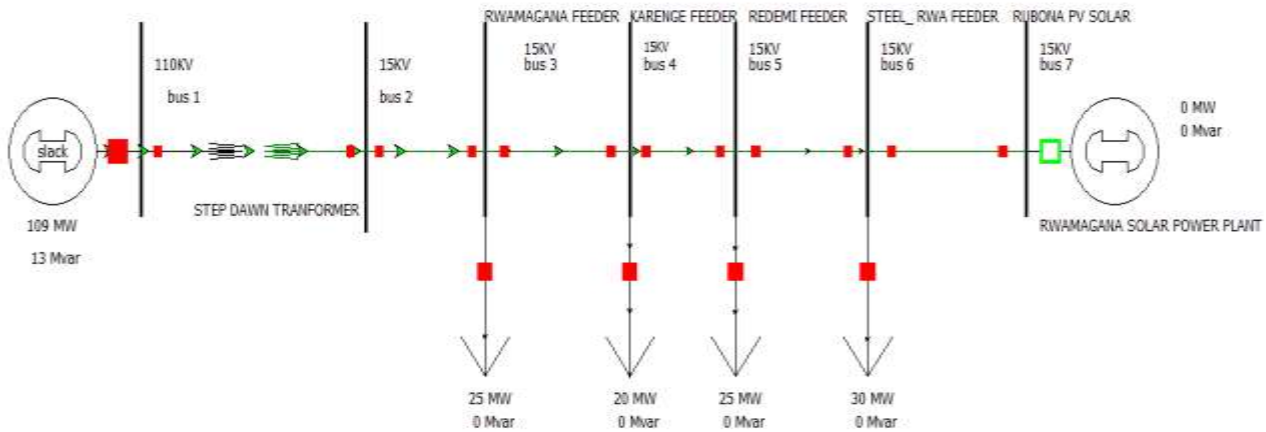

Figure 4. 4: Running mode without DG

This figure demonstrated what happen on voltage when PV is disconnected directly because of climate change. Referring on the data obtained in the table below, when PV is disconnected cause the voltage fluctuation on the grid because there is rapidly decrease of voltage at this feeder which cause the voltage fluctuation on the grid.

Buses

	Name	Area Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar
1	bus 1	1	110.00	1.05000	115.500	0.00			108.78	13.15
2	bus 2	1	15.00	1.02501	15.375	-2.18				
3	bus 3	1	15.00	1.01309	15.196	-3.31	25.00	0.00		
4	bus 4	1	15.00	0.97874	14.681	-5.48	20.00	0.00		
5	bus 5	1	15.00	0.94157	14.124	-7.87	25.00	0.00		
6	bus 6	1	15.00	0.91488	13.723	-9.67	30.00	0.00		
7	bus 7	1	15.00	0.91488	13.723	-9.67			0.00	0.00

Figure 4. 5: Voltage variation without DG

Table 4. 2:Voltage variation without DG

Buses	Pu volt
1	1.05
2	1.02
3	1.01
4	0.97
5	0.94
6	0.91
7	0.91

With the disconnected of PV on Rubona feeder ,the above table demonstrated how voltage decrease rapidly,means that there is a voltage fluctuation on the grid which disturb the voltage regulation in the distribution system.So,in this time voltage regulation take the time to set it on operating range.

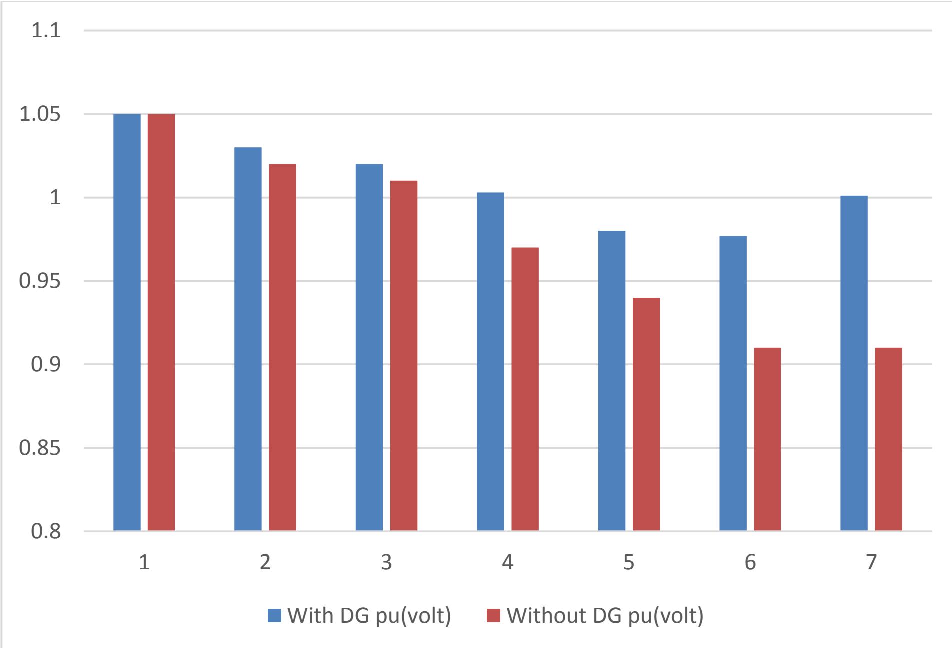

Figure 4. 6: Voltage distribution either with or without DG

Figure 4.6 showed the results of voltage variations between with and without DG on the buses, The figure demonstrated that when Distributed Generation PV connected on the feeder voltage was improved but without Distributed Generation voltage decrease irregularly because of the rain or clouds.

CHAPTER 5: RESULTS AND DISCUSSION

5.1 Introduction

Within these parts, study results are shown as well as discussed in accordance to the study's aim that was to investigate the DG's influence on voltage regulation in distribution systems. Based on specific objectives, simulation and confirmation of both with and without DG have been done and then their comparison based on voltage variation at all buses.

5.2 Voltage variation when DG was connected on Rubona feeder

With power world simulator, when PV was connected on Rubona feeder and run the voltage at all buses varied according load but remained in the range of 1.05 to 0.95pu as the utility was responsible for maintaining the 5% of nominal voltage. By referring on the results obtained when PV was connected on this feeder, grid was stable, voltage is improved as it is shown in the figure below:

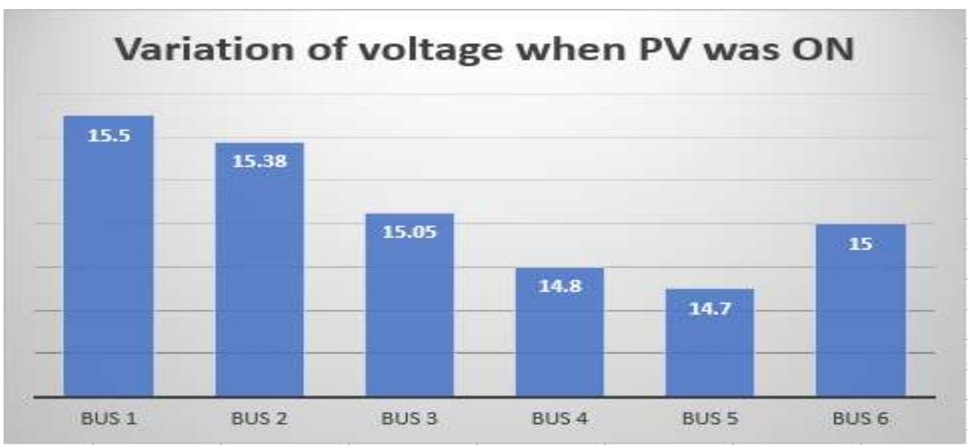

Figure 5. 1: Variation in voltage when PV was turned on

Figure 5.1 showed the variation of voltage when PV was ON, as it is demonstrated by the figure the ON of PV maintained the grid stable and voltage is improved. This occurred in dry season where there was no climate change at every few times, no rapid clouds projected on panels.

5.3 variation of voltage when PV was disconnected

As the utility was responsible to maintain the voltage in range i.e., 1.05 to 0.95, when PV was disconnected on Rubona feeder there was a rapid decreasing of voltage at all buses as it is shown by the figure 5.2, here the voltage was decrease until 0.91 (13.7KV) which was under of the range. This causes the disturbance of the grid, voltage fluctuation, disturb the voltage regulation.

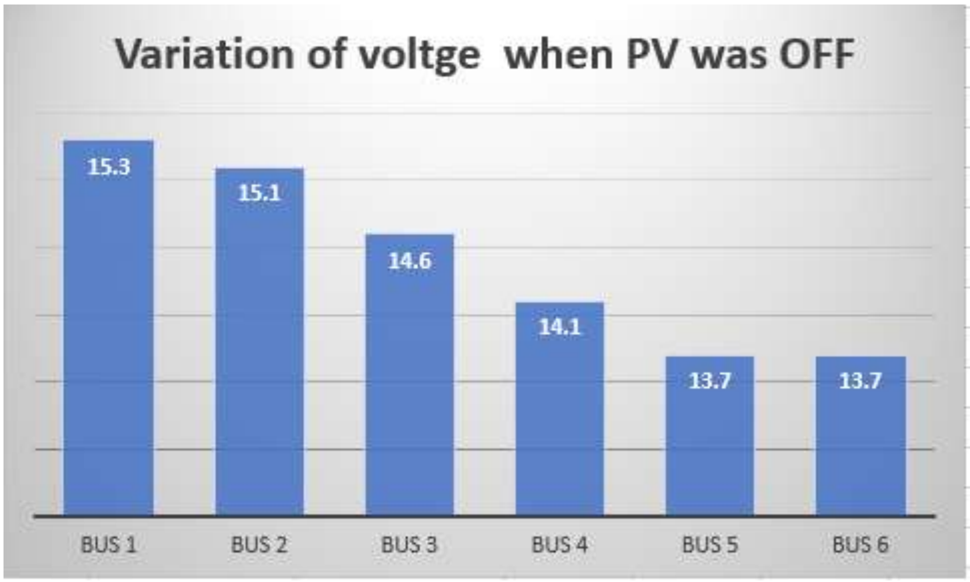

Figure 5. 2: Variation of the voltage when DG was OFF

Figure 5.2 showed how disconnected of PV cause the negative impact on the grid, here disturb the voltage regulation because voltage regulation took the time to put the voltage at allowable.

Refers to the results of Excell sheet as well as software for simulating the power world, the results showed which ON and OFF PV as the form of DG technology connected to the grid cause positive impact in the dry season and negative impact in the rain season here in Rwanda, where in dry season PV make stable of grid but in the rain season PV cause voltage fluctuation on the grid because of intermittent of solar irradiation, rapid clouds projected on panels, the rain of every few minutes etc.

Table 5. 1**:** Comparison between with and without PV on Rubona feeder

Name	**With PV (Volt in KV)**	**Without PV (Volt in KV)**
Bus 1	15.5	15.3
Bus 2	15.38	15.1
Bus 3	15.05	14.6
Bus 4	14.8	14.1
Bus 5	14.7	13.7
Bus 6	15	13.7

Table demonstrated the difference between with and without PV, with PV voltage was normal at all buses. With PV the grid was stable means that no influence of DG in the distribution system's voltage regulation. But without PV there was rapid reducing of voltage as it is shown by the table 5.1, voltage decreased from 15.3 up to 13.7 means that 13.7 was under the normal voltage which cause the disturbance on the grid. This occurred in the rain season because of intermittent irradiation via the sun as well as fluctuation in energy generated relatively the passage of clouds above the panels and other projected shadows caused the panels to move quickly. Without PV cause voltage fluctuation in the network also cause the disturbance for protection equipment like voltage regulator on the substation.

CHAPTER 6: CONCLUSION AND RECOMMANDATION

6.1. CONCLUSION

Distributed generation (PV) at Rubona feeder in dry season support the grid because there is no voltage fluctuation occurs but in the rain season it is big problem because of climate changes every time. In rain season on this feeder there is a voltage fluctuation caused by ON and OFF of Gigawatts connected on this feeder. ON and OFF of every few times occurred in the rain season cause the disturbance of voltage regulation on Musha substation, also cause the instability in the grid.

6.2. RECOMMANDATION

Because of Solar is not constant at all time, and also because of intermittent of solar irradiation, rapidly clouds projected on panels, rain season, I recommended to all personally or private sector who want to use DG connected to the grid to use batteries to storage the surplus energy in order to use it in the rain season, and to avoid voltage fluctuation occurs every few times in rain season

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