UNIVERSITY OF BUEA **REPUBLIC OF CAMEROON**

FACULTY OF ENGINEERING AND TECHNOLOGY

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING

POWER SYSTEM ENGINEERING

PERFORMED AT: EDEA HYDROELECTRIC POWER PLANT

REPORT OF INTERNSHIP FROM:

10th August 2018 to 10th December 2018

PRESENTED BY

PATIENCE MONJOA LYONGA-MOKENGE

Internship Report Submitted to the Department of Electrical and Electronic Engineering,Faculty of Engineering and Technology, University of Buea, in Partial Fulfillment of the Requirements for the Award of the Bachelor of Engineering (B.Eng.) Degree in Electrical and Electronic Engineering.

PROFESSIONAL SUPERVISOR
MR.Azanfack Mikael Jean-Valdez

ACADEMIC SUPERVISOR
DR.Fendji Marie-Danielle

February 2019

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STUDY AND AMELIORATION OF SPEED GOVERNOR SYSTEM OF GENERATOR 12[EDEA 3]

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DECLARATION

This internship report titled ‘Study and Amelioration of Speed Governor’s System of Generator 12 of the EDEA 3 Unit’ was written by Patience Monjoa Lyonga Mokenge and has not received any previous academic credit at the University of Buea or any other institution.

DEDICATION

This piece of work is dedicated to my role model, a hardworking man, he who pushes me to fully discover my potential, a man dedicated to offering the best for his kind, my dad, MR OTTO LYONGA MOKENGE.

ACKNOWLEDGEMENTS

I profoundly wish to acknowledge God Almighty for the strength and wisdom He in His mercy granted me during this internship.

- I wish to appreciate the Faculty of Engineering and Technology of the University of Buea under the capable management of the Dean PROF TANYI EMMANUEL for grooming quality engineers.
- I heartily appreciate the management of ENEO EDEA for granting me an opportunity to affect an academic internship.
- I heartily appreciate my professional supervisors who were always willing to explain and clear my academic doubts. In this light I wish to appreciate:
    - MR AZANFACK Mikael my professional supervisor.
    - MR TUEKAM Gabriel Head of Electrical Department.
    - MR TCHAKOUNTE Celestin
    - MR DJOGUE Aurelin
    - MR DAMBA Pascal
    - Mr. KEGNOU Clement

- I wish to appreciate my academic supervisor, DR FENDJI Marie Danielle for her guidance throughout the drafting of this report.

Finally I wish to appreciate all who contributed financially and socially to make my stay in EDEA a pleasant one.

ABSTRACT

Electrical engineering is an important factor in the development of every country. ENEO Cameroon is the sole provider of electrical energy in Cameroon. It is comprised of various generating plants interconnected all over the country. Hydroelectric power is one of the methods used by the company for electrical energy production. The EDEA hydropower plant has a production capacity of 256MW. The plant uses synchronous machines to produce power which supplies ALUCAM and the Southern Interconnected Network. The production of electrical energy in the EDEA hydropower plant is a complex process which involves other smaller systems for the proper functioning and maintenance of the synchronous machines. One of such systems is the Speed Regulation System which maintains the speed of the generators as stated by the manufacturers in order to maximize efficiency.

We will study and ameliorate the speed governing system of generator 12 of the EDEA 3 unit. This is done by, considering the effects of PID parameters on industrial control.

Through this report, the operators of the plant will have a different view of how the speed regulator functions and can therefore consider the proposed solutions and consider adapting it in the future.

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LIST OF ABBREVIATIONS.

Abbreviation	**Meaning**
C_n	Speed set point
C_p	Power set point
T_w	Water starting time
E_s or b_s	Permanent droop
T_R	Reset time
$C_y l$	Limiter opening

CHAPTER ONE

1.0: BACKGROUND OF HOSTING COMPANY.

1.1 Introduction.

ENEO (ENERGY OF CAMEROON) is solely responsible for energy distribution nationwide. With a consumer base of millions of Cameroonians, they make it a priority to deliver quality and affordable energy. They are concerned with the production, transportation and safe distribution of electrical energy to final destinations. However, for this 4 month academic internship, the production department in particular the EDEA hydro power plant will be the case study.

The EDEA hydro power plant is situated in the Sanaga Maritime division of the Littoral region of Cameroon. It has a production capacity of 273MW. The dam is built on the River Sanaga, which has an estimated fall of 26m during the season of excess and 22m in the shortage season. It has as its closest neighbor the aluminum processing factory, ALUCAM which is the largest client of the plant consuming 190MW of output.

The power plant consists of 14 synchronous generators which are divided into 3 groups referred to as EDEA 1, EDEA2 and EDEA 3.

The following table shows the stages of construction of the power plant.

Table 1: Construction of the plant.

UNIT	NUMBER OF GENERATORS	DURATION OF CONSTRUCTION
EDEA 1	Gen1 to Gen 3	1949-1953 but renovated in 2012
EDEA 2	Gen 4 to Gen 9	1955-1958
EDEA 3	Gen10 to Gen 14	1971-1975

The following table outlines the terminal characteristics of the Synchronous Generators of EDEA 1

Table 2: Terminal characteristics of EDEA1

Terminal characteristic	**Rated Value**
Voltage	10.3kv
Speed	187.5rpm
Current	1054A
Power	16MW
Frequency	50hz
Reactive power	18.9MVAR

The following table outlines the terminal characteristics of the synchronous generators of EDEA2.

Table 3: Terminal characteristics of EDEA2.

Terminal characteristic	**Rated value**
Voltage	10.3KV
Speed	167rev/min
Current	896A
Power	20MW
Frequency	50Hz
Reactive power	24.5MVAR

The following table outlines the terminal characteristics of the synchronous generators of EDEA 3.

Table 4: Terminal characteristics of EDEA 3.

Terminal characteristic	**Rated value**
Reactive power	24.5MVAR
Voltage	10.3KV
Speed	167rev/min
Current	896A
Power	21MW
Frequency	50Hz

1.2: VISION

The vision of ENEO is to provide quality energy without jeopardizing the safety and security of its work force. The workers are faced with a range of hazards such as:

- Exposure to chemicals such as petrol used to clean the actuator filters.
- Danger of high voltage
- Danger of electric shock
- Rodents such as snakes and mosquitoes
- Considering the fact that the plant is surrounded by water, the risk of slipping cannot be ignored.
- Sound pollution as workers are exposed to sounds higher than the audible sound range of 60db. The turbine gallery has a sound pollution rate of 180db which is not healthy for human.

  In an attempt to resolve the afore mentioned hazards, the following security measures must be implemented:
- Compulsory safety and security meetings every Tuesday mornings organized by the administrative staff of the DUE. This meeting is aimed at reminding the work body of the safety rules and regulations, alongside revise hazardous incidents which might be a threat to security.
- Personal protective equipment MUST be worn on enterprise premises. These include:

- Close well insulated safety shoes.
- Protective helmets.
- Long sleeved protective overalls.
- Rubber gloves when working with fluids, hard gloves when dealing with machine parts and highly insulated gloves when dealing with energized lines.
- Ear plugs for areas of high sound pollution.
- Nose masks when working with chemical and toxic substances.
- Protective lenses for the eyes.

- Before any task is effectuated, the chief of the group must explain the task to be performed and the risks involved.
- Every task must be performed in groups of at least 3 persons, with a mode of communication in case of danger at the work site.
- All workers are advised to hold the ramp when ascending or descending stair cases to avoid slipping.
- Before any task is performed, all group members must write their names in the fitness register after having read through its work instructions. The team must proceed to the worksite with a first aid box.
- In case of an unforeseen incident, the enterprise is equipped with a clinic which takes care of health needs of the workers.
- The ringing of three consecutive alarms alerts the possibility of great danger. To this effect, everyone must abandon whatsoever activity and head towards the muster point.
- For workers who have as task working on high tension lines, above 1000V, the line must be de energized and checked before work continues.

1.3: MISSION

Its mission is to safely and promptly produce, transport and distribute and commercialize quality energy over the national territory via the Southern Interconnected Network.

The EDEA hydro power plant produces a total of 256MW of energy.

ALUCAM alone consumes all units of EDEA 2. In the case of a breakdown in EDEA 2, generator 10 of EDEA 3 serves as a backup.

The energy of EDEA 1 and EDEA 3 are supplied to the public via the national grid system to Kribi, Mangombe, Yaoundé, Douala and Limbe as shown in the figure below:

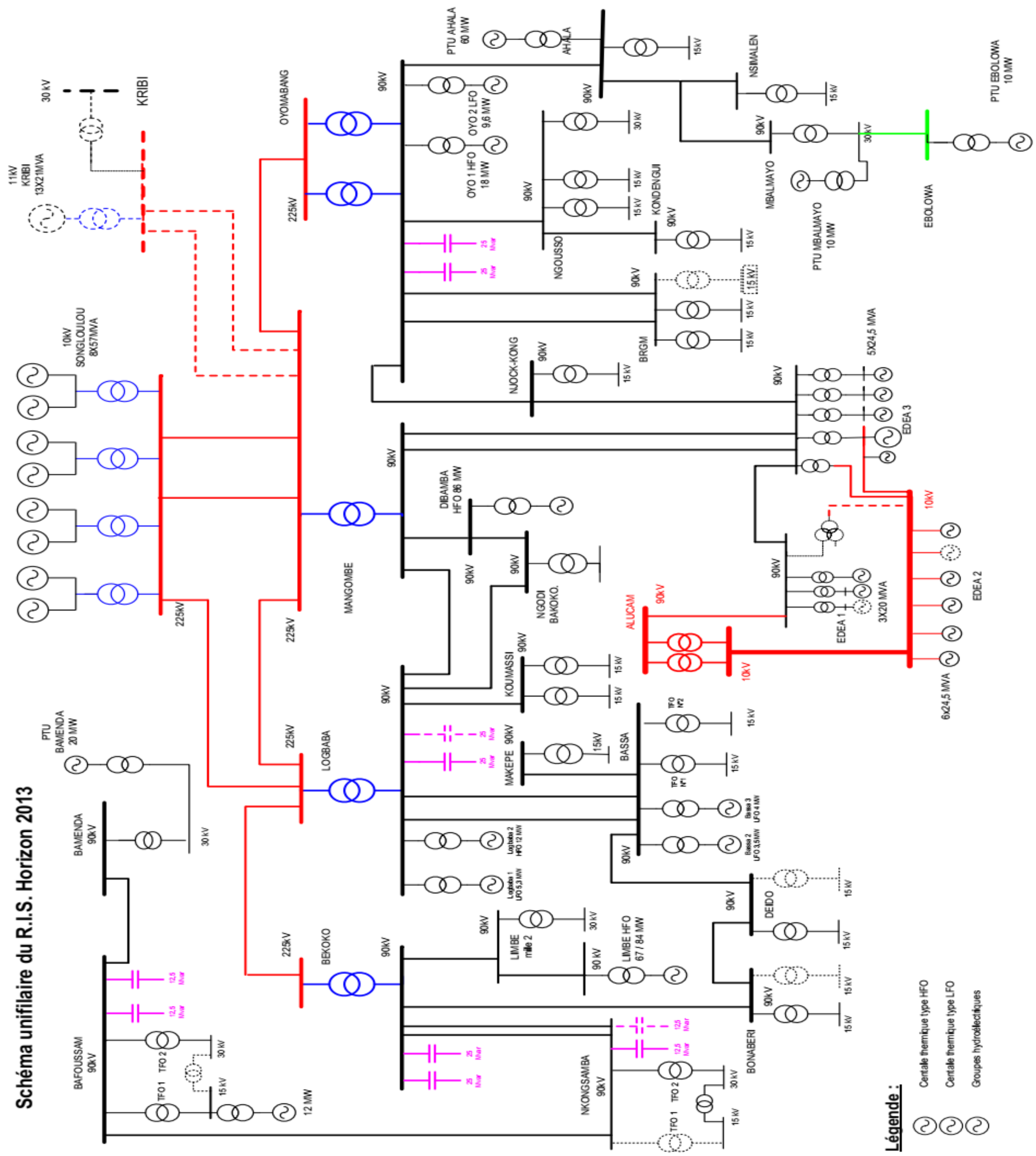


Figure 1: Southern Interconnected Network

1.4: CORE VALUES

The company believes that in order to keep up to standard; some core company values must be respected. These values include:

- Respect: Every employee must exhibit mutual respect for each other's job description and refute from making comments which might demoralize the work spirit of any agent.
- Engagement: Every employee must put in his/her best in every task assigned to make sure it is executed properly within the shortest possible time.
- Cohesion: Team spirit must be adopted towards every assigned task.
- Integrity: Employees are encouraged to be honest and not be an eye servant. They are encouraged to refrain from malicious practices such as theft, intentional littering of the compound, etc.

1.5: ORGANIZATION AND MANAGEMENT.

The plant is under the general supervision of the plant manager**, MR HAMADOU NDOTTI**. Under the afore mentioned personality, the following departments can thus be identified.

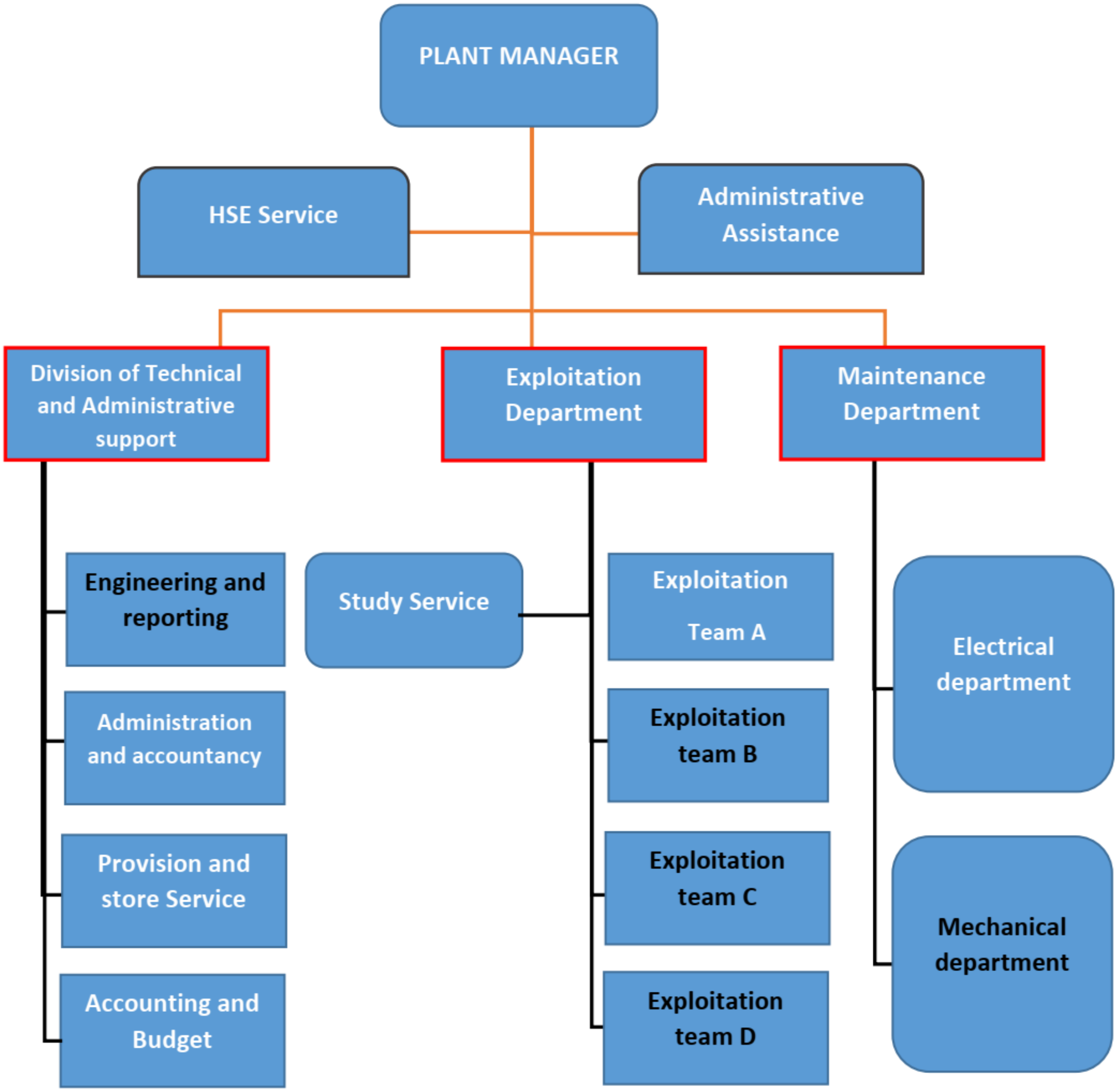


Figure 2: Organization of the plant

1.5.1: Division of technical and administrative support.

They perform the following functions:

- Proper implementation of the working values of the enterprise which are: respect, cohesion, respect and engagement.
- Ensure lodging facilities for workers.
- Implementation of strict policies in the domain of security, health and protection of the environment.

- Ensure the availability of quality electrical energy to public consumers, likewise industries.
- Acquisition of material for electrical installations.
- Payment of salaries, bonds and other financial transactions
- Provides transport services by providing readily fuelled buses or cars alongside stand by drivers.

1.5.2: EXPLOITATON DEPARTMENT

Headed by the director in charge of exploitation, MR Wefonge James. They perform the following activities:

- Supervise the overall functioning of the generators, including distribution and control parameters.
- Ensure that all contract terms between ALLUCAM and ENEO are respected.
- Ensures that the water the energy leaving through the bus bars is either 10KV (EDEA 2) OR 90KV (EDEA 1&3).
- Hourly checks of control values both in the control room and at production sites to ensure that there are no unnecessary fluctuations which may be harmful to the plant. E.g. over speeding and 'flooding" of a generator.
- Log out of work sites from the grid.

1.5.3 ELECTRICALMAINTAINANCE

Headed by MR TCHUENKAM GABRIEL. They perform the following functions:

- Responsible for electrical installation and proper maintenance at the premises of the enterprise, likewise lodging facilities.
- Responsible for electrical maneuvers of the generators such as excitation malfunctions, commutation malfunctions, re starting of a generator, synchronism of the generator before coupling to the grid etc.
- Ensure that the conditions imposed by the grid are properly implemented.
- Proposes new ideas on changes to be made in order to ensure quality output.

- Weekly inspection of electrical parameters such as current charges, output voltages, etc.
- Repairs of broken down electrical parts such as pumps, circuit breakers.

1.5.4: MECHANICAL MAINTAINANCE

Headed by MR NGUEDA EMILE. They perform the following activities:

- The mechanical services ensure that all electrical instructions relayed to mechanical organs are executed.
- They deal with the production of mechanical worn out parts of the machines.
- Regular checks of mechanical control parameters such as oil level in the machine which is very essential.

1.6: REFERENCE PROJECTS AND SERVICES FURNISHED BY THE COMPANY.

- Education services are provided by the company as they have a nursery school available to the public at affordable price.
- The company organizes sensitization to the public on the dangers of misusing and mishandling electric lines. This sensitization is carried out in areas such as markets, schools, hospitals and neighborhoods.
- The company treats portable water and supplies to its area residents.
- Sporting activities and health talks are also some services provided by the company.
- Projects such as the rehabilitation of generators 8 and 9 to increase efficiency.
- The integration of asset management software, MAXIMO to facilitate internal procedures and onsite intervention.

1.7: INTERNATIONAL EXPERIENCE.

ENEO partners with international companies like:

- ANDRITZ HYDRO in charge of furnishing the generators.
- GENERAL ELECTRICS, in charge of general inspection of electronic gadgets, measuring equipment and transmission material.
- SCHNEIDER Programmable Logic Controllers and other electronics are also the benefits ENEO enjoys from international partnerships with foreign companies.

CHAPTER TWO

2.0: OVERALL INTERNSHIP EXPERIENCE.

2.1: Joining of the company.

Admission into the company for an academic internship is by applying online through the ENEO portal. The request is processed over a period of 3 months and an admission letter is sent to an official email as the applicant stated in the application letter. The intern is expected to report for internship duties as stated in the admission letter.

Upon arrival at the company site, the first official visit is to the safety and security office where the intern is thoroughly drilled on the importance of respecting security rules put in place. The intern's work attire is then inspected to ensure it meets security standards. After the training, an attestation of security is awarded to the intern before she is introduced to the department where her services will be required.

2.2: ACTIVITIES AND JOB DESCRIPTIONS CARRIED OUT.

As part of the electrical department where I worked with the electrical team, a variety of activities were executed at the plant which helped to improve technical know-how. Such activities were:

- Formation HSE: Security meetings every Tuesday to re itinerate security rules and company values while at the plant.
- Monthly general cleaning of the plant commonly called housekeeping, every last Thursday of the month.
- Cleaning of MIPREG filters every Monday.
- Mounting of generator number 8 unit from wicket gates to excitation system.
- Replacing of damaged circuit breaker and isolators on depart 4.
- General electrical works such as AC maintenance, bulb replacements, circuit breakers etc.
- Work site visits with professional supervisors to reinforce understanding of how the plant functions.
- Departmental meetings to rate performance for the week and plan for the upcoming week. The meetings also serve as a platform to evaluate the intern's development rate.

2.3: Work piece Executed.

The main objective is to maintain the output speed of generator 12 at 50Hz despite external disturbances such as variable head of water and grid imposed conditions.

SPECIFIC OBJECTIVES

- Study and understand the existing speed governor system.
- Design and model the existing system.
- Implement the existing system with MATLAB.
- State the failures of the present governor system.
- Ameliorate the system.
- Since the system is electromechanical, propose some mechanical solutions.

2.3.1: GENERAL OVERVIEW OF SYNCHRONOUS GENERATORS

Synchronous machines are mostly used as generators of electrical energy since its rotating air gap field and its rotor rotate at the same speed known as synchronous speed. The rotor carries the field winding, while the stator carries the armature winding. The field winding is excited by DC thereby producing flux in the air gap according to the equation below[4]

$$NI = \varphi R \dots\dots\dots\dots\dots\dots\dots.(1)$$

The figure below is a synchronous machine used as a generator at the plant. It illustrates the parts of the generator.

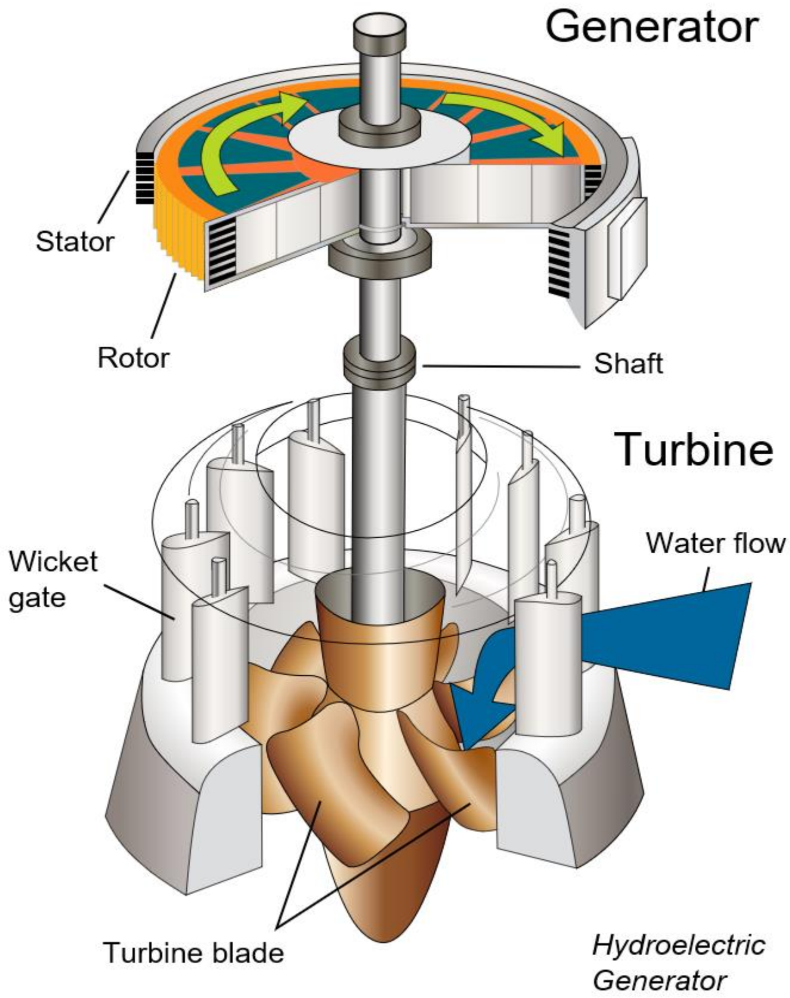


Figure 3: Synchronous Generator

2.4: LITERATURE REVIEW.

Energy conversion is an important process in the production plant. The kinetic energy of the water is transferred via the penstock, where it enters the turbine. It is then converted to mechanical energy through the rotation of the turbine. The turbine is connected to the alternator via a shaft. The rotating action of the shaft rotates the rotor. This process produces electrical energy. Hence the conversion process is from kinetic to mechanical energy then electrical energy.

Water is the prime mover at the plant. Hence the quantity of water flowing into the turbine at each instant must be regulated if the desired power output is to be achieved, at rated speed and grid frequency, throughout is coupling to the grid despite varying load conditions. The aim of this project is to study, model, point out the defects and finally ameliorate the speed governor system of generator 12 of the EDEA 3 plant so long as the alternator is coupled to the grid.

2.4.1: METHODOLOGY

The following flow chart explains the procedure used to perform the assigned work task of studying the speed governor system.

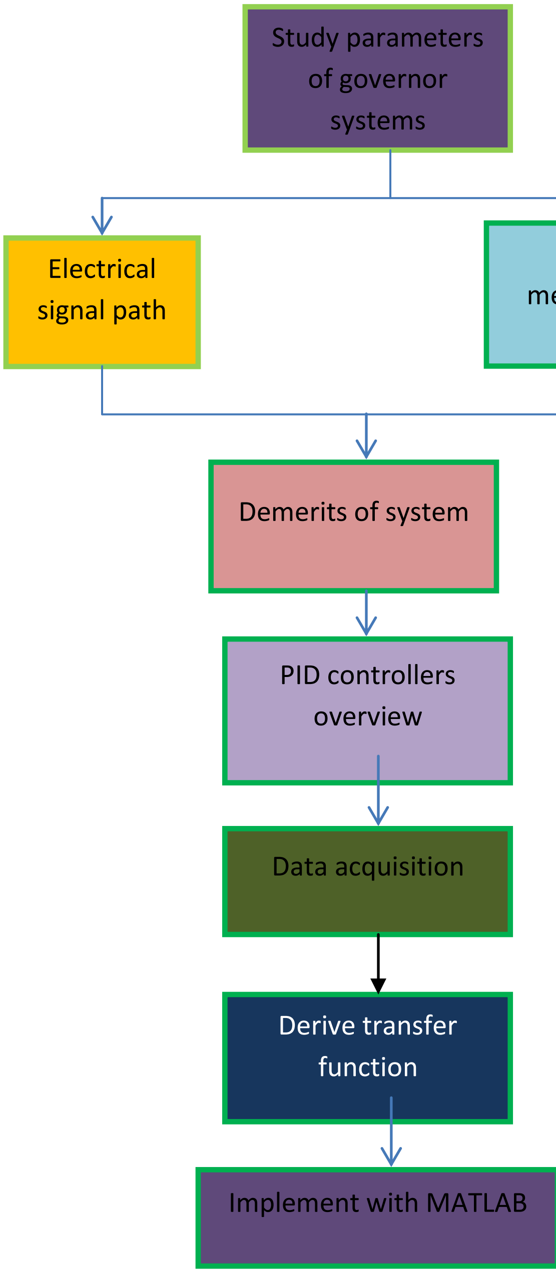


Figure 4: Flowchart explaining methodology adopted.

2.4.2: PARAMETERS OF THE SPEED GOVERNOR SYSTEM.

The speed governor system divided into 2 sections: the electrical, and the Hydro mechanical part.

A. The figure below is the electrical part of the speed governor otherwise known as the MIPREG 500.

Figure 5: The MIPREG 500

The MIPREG 500 is the calculator of the system. It is made up of many modules, which are connected by a bus system. By a sequence that is rapidly repeated, the microprocessor inquires from each module the various parameters of the machine such as the speed, position of the circle of winnowing, output power etc., in order to execute necessary calculations in function of input parameters in the memory module to obtain values which will be transmitted to output elements such as amplification of servo valves,. A keyboard display terminal serves as a human machine interface to enable communication with the calculator. It is composed of the following modules [1]:

- Microprocessor module: It links the alternator to the calculation unit
- Programmed module: It contains a set of instructions which define the working principle of regulation.
- Input output module: As an input, this module permits transmission of commands to the microprocessor. As an output, this modules transmits digital information to
- Programmable counter module: This module is responsible for speed data acquisition. It performs a digital measurement of the period of the signals coming from the speed sensors. This period is converted to frequency by the microprocessor.
- Analogue to digital module: This module converts analogue signals such as position of the Circle of winnowing to digital so that the microprocessor can process the information.
- Digital to analogue module:

  This module enables the calculated values of the microprocessor to be implemented on mechanical parts such as the servo valves.

- Power supply of the MIPREG 500

Electrical energy necessary for the MIPREG is supplied by batteries. This voltage is first of all filtered to eliminate harmonics caused by other equipment connected to the same source.

- Electro mechanical supply: The servo valves are supplied by 2 oil networks. The first network is thoroughly filtered.
- Speed chain
- Speed transducer

It is made up of 2 groups of 2 fixed magnetic sensors, distributed symmetrically around the shaft. A ring with permanent magnets is also mounted around the shaft. The distance between the sensors is calculated in such a way that the time taken for a magnet to travel between two sensors corresponds to the period of rotation of the machine. Impulses generated from the sensors are registered in the program counter. The inverse function (line 4) gives a linear function of the speed of the machine.

- Speed set point

The speed set point is entirely static and it's a numerical value permanently memorized in the regulator. The set point can be read directly from the regulator in hertz. Immediately a generator is coupled to the grid, a circuit breaker contact (line 9) sends an order to maintain the speed of the generator at its set point value. The signal from the accelerometer plus the speed signal (line 18) introduces a PD control mode on the servo valve.

- Accelometric effect (line 16)

The accelometric signal is proportional to the angular acceleration of the generator. It is obtained by calculations from the speed signal. The calculation algorithm takes into account the filter necessary for the normal operation of the accelerometer

- Suppressor with thresholds

The role of the suppressor is to create a zone of insensitivity adjustable around the rated frequency of the machine. In fact when the machine is coupled to the network, the adjustment devices, these variations are suppressed within the limits set by the suppressor at thresholds. In the event of greater perturbation that is to say, when the speed difference exceeds threshold value, the speed signal acts normally.

In general, the commissioning of the suppressor with thresholds is controlled by closing of the circuit breaker. However, the two inputs are separated to allow a greater flexibility of adaptation.

- Power chain or opening of circle of winnowing
- Power transducer line 3

The power transducer measures active power line 1 in the alternator caused by the turbine. It provides an electrical signal proportional to the instantaneous power which is transmitted to the regulator via a constraint current. The value of the current is then converted to a numerical value by the regulator

- Choice of command P or Y (line 6)

An entry command permits the operator to choose a mode of command. If the generator is coupled to the grid, the speed determining factor is the power hence the power transducer will be in use. If the machine is not coupled to the grid, the opening of the circle of winnowing is the determining factor hence the transducer will be in use.

- Power set point(Cp) or Opening of winnowing circle(Cy)(line 7)

If the generator is coupled to the grid, the value of Cp can vary from 0 to 110% of the nominal power. Before the generator is coupled, the position set point is set to 25%. Immediately the permanent droop is zero, the effect of the power chain on regulation is annulled. The machine will respond only to the speed chain

- Permanent droop(es) or(bs) line 12

The power deviation (or opening deviation) is obtained by making the difference between the set point value and the transducer value. The permanent statism (power servo, es or opening servo, bs) governs the statism law, speed-power and velocity- opening, respectively. That is, the influence of the difference of power (or opening) with respect to the speed difference on the setting of the machine.

- Chain of limiter opening

The limiter as its name suggests, is a precaution which controls the opening of the distributor despite the speed conditions or load conditions.it prevents the start of the turbine when all the other necessary signals have not been properly checked.

- Limiter opening (Cyl) line 7

It varies from -5% to 110% to ensure that whether the winnowing circle is opened or closed there should always be an order conveyed to the servo valves even if the servomotor has stopped. Atthe start of the machine the limiter opens to 100%. The limiter is a protective mechanism against excess speed as the winnowing circle will always be less than the limiter.

- Startup opening line 7

Before the machine is coupled to the grid, this value is compared to that of the limiter line 11 and the smaller of the values is selected. After the machine has been connected to the grid, only the position of the limiter is considered.

- Limiter gain(bl)

From the value of the limiter, we subtract the real position of the winnow circle line 15 to obtain an error signal. The error signal is amplified to ensure rapid speed response time.

It has the same electrical property as the set point. Its variation is between -5 and 110% for insure in opening like in closing that it remains an order on the servo valve when the servomotor is stopped. At the starting of the machine the limited directly goes to 100% to reach the nominal speed of the turbine. When we are connected to the network, the value of the limiter would decrease progressively and is linked to the power set point and would vary in function of the parameters of the network. The value of the gate position is equal to the value of the limiter.

- GATE POSITION TRANSDUCER(LINE 37)

It is made up of a rotating differential transformer which converts the angular motion of the winnowing circle to voltage which in turn is converted to constraint current for signal transmission to the Mipreg. The differential transformer set up is in a robust water proof box which supports the humid condition of the turbine. The drive of the transducer by levers produces non linear angular strokes with respect to the movement of the servomotor. To avoid mounting a mechanical system for linearization, a spool is introduced representing the relation between the displacement of the servomotor and the electrical signal of the transducer in the memory of the regulator which compensates for all the non linearity of the position measurement.

- ACCELEATION OF LOAD CHARGE

The effect of a variation of the power set point on the winnowing position is done through the relation of the speed – power statism. This means that the resulting order on the servo valve will be small as the permanent droop is small. It can result in a very long time following the values of bt and td for the machine to take charge. This can especially be troublesome if the machine does not have to participate in the regulation of the grid. To avoid this inconvenience, we introduce directly the value of the power set point in the transient reaction with a negative sign to give an order in the direction imposed by the instruction on the servo valve. With this device, it is possible to follow the load with changes of set point almost without delay.

- CONTROL ELEMENTS OF THE TURBINE BLADES POSITION

The control signal of the blades position is the sum of the primary action (chain speed + power chain) and the gap of the conjugation between the winnowing circle and the turbine blades. .As for the winnowing circle, its primary action is limited by comparing its value to the signal of the limiter(line 21 to avoid over opening of the limiter.

- OUTPUT GAIN AMPLIFICATION

As well as for the winnowing circle, the gain of the output amplifier makes it possible to adjust the characteristic time of the promptness of the turbine blades.

- TRANSIENT REACTION(TdB , btB)

It makes it possible to obtain modes of action P+I of the signal on the position of the servomotor of the turbine blades with parameters different from those of the action P+I on the servomotor of the winnowing circle.

- TURBINE BLADES POSITION TRANSDUCER(TA line 37)

The movement of the turbine blades is transmitted via its transducer. To linearize the movement, a program programmed according to the same principle as for the winnowing is introduced. With the conjugation curves memorized in the control and the signal drops, it is possible at any time to calculate the opening of the winnowing circle permissible for the maximum position of the turbine blades. This value is compared to that of the opening of the limiter line 13 to transmit the smaller of the two to the summation and thus prevent the machine from running in unauthorized range.

- OUTPUT ORGANS OF THE REGULATOR

For the transmission of the output signals, the following devices take part:

- Servo valve amplifiers

  The output value of the regulator converted to + or – 10V analogue signal is transmitted to a booster amplifier which can deliver a current of 0.5A to the servo valve. This amplifier is protected to be able to withstand overload or short circuit without damage.

- Amplifiers for indicators:

  The values of the set points as well as those of position velocity of the adjustment devices can also be converted analog signals. These analog signals are sent to current amplifiers built from 0 to 5mA to power the indicators of the plant. These outputs can support a load of 0 to 2Kohm. They are protected against transient signals induced on the lines.

B: THE ACTUATOR:

Otherwise referred to in the course of this report as the hydro mechanical speed regulator. It is the pre actioner to the displacement of the servo motors of the winnowing circle. The mechanical and electrical displacements in the actuator lead to movement amplification.

The figure below is an actuator unit:

Figure 6: An Actuator Unit.

In summary, the actuator functions on 3 main principles which are:

- **Converter**: Converting electrical signals to a mechanical spring displacement.
- **Amplifier**: A series of mechanical motions which amplify the electrical signal.
- **Distributor:** Distributes pressurized hydraulic fluid for opening the winnowing circle.

2.4.3: DEMERITS OF THE MIPREG- ACTUATOR SYSTEM.

- The wear and tear of mechanical parts such as joints.
- The lack of synchronization between instructions given by the MIPREG and its proportional execution by the actuator. A repeated example of this scenario occurred with generator 12 when the MIPREG relayed instructions for the limiter to be opened at 100%. However, due to blockage caused by oil particles, the instructions were not properly relayed hence the limiter didn't open.

- Another effect of faulty synchronization is the long settling time before stability. That is the ability to reach and maintain its speed settling time without harmonics and overshoots.
- Overheating of microprocessor boards since the cards are composed of analogue components such as capacitors, etc.
- The microprocessor cards get damaged hence the need to replace and reprogram.

2.4.4: GENERAL OVERVIEW OF PID CONTROLLERS.

In order for our system to be stable, it must respond speedily to variations in the system. Reason why, we are going to study and implement PID controller parameters in our existing system which has a long response time.

It should however be noted that the PI and PD controllers have been used in the transient loop to achieve zero steady state error and reject system perturbations respectively.

A Proportional Integral Derivative controller is a control loop feedback mechanism used in industrial control systems which require continuous control. It continuously calculates an error value, e(t) as the difference between the desired set point value (SP) and the present measured process variable, (PV). It can then apply corrections, based on the characteristics of the parameters of the PID controller.

In our system, the PID controller algorithm is expected to:

- Eliminate overshoots around set point value and decrease time to reach set point speed value.
- How fast and smooth the error between SP and PV is driven to 0.
- How well the system adapts to unexpected external devices and sensor noises.

The proportional term, P produces an output value that is proportional to the current error value. e(t).proportional response is achieved my multiplying the error by the proportional gain constant, k_p.For a given change in error, a large proportional gain results to a proportionately large output change which can lead to instability of the system. On the other hand, if the proportional gain is too small, the output response change may be too small when responding to system disturbances.

The Integral parameter takes into consideration past errors. The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error.

It is the sum of the instantaneous error over time and gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain, k_i and added to controller output.

The derivative term gives an estimate of the future trend of error, based on the current rate of change of the system. It seeks to reduce the error by exerting a control influence generated by the rate of error change. It is calculated by determining the slope of the error over time and multiplying this rate of change by the derivative gain K_d. k_d is the magnitude of the contribution of the derivative term to the overall control of the system. The derivative term aims at flattening the error trajectory to a horizontal line, thus reducing the overshoot

A. CHARACTERISTICS OF KP, KI and KD.

In order to understand why the PID controller was chose, we must know the characteristics of each parameter and how they affect the system. This is important because all the parameters are interdependent. The following table describes the various tuning parameters.

Table 5: Effects of tuning parameters on system stability.

Parameter	Rise time	Overshoot	Settling time	Steady state error
KP	Decrease	Increase	Little effect	Decrease
KI	Decrease	Increase	Increase	Eliminate
KD	Minor change	Decrease	Decrease	No effect

B. MATHEMATICAL REPRESENTATION OF THE PID CONTROLLER.

The transfer function of the PID controller in the Laplace domain is defined below [2]:

$$k_p + \frac{k_i}{s} + k_d s = k_p + k_i + kds \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

The overall control function in the time domain can be expressed as

$$U(t) = k_p \left[e(t) + k_i \int_0^t e(t')dt' + k_d \frac{de(t)}{dt} \right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where

U(t) = system equation

Kp= proportional coefficient

Ki= integral coefficient

Kd=derivative coefficient

The standard form of the overall equation can be written as:

$$U(t) = k_p [e(t) + \frac{1}{T_i} \int_0^t e(t)dt + T_d \frac{de(t)}{dt} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Where ki and kd respectively are replaced by kp/ti and KpTd since ti and td have a physical meaning as they represent the integral and derivative time respectively.

2.4.5: DATA ACQUISITION.

Penstock diameter=6m

Permanent droop constant= 0.04

Amplification constant for servo valves=5

Penstock length=43m

Height of fall of water =23m

Head of water at intake gate=32m

Flow rate of water per penstock=92.86m/s

Generator mass= 137tons

Number of poles=36

Electrical power (P_E) =21.4MW

2.4.6: SYSTEM MODELING

We start with the development of a system model, then choosing K_p ,K_i and K_d depending on dynamic model parameters. The Ziegler-Nichols loop tuning methods will be used.

The following assumptions shall be taken into consideration in the first order model of the KAPLAN Hydraulic Turbine model: [3][5]

- The incompressible nature of water.
- Turbine power is proportional to the product of water head and volume flow rate (velocity of water in penstock)
- The velocity of water varies with gate opening and square root of the net head.

From the above assumptions, we deduce that:

- Velocity of water in the penstock:

$$u = k_u G\sqrt{H} \dots\dots\dots\dots\dots\dots\dots (5)$$

Where

K_u= velocity constant

G= Gate opening (30cm/260s)

H= net head of water (32m)

Literalizing with respect to rated quantities, we have

$$\frac{\Delta u}{u_0} = \frac{G}{G_0} + \frac{H}{2H_0} \dots\dots\dots\dots (6)$$

The turbine mechanical power

$$P_m = k_p HU \dots\dots\dots\dots (7)$$

Liberalizing with respect to rated quantities, we have

$$\frac{\Delta P_m}{P_0} = \frac{\Delta H}{H_0} + \frac{\Delta U}{U_0} \dots\dots\dots\dots\dots\dots (8)$$

Substituting for $\frac{U}{U_0}$ in eqn 5 we have

$$\frac{\Delta P_m}{P_0} = 1.5\,\frac{\Delta H}{H_0} + \frac{\Delta G}{G_0} \dots\dots\dots\dots (9)$$

Substituting for $\frac{\Delta H}{H_0}$ in eqn 6, we have

$$\frac{\Delta P_m}{P_0} = 3\frac{\Delta U}{U_0} - \frac{\Delta G}{G_0} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (10)$$

Hence we see the relationship between the output power and the velocity of the generator.

Replacing d/dt by the Laplace operator in equations 6 and10, the following transfer functions are obtained as proved by the mathematician, Prabha Kundur in his journals published in :

$$\frac{\frac{\Delta U}{U_0}}{\frac{\Delta G}{G_0}} = \frac{1}{1 + 0.5T_w s} \ldots\ldots\ldots\ldots.. (11)$$

$$\frac{\frac{\Delta P_m}{P_0}}{\frac{\Delta G}{G_0}} = \frac{1 - T_w s}{1 + 0.5\, T_w s} \ldots\ldots\ldots\ldots. (12)$$

Equations 11 and 12 illustrate change in speed and change in torque with respect to gate opening respectively.

The gate opening $\frac{\Delta G}{G_0}$is controlled by two stages: a pilot valve and a larger power gate servo motor.

The table below defines the parameters a modeled system must incorporate:

Table 6: Parameters of a modeled system.

Parameter	Description	Value
T_{pv}	Pilot valve with time constant	0.05s
T_{gv}	Main gate servomotor time constant	0.2s
K_v	Servo gain	2
T_R	Reset time	2.1s
R_p	Permanent droop	0.04
R_T	Transient drop	0.4

The closed loop transfer functions for the pilot valve is:

$$\frac{1}{1 + sT_{pv}} \cong \frac{1}{1 + 0.05s} \ldots\ldots\ldots\ldots\ldots. (13)$$

The closed loop transfer function for the servo motors is:

$$\frac{1}{1 + sT_{gv} + s^2 K_V T_{gv}} \cong \frac{1}{1 + 0.2s + 0.4s^2} \quad \dots\dots\dots..(14)$$

The closed loop transfer function for the transient droop is:

$$\frac{R_T s T_R}{1 + sT_R} \cong \frac{1.4s}{1 + 3.6s} \dots\dots.(15)$$

The constants, T_w,T_R are derived as follows:

$$T_W = \frac{LQ_0}{AgH_0} \cong \frac{45 * 92.86}{9.82 * 23 * 9 * \pi} = 0.7s \dots\dots\dots\dots.(16)$$

T_w=Water starting time

Where L=length of penstock.

Q_0=Flow rate of water in penstock.

G=acceleration due to gravity

H=head of water at intake gate.

A=area of penstock

Reset time is gotten as:

$$T_r = [5.0 - [T_w - 1.0]0.5]T_w \cong 3.6s \dots\dots\dots.(17)$$

The speed closed loop transfer function with respect to gate opening is therefore:

$$\frac{\frac{\Delta U}{U_0}}{\frac{\Delta G}{G_0}} = \frac{1}{1 + 0.4s} \dots\dots\dots\dots.(18)$$

The speed transducer gain block which relates output speed to frequency is gotten as follows:

$$f = \frac{p}{120} n_s = \frac{36}{120} n_s \dots\dots\dots\dots\dots..(19)$$

Where f=frequency

P=number of poles

Ns = synchronous speed

- The power closed loop transfer function with respect to gate opening is therefore:

$$\frac{\frac{\Delta P}{P_0}}{\frac{\Delta G}{G_0}} = \frac{1-0.7s}{1+0.4s} \ldots \ldots \ldots \ldots . (20)$$

- Mechanical power is related to nominal speed by the following formula:

$$C_{em} = \frac{1}{2\pi n_s} P_{mech} \ldots \ldots \ldots \ldots \ldots (21)$$

The ratio $\frac{P_E}{P_{MECH}} = 95\%$. Therefore, $P_{MECH} = \frac{P_E}{0.95} = 22.5MW$. The figure below depicts a simplified figure of the schematic diagram of a speed governor system

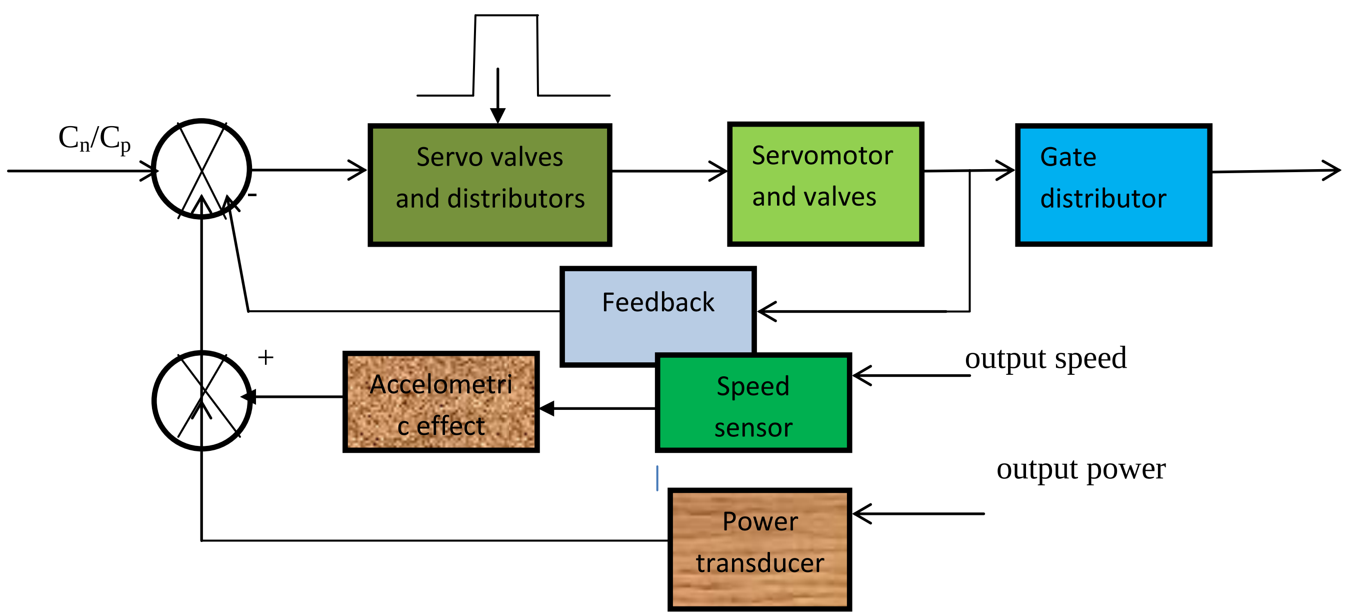
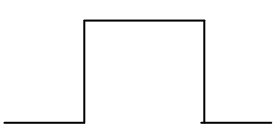


Figure 7: Schematic block diagram of a speed regulator system



Servo valve amplification (+ or- 10V)

C_P = Power set point

C_n= Speed set point

2.4.7: DATAIMPLIMENTATION

The following diagram is the model used to simulate the existing governing system in MATLAB without PID controller.

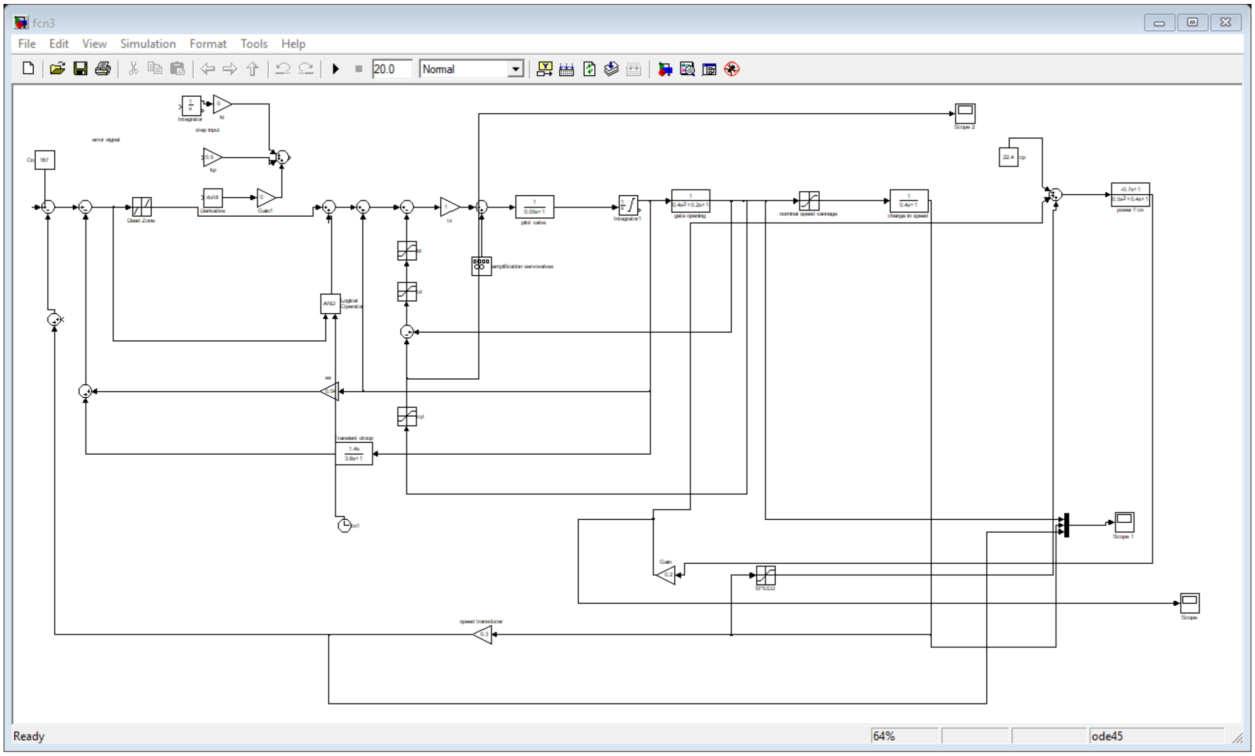


Figure 8: Present speed governor system modeled on Matlab

Table 7 describes keywords of fig 8.

Representation	Description	Value
c_n	Speed set point	167rev/min
T_n	Accelometric effect	2s
e_s	Permanent droop	0.04
T_d	Winnowing circle droop	6.06s
c_y	Limiter opening	-5% to 110%
t_x	Gate output gain	1.047
k_v	Total servo gain	5

2.4.8: RESULTS.

- Scope 1 displays the curves of the opening of the winnowing circle to 25%, achievement of nominal speed and nominal frequency of generator 12 before coupling to the grid. From the scope I steady state error is observed with a steep rise time slope. The rise time however is dependent on fixed factors of the transfer function parameter, T_w which is dependent on factors such as the length of the penstock. It should be noted that the scope below is achieved With respect to the PI and PD control introduced already in the bt and accelerometric signal respectively. It should be noted that introducing a PD control is supposed to eliminate steady state errors. Reason for the proposed attaining of stability of the curves below after a few oscillations.

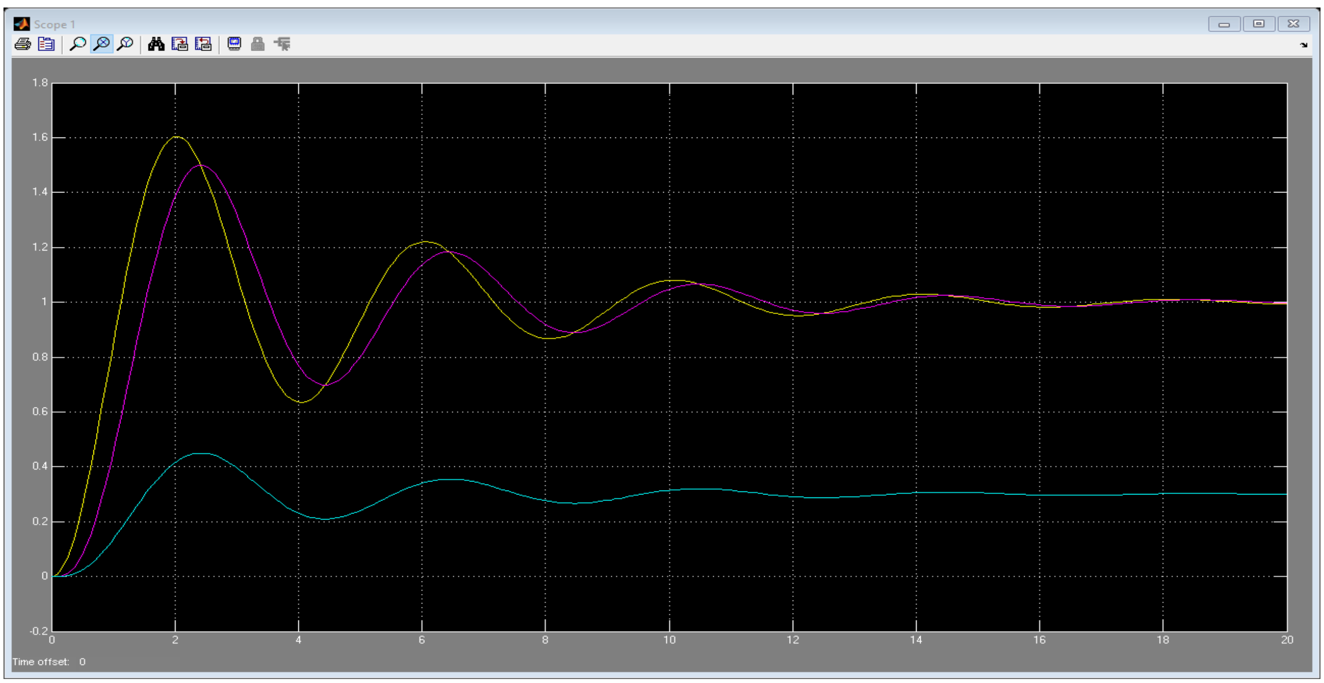


Figure 9: Scope 1

The integrator limits the function to run from 0 to 1 implying 1 is the maximum PU value.

KEY:

Grid frequency stabilization.

Gate opening

How fast nominal speed is attained.

The scope below illustrates how fast the output power of 21MW is attained after coupling to the grid.

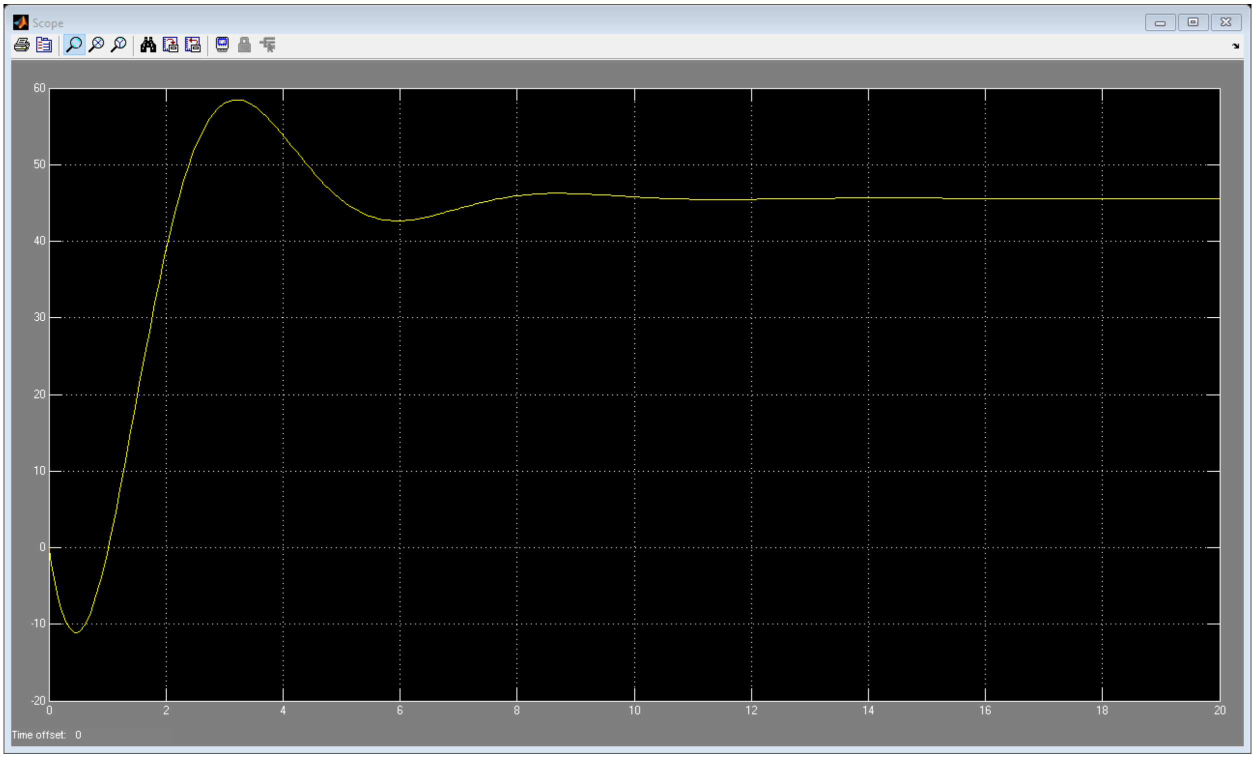


Figure 10: Scope 2 displaying how fast grid frequency is attained.

After coupling to the grid, the generator has the tendency to first of all behave like a motor. Reason for the drop below 0 but it is rapidly brought back to grid frequency of 50 Hz+or-2.5%.

However introducing a PID controller to the above system doesn't affect the number of oscillations no matter how much the k_p is varied. Consequently loop tuning methods are ineffective. To view how a PID controller will ameliorate the real system without the pre Introduced PI and PD control parameters are shown in in the following figure:

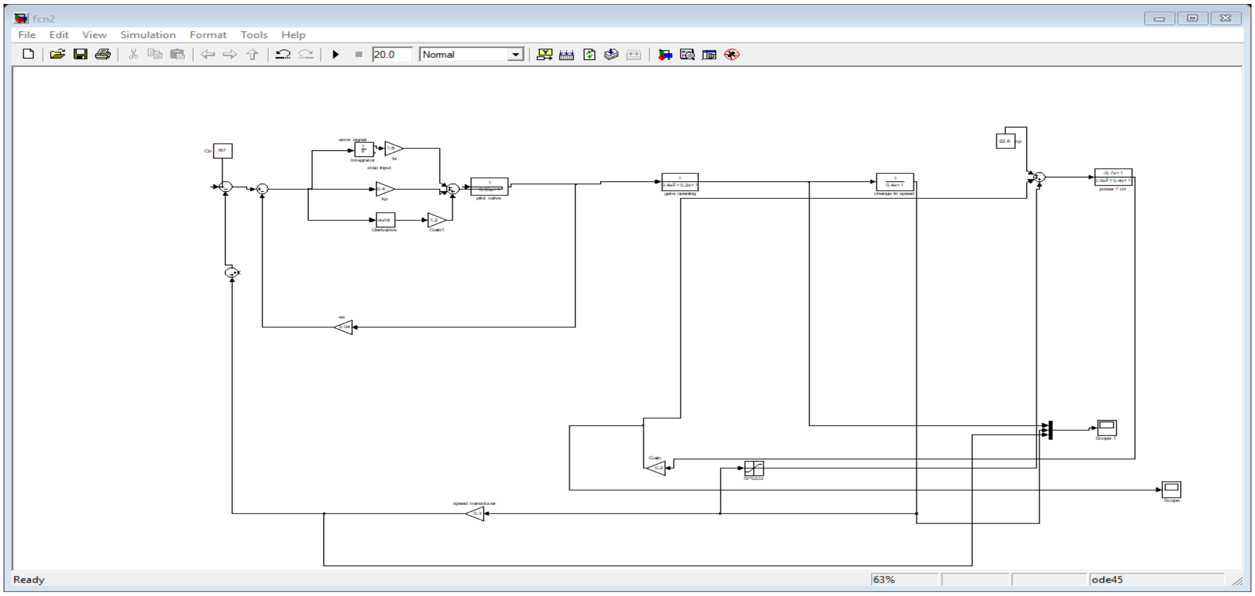


Figure 11: PI and PD control eliminated

The oscillations are more visible as shown in scope 3 below:

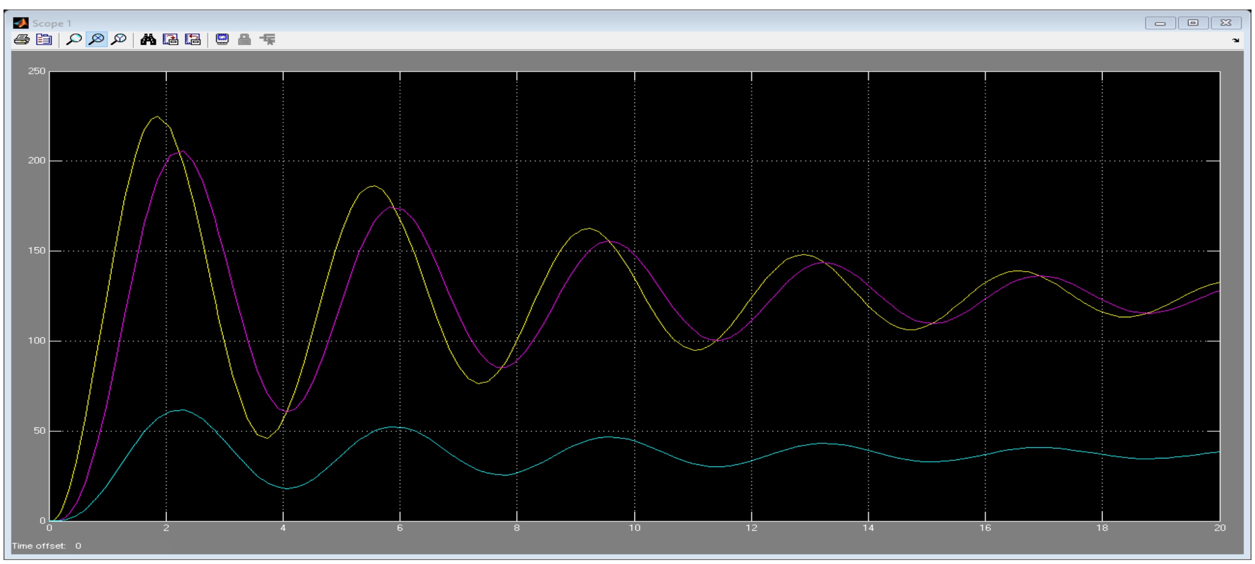


Figure 12: Scope 3 displaying long settling time.

KEY:

Gate opening

Nominal speed

grid frequency.

- Introducing the PID controller and setting $k_p=K_u$ where k_u represents the value of kp where the curves will have consistent oscillations when all the other parameters are set to 0.the following curve is attained as shown in Figure 13:

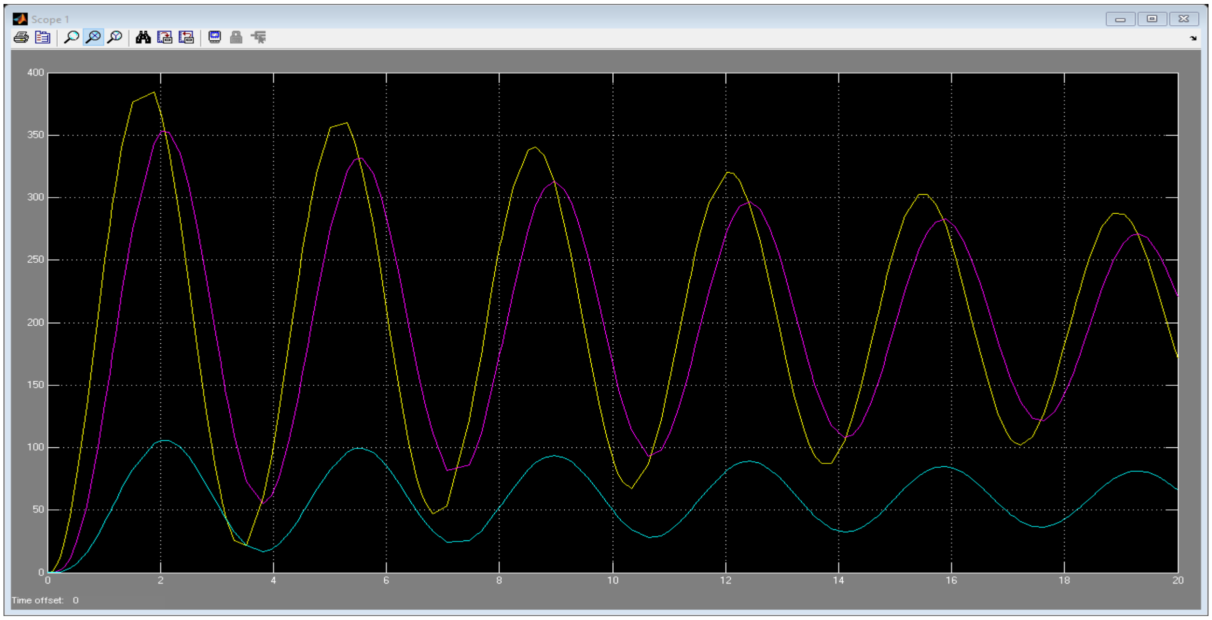


Figure 13: Loop Tuning.

Where $k_u=2$

$T_u=3.5s$ where T_u is the period of oscillation.

Using the ‘no overshoot rule’ of Ziegler-Nichols we derive the tuning values as on the following table:

Table 8: Ziegler Nichols no overshoot rule.

Rule name	Tuning parameters		
No overshoot rule	$K_p=0.2k_u$	$T_i=0.5T_u$	$T_d=0.33T_u$
Results	$K_p=0.4$	$T_i=1.6$	$T_d=1.2$

Figure 14 shows the ameliorated speed governor system with tuned PID parameters as shown in table 8 above.

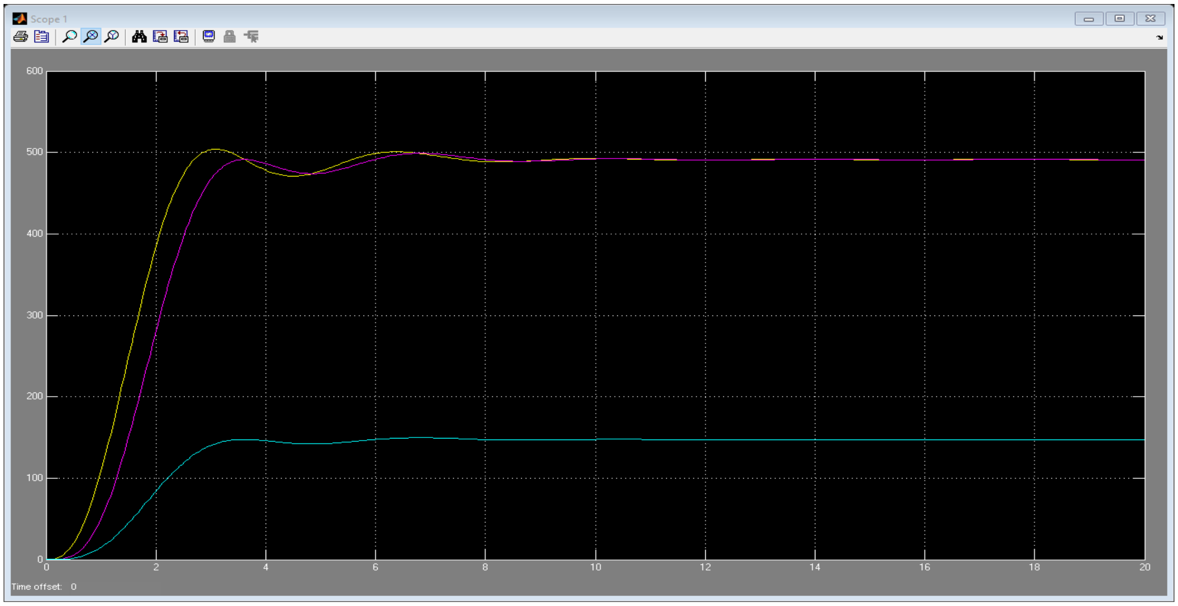


Figure 14: PID implementation.

KEY:

Gate opening

Nominal speed

Grid frequency.

- Eliminating the overshoots however leads to a longer rise time. Hence from my observation, a total loss in steady state error can probably lead to a longer rise time period.

2.4.9: PROPOSEDMECHANICAL SOLUTION TOWARDS AMELIORATING THE SPEED GOVERNOR SYSTEM OF GENERATOR 12.

Foreign particles in the hydraulic system influence the speed regulation. The present filters are not super-efficient as oil particles are still capable of blocking the diaphragm, hence disrupting signal flow. However, manual cleaning of the filters is still required. In this light solution to some root cause problems can be implemented such as:

- Programmed emptying and cleaning of oil tanks. This is to get rid of tank wall particles which over the years might have accumulated on the tank bed. Hence the tank particles are recycled throughout the hydraulic circulation process. This programmed work can be carried out semester. This will help not to over work the filters.

- The filters presently in use can also be replaced since it has suffered depreciation; hence its efficiency is minimized.
- Furthermore during the weekly cleaning of filters, a mini compressed air system of cleaning can also be implemented, synonymous to the compressed air used on generator number 13 during commutation maintenance.
- Personnel engaged in cleaning the filters must be cautious in order to avoid introducing external impurities.

2.5 DISCUSSION

- Why is more water admitted into the turbine blades when the generator is coupled to the grid?

The input to the hydro generator is mechanical, while the loading is electrical. Hence, if electrical load increases, the generator seeks to increase mechanical intake to keep up with demand, increasing mechanical torque. This is achieved by opening of the winnowing circle to admit more water to the turbine blades. But the intake, being mechanical, exercises some inertia. This inertia lag leads to a slight decrease in speed of the generator which is however corrected via the feedback system.

- The accelerometric effect, T_n ensures that variations in speed is integrated in the regulation loop.
- The permanent droop,es or bs defines the relationship between a given amount of water admitted to the turbine blades and its proportional estimated speed or power respectively.
- How does rotor mass inertia affect output frequency oscillations? Inertia is the reluctance of a body in motion to stop moving and a body at rest to start moving. When a generator is coupled to the grid, the speed tends to reduce. However , the inertia constant enables the speed not to drop very fast as necessary signals are transmitted simultaneously to the circle of winnowing to admit more water to the turbine blades. The reverse is true if load is decreased as the generator instead has a tendency to over speed.

- T_W is referred to as water starting time and it represents the time necessary for head of water to increase speed of water in penstock from idle to the velocity U_0. Water starting time varies with load conditions and is typically in the range of 0.5s to 4s.
- The above analysis are referenced to the mathematical assumptions and calculations performed by Prabha Kundur in the year 1994.

2.6: PERFORMANCE DURING ACCOMPLISHING TASKS.

In accomplishing any tasks assigned to me, I did so diligently and with zeal to learn.

2.7: DIFFICULTIES ENCOUNTERED.

- Conversion from rpm to frequency.
- Assigning set points.
- No oscillation of scope output despite varying of PID values.
- Translation of technical terms from French to English.
- Lodging challenges.

2.8: SOLUTIONS TO PROBLEMS ENCOUNTERED.

- In order to convert from rpm to frequency, the following formula is analyzed

Ns= synchronous speed

F= frequency

P=pole number

Hence we use a gain block with output speed as its input and frequency as block output to be fed as a feedback signal.

- Set points were assigned by constant blocks instead of signal generator blocks.
- In order to solve the language huddle I consulted engineers at the department who mastered English.
- Renting a room was inevitable as I was a total stranger to EDEA.

2.9: FUTURE SCOPE OF STUDY

There are better adapted and newer controllers compared to the PID. An example of such is the LQG control system.

Use the frequency response method to analyze and study the stability of the system.

A. CONCLUSION

The speed regulator system comprises a system of well harmonized actuators and transducers interconnected via a closed loop feedback system to maintain the speed of the generator at its nominal rotation of 167rev/min. the present system as modeled and verified oscillates about its set point. However, eliminating oscillations from my point of view will lead to a longer transient time.

CHAPTER THREE

3.0: OVERALL BENEFITS OF INTERNSHIP.

3.1: IMPROVING PRACTICAL SKILLS.

This internship opportunity upgraded my practical skills especially in the domain of electrical installations as I was always assigned to tasks such as installing circuit breakers, light bulbs, protective relays and air conditioning systems.

3.2: UPGRADING THEORITICAL KNOWLEDGE.

My theoretical knowledge on the following concepts was greatly enhanced;

- Electric machines.
- Power System Components.
- Industrial control using PID controllers.
- System modeling.
- Simulating on MATLAB.

3.3: UPGRADING INTERPERSONEL COMMUNICATION SKILLS.

Sharing ideas towards accomplishing an assigned task is very important. I learned to propose solutions and listen to other personnel’s ideas before drawing conclusions.

3.4: IMPROVING TEAM PLAYING SKILL.

Team playing skill serves as a security measure and a forum to bring forth positive contributions.

3.5: IMPROVING LEADERSHIP SKILLS.

As a longer serving intern, I was assigned to newer interns to help them come through with the weekly Monday mornings value recordings. This greatly improved my leadership skill as I learnt to be patient while explaining how a process ought to be executed. Furthermore, it improved my sense of responsibility.

3.6: WORK ETHICS AND RELATED ISSUES.

- Marking out an active working area.
- Full security measures before any work task is done.
- Respect for each other’s job description.
- Keeping strictly to working hours and readily available if extra work comes up.
- Respecting hierarchy.
- Respecting security measures put in place.

- Active participation in teamwork.

3.7: ENTREPRENEURSHIP SKILL.

As engineers we are expected to bring solutions to the day by day challenges faced by the common man. This includes making use of the creativity built in us during our training in school. One way to impact the society positively is by creating jobs to help employ the very rapidly increasing job market. With the experience I had during this internship, I was enlightened on various entrepreneurial ideas which if realized will help our nation Cameroon to develop better.

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