OPTIMAL LOAD DISPATCH FOR HYDRO POWER PLANTS

BY

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IN

ELECTRICAL ENGINEERING DEPARTMENT

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DECLARATION

I declare that the information provided in this report is entirely ideas in my own words through my research efforts.

………….........29/12/2020…
(Signature) (Date)
Nkwasibwe WILBER

This is to certify that this project report belongs to Nkwasibwe WILBER and the information here was compiled by him.
Main supervisor

27/Dec/2020
…………………………………………
(Signature) (Date)
Mr. Seruyange WILLIAM
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APPROVAL

Having supervised NKWASIBWE WILBER in his final year project and thereafter read this report; I do approve it to be submitted to Kabale University for an academic award of a Bachelors degree of electrical engineering.

Supervisor

Sign: ……………………..

Date: 27/Dec/2020 ……………………..

DEDICATION

I dedicate this to my MOM and all my siblings for the great love and encouragement they have given me in this journey.

ABSTRACT

This report is about an optimization of hydro power generation by using least possible amount of water to generate the demand power. The case study of the project has two generating units and total generation capacity of 6.5 MW, Unit 1 generates 2.5 MW and Unit 2 generates 4.0 MW. The turbines and generators of the generating units have different efficiencies which contribute to different rates at which water is discharged by generator turbines.

The solution is obtained by comparing the amount of water discharged by each generating unit for the old approach currently being used by power plant operators and after comparing, a new approach is suggested in this report for optimization. The optimization method used is the lambda method and the software used is Matlab which gives the values of load power to be generated by each generating unit.

ACKNOWLEDGEMENT

I first thank God for he has given me this life and given me the strength to finish this project.

I extend my humble appreciation towards the efforts put by the following who led to the success of my final year project.

I also express my heart felt gratitude to my supervisor, Eng. SERUYANGE WILLIAM who spared his time to inspect me and later on inspired and encouraged me up to the end of the project.

I also thank Dr. Sabo Miya for his tireless effort in guiding me during project development. All their efforts are greatly appreciated.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ELD - Economic Load Dispatch

MW - Mega Watt

KW - Kilo Watt

LTD - Limited

KWh - Kilo Watt hour

CHAPTER ONE

1.0 INTRODUCTION

Economic power dispatch is the short-term determination of the optimal output of a number of electricity generation facilities, to meet the system load, at the lowest possible cost, subject to transmission and operational constraints. Power systems are built and maintained to achieve reliable and economic power supply. Analysis and computations have to be done to determine the most efficient generators to load (unit commitment) problem and how much of the load each generator will carry for economic dispatch. The economic dispatch problem has been formulated as a mathematical optimization problem and its objective is to minimize the fuel cost as the load demand increases by calculating the amount of load each generator should carry for maximum efficiency [1].

1.1 Problem Statement

Hydro power plants are required to account for water flow rate and thermal power plants use fuel as the raw material in power generation which rises need to account for the costs incurred on each running generation unit and the total cost of generation. Hence a need to evaluate how loads can be supplied at the lowest cost using economic load dispatch (ELD). The cost function for each generator is represented by an increasing linear constraints. Linear constraints can be Generation capacity constraints or Power balance constraints [2].

Table 1: machine tripping, duration and the reason.

From TIME	To TIME	U_1	U_2	TOTAL KWhr	REASON
00:00	00:00	-	3903	3903	14 Bus vector shift 78
00:20	00:30	-	3765	3765	Low water level
01:00	03:00	-	3867	3867	Low water level
02:00	04:00	-	3692	3692	Low water level
04:00	05:00	-	3778	3778	Low water level
05:30	06:00	-	5828	5828	Low water level
06:45	07:00	-	3553	3553	Low water level
07:50	08:10	-	3124	3124	14 Bus vector shift 78
10:00	11:00	-	2921	2921	Power failure
11:30	12:00	-	2728	2728	Power failure & 14 bus vector shift 78
12:50	13:00	-	3624	3624	Low water level
14:00	15:00	-	3450	3450	Low water level

Table 1 above shows the tripping time, generating unit, and the reason for the machine tripping. The tripping time is when the generation is at stand still and if the machine trips then it means it's shutdown due to the fault. It's a protective measure which isolates the important devices from the fault section.

1.2 Main objective

2. To achieve economic dispatch of load power generation among the generating units.

1.3 Specific objectives

1. To identify factors affecting power generation costs.
2. To develop mathematical models for generation optimization.
3. To develop an optimization program using MATLAB program and recommendations.

Location of Muvumbe hydro (U) Ltd

The power plant is located in Kahondo village, Kahondo parish, Maziba sub-county, Ndorwa East, kabale district in south Western Uganda near the border of republic of Rwanda and Uganda shown in figure 1.

Figure 1: Location of Muvumbe hydro on the map of Uganda.

It produces electrical energy using water that runs turbines connected to the generator shafts producing 6.5 MW on Maziba River using two units. One producing 4.0 MW and other 2.5 MW as shown in figure 2.

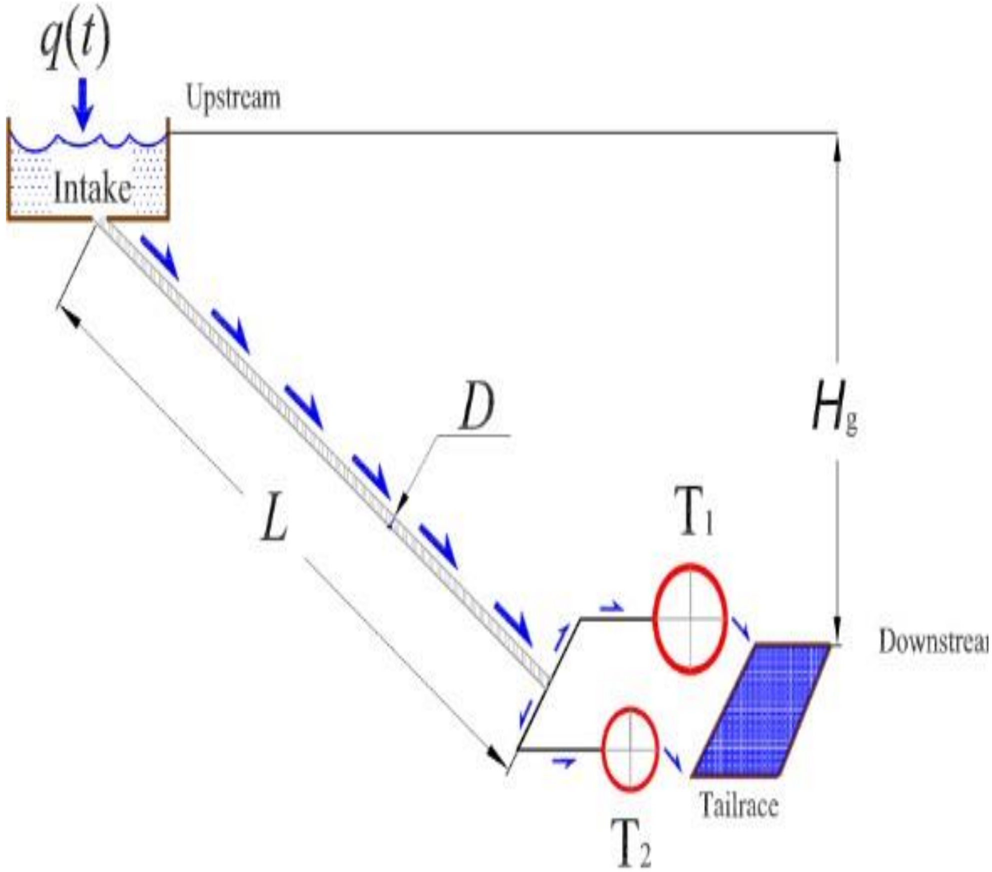


Figure 2: Schematic representation of two parallel turbines at Muvumbe Hydro (U) Ltd.

T_1 represents the bigger turbine for generating 4.0 MW and **T_2** represents a smaller turbine for generating 2.5 MW.

Generation calculations formulae used at Muvumbe hydro (U) ltd.

Generation loss in watts is given by,

$$\text{Generation loss} = \frac{\text{average load} * \text{tripping period}}{60\text{min}}$$

Daily power factor is given by,

$$\text{Daily power factor} = \frac{\text{total units generated in 24hrs} * 100}{\text{max demand}}$$

Monthly power factor is given by,

$$\text{Monthly power factor} = \frac{\text{total units generated in a month} * 100}{\text{max demand} * \text{month dates}}$$

Maximum demand in KW/hour is given by,

$$\text{Maximum demand} = \text{plant capacity in KW} * 24\text{hours}$$

Machine running hours in hours is given by,

$$\text{Machine running hours} = 24\text{hrs} - \text{tripping time in } 24\text{hours}$$

Rain fall at the site in mm is given by,

$$\text{Rain fall at the site} = \text{total readings} * 1.7$$

The readings are taken from the rain gauge in mm.

Francis turbines are the ones used at Muvumbe hydro (U) ltd and are controlled by servomotor to open wicked gates to allow water to enter into the turbine and water strikes the edges of the runner as it pushes the blades and flows towards the axis of the turbine then it goes out axially through the draft tube to the tail race. It has circular plate fixed to the rotating shaft perpendicular to its surface and passing through its center [3].

CHAPTER TWO

LITERATURE REVIEW

2.1 Factors affecting hydro power generated

Hydro power generation is affected by various factors as follows;

The Power demand on the line

For mini hydro power plants, the load power to be generated is determined by Uganda Electricity Transmission Company a day before. This is because the power generated by mini hydro power plants is negligible compared to the national grid demand.

The amount of water available for generation

The amount of water available for generation dictates the power to be generated by hydro power plants since the generator's turbines are driven by moving water at a high speed from the penstock.

The required ideal conditions/factors for development and generation of hydro power are as follows:

Physical Factors

The following physical conditions are necessary for the construction and success of hydro-electric plants:

(i) Regular and abundant supply of water or quantity of water;

(ii) Rugged topography or degree of slope;

(iii) Existence of rapids and waterfalls;

(iv) Solid rock structure or geological stability for construction of dams;

(v) Suitable climate, i.e., temperature above freezing point;

(vi) Presence of lakes; and

(vii) Silt-free water, etc.

Among physical factors two prime factors are quantity of water and degree of slope. The greater the quantity of water available, and steeper or longer the slope, the greater is the energy generated.

These two factors, water and slope, are compensatory; that is to say, if a small quantity of water falls from a great height it will yet be able to generate large amount of power or a great amount of water can do the same thing on a slight slope. The power-producing streams may thus be divided into two categories: (a) streams of high fall and small discharge, and (b) streams of low fall and considerable discharge. .

Economic Factors:

Economic factors play an important role in the development of hydro-electric power. These factors include the following [4]:

(i) Demand of power:

In order to compensate the high construction cost of the hydro projects demand for power is necessary. So that the generated electricity should be easily utilized in the nearby area. A densely-populated area is more suitable, where demand for power is more.

(ii) Lack of other energy sources:

The hydro power projects are more successful where other sources of power are not available. In countries where coal and petroleum are available in abundance, electricity is also generated with them. Coal and oil deficient countries like Japan, Sweden, etc., are more dependent on hydro-electricity.

(iii) Capital investment:

Modern large-scale hydro-projects are expensive involving dam erection, power plant construction, costs of transmission and round-the-year maintenance as well as incidental costs of compensation, etc.

The delivery of the power supply from the point of generation to consumers, sometimes hundreds of Kilometers away, involves the construction and servicing of pylons, high-tension cables, even undersea cables in some cases, and transmission lines often cross very difficult terrain.

(iv) Other factors:

Among other economic factors:

(a) Location of industrial and commercial centers,

(b) Improved modern technology, and

(c) Transport and communication are important.

2.2 Economic load dispatch

By economic load scheduling we mean to determine the generations of different plants such that total operating cost is minimum and at the same time the total demand and the losses at any instant is met by the total generation. The operating cost of thermal plants is mainly the cost of fuel. It is given as a function of generation .This cost function is defined as a nonlinear function of plant generation's .Normally, a graph is given between the heat value of fuel and power generation and knowing the cost of fuel .We can definitely determine the fuel cost as a function of generations for each thermal plant [5].

Scarcity of energy resources, increasing power generation costs and ever growing demand for energy necessitate optimal economic dispatch in modern power systems. The main objective of economic dispatch is to reduce the total power generation cost while satisfying various equality and inequality constraints. A wide variety of optimization techniques have been applied to solving Economic Load Dispatch (ELD). Some of these techniques are based on classical optimization methods, such as linear programming or quadratic programming to solve ELD problems. Such classical optimization methods are highly sensitive to starting points and often converge to local optimum or diverge altogether [6].

Linear programming methods are fast and reliable but have a disadvantage associated with the piecewise linear cost approximation. Nonlinear programming methods have been known for problems of convergence and algorithm complexity .Newton based algorithms have difficulty with handling a large number of inequality constraints .Methods based on artificial intelligence techniques, such as artificial neutral networks have also been applied successfully. Lately, many heuristic search techniques, such as particle swam optimization, have been considered in the context of ELD problems [6].

2.1.1 Formulation of economic load dispatch (ELD)

$F_t = \sum_{i=1}^{n} Fi(Pi)$ ....(1)

Where,

F_t = total fuel cost

i = no of generating units

$F_i(P_i)$ = Fuel cost of generating unit i.

The fuel cost of the thermal generating unit is a polynomial given by,

$F_i(P_i) = a_i + b_iP_i + c_iP_i^2$.

Where, a_i, b_i, c_i are coefficients of unit i.

The ELD is subject to power balance constraints and generation limit constraint.

Equality constraints

Equality constraints are the basic power balance equations in compliance with the fact that total generation equals total demand minus transmission losses.

$\sum_{i=1}^{n} P_L = P_{G-} P_D = 0$………………………………………..…… (2)

where, P_L - the transmission losses, P_G - the total power generated, P_D - the total load demand.

Inequality constraints

Inequality constraints include the following;

Generator Constraints:

The KVA loading of a generator is given by,

$$\text{KVA loading} = \sqrt{P2 + Q2} \quad (3)$$

where P is the active power and Q is the reactive power.

The KVA loading should not exceed a pre-specified value to limit the temperature rise. The maximum active power generated 'P' from a source is also limited by thermal consideration to keep the temperature rise within limits. If the power generated out of a generator falls below a pre-specified value Pmin, the unit is not put on the bus bar:

$$\text{Pmin} \le \mathbf{P} \le \text{Pmax} \quad (4)$$

The maximum reactive power is limited by overheating of rotor and minimum reactive power is limited by the stability limit of machine. Hence the generator reactive powers Q should not be outside the range stated by inequality for its stable operation.

$$\text{Qmin} \le \mathbf{Q} \le \text{Qmax} \quad (5)$$

Voltage Constraints:

The values of voltage magnitude and phase angle at different nodes must be within a specific range. The power angle of transmission must lie between 30 degrees and 45 degrees to comply with transient stability. The higher the power angle, the lower is the stability in case of faults. The lower limit of operating angle assures optimum use of transmission capability that is available [7].

Transformer tap settings:

If an auto-transformer is used, the minimum tap setting could be zero and maximum one,

$0 \leq t \leq 1.0$...(6)

Similarly for a two winding transformer if tapping are provided on the secondary side,

$0 \leq t \leq n$...(7)

where n is the ratio of transformation.

Running spare capacity constraints:

Apart from meeting the load demand and transmission losses, the total generation should be such that a minimum spare capacity is available. These constraints are needed to meet unpredicted extra load on the system [8].

Transmission Line Constraints:
The flow of active and reactive power through the transmission line circuit is limited by the thermal capability of the circuit and is expressed as,

$Cp \leq Cpmax$...(8)

where Cpmax is the maximum loading capacity of the P_{th} line.

Network security constraints:
If initially a system is operating satisfactorily and there is an outage, may be scheduled or forced one, it is natural that some of the constraints of the system will be violated. The complexity of these constraints (in terms of number of constraints) is enhanced when a large system is being analyzed. In this a study is to be made with outage of one branch at a time and then more than one branch at a time. The natures of the constraints are same as voltage and transmission line constraints. The complication in the constraints is increased in the analysis of a large power system .one or more branches at a time are taken out to study the effect [9].

Network security constraints:

In case of an outage, be it a scheduled or a forced one, some constraints of the network are not complied with. In order to overcome the problem, several optimization techniques discussed in [10] [11] [12] have been developed. They include;

Genetic Algorithms (GA)
Artificial Neural Networks (ANN)
Particle Swarm Optimization (PSO)
Ant colony optimization (ACO)

Simulated Annealing (SA)
Tabu Search (TS)

Particle Swarm Optimization

PSO is a biologically inspired computational search and optimization technique developed by Eberhart and Kennedy, in 1995, which was inspired by the social behavior of bird flocking and fish schooling in search of food without a leader. PSO has its roots in artificial life and social psychology, as well as in engineering and computer science. It utilizes a "population" of particles that fly through the problem hyperspace with given velocities. At each iteration, the velocities of the individual particles are stochastically adjusted according to the historical best position for the particle itself and the neighborhood best position. Both the particle best and the neighborhood best are derived according to a user defined fitness function. The movement of each particle naturally evolves to an optimal or near-optimal solution. The word "swarm" comes from the irregular movements of the particles in the problem space, now more similar to a swarm of mosquitoes rather than a flock of birds or a school of fish [13].

Most of the conventional computing algorithms are not effective in solving real-world problems because of having an inflexible structure mainly due to incomplete or noisy data and some multidimensional problems. Artificial intelligent computing methods are best suited for solving such problems. PSO is a computational intelligence-based technique that is not largely affected by the size and nonlinearity of the problem, and can converge to the optimal solution in many problems where most analytical methods fail to converge. It can, therefore, be effectively applied to different optimization problems in power systems [13].

Artificial Neural Networks (ANN)

Artificial neural networks is a computational model inspired by animal central nervous system (in particular the brain) that are capable of machine learning and pattern recognition. They are usually presented as systems of interconnected 'neurons' that can compute values from inputs by feeding information through the network. For example, in a neural network for handwriting recognition, a set of input neurons may be activated by the pixels of an image representing a letter or digit. The activation of the these neurons are then passed on, weighted and transformed by some function determined by the network's designer to other networks etc. until finally an output neuron is activated that determines which character was read. ANN is used to solve wide tasks that are hard to solve using ordinary rule- based programming, including computer vision and speech recognition. Network in the term ANN refers to the interconnection between the neurons in the different layers of each system [14].

Simulated Annealing

Simulated Annealing is basically a stochastic optimization technique inspired by the natural process of crystallization i.e. gradual cooling of metal. Annealing (in metallurgy & material science) is a process involving heating and controlled cooling of a material to get

perfect crystal with minimum defects. The name and inspiration come from annealing in metallurgy, a technique involving heating and controlled cooling of a material to increase the size of its crystals and reduce their defects, both are attributes of the material that depend on its thermodynamic free energy [15].
Heating and cooling the material affects both the temperature and the thermodynamic free energy. While the same amount of cooling brings the same amount of decrease in temperature it will bring a bigger or smaller decrease in the thermodynamic free energy depending on the rate that it occurs, with a slower rate producing a bigger decrease. The problem with this approach is that the neighbors of a state are not guaranteed to contain any of the existing better solutions which means that failure to find a better solution among them does not guarantee that no better solution exists [16].

Genetic Algorithm

Genetic algorithm is a search heuristic that mimics the process of natural selection. It belongs to a group of class of evolutionary algorithms which generate solutions to optimization problem using techniques inspired by natural evolution, such as inheritance, mutation, selection and crossover. In GA, a population of candidate solution (called individuals, creatures,) to an optimization problem is evolved toward better solution. Each candidate solution has a set of properties (its chromosomes) which can be mutated and altered. Initially many individual solution are randomly generated to form an initial population. The population size depends on the nature of the problem but typically contains several hundreds or thousands of possible solutions. During each successive generation, a proportion of the existing population is selected to breed a new generation. Individual solution are selected through a fitness based process, where the fitness solution (as measured by the fitness function) are typically more likely to be selected [17].

Tabu Search

Tabu search, created by Fred W. Glover in 1986 and formalized in 1989, is a metaheuristic search method employing local search methods used for mathematical optimization.
Local (neighborhood) searches take a potential solution to a problem and check its immediate neighbors (that is, solutions that are similar except for one or two minor details) in the hope of finding an improved solution. Local search methods have a tendency to become stuck in suboptimal regions or on plateaus where many solutions are equally fit. Tabu search enhances the performance of these techniques by using memory structures that describe the visited solutions or user-provided sets of rules [18].

Ant Colony Optimization

The Anti-Colony Optimization (ACO) algorithm is a probabilistic technique for solving computational problems which can be reduced to finding good path through graphs. It was proposed by Marco Dorigo in1992 in his PhD thesis, in which algorithm was aiming to search for an optimal path in a graph, based on the behavior of ants seeking a path between their colony and a source of food. In the natural world, ants wander randomly, and upon finding food return to their colony while laying down pheromone trails. If the ants find such a path, they are likely not to keep travelling at random, but to instead follow the trail, returning and reinforcing it if they eventually find food.

Over time, however, the pheromone trail starts to evaporate, thus reducing its attractive strength. The more time it takes for an ant to travel down the path and back again, the more time the pheromones have to evaporate. A short path, by comparison, gets marched over more frequently, and thus the pheromone density becomes higher on shorter paths than longer ones. Pheromone evaporation also has the advantage of avoiding the convergence to a locally optimal solution [18].

Lambda method (Lambda iteration)

Lambda method is used to generate the mathematical models which are used to develop a MATLAB code that prompts a user to input the total power demand to be generated. The user presses the enter button and the results of load power to be generated by each generating unit is depicted in the command window. Also the value of lambda is shown in the command window after every iteration.

MATLAB software is used in developing the program that shows optimized load power generation between the two generating units.The lambda iteration method is one of the most popular traditional techniques used to solve the ELD problem for optimizing the generation. The detailed algorithm of lambda iteration method is shown below.

Procedure of lambda method

The following procedure of the lambda method is given in [19];

1) Read the given data, for example minimum power for each unit and maximum power for each unit.

2) Assume the starting value of λ.

3) Calculate the generated power Pi from each unit

4) Check the generating limits for each unit.

If Pi > $Pi{-}max$ set Pi= $Pi{-}max$ Pi < $Pi{-}min$ set Pi= $Pi{-}min$

5) Enter the total power demand

6) Calculate the mismatch in power given by the equation below

$\Delta P = \Sigma Pi - PDNi = 1$

Where Pi $is\ the\ power\ generated$

$PD\ is\ the\ total\ power\ demand\ of\ the\ system$

7) Calculate the power to be generated by each generating unit.

8) Set a tolerance Lambda, λ value for the calculations.

SOFTWARES USED

GAMS

The General Algebraic Modeling System (GAMS) is a modeling tool for mathematical programming and optimization purpose. It can be used in solving different types of optimization problems [20].

MATLAB

Matlab is a programming language for technical computing developed by MathWorks. It allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces and interfacing with programs written in other languages such as C, Java, Python [21].

CHAPTER THREE

METHODOLOGY

3.1 Mathematical models to determine the power generated by each generator

The power generated available from falling water can be expressed as,

$$P = \mu \rho Q g H \text{...} (9)$$

where μ = efficiency (in general in the range 0.75 to 0.95), P = power generated (W), ρ = density (kg/m^3), Q= water flow (m^3/s), g = acceleration of gravity (9.81 m/s^2) and H = falling height, head (m).

The parameters of the case study **(**Muvumbe Hydro (U) Ltd**)** are as follows; Plant head, H = 115 m, The density of water, ρ is 1000 kg/m^3

The power generated, P is given by,

$$P = Q * \mu * 1000 * 9.81 * 115 \text{..} (10)$$

The water flow rate (m^3/s) is given by,

$$\mathbf{Q} = \frac{P}{\mu * 1000 * 9.81 * 115} \text{..} (11)$$

But μ_1 = 0.939 and μ_2 = 0.918 for unit 1 and unit 2 respectively.

Hence;

Q1=.000000471*p1 and Q2=.000000482*p2

The power generated by each generator can be obtained by;

$$P1 = k * P1Max * Q1 * \mu1 * 1000 * 9.81 * 115 \text{..} (12)$$
$$P2 = \frac{1}{k} * p2max * Q2 * \mu2 * 1000 * 9.81 * 115 \text{..} (13)$$

Where k is a factor multiplied by P_{1Max} to get the optimized power generated by unit 1 and P_{2Max} is divided by the factor k to obtain the optimized power of unit 2. The factor k is constant equal to 1.66.

The minimum power generated by unit1, P_{1Min} = 450 KW

The minimum power generated by unit2, P_{2Min} = 800 KW

The maximum power generated by unit1, $P_{1Max} = 2.5$ MW

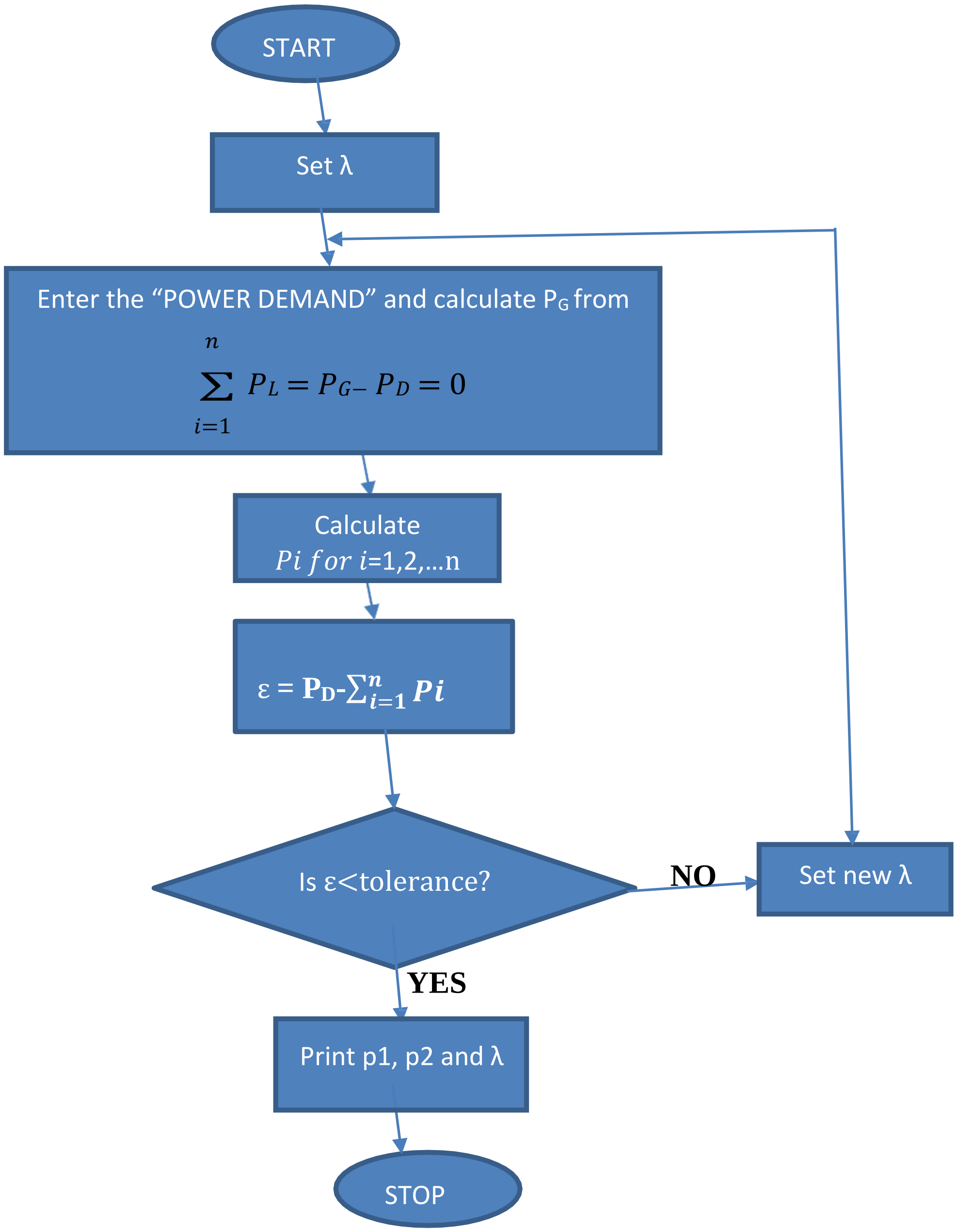
The maximum power generated by unit2, $P_{2Max} = 4.0$ MW

The total generating capacity of Muvumbe Hydro (U) Ltd is **6.5 MW**.

These mathematical models can be implemented by any programing languages to obtain how much power each generator should output for optimization. For this project MATLAB is used to develop a program that dispatches the loads between the two generating units.

3.3 AN OPTIMIZATION PROGRAM USING MATLAB.

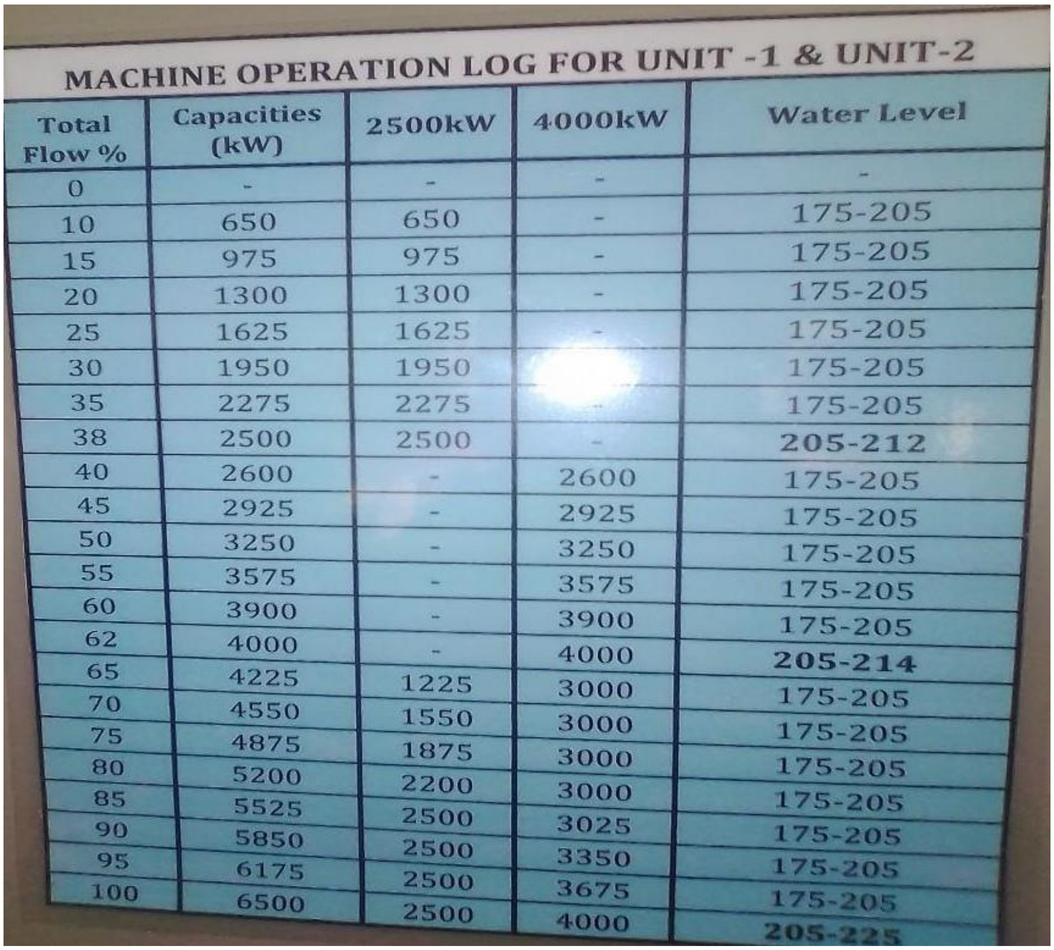
Flow chat of the Matlab program



Generation at Muvumbe hydro (U) Ltd

The two generating units at Muvumbe hydro (U) Ltd are set to generate load power according to transmission pre-set maximum power the small power plant should generate since its contribution to the total load power generated is insignificant compared to big power plants such as Nalubale power plant and Isimba hydro.

The chart in figure 3 guides the machine operators on how much power to generate according to the water levels.



MACHINE OPERATION LOG FOR UNIT -1 & UNIT-2

Total Flow %	Capacities (kW)	2500kW	4000kW	Water Level
0	-	-	-	-
10	650	650	-	175-205
15	975	975	-	175-205
20	1300	1300	-	175-205
25	1625	1625	-	175-205
30	1950	1950	[illegible]	175-205
35	2275	2275	-	175-205
38	2500	2500	-	205-212
40	2600	-	2600	175-205
45	2925	-	2925	175-205
50	3250	-	3250	175-205
55	3575	-	3575	175-205
60	3900	-	3900	175-205
62	4000	-	4000	205-214
65	4225	1225	3000	175-205
70	4550	1550	3000	175-205
75	4875	1875	3000	175-205
80	5200	2200	3000	175-205
85	5525	2500	3025	175-205
90	5850	2500	3025	175-205
95	6175	2500	3350	175-205
100	6500	2500	3675	175-205
		2500	4000	205-225

Figure 3: Generation log for both units.

Figure 3 shows the load power to be generated by each unit depending on the water level and the total flow.

As the total water flow increases, the load power to be generated is also increased. This demands for more water from the Forebay tank and the discharge rate of generator turbines increase. When the water flow rate goes to 100 the generators can be operated at full load capacity (2.5 and 4.0) KW.

RESULTS AND DISCUSSIONS

Economic load dispatch problem has been solved using lambda method. The validity of the proposed techniques has been verified on a two generator set for a demand of 650 KW to 6.5 MW. The objective function that is the cost of generation was solved using the proposed optimization techniques to get desired results for the two generator sets. All the lambda method based optimization was done in MATLAB R2015a on 64 bit Intel duo Core Computer with 4 GB RAM Windows 10 operating system. Using MATLAB to run the program created to solve the problem, the values in the table 2 are obtained.

Table 2: First results using MATLAB.

First results using MATLAB				
%age flow (%)	**Capacities (kw)**	P_1 **2.5(MW)**	P_2 **4.0(MW)**	**Water level**
0	0	0	0	BELOW175
10	650	0.2507	0.3993	175-205
15	975	0.3760	0.5990	175-205
20	1,300	0.5014	0.7986	175-205
25	1,625	0.6267	0.9983	175-205
30	1,950	0.7520	1.1980	175-205
35	2,275	0.8774	1.3976	175-205
38	2,500	0.9642	1.5358	**205-212**
40	2,600	1.0027	1.5973	175-205
45	2,925	1.1281	1.7969	175-205
50	3,250	1.2534	1.9966	175-205
55	3,575	1.3788	2.1962	175-205
60	3,900	1.5041	2.3959	175-205
62	4,000	1.5427	2.4573	**205-214**
65	4,225	1.6294	2.5956	175-205
70	4,550	1.7548	2.7952	175-205
75	4,875	1.8801	2.9949	175-205
80	5,200	2.0055	3.1945	175-205
85	5,525	2.1308	3.3942	175-205
90	5,850	2.2561	3.5939	175-205
95	6,175	2.3815	3.7935	175-205
100	6,500	2.5068	3.9932	**205-225**

Table 2 shows the results of P_1 and P_2 obtained from running the MATLAB program for solving the load dispatch. Since the discharge rate of generator turbine 1 is less than that of generator turbine 2, it makes unit one suitable for generation when water levels are low. This drains less water from the forebay tank compared to using generator 2 and it gives a chance for increase in water levels.

Considering the minimum power generated by unit 1, P_{1min} = 450 KW and the minimum power generated by unit2, P_{2Min} = 800 KW. Unit one is used for low water levels but with increase in the water levels both units are operated. On comparison of the results from the table 2 and the machine operation log from Muvumbe, results that yield lesser water discharge are considered and put in table 3.

Table 3: Results based on comparison between the used generation log and MATLAB results.

Results based on comparison between the used generation log and MATLAB results				
Total flow (%)	**Capacities (KW)**	**2,500 KW**	**4,000 KW**	**Water level**
0	0	0	0	BELOW175
10	650	650	0	175-205
15	975	975	0	175-205
20	1,300	1300	0	175-205
25	1,625	1625	0	175-205
30	1,950	1950	0	175-205
35	2,275	2,275	0	175-205
38	2,500	1,000	1,500	**205-212**
40	2,600	1,000	1,600	175-205
45	2,925	1,125	1,800	175-205
50	3,250	1,250	2,000	175-205
55	3,575	1,380	2,195	175-205
60	3,900	1,500	2,400	175-205
62	4,000	1,500	2,500	**205-214**
65	4,225	1,625	2,600	175-205
70	4,550	1,750	2,800	175-205
75	4,875	1,875	3,000	175-205
80	5,200	2,000	3,200	175-205
85	5,525	2,125	3,400	175-205
90	5,850	2,250	3,600	175-205
95	6,175	2,375	3,800	175-205
100	6,500	2,500	4,000	**205-225**

During comparison the water discharged by each generator turbine is obtained by,

$$\mathbf{Q} = \frac{P}{\mu * \rho * g * H} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(14)}$$

$$\mathbf{Q} = \frac{P}{\mu * 1000 * 9.81 * 115} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(15)}$$

where Q – Water discharge rate (m^3/s), P – Power generated, μ - The efficiency of the turbine, H - The plant head from the machine floor to the Forebay tank, ρ - Water density (kg/m^3) and g - Acceleration due to gravity ($9.81\ m/s^2$).

On substituting the values of μ for both turbines in equation 15, equations 16 and 17 are obtained.

$$\mathbf{Q1 = 0.000000943P1} \qquad (16)$$

$$\mathbf{Q2 = 0.000000965P2} \qquad (17)$$

The total amount water discharged by the generator turbines is obtained by adding $\mathbf{Q_1}$ and $\mathbf{Q_2}$;

$$\mathbf{Q = Q1 + Q1} \qquad (18)$$

Q is calculated for both old chart (figure 3) and the newly generated table (table 2) and the results are compared. If results which give the needed load power at less water discharge are considered in the new table (table 4) then the results that give more water discharge for the same load power are neglected.

Table 4: Discharge for both approaches and %water saved after optimization.

Comparing water discharged(**Q**) using the Old and the New approach				
Total flow	$\mathbf{Q_{OLD}}$	$\mathbf{Q_{NEW}}$	$\mathbf{Q_{OLD} - Q_{NEW}}$	**%Water saved**
0	**0**	**0**	**0**	**0**
10	**6.13**	**6.22**	**-0.09**	**-1.45**
15	**9.19**	**9.33**	**-0.14**	**-1.50**
20	**12.26**	**12.43**	**-0.17**	**-1.37**
25	**15.32**	**15.54**	**-0.22**	**-1.42**
30	**18.39**	**18.65**	**-0.26**	**-1.39**
35	**21.15**	**21.76**	**-0.61**	**-2.90**
38	**23.36**	**23.91**	**-0.55**	**-2.30**
40	**25.09**	**24.87**	**0.22**	**0.88**
45	**28.23**	**27.98**	**0.25**	**0.89**
50	**31.36**	**31.09**	**0.27**	**0.87**
55	**34.45**	**34.19**	**0.26**	**0.76**
60	**37.64**	**37.30**	**0.34**	**0.92**
62	**38.60**	**38.26**	**0.34**	**0.90**
65	**40.50**	**40.41**	**0.09**	**0.20**
70	**43.57**	**43.52**	**0.05**	**0.11**
75	**46.63**	**46.63**	**0**	**0**
80	**49.70**	**49.74**	**-0.04**	**-0.08**
85	**52.77**	**52.85**	**-0.08**	**-0.02**
90	**55.90**	**55.96**	**-0.06**	**-0.01**
95	**59.04**	**59.06**	**-0.02**	**-0.03**
100	**62.18**	**62.18**	**0**	**0**

Table 4 shows the comparison of the two approaches and the difference in water discharged ($\mathbf{Q_{OLD} - Q_{NEW}}$) is used to calculate the percentage water saved if the new approach is chosen over the old one.

From total flow 80 to 100 the difference in water saved is very negligible and any approach you choose gives you almost the same results. This is a limitation to the new approach for solving the problem.

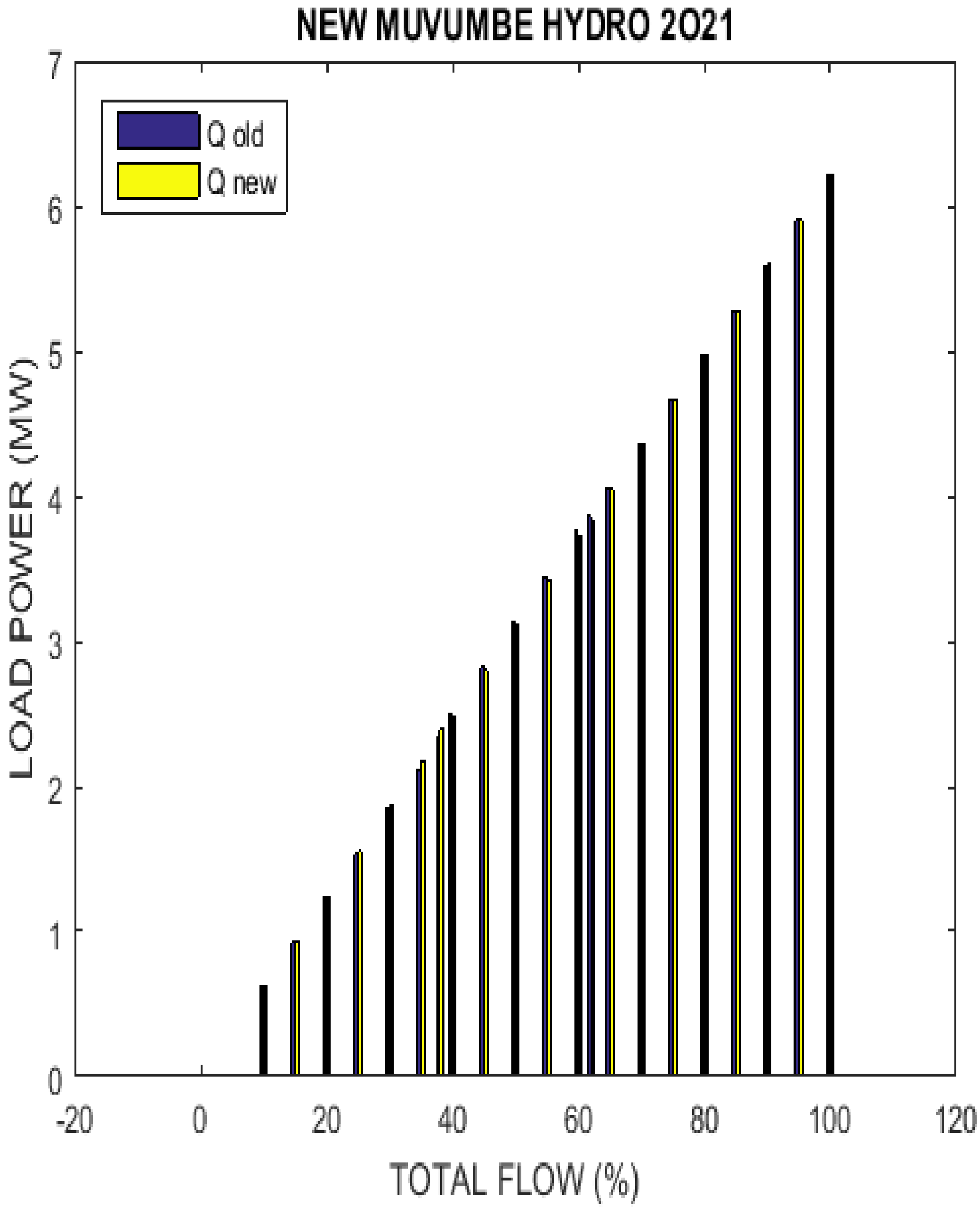


Figure 4: load power against the total flow for Qold and –Qnew.

Figure 4 shows the plot of power generated against the total percentage flow. The shorter the bar the better the approach and the bars represent the total water discharged by both turbines. The total water discharged (**Q**) is proportional to the total flow.

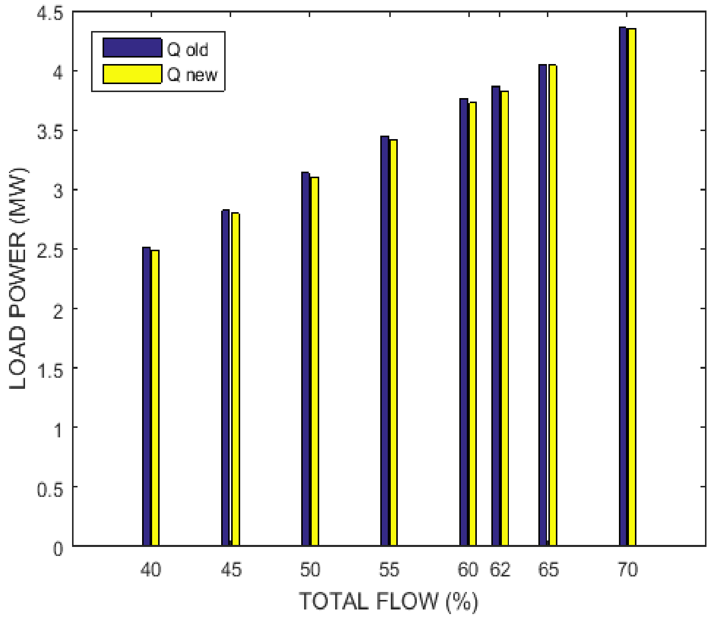


Figure 5: load power against total flow (from 40 to 70) for Qold and Qnew.

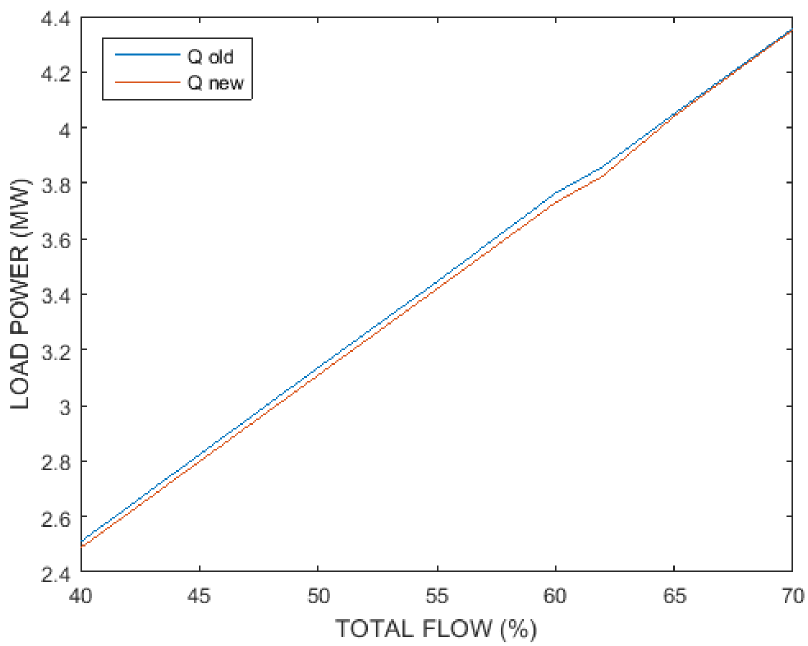


Figure 6: A line graph of load power against total flow (from 40 to 70) for Qold and Qnew.

Figure 5 and 6 show a bar graph and a line graph for the total flow ranging from 40 to 70. From the graphs it is shown using the new approach, the generator turbines discharge less water compared to using the old approach when generating the same load power.

CHAPTER FOUR

CONCLUSION AND RECOMMENDATIONS

4.1 CONCLUSION

Increase in load power generated demands increased water discharge by the generator turbines. This call for optimized load scheduling to use the least possible amount of water to produce the maximum power demand. In this project, lambda optimization techniques have been implemented to solve economic load dispatch problem and the obtained results have been compared. Lambda iteration method is a conventional method. These techniques are used to solve economic load dispatch which only considers the generator constraints. We later considered the power flow constraints to assess the effect of these constraints considered. The results obtained show that there is a change in the data obtained compared to the generation log values the power plant has been basing on for generation.

Advantages of operating at full capacity

- Minimizes unit cost because the fixed costs per unit are at its lowest possible level
- Effectiveness
- Profits tend to be higher as it can generate high revenues
- The chance of reaching break-even point is high.

4.2 RECOMMENDATIONS

To satisfy the increased desire to maintain stability of power systems, the solution to optimizing hydro power generation in power plants should not only focus on economic optimization but also ensure reliability of system operations at lowest cost possible.

To ensure low cost production of hydro power generation power plant maintenance should be observed to the highest level. This enables generators and other machines to operate in good mechanical conditions.

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APPENDIX

The MATLAB code

```
clc
clear all
close all

p=0;

syms p1

syms p2

syms M

%The minimum power generated by unit1, P1Min = 450 KW
P1Min = 450;

%The minimum power generated by unit2, P2Min = 800 KW
P1Min = 800;

%The maximum power generated by unit 1 in MW.
p1max = 2.517

%The maximum power generated by unit 2 in MW.
p2max = 4.183

% a prompts a user to input the maximum generation demand
a=input('ENTER THE TOTAL POWER DEMAND@MUVUMBE HYDRO(MW)=');

% Q1 and Q2 are the water discharge formulae for unit 1 and unit 2
q1=.000000471*p1.^2;

q2=.000000482*p2.^2;

% The total power demand p to be generated by both units should be
% equivalent to the user input
p=p1+p2==a;

% power generated by both units at peak water discharge.
discharge1=1.662*p1max;
discharge2=p2max/1.662;
```

```
f1=discharge1*q1;
f2=discharge2*q2;


% differentiating d1 and d2 with respect to power generated %
d1=diff(f1,p1)==M;
d2=diff(f2,p2)==M;

sol=solve(d1,d2,p);
p1=double(sol.p1)
p2=double(sol.p2)

% calculating lambda
lambda=double(sol.M)
```

Figure 7: Muvumbe Hydro (U) Ltd.

Figure 8: Generator nameplate.

Figure 9: Hydraulic turbine name plate for unit 1.

Figure 10: Hydraulic turbine name plate for unit 2.