NETWORK IMPLEMENTATION PETRI NET MODEL FOR LAXAPANA POWER PLANT COMPLEX

A dissertation submitted to the
Department of Electronic & Telecommunication Engineering,
University of Moratuwa
in partial fulfillment of the requirements for the
Degree of Master of Science

by

D.T.Ganegoda
(148457G)

Supervised by: Dr. Upeka. Premaratne

Department of Electronic & Telecommunication Engineering
University of Moratuwa, Sri Lanka

July 2019

DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a Degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Also, I hereby grant to University of Moratuwa the non-exclusive right to reproduce and distribute my thesis, in whole or in part in print, electronic or other medium. I retain the right to use this content in whole or part in future works (such as articles or books).

…………………………… ………………………

Signature of the candidate Date:

The above candidate has carried out research for the Masters Dissertation under my supervision.

…………………………… ………………………

Signature of the supervisor Date

(Dr Upeka. Premaratne)

Acknowledgments

I would like to acknowledge and express my heartfelt gratitude to my supervisor Dr.Upeka Premaratne, Senior Lecturer, Department of Electronic and Telecommunication Engineering, University of Moratuwa and Eng.A.L.Deshapriya for being with me in each and every step which took this research into a success while giving vital encouragement.

I am also heartily thankful to the coordinators of the MSc in Electronics and Automation Engineering programme and, all the staff members of department of Electronic and Telecommunication Engineering, University of Moratuwa.

I am grateful Eng.A.L.Deshapriya and my parents and wife for encouraging me toward this task.

Abstract

Laxapana Hydro Power complex consists of five Reservoirs & five Power stations. These power stations are located along the Kehelgamuwa Oya & the Muskeli Oya.

The total capacity of the Laxapana Complex is 354.8Mw and 13 Generators contribute their service to fulfill the service. It does not have a precise method to schedule these Generators. The Rule of thumb methods derived from past experiences is the only methodology which is used to schedule the generators. There is a cascaded system operating from water levels & flow rates of the reservoirs. it is essentially required a special Modeling Technique to optimize as the water level & the flow rates of the reservoirs are unpredictably change time to time.

It had been used a generator optimization method via Petri net Software by Engineer Lankanath. The purpose of this research is implementing the system after studying these data.

Most of the researches have been based on analyzing the previous data but in this (my) research real time data is used for the requirement. In this case, water flow rates, water levels data is rapidly acquired by the control system. Moreover all the data of generators are gained by the system.

It is decided the procedures & quantities which the generators should operate after analyzing all this data and it is monitored whether they work properly.

Eventually, Procedures & Preventive Maintenance dates etc. are decided & displayed by the AI after analyzing the data acquired. Because of this it is possible to optimize power with less failure.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

IoT	Internet of Things
DSM	Global System for Mobile Communication
ASIC	Application Specific Integrated Circuit
ANN	Artificial Neural Network
M2M	Machine to Machine
GUI	Graphical User Interphase
LCD	Liquid Crystal Display
MQTT	Message Queuing Telemetry Transport

CHAPTER-1

Introduction

1.1 Motivation

1.1.1 Importance of Hydropower in Sri Lanka

Hydro Electrical power generation is the most success & the most economical method of power generation to fulfill the power requirement of the countries like Sri Lanka as there are adequate water resources. But when considering the increasing power demand, it is not sufficient at all. Hence Hydro Power plants provides the required electrical power in collaboration with thermal &Coal Power plants.

The maximum electrical power requirement of the country has been provided by the Thermal Power Plants for the last few years.

Table1. 1Power generation table of previous 5 years

Power Generation Sri Lanka(GWh)					
	2012	**2013**	**2014**	**2015**	**2016**
CEB Hydro	2726.7	6010.1	3649.7	4904.4	3481.9
Thermal	8416.5	4819.7	7944.3	6800.7	9630.0
Wind	2.3	2,3	2.1	1.1	2.1
New Renewable Energy	733.3	1168.7	1215.4	1466.0	1157.8
Net Metering	0	4.7	18.6	38.8	70.7
Self-Generation	0	0	0	0	0
Off Grid-Conventional	0	0	0	0	0
Off Grid-non Conventional	18.8	18.8	18.8	18.8	18.8
Gross Power Generation	**11897.6**	**12024.3**	**12848.9**	**13229.8**	**14361.3**

Again, it is being tried by the Engineers to develop the Hydro Power Generation due to the increasing Electrical Power demand &fuel price.

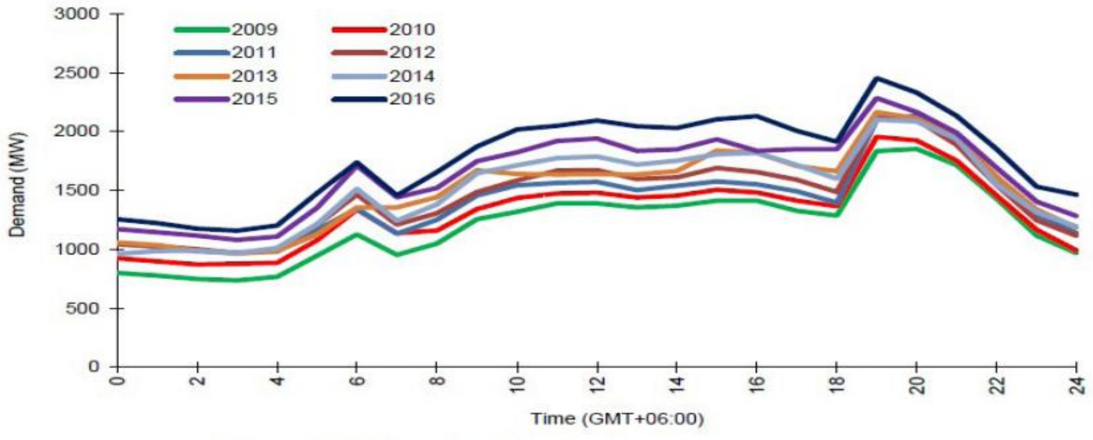

Figure1. 1Electrical power demand in srilanka

Because of the above fact, it is required to generate maximum electrical power from the Hydro Power plants. [1]

The maximum Electrical Power generation is being provided by the Lakshapana Complex comparing with the other Hydro Power plants in the country.

Table1. 2Power generation table of Laxapana complex previous 5 years

Gross Generation in Laxapana Complex (GWh)					
	2012	**2013**	**2014**	**2015**	**2016**
Laxapana PS	177.30	339.28	292.31	314.34	236.66
Wimalasurendra PS	74.32	168.64	114.89	131.00	84.69
Samanala PS	246.98	465.11	332.49	387.52	324.85
New Laxapana PS	300.33	628.18	304.09	474.87	431.42
Canyon PS	85.98	212.85	101.25	136.49	122.73
Total	**884.91**	**1814.07**	**1145.03**	**1444.22**	**1200.34**

The main purpose of this research is studying about the methods which help to increase the Efficiency of the above mentioned power plant.

1.1.2 Laxapana Complex

Figure1. 2 Geographical Location of Laxapana Power Plant

Laxapana Complex is called as Kehelgamu-Maskelioya complex. Five Power stations are situated along the Kehelgamuwa Oya &Maskeli Oya.The main largest reservoir is Castlereagh which is situated at the highest place & two Generators (25 MW) are operated in the Wimalasurendra Power Station from the water of this reservoir. After that the water is collected to the Norton Pond Reservoir & five Generators are operated in the Old Laxapana Power Station. Three of these generators are 9.6MW & two of them are 12.5MW. Then water is collected to the Laxapana pond. Accordingly the water is collected to the Maussakele Reservoir & generates 30MW electricity and then flows in to Canyon Pond. This water operates two turbines (each 58MW) in the New Laxapana Power Station and then flows & collected in the Laxapana pond. [1]

Two turbines (37.5 MW each) are operated using the water in the Laxapana pond. Accordingly the total installed Capacity of the Power Generating Scheme is 354.8 MW.But it does not have a precise methodology to schedule the generator loads & to regulate the water levels of the pond. It was found that there are different types of

Optimization Research Details during my Literature Survey. The Generator Optimization Research using Petri-Net software by Eng. Lankanath has a special place among the above mentioned surveys. But the most of the researches are only based on past experience & past Data records. The other thing is most of them are simulators. Hence it is a must to have a method to optimize generators according to real data which varies rapidly.

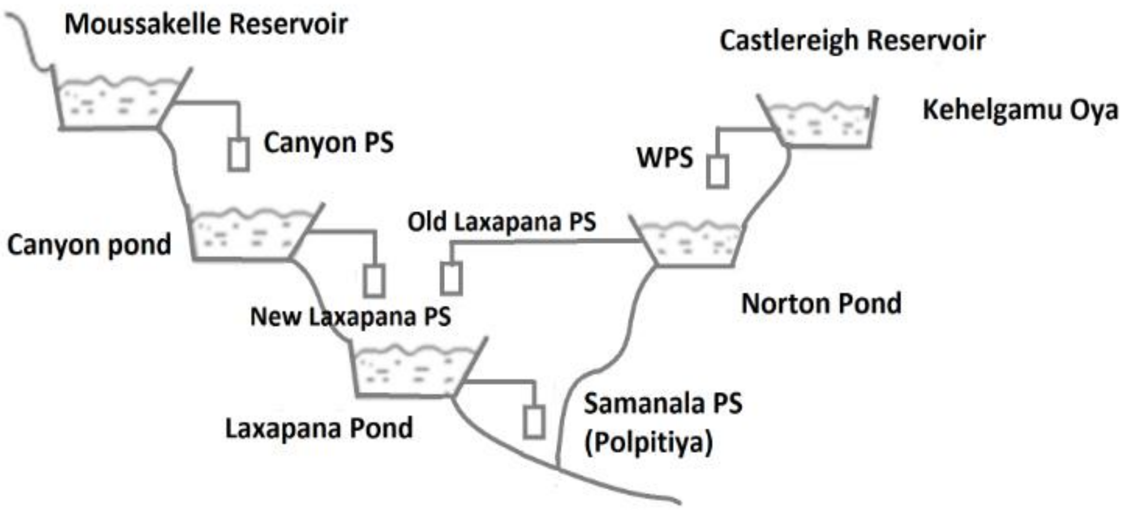

Figure1. 3Reservoirs and plants of Laxapana complex

1.2. Objective

The objective of this thesis is network implementation a petri net model of the Laxapana power complex system in order to optimize the generator dispatching of the Laxapana complex. This is expected to achieve from following principle milestones.

- Analyzing input outputs data (water flow rates, water level etc.) of the laxapana complex.
- Analyzing water flow rates, water level details in complex.
- Study the previous power optimization method using Petri -net software.
- Study the relationship between water level, flow rates, power demand and the generators priorities.
- Design the system to implement power optimization of the laxapana power plant.

CHAPTER-2

Literature review

2.1 Optimizing Hydroelectric Power Generation

The method of hydroelectric power generation is a very vital method which is used for electrical power generation using a renewable source. According to invention electrical power mainly depends on a few Systematic variables.[1]

They are,

- Plant efficiency
- The Volumetric water flow through the Turbine

The amount of generating Electrical Power can be calculated using simple mathematical equations.

During some periods of time, the maximum amount of water is flown through the Turbine from the Reservoir. But it is only possible to generate electricity up to the maximum capacity of the Turbine. During some periods of time water flow through the turbine is not enough to produce electricity. The amount of electricity that can be generated at Hydroelectric Plant depends on two factors.

The vertical distance through which waterfalls. It is usually refers as the head.

The rate of flow of water.

The basic equation that relates release with energy production in on hydroelectric system is,

$$kWH_t = 2725\ R_t H_t n$$

R_t = Release into the penstock in Mm^3

H_t = Head (m)

N = Efficiency of turbine

The efficiency values of the turbines are in the following table.

Table2. 1Generators efficiency percentages

SUMMARY OF EFFICIENCY OF VARIOUS PUMPS

Impulse turbines	
Prime Mover	Efficiency Range
Pelton	80-90%
Turgo	80-95%
Cross-flow	65-85%
Reaction turbines	
Prime Mover	Efficiency Range
Francis	80-90%
Pump-as-turbine	60-90%
Propeller	80-95%
Kaplan	80-90%
Water wheels	
Prime Mover	Efficiency Range
Undershot	25-45%
Breastshot	35-65%
Overshot	60-75%

2.3 Optimization of power output of a micro hydro power station using Fuzzy logic algorithm.

In this research study the electric power generation from the Kayabogazi dam has been investigated using Fuzzy logic algorithm to optimize the required power demand. They recorded real data of monthly average water flow of the Dam by the state water works. Turkey has an economic capacity of 128billionkWh hydroelectric energy per annum. The Kayabogaz Dam is commissioned on Kacacay River for irrigation and flood control purpose. The Dam is 237m long and volume is 628000m^3.after studying found the monthly average water flow and it varies from 2.86 to 7.11m^3/s. Then studying operation speed and head selected the suitable turbine type. After that use fuzzification and diffuzzification is done according to fuzzy rules.

2.4 Neural Network Based Optimum Model for Laxapana Hydro Power System

In this research [6] a range of historical data available, have been used to investigate and to evaluate the correlation between inputs and outputs. Artificial Neural Network (ANN) technology to model this system is explored by discovering a working mechanism of the system from the examples of past behavior. Then, by coupling the two neural network models, developed for generator load scheduling and pond water level monitoring, system was dynamically simulated to explore the feasibility of maximum electrical power generation, while keeping the pond water levels stable, within the feasible operating constraints. When evaluating the economic benefit, the relative unit costs of thermal and hydro have to be considered which depend on unit commitment constraints and water value respectively. This model optimizes the usage of water by generating the maximum possible electrical power, while keeping the water levels of the three ponds stable. During a period where the upper main two reservoirs are spilling or about to spill, extracting the maximum possible usage of water by generating the highest possible electrical power would be an obvious economic benefit irrespective of the thermal unit cost or the prevailing water value. In other situations the economic benefit depends on the relative prevailing water value and the thermal unit cost which involves with the unit commitment constraints.

2.5 Neural network based short term forecasting engine to optimize energy and big data storage resources of wireless sensor networks.

An energy efficient wireless network is the primary research goal for evolving billion device applications like IoT, smart grids and CPS. Monitoring of multiple physical events using sensors and data collection at central gateways is the general architecture followed by most commercial, residential and test bed implementations. Most of the events monitored at regular intervals are largely redundant variations leading to large wastage of data storage resources in Big data servers and communication energy at relay and sensor nodes Gateway generates an optimal transmit schedules based on NN outputs thereby reducing the redundant sensor data when there is minor variations in the respective predicted sensor estimates. It is observed that NN based load forecasting for power monitoring system predicts load with less than 3% Mean Absolute

Percentage Error (MAPE). Gateway forward transmit schedules to all power sensing nodes day ahead to reduce sensor and relay nodes communication energy. Mat lab based simulation for evaluating the benefits of proposed model for extending the wireless network life time is developed and confirmed with an emulation scenario of our testbed. Network life time is improved by 43% from the observed results using proposed model.

2.7 Comparative analysis of optimization methods applied to thermal cycle of a coal fired power plant

This research explained a thermodynamic optimization of 900 MW power units for ultra-supercritical parameters, modified according to AD700 concept. The aim of the study was to verify two optimization methods as examples the finding the minimum of a constrained nonlinear multivariable function and the Nelder-Mead method with their own constrain functions. The analysis was carried out using IPSE pro software combined with MATLAB, where gross power generation efficiency was chosen as the objective function. In comparison with the Nelder-Mead method it was shown that using fmincon function gives reasonable results and a significant reduction of computational time. Unfortunately, with the increased number of decision parameters, the benefit measured by the increase in efficiency is becoming smaller. An important drawback of fmincon method is also a lack of repeatability by using different starting points. The obtained results led to the conclusion, that the Nelder-Mead method is a better tool for optimization of thermal cycles with a high degree of complexity like the coal-fired power unit.

2.8 Modeling and simulation of unified Petri-net model for Laxapana hydro power complex.

This research is dedicated to developing a well-defined methodology to model the system characteristics and to getting the maximum hydro power generation from the Laxapana Complex. Laxapana hydro power complex consists with cascaded five reservoirs and five hydro power stations which are situated along Kehelgamu oya and Maskeli Oya. The main large reservoirs are Castlereagh and Maussakelle. Total capacity of the complex is 354.8 MW which comes from thirteen generators in five power stations. These generators are in different capacities with different types. Currently a precise methodology is not available to schedule generator loads and regulate pond water level. Only methodology used is the rule of thumb methods derived from past experience. This is a cascaded system operating from three levels which has complex other parameters that impact the characteristics of the system.

An algorithm is developed to identify the availability and non-availability of generators according to the different water level of reservoirs/ponds and different water in flows to the reservoirs/ponds. Generators are prioritized according to the water value of reservoirs/ponds. If the load dispatch tokens are issued to the system this model will distribute all tokens to generators by optimizing the usage of water and generate the maximum possible power. When load tokens are assigned to generators most priority generator start to run and increase the load of generators according to the assigned tokens. When there is a load reduction request, First load tokens are removed from least priority generator. If a generator is under maintenance, priority of particular generator will be cancelled. Similarly if the water levels of reservoirs are low and flow rates to the reservoirs are low, then the priorities of generators which are run using the water in particular reservoir will be cancelled.

2.9 Summery

A research conducted by Kayabager has used average water flow of the month record as input data to optimize hydro power plant.This data had been analyzed over a period of time to develop a model for optimizing generator. Fuzzy logic has been used for this process.

Many researchers have also done software simulation using Tools such as ANN for generator optimizing. A study conducted by Lankanath has developed a model using pertinent software by utilizing water flow rate, water level and water value.

Up to date research have been conducted using simulations but these researches have not been attempted to optimize generators using real data. Therefore, my research study intends to investigate the way that generator is optimized in a real system thereby to compare the results received by the simulation.

CHAPTER-3

Theoretical approach

3.1. Internet of Things

IoT means a vast network of devices connected to the Internet, including smart phones, tablets and almost anything with a sensor on it. These "things" collect and exchange data. An IOT platform makes it possible to develop, deploy, and manage IOT and M2M (Machine-To-Machine) applications. Automate processes and network connections, store and manage sensor data, connect and control devices, and analyze data. These days IOT has already become the trend and most of the devices have designed for this. Devices in the industries like automation, building services are closer to this technology.

IoT systems allow users to achieve deeper automation, analysis, and integration within a system. They improve the reach of these areas and their accuracy. The most important features of IoT include artificial intelligence, connectivity, sensors, active engagement, and small device use.

3.2 Basic Petri Net Notions

Mathematically, a Petri net (PN) (Figure 3.1) is defined as a 5-tuple [xxxx], PN = (P, T, A, W, M0) where:

$P = p1, p2, ..., pm$ is a finite set of places,

$T = t1,t2, ...,tn$ is a finite set of transitions,

$A \subseteq (P \times T) \cup (T \times P)$ is a set of arcs,

$W : A \rightarrow 1, 2, 3...$ is a weight function,

$M0 : P \rightarrow 0, 1, 2, 3...$ is the initial marking,

$P \cap T = \varphi$ and $P \cup T$ 6= φ

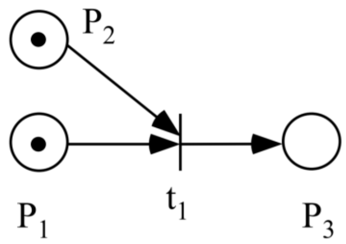

Figure 3.1: A simple petri net model

A PN consists of two types of nodes, called “places” (P) and “transitions” (T). Arcs (A) are either from a place to a transition (P × T) or from a transition to a place (T × P). Places are drawn as circles. Transitions are drawn as bars or boxes. Arcs are labelled with their weights (W), which take on positive integer values. The class of nets where we allow arc weightings greater than 1 are known as generalized Petri nets. When arc weightings are 1, the class is known as ordinary PNs. The ordinary PN is considered to be the common language linking various versions of PNs. Table 3.1 gives a few possible interpretations of the places and transitions.

Few possible examples of Interpretation of places and transitions are as follows.

Table 3.1: Possible interpretations of places and transitions

Input places	Transition	Output places
Resources needed	Task or job	Resources Released
Conditions	Clause in logic	Conclusion
Preconditions	Event	Postconditions

The marking at a certain time defines the state of the PN. The evolution of the state corresponds to an evolution of the marking, which is caused by the firing of transitions. A marking is denoted by M, an m × 1 vector, where m is the total number of places. The p th component of M, denoted by M(p), is the number of tokens in the p th place. The initial marking for the system represents the initial condition of the system and is denoted as M0.

The state of the PN evolves from an initial marking according to two execution rules: enabling and firing. In an ordinary Petri net, if all the places that are inputs to a transition have at least one token, then the transition is said to be enabled and it may fire. When an enabled transition fires, a token is removed from each of the input places and a token is placed in each of the output places.

3.3 Matrix Analysis

Figure 3.2 gives an example of firing a Petri net. The initial marking is M0 = (1 1 0 1 0)T as shown in Figure 3.2a. With a default arc weighting of one, transition t1 is enabled by the tokens in its upstream places p1 and p2. t1 then fires, resulting one token removed from p1 and p2 and one token put into p3 as shown in Figure 3.2b. The marking evolves to M1 = (0 0 1 1 0)T after the firing of t1. The tokens in p3 and p4 then enable transition t2, the firing of which results in a marking of M2 = (0 0 0 0 1)T , as shown in Figure 3.2c. Note that the number of the tokens is not necessarily conserved in a PN model.

Enabling rule:-

A transition, tj , of a PN is said to be enabled in a marking M if and only if M(pi) ≥ I(pi ,tj) for all pi which are members of the set of input places of tj .

Firing rule:-

An enabled transition can fire at any time and a new marking is reached according to the equation

$$M_k(p_i) = M_{k-1}(p_i) + O(p_i, t_j) - I(p_i, t_j)$$

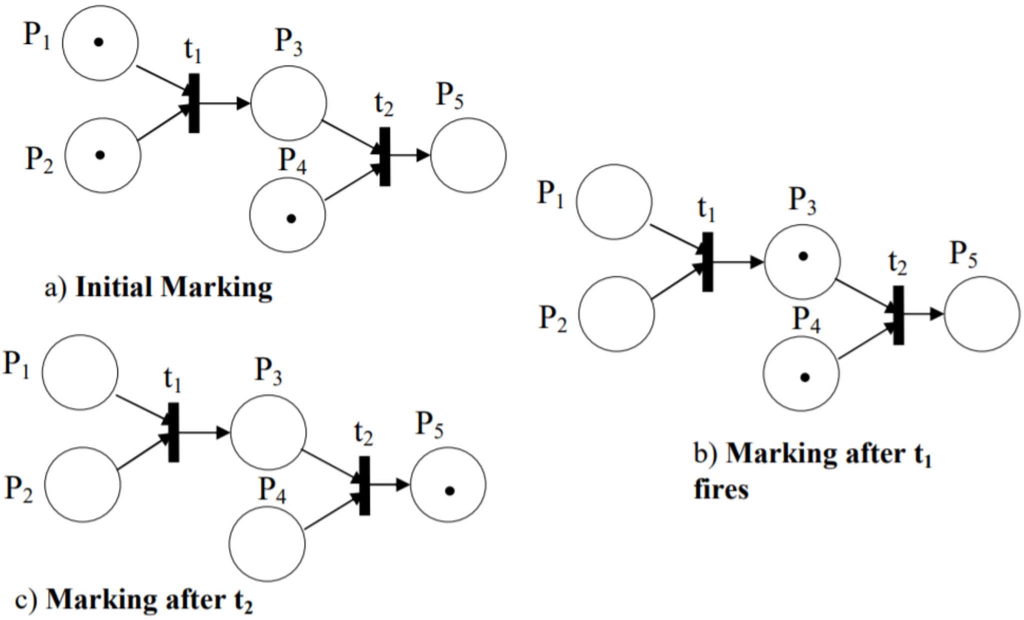

Figure 3.2: Possible interpretations of places and transitions

There are several behavioral properties of PNs.

- Reachability

Reachability is a fundamental basis for studying the dynamic properties of any system. A marking Mn is said to be reachable from a marking M0 if there exists a sequence of firings that transforms M0 to Mn. The set of markings reachable from M0 is denoted by R(M0).

- Boundedness

A Petri net (P, T, A, W, M0) is said to be k-bounded or simply bounded if the number of tokens in each place does not exceed a finite number k for any marking reachable from M0, i.e. $k \geq M(p)$ for every place p and every marking $M \in R(M0)$. A Petri net (P, T, A, W, M0) is said to be safe if it is 1-bounded. By verifying that the net is bounded or safe, it is guaranteed that there will be no overflows in the buffers or registers, no matter what firing sequence is taken, and that the number of tokens in a place will not become unbounded.

- Liveness

The concept of liveness is closely related to the complete absence of deadlocks in operating systems. A Petri net (P, T, A, W, M0) is said to be live if no matter what marking has been reached from M0, it is possible to ultimately fire any transition in the net by progressing through some further firing sequence. This means that a live Petri net guarantees deadlock-free operation, no matter what firing sequence is chosen.

- Reversibility

A Petri net (P, T, A, W, M0) is said to be reversible if, for every possible marking reachable from M0, M0 is reachable from it. Thus, in a reversible net one can always get back to the initial marking or state.

3.3 Modeling power of petri nets

The typical characteristics exhibited by the activities in a dynamic event-driven system, such as concurrency, decision making, synchronization and priorities, can be modeled effectively by Petri nets.

1. Sequential Execution. In Figure 3.3(a), transition t2 can fire only after the firing of t1. This imposes the precedence constraint "t2 after t1." Such precedence constraints are typical of the execution of the parts in a dynamic system. Also, this Petri net construct models the causal relationship among activities.
2. Conflict. Transitions t1 and t2 are in conflict in Figure 3.3(b). Both are enabled but the firing of any transition leads to the disabling of the other transition. Such a situation will arise, for example, when a machine has to choose among part types or a part has to choose among several machines. The resulting conflict may be resolved in a purely non-deterministic way or in a probabilistic way, by assigning appropriate probabilities to the conflicting transitions.
3. Concurrency. In Figure 3.3(c), the transitions t1, and t2 are concurrent. Concurrency is an important attribute of system interactions. Note that a necessary condition for transitions to be concurrent is the existence of a forking transition that deposits a token in two or more output places.
4. Synchronization. It is quite normal in a dynamic system that an event requires multiple resources. The resulting synchronization of resources can be captured by transitions of the type shown in Figure 3.3(d). Here, t1 is enabled only when each of p1 and p2 receives a token. The arrival of a token into each of the two places could be the result a possibly complex sequence of operations elsewhere in the rest of the Petri net model. Essentially, transition t1 models the joining operation.
5. Mutually exclusive. Two processes are mutually exclusive if they cannot be performed at the same time due to constraints on the usage of shared resources. Figure 3.3(e) shows this structure. For example, a robot may be shared by two machines for loading and unloading. Two such structures are parallel mutual exclusion and sequential mutual exclusion.

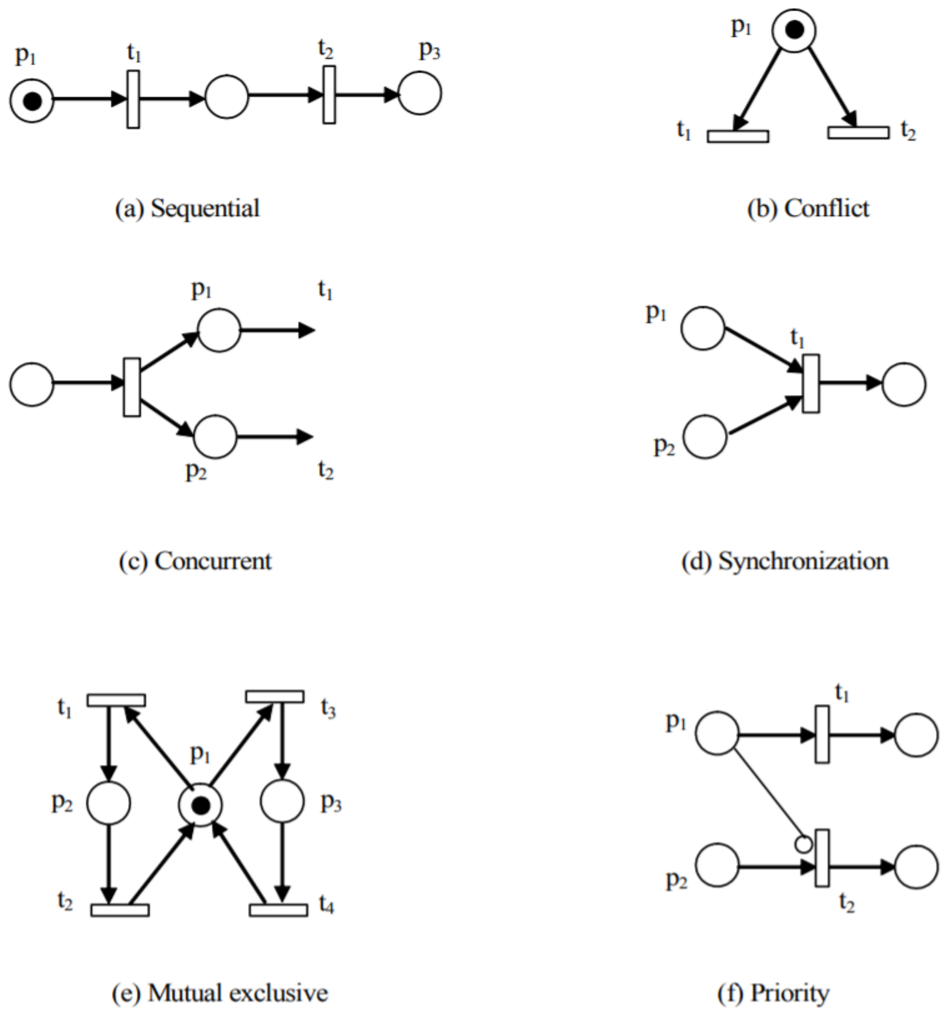

Figure 3.3: Characteristics of petri nets

6. Priorities. The classical Petri nets discussed so far have no mechanism to represent priorities. Such a modeling power can be achieved by introducing an inhibitor arc. The inhibitor arc connects an input place to a transition, and is pictorially represented by an arc terminated with a small circle. The presence of an inhibitor arc connecting an input place to a transition changes the transition enabling conditions. In the presence of the inhibitor arc, a transition is regarded as enabled if each input place, connected to the 5 transition by a normal arc (an arc terminated with an arrow), contains at least the number of tokens equal to the weight of the arc, and no tokens are present on each input place connected to the transition by the inhibitor arc. The transition firing rule is the same for normally connected places. The

firing, however, does not change the marking in the inhibitor arc connected places. A Petri net with an inhibitor arc is shown in Figure 3.3(f). t1 is enabled if p1 contains a token, while t2 is enabled if p2 contains a token and p1 has no token. This gives priority to t1 over t2.

CHAPTER-4

System analysis

4.1 Operational details of the Laxapana Power plant.

According to research Operation of the hydro generators in Laxapana complex depend on the water levels of the reservoirs/ponds, water level of the Kelani River, water in flow rates to reservoirs/ponds and most importantly the system demand.

In this context three levels of reservoir/pond levels and two levels of flow rates were calculated for each and every pond. Availability and non-availability of a generator is decided by considering these water levels and water in flow rates. A generator availability and non-availability criterion is in Table 4.1.

Table4. 1Generator availability Selection water levels and flow rates

Generator Capacity (MW)	Hydro power station	Only with water level (m MSL)	With water level and water in flow rate (m. MSL, m^3/s)
9.6	Old Laxapana	865	864.5, 538
9.6	Old Laxapana	865	864.5, 538
9.6	Old Laxapana	865	864.5, 538
12.5	Old Laxapana	865	864.5, 538
12.5	Old Laxapana	865	864.5, 538
58	New Laxapana	956	955, 464
58	New Laxapana	956	955, 464
37.5	Polpitiya	376.5	375.6, 1200
37.5	Polpitiya	376.5	375.6,1200
30	Caniyon	1147	Operate only with water level
30	Caniyon	1147	Operate only with water level

There are two main reservoirs and three ponds are in Laxapana complex. Generator capacities are presented in table 4.2.

Table4. 2Generator capacities in Lakshapana Complex

Power Station	Generator capacity (MW)	Number of Generators	Total capacity (MW)
Old Laxapana	9.6	3	28.8
	12.5	2	25
New Laxapana	58	2	116
Polpitiya	37.5	2	75
Canyon	30	2	60
Wimalasurendra	25	2	50
Capacity of the Laxapana			354.8

4.2. Description of the water flows in Laxapana complex

Flowing of the water of the complex is different with the generation mix and the season of the year due to the variation of the water inflow from catchment area of reservoirs/ponds, main two rivers and spilling of reservoirs/ponds.

High water level in downstream of Kelani River leads to floods in downstream areas. Therefore it is very essential to maintain the water level of Kelani River to avoid floods in downstream in rainy season. Water level of Ambatale reduces in the drought season. Water board distributes the water in Colombo by taking the water from Ambatale. Low water level in Ambatale leads to mix the Kelani river water with sea water. Therefore, water should be released from Polpitiya power station to flush the sea water back to the sea with water released from Polpitiya and make available the fresh water in Ambatale for intake from Ambatale. Therefore water flows within the Laxapana complex and water out flow from Laxapana complex should managed very carefully.

There are thirteen generators in the Laxapana complex in five different power stations which is feed by five power stations. Usage of generators depend on the water level of reservoirs/ponds, water in flows to the complex, water out flow from the complex, break downs of generators

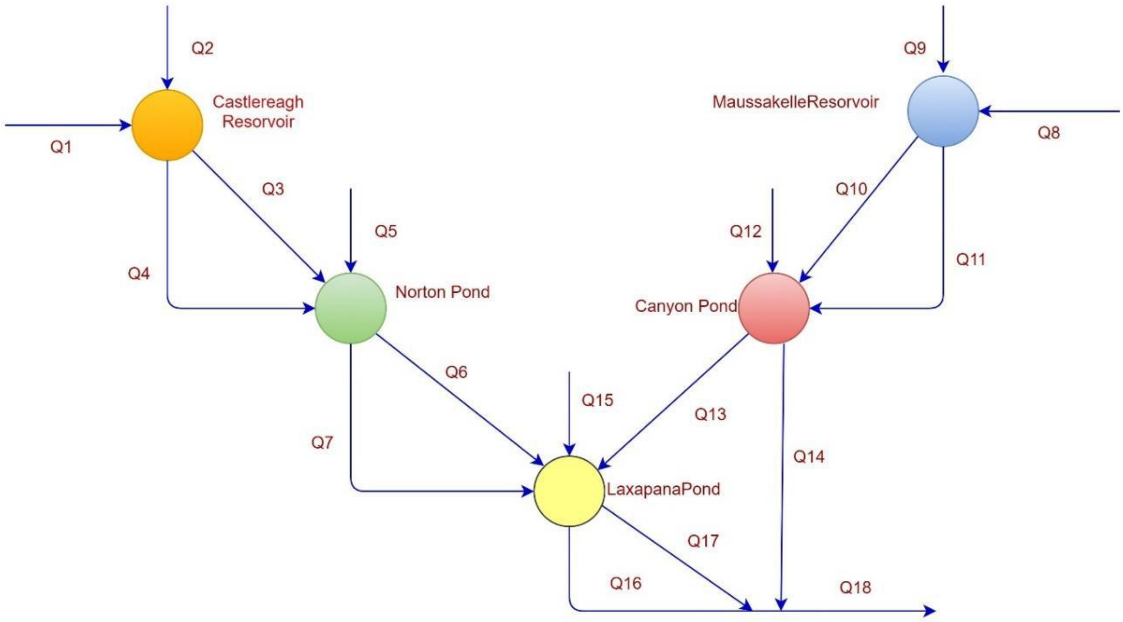

Figure 4. 1Water flow in Laxapana complex

Table4. 3Description of water flows in figure 4.1

in flow	description
q1	water in flow from kehelgamu oya
q2	catchment area inflow to castlereagh reservoir
q3	water in flow from wimalasurendra generators
q4	spilling water flow of catlereigh
q5	catchment area in flow to norton pond
q6	water in flow from old laxapana generators
q7	spilling water flow of norton
q8	water in flow from maskeli oya
q9	catchment area in flow to maskeliya reservoir
q10	water in flow from canyon generators
q11	spilling water flow of maussakelle
q12	catchment area in flow to canyon pond
q13	water in flow from new laxapana generators
q14	spilling water flow of canyon
q15	catchment area in flow to laxapana pond
q16	spilling water flow of laxapana
q17	water in flow from polpitiya generators
q18	water flow of kelani river

4.3. Priority list of generators in Laxapana complex

Initially generators are characterized according to the water value of reservoirs/ponds. Some generators got same priority after the categorization according to the water value. Water value of reservoirs was evaluated with the location of the reservoirs. Water value of reservoirs is changed from highest to lowest according to the following table.

1. Castlereigh reservoir
2. Maussakelle reservoir
3. Norton pond
4. Canyon pond
5. Laxapana pond

Such generators categorized again according to the efficiency curves of the generators. List of priorities for generators is shown in the Table 4.4

Table4. 4 Priority list of generators in Laxapana complex

Generator	Priority
Polpitiya,37.5 MW	1
Polpitiya, 37.5 MW	2
New Laxapana, 58 MW	3
New Laxapana, 58 MW	4
Old Laxapana, 12.5 MW	5
Old Laxapana, 12.5 MW	6
Old Laxapana, 9.6 MW	7
Old Laxapana, 9.6 MW	8
Old Laxapana, 9.6 MW	9
Canyon, 30 MW	10
Canyon, 30 MW	11
Wimalasurendra 25 MW	12
Wimalasurendra 25 MW	13

Water levels of reservoirs and ponds increase with the rain to the catchment areas of reservoirs. Hence the water levels of reservoirs depend on the rain. More Electricity can be generated with high water level of reservoirs. High electricity generation increases the releasing flow rates of water from reservoirs. Because of this water level of the Kelani River is increased and start to flood in downstream of Kelani River. High water levels in reservoirs can damage to the dam. If reservoirs spill over then the water is not fully utilized for power generation. Water levels of lower ponds must maintain below the spill level if water levels of higher reservoirs are not in the spill level, unless the catchment areas of lower level ponds get the rain. When the water levels of lower level ponds are in spill level, all generators fed by lower level ponds should run in full load. High water levels of reservoirs should be managed very carefully. Reservoir spill water levels and high flood water levels of reservoirs are presented as follows,

Table4. 5Reservoir spill water levels and high flood water levels

Reservoir	Spill water level (m. MSL)	High flood water level (m. MSL)
Maussakelle	1167.4	1170.4
Castlereigh	1094.5	1096.4
Canyon	962.3	963.2
Norton	866.9	870.2
Laxapana	380.1	381.0

Petri-net system for generators

5.1 Introduction

This chapter describes developing of the petri net model for single generator by selecting the places, transitions and arcs.

5.2 Petri net model for a generator

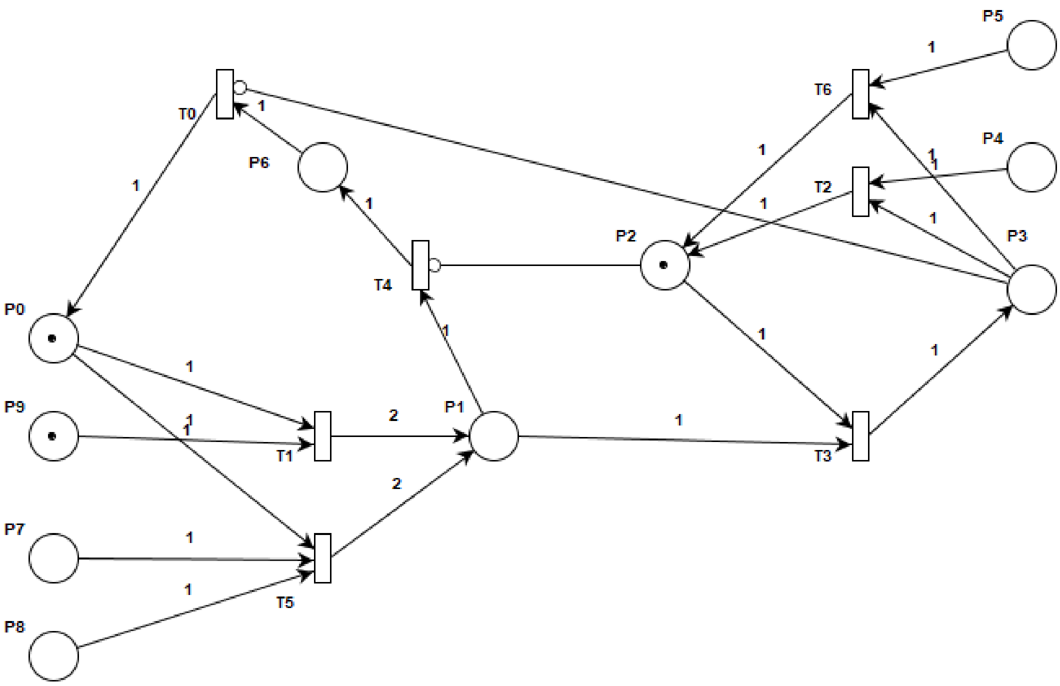

Figure 5.1: Petri net model for hydro generator

Table 5.1: Places and transitions of PN model of hydro generator

Place/ Transition	Notation	Meaning of Place or Transition
Places	P0	Generator is not available
	P1	Generator is available
	P2	Generator is not working
	P3	Generator is working
	P4	Generator stop command – Emergency & planned
	P5	Generator stop command due to the water level
	P6	Generator is working and also available
	P7	Water level L2 triggered
	P8	Flow rate F2 triggered
	P9	Water level L3 triggered
Transitions	T0	Generator availability changes availability to non availability
	T1	Generator availability changes not availabile to availabile due to the high water level
	T2	Generator stop due to Emergency & planned stop command
	T3	Generator starting transition
	T4	Generator status changes availability to availability when it is running
	T5	Generator availability changes not availabile to availabile due to the medium water level and considerable water flow rate
	T6	Generator stop due to low water level

5.3 Operation of the petri net model of generator

Initially generator is not working which is denoted by tokens in P0 and generator is not available for operation which is denoted by tokens in P2. P9 place gets a token when the water level reaches L3 and enables the transition T1. Marking of the model after the presence of tokens in P0, P2 and P9 is represented in figure 5.1. Then T1 fires and tokens in P0 and P9 move to P1. It will mark the generator as available in the petri net model. Marking of the petri net model is changes as per the table 5.3. Changes of the markings of the places are highlighted in grey colour in the following table and for all changes of markings in this document are highlighted in grey colour.

Table 5.2: Marking of the PN model for generator availability with water level

	P0	P1	P2	P3	P4	P5	P6	P7	P8	P9
M0	1	0	1	0	0	0	0	0	0	1
M1	0	2	1	0	0	0	0	0	0	0

6.1 Introduction

Laxapana Complex

Laxapana Complex has five (5) Reservoirs & thirteen (13) Generators. It is always required to get data of Water flow rates & Water Level of each reservoir by the plant. This Raw data which is collected from reservoirs is sent to power stations. According to the power demand, it is decided the procedure & quantities which the generators should operate after analyzing data such as Flow Rate, Water Levels & Flood Conditions of reservoirs.

After that, all this data is displayed on Graphical User Interface. Status, percentages & Temperature data of Generators is sent to the Control Room. It is possible to verify at the control room whether the Generators work properly.

It is decided the procedure of power optimization & predictions after analyzing all the data received -how the generators work throughout the past years, flow rates & water levels.

It is possible to supply electricity at a maximum efficiency & to minimize failures according to power demand. In addition to that, it is possible to process preventive maintenance to minimize failures as continuous analyzing of data of Generators.

6.2 Block Diagram of the System

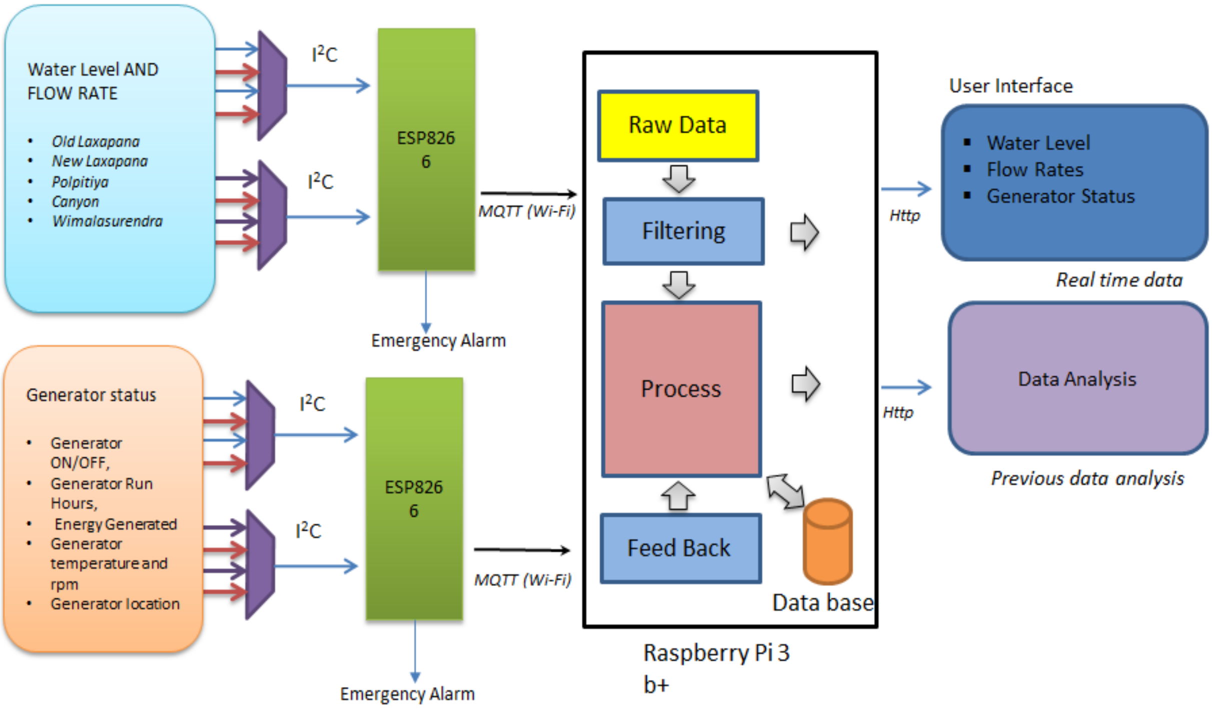

Figure 6. 1Block diagram for the system

According to the Block Diagram, inputs such as water flow rates, water levels of reservoirs are collected by the ESP 8266. Then they are provided to the Control System via Wi-Fi to process. MQTT technology is used to send this data. Raspberry PI is used to analyze that data. After the data is being analyzed by the Raspberry PI it is decided how the generators should operate & at what percentages.

After that data is displayed on GUI & the data is processed after it is being filtered inside the Raspberry PI. Here the required data is stored in a Database. The Details of the generators are collected by the ESP 8266 Module & provides to the Raspberry PI as usual.

That data is also displayed on the GUI & it is verified whether the generators work properly.

6.3 Flow chart of the system

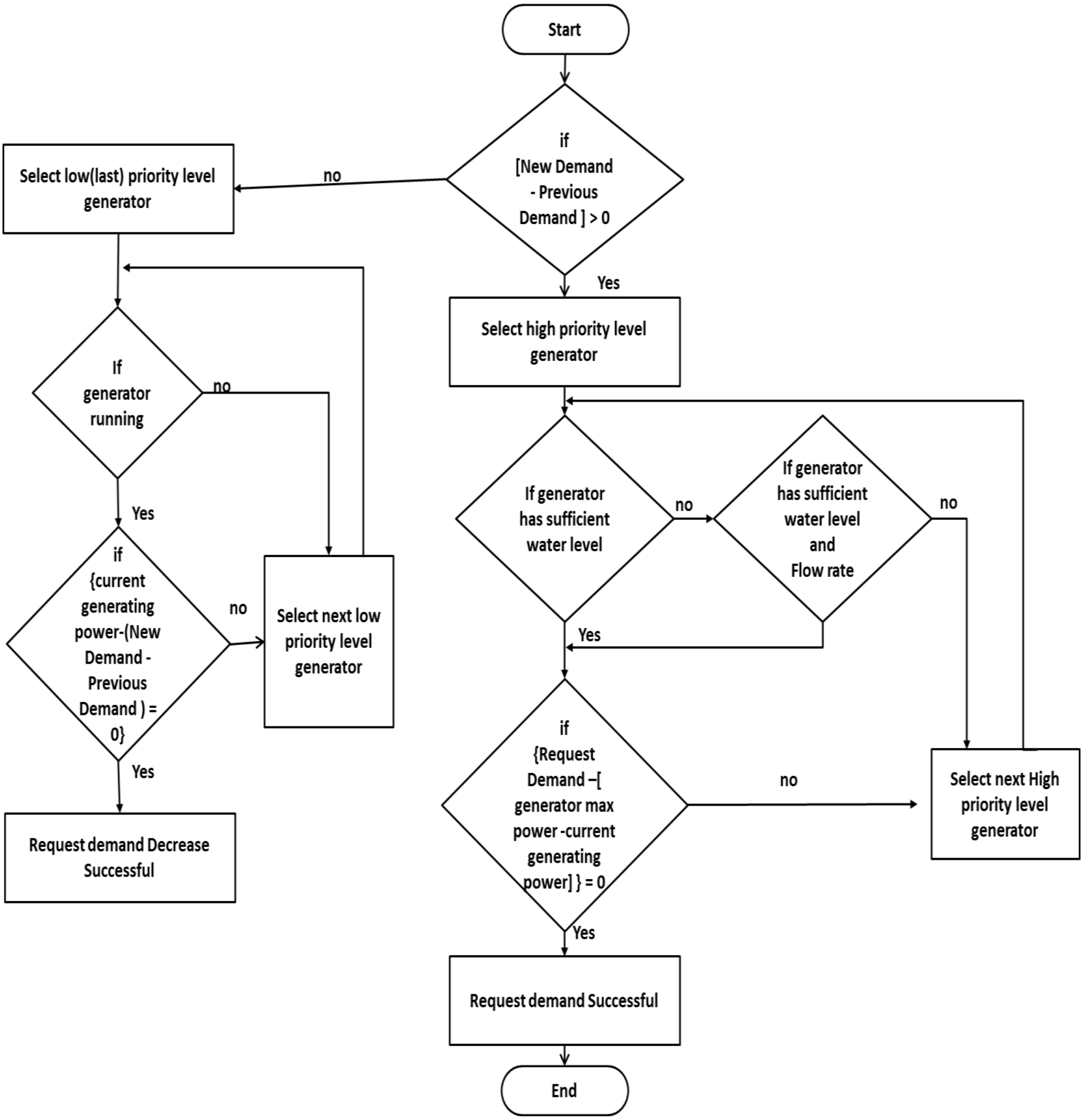

Figure 6. 2Flow chart for the system

Steps of the flow chart

- First consider the new electrical power demand and the previous power demand of the system.
- Then calculate power difference new demand and the previous demand.
- If power demand difference is plus value, select highest priority level from the generators.
- If power demand difference is minus value, select lowest priority level from the generators.
- Then check the highest priority generators related reservoir water level.
- If it has sufficient water levels, switch on the generator and calculate difference generator power and the request power demand.
- If reservoir hasn’t sufficient water level, consider water level with the flow rate.
- If it is sufficient, flow the previous procedure.
- If first priority generator generating powers not enough, select second priority generator.
- If power demand value is minus value, same follow same procedure in reverse order. It means first switch on from the last priority generators to first priority generator.

CHAPTER-7

Model designing

7.1 Introduction

Power generation of the Laxapana Power Plant is processed on the power demand and it is affected by the level & flow rates of water in the reservoir. Previous Petri-Net model is studied when creating the model for each generator. Two potentiometers are used to generate data of water level and flow rate. It was designed to get water level accurately to one decimal point adjusting these potentiometers. Two analog input ports of ESP 8266 board are used to get this data.

Emergency stop command and generator availability or not availability commands are provided using two more push buttons. The status of the generator is decided by the ESP 8266 board according to the water level, flow rates and power demand.

All these data is displayed on an LCD and data of generator status is showed in numbers from P-0 to P-9. The instructions are shown in below table which stands for the numbers from P-0 to P-9.

Table7. 1. Notation and meaning of the instructions.

Notation	Meaning
P0	Generator is not available
P1	Generator is available
P2	Generator is not working
P3	Generator is working
P4	Generator stop command – Emergency & planned
P5	Generator stop command due to the water level
P6	Generator is working and also available
P7	Water level L2 triggered
P8	Flow rate F2 triggered
P9	Water level L3 triggered

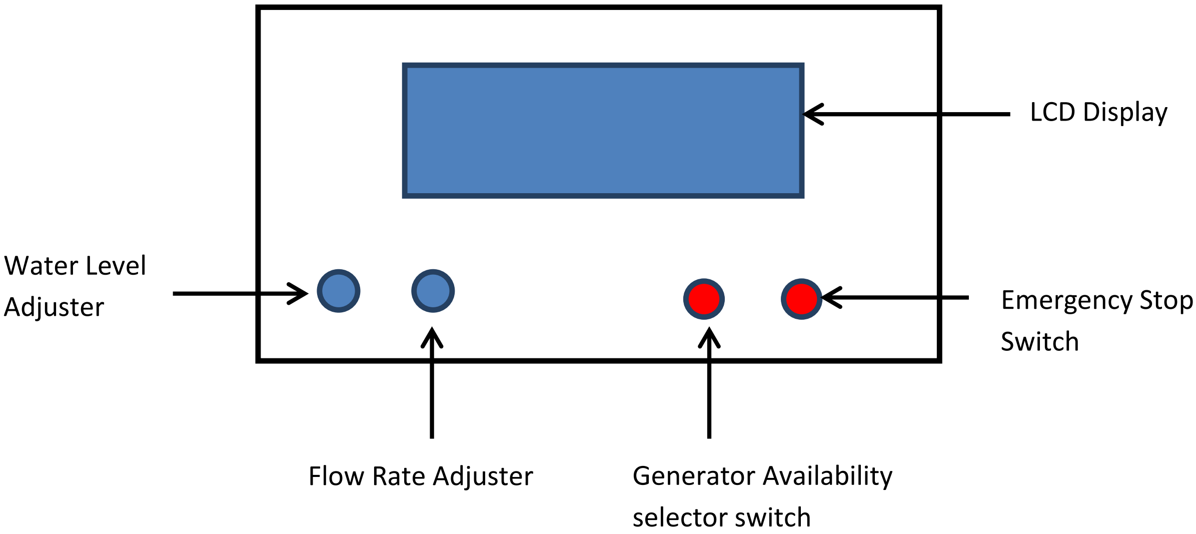

Figure7. 1 Components of the front panel

Figure7. 2Picture of the front panel on reservoir model

After studying for a long duration the water level and flow rates of the reservoir ponds, the main 3 water levels and 2 flow rates are selected.

L1< L2<L3

L1- lower water level

L2 – medium water level

L3 – maximum water level

F1<F2

F1 – minimum flow rate

F2 – maximum flow rate

7.2. Operation of the single generator model

At the beginning unless the generator works, it is displayed as P-2 & generator not working instruction is generated.

The availability of the generator is checked under this condition & this data is provided as P-0

P-9 instruction is shown after the reaching the water level to L3 level of the reservoir. Moreover the generator availability is changed **not available** to **available condition** due to the high water level.

According to this P-7 is enabled when reaching the water level to L- 2 position & the generator availability is changed **not available** to **available condition** due to medium water level and considerable water flow rate. With this P-0 and P-8 are moved to P-1 position.

After reaching the water level to L-1 lowest Operating water level, the related generators proceed to **STOP** and P-5 command is activated. These information is shown in the below table 7.2.

Table7. 2 Lowest operating water levels of reservoirs for generators

Generator Capacity (MW)	Hydro power station	Lowest operating water level (MSL) in meters
9.6	Old Laxapana	863.8
9.6	Old Laxapana	863.8
9.6	Old Laxapana	863.8
12.5	Old Laxapana	863.8
12.5	Old Laxapana	863.8
58	New Laxapana	953.4
58	New Laxapana	953.4
37.5	Polpitiya	374.3
37.5	Polpitiya	374.3
30	Canyon	1145.4
30	Canyon	1145.4
25	Wimalasurendra	1076.4
25	Wimalasurendra	1076.4

7.3. Operation of the Single Generator

Five models have been created separately for **Old Laxapana, New Laxapana, Polptitya, Canyon and Wimalasurendr**a power stations during the modeling process. Generator capacities of them are shown in the below table as main five power stations and all this data is transmitted via Wi-Fi.

Table7. 3 Power stations and Capacities.

Power Station	Generator capacity (MW)	Number of Generators	Total capacity (MW)
Old Laxapana	9.6	3	28.8
	12.5	2	25
New Laxapana	58	2	116
Polpitiya	37.5	2	75
Canyon	30	2	60
Wimalasurendra	25	2	50

7.4. Data Communication System

It is always studied the information of reservoirs such as Flow rates, water levels and generator availability etc. when selecting the order which the generators should operate to provide the required Power Demand. Moreover, it is required the condition of other reservoirs.

Because of this, it is essential to exchange this information among the generators rapidly. In addition to that it should display the data of Generators at reservoirs. In a Control Room, it is required to display all the Water levels, Flow rates of all reservoirs.

Massive data bundles should be exchanged at one time and it is very important not to lose data.

7.5. Reason to use Raspberry Pi-3

Though it is used ESP 8266 Arduino to get input data & transmit through Wi-Fi, it is possible to transmit data to one direction only (Half Duplex). Raspberry PI-3 is the most suitable to exchange data of all five reservoirs as receiving & Displaying of massive data traffic.

Moreover, it is easy to handle & Display details of reservoirs, generator details and priority order etc. via a graphical interface from one place using Raspberry PI-3.

7.6. Methods to overcome data losing & Error occurring

Each & Every data is transmitted by four to overcome losing data and occurring errors. Moreover it is transmitted until the feedback is received.

7.7. Comparison of ESP8266 development board with Raspberry Pi as IoT development board

Table7. 4Comparison of ESP8266 development board with Raspberry Pi

Parameters	Raspberry Pi	ESP-8266
Processor	Quad-core ARM Cortex A53	
GPU	Broadcom VideoCore IV with 400 MHz -	
Clock speed	1.2GHz	26 MHz – 52 MHz
System memory	1 GB	<45kB
Development environments	Any linux compatible IDE	Arduino IDE, Lua Loader
Programming language	Phython,C,C++	C,C++

Raspberry Pi

The Raspberry pi Development Board is small sized Broadcom BCM 2835 SoC based ARM11 power minicomputer. The raspberry pi can be easily plugged into monitor because of its inbuilt GPU and audio-visual capabilities. Also it uses standard mouse and keyboard. This is easily programmable by powerful languages like C, python etc, giving it a capability to store and analyze the data. The inbuilt wifi, BLE, storage capability of this board and the available RAM being very huge in comparison to other boards enables it to act as an IoT server in most of the IoT network configurations.

ESP-8266

The ESP-8266 module is an extremely capable wireless programmable microcontroller board. The ESP8266 Wi-Fi board is a SOC with integrated TCP/IP protocol stack that can give any secondary microcontroller access to Wi-Fi network. The ESP8266 board is capable of either hosting an application or offloading all Wi-Fi networking functions from another application processor and therefore this is more suitable to be used as a sensing node that is capable to sense the data from various wirelessly connected IoT sensor nodes and send data to the central server like comes to device level sensor networking abilities due to its small form factor and wireless connectivity. ESP-8266 being a low cost device is a first choice for implementing sensor networks in an IoT scenario.

Comparison

- The higher end development boards such as Raspberry Pi-3 have higher performance in comparison with other boards like ESP8266 in terms of its storage and computing speeds but at the cost of higher price.
- Raspberry Pi equipped with inbuilt Wi-Fi and Bluetooth serves as an easy means to connect to internet and push the data to the cloud servers if required for further processing.
- Based on the specification and performance analysis Raspberry Pi definitely emerges as a winner when it comes to satisfying most of functional requirements of an IoT system'.
- ESP-8266 on the other hand stands out strongly when it comes to device level sensor networking abilities due to its small form factor and wireless connectivity.

7.8. IBM Cloud and the Watson IOT Platform

The IBM Watson IoT Platform is a service that is available in IBM Cloud. It can access Watson IoT Platform organization dashboard by using IBM Cloud dashboard. Watson IoT Platform can be integrated with other services that are hosted on IBM Cloud.

Instances of the Watson IoT Platform can be created in the IBM Cloud dashboard. The Watson IoT Platform can be integrated with other IBM Cloud services and accessed by using the IBM Cloud dashboard. Watson IoT Platform does not run on IBM Cloud hardware, which allows for continual data collection by our Watson IoT Platform service.

Watson IoT Platform allows performing powerful device management operations and store and access device data, connecting a wide variety of devices and gateway devices. Watson IoT Platform provides secure communication to and from your devices by using MQTT

Architecture of the Watson IoT Platform

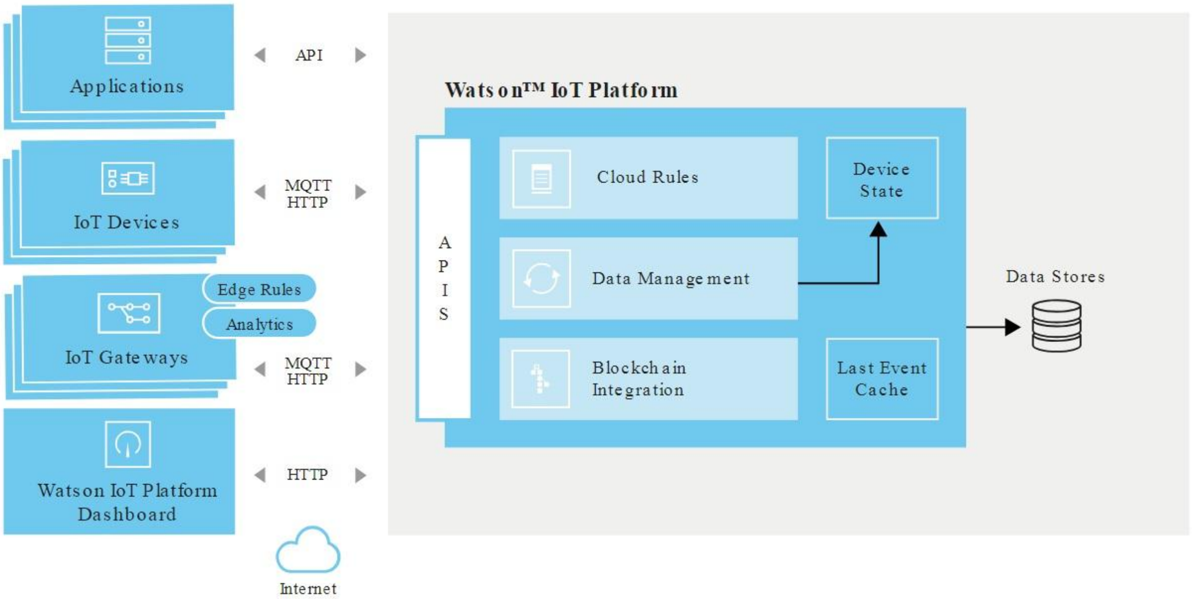

Figure 7.3: Watson IoT Platform

The Watson IoT Platform communicates with the applications and devices by using the Watson IoT Platform API and the Watson IoT Platform messaging protocol. The Watson IoT Platform dashboard connects as a front end user interface to simplify operations within the platform. Device data can be stored or used with analytics solutions. It gives a lot of advantages.

To registering Watson IoT Platform needs an organization ID and it must be unique six character identifier for the account. Organizations ensure that system data is only accessible by user devices and applications. After registration the devices and API keys are bound to a single organization. When an application connects to the service by using an API key, it will register to the organization that is associated with the API key that is used. Devices in the Watson IoT Platform are identified by a unique authentication token. Devices must be registered before they can connect to the Watson IoT Platform. And there have gateways. Gateways are specialized devices that have combined capabilities of an application and a device. It allows them to serve as access points for other devices. Devices that cannot connect directly to the Internet can access the Watson IoT Platform service by first connecting to the gateway device. Gateways must be registered before they can connect to the service. This can use some kind of applications to control our data. An application has a connection to the Internet and interacts with data from devices and control the behavior of those devices. Applications identify themselves with the Watson IoT Platform by using application ID. Unlike devices, individual applications do not need to register before they can connect to the Watson IoT Platform.

7.8.1. IBM Site Facilities

IBM Watson IOT Platform gave Powerful web dashboard. It was Flexible, scalable and easy to use. It provides a clean and simple UI where can simply and easily add and manage our devices, control access to our IoT service and monitor our usage. It was a fully managed and cloud-hosted service that is designed to simplify and derive the value from your IoT devices.

Using its device management service, we can perform device actions like rebooting or updating firmware, receive device diagnostics and metadata, or perform bulk device addition and removal. We use the industry-standard MQTT protocol to connect devices and applications. MQTT is designed for efficient exchange of data to and from devices in real time. It facilitate for secure communication. Using that we can securely receive data and send commands to our devices. And we can access real time data coming from our devices. We can store data for a period of our choice.

Experiment and results

8.1 Simulation Results of the Petri-Net and Implemented results of the Laxapana Hydro power Plant.

A petri net model is developed for Laxapana complex as described in by prioritizing generators. Thirteen separate generator models which are used to develop laxapana complex. In this model tokens were added to generators to represent the generator capacity. One token represents 1MW of capacity. This model is used to simulate the following scenarios for Laxapana complex. In this simulation 1 token has assigned to load values which are smaller than 1 MW.

Grey colour cells shows Feasible but inaccurate Power Demand range and Orange colour cells show inefficient power demands.

8.1.1 Load dispatching when the generators are available without Polpitiya power station

Table 8.1 Changes in Generator load and generator capacity during load dispatching when the generators are available without Polpitiya power station.

Power Demand	Total Power	Polpitiya		New Laxapana		Old Laxapana					Canyon		WPS	
		38 MW	38 MW	58 MW	58 MW	10 MW	10 MW	10 MW	13 MW	13 MW	30 MW	30 MW	25 MW	25 MW
50	50	NA	NA	50	No	No	No	No	No	No	No	No	No	No
70	70	NA	NA	58	12	No	No	No	No	No	No	No	No	No
100	100	NA	NA	58	42	No	No	No	No	No	No	No	No	No
125	125	NA	NA	58	58	9	No	No	No	No	No	No	No	No
150	150	NA	NA	58	58	10	10	10	4	No	No	No	No	No
170	170	NA	NA	58	58	10	10	10	13	11	No	No	No	No
200	200	NA	NA	58	58	10	10	10	13	13	28	No	No	No
220	220	NA	NA	58	58	10	10	10	13	13	30	18	No	No
250	250	NA	NA	58	58	10	10	10	13	13	30	30	18	No
275	275	NA	NA	58	58	10	10	10	13	13	30	30	25	18
300	282	NA	NA	58	58	10	10	10	13	13	30	30	25	25
340	282	NA	NA	58	58	10	10	10	13	13	30	30	25	25

Table 8.1 shows the Generators Priority Order and generated power details simulated by Petri-Net when they are available without Polpitiya power station. The maximum power is **282Mw** without the Polpiptiya Power Station. Hence it is not possible to provide the power demand more than **282 MW** without polpitiya Power Station.

It is shown from the table 8.1, the way of Optimizing Generators feeding the Power Demand Input randomly from **50Mw** to **340Mw.**

Here, from 50MW to 116MW it is provided by the New Laxapana Power station and the Old laxapana Power station is used when there is more demand. From that power is generated up to 172MW. Up to 232MW from Canynon Power Station and up to 282MW from Wimalasurendra Power Station power is generated.

8.1.2 Load dispatching in real system when the generators are available without Polpitiya power station

Table 8.2 Changes in Generator load and generator capacity during load dispatching when the generators are available without Polpitiya power station.

Power Demand (MW)	Total power (MW)	Polpitiya (MW)	New Laxapana (MW)	Old Laxapana (MW)	Canyon (MW)	Wimalasurendra (MW)
50	50	NA	50	No	No	No
70	70	NA	70	No	No	No
100	100	NA	100	No	No	No
125	125	NA	116	9	No	No
150	150	NA	116	34	No	No
170	170	NA	116	54	No	No
200	200	NA	116	54	30	No
220	220	NA	116	54	50	No
250	250	NA	116	54	60	20
275	275	NA	116		60	45
300	280	NA	116	54	60	50
340	280	NA	116	54	60	50

It shows how the generators are optimized after feeding the real time data in to the system at various power demands when the Polpitiya Power Station is not available.

The maximum power which is generated is 280MW when New Polpitiya Power station is not available & because of this it is not possible to generate 300Mw & 340MW.

8.1.2 Load dispatching when the generators are available without New Laxapana power station

Table 8.3 Changes in Generator load and generator capacity during load dispatching when the generators are available without New Laxapana power station.

		Polpitiya		New Laxapana		Old Laxapana					Canyon		WPS	
Power Demand	**Total Power**	**38 MW**	**38 MW**	**58o MW**	**58 MW**	**10 MW**	**10 MW**	**10 MW**	**13 MW**	**13 MW**	**30 MW**	**30 MW**	**25 MW**	**25 MW**
50	50	38	12	NA	NA	No	No	No	No	No	No	No	No	No
70	70	38	32	NA	NA	No	No	No	No	No	No	No	No	No
100	100	38	38	NA	NA	10	10	4	No	No	No	No	No	No
125	125	38	38	NA	NA	10	10	10	13	6	No	No	No	No
150	150	38	38	NA	NA	10	10	10	13	13	18	No	No	No
170	170	38	38	NA	NA	10	10	10	13	13	30	8	No	No
200	200	38	38	NA	NA	10	10	10	13	13	30	30	8	No
220	220	38	38	NA	NA	10	10	10	13	13	30	30	25	3
250	242	38	38	NA	NA	10	10	10	13	13	30	30	25	25
275	242	38	38	NA	NA	10	10	10	13	13	30	30	25	25
300	242	38	38	NA	NA	10	10	10	13	13	30	30	25	25
340	242	38	38	NA	NA	10	10	10	13	13	30	30	25	25

Table 8.3 shows the Generators Priority Order and generated power details simulated by Petri-Net when they are available without New Laxapana power station. The maximum power is **242MW** without the New Laxapana Power Station. Hence it is not possible to provide the power demand more than **242 MW** without polpitiya Power Station.

It is shown from the table 8.3, the way of Optimizing Generators feeding the Power Demand Input randomly from **50MW** to **340MW.**

Here, from 50MW to 70MW it is provided by the Polpitiya Power station and the Old laxapana Power station is used when there is more demand from that power is generated up to 128MW. Up to 188MW from Canynon Power Station and up to 242MW from Wimalasurendra Power Station power is generated.

8.1.3 Load dispatching in real system when the generators are available without New Laxapana power station

Table 8.4 Changes in Generator load and generator capacity during load dispatching when the generators are available without New Laxapana power station.

Power Demand (MW)	Total power (MW)	Polpitiya (MW)	New Laxapana (MW)	Old Laxapana (MW)	Canyon (MW)	Wimalasurendra (MW)
50	50	50	NA	No	No	No
70	70	70	NA	No	No	No
100	100	75	NA	25	No	No
125	125	75	NA	50	No	No
150	154	75	NA	54	25	No
170	174	75	NA	54	45	No
200	204	75	NA	54	60	15
220	224	75	NA	54	60	35
250	239	75	NA	54	60	50
275	239	75	NA	54	60	50
300	239	75	NA	54	60	50
340	239	75	NA	54	60	50

It shows how the generators are optimized after feeding the real time data in to the system at various power demands when the New Laxapana Power Station is not available.

The maximum power which is generated is 239MW when New Laxapana Power station is not available & because of this it is not possible to generate 250MW, 275MW, 300MW & 340MW.

As it is capable to generate power by 5MW in Canyon & Wimalasurendra Power stations, it is not possible to get the required values accurately like 150MW, 170MW, 200MW or 220MW. Hence it is generated a bit higher value more than the required power level.

8.1.4 Load dispatching when the generators are available without Old laxapana power station

Table 8.5 Changes in Generator load and generator capacity during load dispatching when the generators are available without Old Laxapana power station.

Power Demand	Total Power	Polpitiya		New Laxapana		Old Laxapana					Canyon		WPS	
		38 MW	38 MW	58 MW	58 MW	10 MW	10 MW	10 MW	13 MW	13 MW	30 MW	30 MW	25 MW	25 MW
50	50	38	12	No	No	NA	NA	NA	NA	NA	No	No	No	No
70	70	38	32	No	No	NA	NA	NA	NA	NA	No	No	No	No
100	100	38	38	24	No	NA	NA	NA	NA	NA	No	No	No	No
125	125	38	38	49	No	NA	NA	NA	NA	NA	No	No	No	No
150	150	38	38	58	16	NA	NA	NA	NA	NA	No	No	No	No
170	170	38	38	58	36	NA	NA	NA	NA	NA	No	No	No	No
200	200	38	38	58	58	NA	NA	NA	NA	NA	8	No	No	No
220	220	38	38	58	58	NA	NA	NA	NA	NA	28	No	No	No
250	250	38	38	58	58	NA	NA	NA	NA	NA	30	28	No	No
275	275	38	38	58	58	NA	NA	NA	NA	NA	30	30	23	No
300	300	38	38	58	58	NA	NA	NA	NA	NA	30	30	25	23
340	302	38	38	58	58	NA	NA	NA	NA	NA	30	30	25	25

It is described the generator priority order & the generated power details from the table 8.5 when the Old Laxapana Power Station is not available. This is simulated via petri-Net.

The maximum power which could be generated is 302MW when the Old Laxapana Power Station is not available. Hence it is not possible to provide the power demand 340MW.

It is randomly fed the power demand 50MW -340MW to the system & Generators optimizing process is shown in the table 8.4.

From 50MW up to 70MW is provided by the Polpitiya Power Station & from 70MW to 192MW is provided by Polpitiya & New Laxapana Power Station.

Power Generation from 192MW up to 252MW is done by Polpitiya, New Laxapana & Canyon power stations.In addition to this Power Generation from 252MW up to 302MW is done by Polpitiya, New Laxapana Canyon & Wimalasurendra power stations.

8.1.5 Load dispatching in real system when the generators are available without Old laxapana power station

Table 8.6 Changes in Generator load and generator capacity during load dispatching when the generators are available without Old Laxapana power station.

Power Demand (MW)	Total power (MW)	Polpitiya (MW)	New Laxapana (MW)	Old Laxapana (MW)	Canyon (MW)	Wimalasurendra (MW)
50	50	50	No	NA	No	No
70	70	70	No	NA	No	No
100	100	75	25	NA	No	No
125	100	75	50	NA	No	No
150	150	75	75	NA	No	No
170	170	75	95	NA	No	No
200	201	75	116	NA	10	No
220	221	75	116	NA	30	No
250	251	75	116	NA	60	No
275	276	75	116	NA	60	25
300	301	75	116	NA	60	50
340	301	75	116	NA	60	50

It is described in the table 8.6 how the generators are optimized feeding the Real Time Data in to the System at various power demands when the Old Laxapana Power Station is not available.

The maximum generated power is 301MW when the Old Laxapana Power Station is not available. Hence it is not possible to provide 340MW power demand. In Polpitiya

& New Laxapana Power Stations power is generated by 1Mw hence it has to generate bit higher Power values when supplying 200MW, 220MW, 250MW or 300MW power demands.

8.1.6 Load dispatching when the generators are available without Canyon power station

Table 8.7 Changes in Generator load and generator capacity during load dispatching when the generators are available without Canyon power station.

Power Demand	Total Power	Polpitiya		New Laxapana		Old Laxapana					Canyon		WPS	
		38MW	38MW	58MW	58MW	10MW	10MW	10MW	13MW	13MW	30MW	30MW	25MW	25MW
50	50	38	12	No	No	No	No	No	No	No	NA	NA	No	No
70	70	38	32	No	No	No	No	No	No	No	NA	NA	No	No
100	100	38	38	24	No	No	No	No	No	No	NA	NA	No	No
125	125	38	38	49	No	No	No	No	No	No	NA	NA	No	No
150	150	38	38	58	16	No	No	No	No	No	NA	NA	No	No
170	170	38	38	58	36	No	No	No	No	No	NA	NA	No	No
200	200	38	38	58	58	8	No	No	No	No	NA	NA	No	No
220	220	38	38	58	58	10	10	8	No	No	NA	NA	No	No
250	250	38	38	58	58	10	10	10	13	13	NA	NA	2	No
275	275	38	38	58	58	10	10	10	13	13	NA	NA	25	2
300	298	38	38	58	58	10	10	10	13	13	NA	NA	25	25
340	298	38	38	58	58	10	10	10	13	13	NA	NA	25	25

It is described the generator priority order & the generated power details from the table 8.7 when the Canyon Power Station is not available. This is simulated via petri-net.

The maximum power which could be generated is 298MW. Hence it is not possible to provide the power demand 300 MW & 340MW.

From 50MW up to 76MW is provided by the Polpitiya Power Station & from 76MW to 192MW is provided by New Laxapana Power Station.

Power Generation from 192MW up to 248MW is done by Old Laxapana power station.

In addition to this Power Generation from 248MW up to 298MW is done by Wimalasurendra power stations.

8.1.7 Load dispatching in real system when the generators are available without Canyon power station

Table 8.8 Changes in Generator load and generator capacity during load dispatching when the generators are available without Canyon power station.

Power Demand (MW)	Total power (MW)	Polpitiya (MW)	New Laxapana (MW)	Old Laxapana (MW)	Canyon (MW)	Wimalasurendra (MW)
50	50	50	No	No	NA	No
70	70	70	No	No	NA	No
100	100	75	25	No	NA	No
125	125	75	50	No	NA	No
150	150	75	75	No	NA	No
170	170	75	95	No	NA	No
200	200	75	116	9	NA	No
220	220	75	116	29	NA	No
250	255	75	116	54	NA	10
275	275	75	116	54	NA	30
300	295	75	116	54	NA	50
340	295	75	116	54	NA	50

It is described in the table 8.8 how the generators are optimized feeding the Real Time Data in to the System at various power demands when the Canyon Power Station is not available.

The maximum generated power is 295MW when the Canyon Power Station is not available. Hence it is not possible to provide 340Mw power demand.

In Wimalasurendra Power Stations power is generated by 5MW hence it has to generate bit higher Power values when supplying 250MW power demand.

8.1.8 Load dispatching when the generators are available without Wimalasurendra power station

Table 8.9 Changes in Generator load and generator capacity during load dispatching when the generators are available without Wimalasurendra power station.

Power Demand	Total Power	Polpitiya		New Laxapana		Old Laxapana					Canyon		WPS	
		38 MW	38 MW	58 MW	58 MW	10 MW	10 MW	10 MW	13 MW	13 MW	30 MW	30 MW	25 MW	25 MW
50	50	38	12	No	No	No	No	No	No	No	No	No	NA	NA
70	70	38	32	No	No	No	No	No	No	No	No	No	NA	NA
100	100	38	38	24	No	No	No	No	No	No	No	No	NA	NA
125	125	38	38	49	No	No	No	No	No	No	No	No	NA	NA
150	150	38	38	58	16	No	No	No	No	No	No	No	NA	NA
170	170	38	38	58	36	No	No	No	No	No	No	No	NA	NA
200	200	38	38	58	58	8	No	No	No	No	No	No	NA	NA
220	220	38	38	58	58	10	10	8	No	No	No	No	NA	NA
250	250	38	38	58	58	10	10	10	13	13	2	No	NA	NA
275	275	38	38	58	58	10	10	10	13	13	27	No	NA	NA
300	300	38	38	58	58	10	10	10	13	13	30	22	NA	NA
340	308	38	38	58	58	10	10	10	13	13	30	30	NA	NA

Simulated via Petrinet, it is described the generator priority order & the generated power details from the table 8.9 when the Wimalasurendra Power Station is not available.The maximum power which could be generated is 308MW. Hence it is not possible to provide the power demand 340MW.From 50Mw up to 76MW is provided by the Polpitiya Power Station & from 76MW to 192MW is provided by New Laxapana Power Station.Power Generation from 192MW up to 248MW is done by Old Laxapana power station.In addition to this Power Generation from 248MW up to 308MW is done by Canyon power station.

8.1.9 Load dispatching in real system when the generators are available without Wimalasurendra power station

Table 8.10.Changes in Generator load and generator capacity during load dispatching when the generators are available without Wimalasurendra power station.

Power Demand (MW)	Total power (MW)	Polpitiya (MW)	New Laxapana (MW)	Old Laxapana (MW)	Canyon (MW)	Wimalasurendr a (MW)
50	50	50	No	No	No	NA
70	70	70	No	No	No	NA
100	100	75	25	No	No	NA
125	125	75	50	No	No	NA
150	150	75	75	No	No	NA
170	170	75	95	No	No	NA
200	200	75	116	9	No	NA
220	220	75	116	29	No	NA
250	255	75	116	54	10	NA
275	275	75	116	54	30	NA
300	300	75	116	54	55	NA
340	305	75	116	54	60	NA

It is described in the table 8.10 how the generators are optimized feeding the Real Time Data in to the System at various power demands when the Wimalasurendra Power Station is not available.

The maximum generated power is 305MW when the Canyon Power Station is not available. Hence it is not possible to provide 340MW power demand.

In Canyon Power Stations power is generated by 5MW hence it has to generate bit higher Power values when supplying 250MW and 275MW power demands.

Table 8.11.Summery of the Feasible Power Demand ranges and Feasible but inaccurate demand percentages without one generator at once.

Fail Power Plant	Feasible Power Demand (MW)	Feasible Power Demand Range (MW)	Feasible but Inaccurate Power Demand Range (MW)	Inaccurate Range Percentage (%)
Polpitiya	280	0–275	0	0%
New Laxapana	239	0-220	150-220	29.2%
Old Laxapana	301	0-300	200-300	33.3%
Canyon	295	0-275	250-275	9%
Wimalasurendra	305	0-300	250-275	8.3%

8.1.9 Summery

Comparison of Pertinent simulation results and real system results

Optimization of generators has been tested by the Perti-Net simulation and real system by making not available one generator at a time. When simulating by the Perti-Net taken method is used and one taken is considered as IMW. Therefore, required power demand can be properly generated.

However, when applying real system there is a minimum power that can be generated by the generator and amount of power that can be generated at a time. Therefore, sometimes the amount of power generated slightly exceeds the demand of power.

This process compares how remaining generators are optimized when one generator at a time is made not available.

The results of pertinent simulation and real system results found to be similar. However, there were special cases where the power generated by the real system slightly exceeded the power demand.

9.1. Test Results

In final stage all the system data (Flow rates of the reservoirs, system demand, generator states, water flow rates of the reservoirs etc) can demonstrate all the details in single graphical user interface in the control room. The specialty of the design is all the details are the real data. Therefore the operator can optimize the generators without failures.

Figure 9. 1 GUI of the system.

Figure 8.1 shows all the real time information (water levels, flow rates of the five reservoirs and power demand, generators priorities, and working percentages etc.)

Figure 9.2: Details of the system in Graphical interface

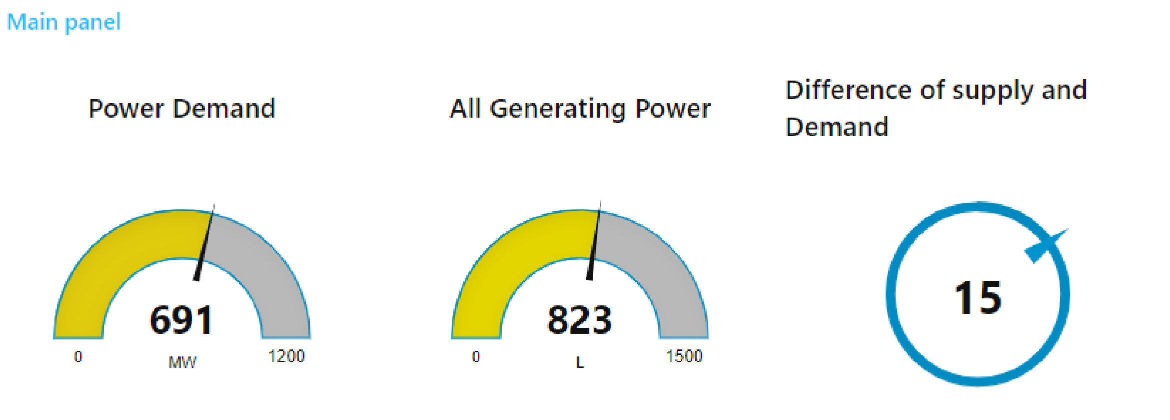

Figure 9.3: Details of the system in Graphical interface

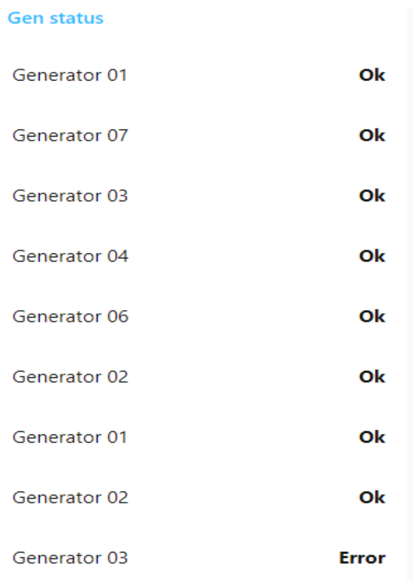

Figure 9 4 status of the generators

Figure 9. 5 Demand with generated power

9.2. Real Model

Figure 9.6 Pictures of the reservoir models

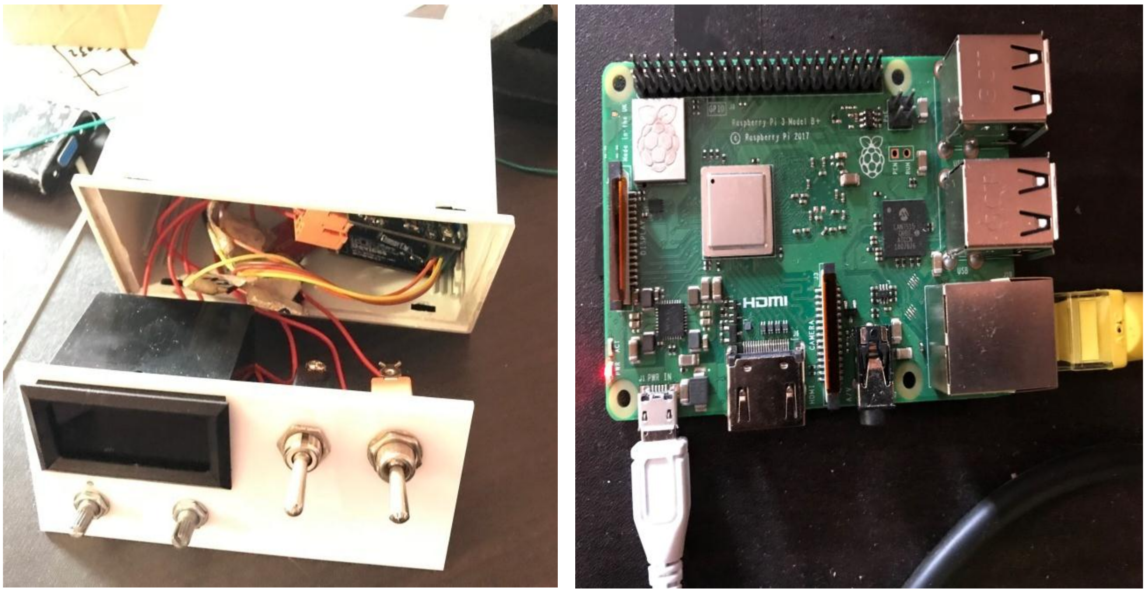

Figure 9. 7 Raspberry Pi-3

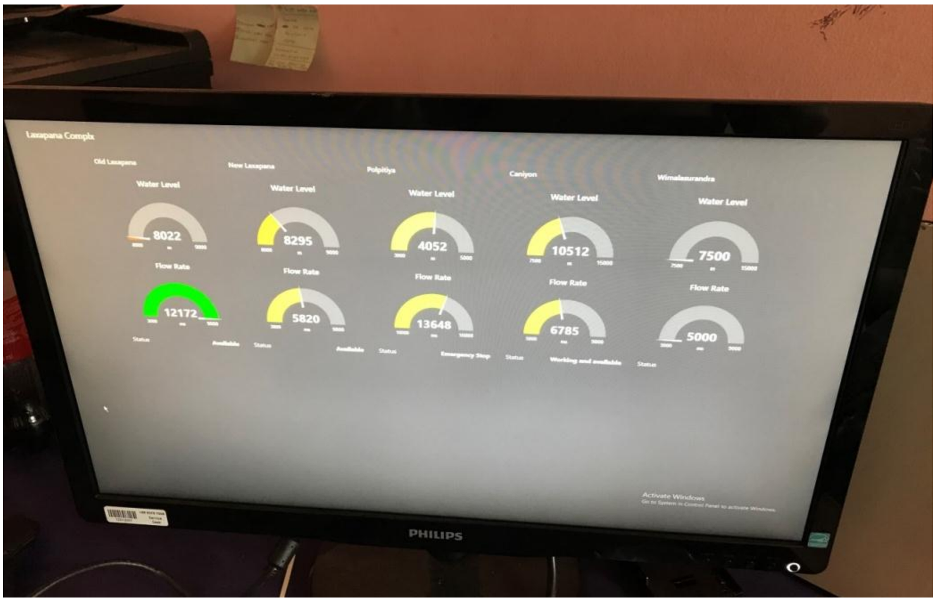

Figure 9. 8 System details view on the GUI

CHAPTER-10

Conclusion and Recommendation

10.1 Conclusion of the study

There is a cascaded system operating from water levels & flow rates of the reservoirs. It is essentially required a special Modeling Technique to optimize as the water level & the flow rates of the reservoirs are unpredictably change time to time.

It had been used a generator optimization method via Petri net Software by Engineer Lankanath. The purpose of this research is implementing the system after studying these data.

Most of the researches have been based on analyzing the previous data but in this (my) research real time data is used for the requirement. In this case, water flow rates, water levels data is rapidly acquired by the control system. Moreover all the data of generators are gained by the system.

It is decided the procedures & quantities which the generators should operate after analyzing all this data and it is monitored whether they work properly.

Eventually, Procedures & Preventive Maintenance dates etc. are decided & displayed by the AI after analyzing the data acquired. Because of this it is possible to optimize power with less failure.

In his research make five models for the reservoirs and generated inputs such as water flow rates, water levels of reservoirs are collected by the ESP 8266. Then they are provided to the Control System via Wi-Fi to process. MQTT technology is used to send this data. Raspberry PI is used to analyze that data. After the data is being analyzed by the Raspberry PI it is decided how the generators should operate & at what percentages.

After that data is displayed on GUI & the data is processed after it is being filtered inside the Raspberry PI. Here the required data is stored in a Database. The Details of the generators are collected by the ESP 8266 Module & provides to the Raspberry PI as usual.

All data also displayed on the GUI & it is verified whether the generators work properly. As it is not capable to handle massive data traffic & Half Duplex technology, ESP 8266 is not suitable for data processing. Raspberry PI-3 is used as solution for this issue.

10.2 Recommendations for future work

- Develop to control the generators fully automatically according to power demand.
- Develop to give sms alert to all the operators and the Engineers if any failure situation.
- This system depends on limited number of input data but can increase number of reservoir data and generator data.
- Studying latest artificial Intelligence methods develop increase the efficiency of the system.

References

[1] Eng.A.L.Deshapriya, "MODELING AND SIMULATION OF UNIFIED PETRINET MODEL FOR LAXAPANA HYDRO POWER COMPLEX," University Of Moratuwa, 2018 March.

[2] C. G. S. Gunasekara, Lanka Udawatta, SanjeewaWitharana, Neural Network Based Optimum Model for Cascaded Hydro PowerGenerating System, IEEE International Conference on Information and Automation, 2006

[3] H. Kurt , Y. Aslan, Optimization of power output of a micro-hydro power station using fuzzy logic algorithm, Published by International Organization of IOTPE,2013

[4] Benedicto N. Fortaleza, Ronnie O. Serfa Juan, Lean Karlo S. Tolentino, IoT-based Pico-Hydro Power Generation System using Pelton Turbine.

[5] Mihai Hulea; RaduMiron; TiberiuLetia, Modular hybrid control system with Petri-Nets enhanced components for hydro power plant control, 2016 IEEE International Conference on Automation, Quality and Testing, Robotics (AQTR)

[6] Łukaszkowalczyk, witoldelsner, Comparative analysis of optimization methods applied to thermal cycle of a coal fired power plant, Czestochowa University of Technology, Institute of Thermal Machinery, ArmiiKrajowej 21, 42-200 Częstochowa, Poland,

[7] RangikaJeewantha Jayawardena, Efficiency improvement of the hydro power plants in the Laxapanacomplex, MSc research,2014

[8] Olawale O. E. Ajibola, Olamide S. Ajala, James O. Akanmu and Oluwaseyi J. Balogun, Optimizing Hydroelectric Power Generation: The Case of Shiroro Dam, Proceedings of the World Congress on Engineering,2017

[9] www.pucsl.gov.lk, study-report-on-electricity-demand-curve-and-system-peak-reduction.pdf, 2013 February

[10] Dalia Fendri, Maher Chaabene, Energy dispatching strategy for micro-grid using hybrid Petri nets model, IEEE Control, Decision and Information Technologies (CoDIT), 2017 4th International Conference, 5 April 2017.

[11] M. Svadova; Z. Hanzalek, An algorithm for the evolution graph of extended hybrid Petri nets, 2004 IEEE International Conference on Systems, Man and Cybernetics (IEEE Cat. No.04CH37583)

[12] T. Olaoye, T. Ajilore, K. Akinluwade, F. Omole and A. Adetunji, 2016. Energy Crisis in Nigeria: Need for Renewable Energy Mix. American Journal of Electrical and Electronic Engineering, 2016, Vol. 4, No. 1, 1-8.

[13] R. E. Rosenthal, 1981. A Nonlinear Network Flow Algorithm for Maximization of Benefits in a hydroelectric Power system” Operational Research, Vol. 29, No. 4, pp 763-786.

[14] U. Karaagac, J. Mahseredjian, S. Dennetière, 2009. Modelling and Simulation of the Start-up of a Pumped Storage Power Plant Unit, International Conference on Power Systems Transients Kyoto, Japan