SIMULATION OF SMALL HYDRO POWER PLANTS

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree of

MASTER OF TECHNOLOGY

in

ALTERNATE HYDRO ENERGY SYSTEMS

By

D. LAKSHMAN KUMAR

ALTERNATE HYDRO ENERGY CENTRE
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE - 247 667 (INDIA)

JUNE, 2010

CANDIDATE'S DECLARATION

I hereby certify that the work which is being presented in this dissertation, entitled **"SIMULATION OF SMALL HYDRO POWER PLANTS"**, in partial fulfillment of the requirement for the award of the degree of Master of Technology in **"Alternate Hydro Energy Systems"**, submitted in **Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee** is an authentic record of my own work carried out during the period from July 2009 to June 2010 under the supervision of **Shri. M.K. Singhal,** Senior Scientific Officer, Alternate Hydro Energy Centre and **Dr. D.K. Khatod,** Assistant Professor, Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee.

The matter embodied in this dissertation report has not been submitted by me for the award of any other degree or diploma.

Date: June २९, 2010.

Place: Roorkee.

(D. Lakshman Kumar)

This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

(M.K. Singhal)
Senior Scientific Officer
Alternate Hydro Energy Centre
Indian Institute of Technology
Roorkee - 247677

(Dr. D.K. Khatod)
Assistant Professor
Alternate Hydro Energy Centre
Indian Institute of Technology
Roorkee – 247677.

ACKNOWLEDGEMENT

Though the deepest gratitude can only be felt inside my heart, but in words with my deepest esteem I wish to express my deep sense of gratitude and sincere thanks to my guides; **Shri. M.K.Singhal,** Senior Scientific officer, Alternate Hydro Energy Centre and **Dr. D.K.Khatod,** Assistant Professor, Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee for teaching me the pleasure of doing dissertation work and thinking broadly. With their advice, help and encouragement, not only do I finish my degree, but I also have better understanding how to think scientifically. Their keen interest and constant encouragement gave me the confidence to complete my dissertation work successfully. I am highly indebted to them for their kind and valuable suggestions and of course their valuable time during the period of this work.

I express my deep and sincere sense of gratitude to **Dr. Arun Kumar**, Head, Alternate Hydro Energy Centre, Indian Institute of Technology, Roorkee and **all the faculty members** of the centre who have contributed directly or indirectly in completion of my dissertation work. I am also indebted to all my friends, over and above all well wishers who gave me moral support and encouragement throughout the duration of my dissertation. As a personal note, I am most grateful to my parents, who are inspirational to me, and for their constant encouragement.

Date: June29,2010.

Place: Roorkee.

D. Lakshman Kumar.

ABSTRACT

Modeling and simulation of small hydro power (SHP) plants helps in studying the dynamic response of the hydraulic systems, governor and electrical systems associated with the plant. It also helps in studying the stability of the system and the co-ordination of governor parameters with those of the hydraulic and electrical systems for optimal selection.

Real Time Digital Simulator (RTDS) for SHP Plant provides a realistic simulation of hydropower plant and control centre environments. It provides efficient initial and advanced training to operators and engineering staff of different types of small hydroelectric plans, by creating training conditions very close to real operating conditions. Real time simulator based training bridges the gap between the theoretical backgrounds and required practically performed actions. A RTDS for SHP plant was developed by ALICES software is available at AHEC, IIT Roorkee. This ALICES software is utilised for present dissertation work.

In this dissertation work, a simulation for Pacha SHP plant is developed and operated under various operating conditions. The various components of SHP plant like weir, channel, penstock, Francis turbine, governor, synchronous generator and exciting system for generator are considered for simulation. The simulation of SHP plant has been performed under ALICES software environment.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

The notations used in this report are listed below:

General

A	Cross-section	m^2
F	Force	N
L	Length	m
M	Mass	kg
P	Pressure	N/m^2
ρ	Density	kg/m^2
Q	Volumetric flow	m^3/s
g	Gravity coefficient	m/s^2
H	Head	m

For Weir , Channel and Penstcok

C_v	Velocity Coefficient	-
h_1	Measured head of water at weir	m
b	Breath of the Weir	m
V	Velocity of water in channel	m/s
v	Dynamic viscosity	$N\ s/m^2$
b	Width of channel	m
d	Depth of channel	m
L	Length of channel	m
R	Hydraulic radius	m
ΔH	Water level difference	m
n	Manning roughness	-
$\Re e$	Reynolds number	-
Z_{up}	Upstream elevation	m

Z_{do}	Downstream elevation	m

For Francis Turbine

P_w	Turbine input power	kW
P_t	Turbine outputpower	kW
P_v	Vanes position	%

For Governor

ω_{ref}	Reference speed
ω_r	Rotor speed
T_p and T_a	Pilot valve time constant of hydraulic governor
K_s	Servo gain of hydraulic governor
T_g	Time constant of hydraulic governor
R_t	Temporary droop of hydraulic governor
T_r	Reset time of hydraulic governor
R_p	Permanent droop
K_p	Proportional gain of PID governor
K_i	Integral gain of PID governor
K_d	Derivative gain of PID governor,
T_c and T_d	Gate servo motor time constant of PID governor
R_{max}	Maximum gate opening rate limit
R_{min}	Minimum gate opening rate limit
Pos_{max}	Maximum gate position

Pos_{min}	Minimum gate postion	

For Synchronous Generator

H	Constant of inertia	MWs/MVA
T_m	Mechanical torque	Nm
T_e	Electromagnetic torque	Nm
K_d	Damping factor representing the effect of damper windings	-
δ	Power angle delta: angle of internal Voltage E with respect to terminal voltage	rad
ω_o	Speed of operation	rad/s
$\Delta\omega$	Speed variation with respect to speed of operation	rad/s
V	Voltage	V
i	Current	A
R	Resistance	Ohm
L	Inductance	H
Ψ	Magnetic flux linkage	weber- turn

Subscripts:

d, q: d and q axis quantity

R,S: Rotor and stator quantity

l, m: Leakage and magnetizing inductance

f, k: Field and damper winding quantity

For Exciter

V_{ref}	Reference voltage	V
V_{ter}	Generator terminal voltage	V
T_t	Voltage time constant	V
T_c, T_b	Transient gain reduction (TGR) time constant	-
K_a	Amplifier gain constant	-
T_a	Amplifier time constant	s
K_e	Exciter gain constant	-
T_e	Exciter time constant	s
A , B	Saturation constant	-
K_f	Stabilizing circuit gain constant	-
T_f	Stabilizing circuit time constant	s
V_{max}	Maximum amplifier output	V
V_{min}	Minimum amplifier output	V
E_{fd}	Exciter output voltage	V
K_c	Rectifier constant depending on	
	Commutating reactance	-
K_d	Ac exciter synchronous and transient	
	Reactance constant	-
I_n	Rectifier load current	A
F_{ex}	Rectifier regulation depending upon I_n	A

I_{fd}	Field current	A

For Modelling in ALICES

arc	arc	-
ext	External	-
m	Mass	-
j	Upstream node index	-
k	Current node index	-
l	Downstream node index	-
E	Internal energy	J/kg
U	Velocity	m/s
T	Temperature	^0C
t	Time	s
Φarc_{jk}	Power supplied by arc 'jk	W
W	Mass flowrate	kg/s
W_{kj}	Flowrate at the connection of node 'k' of arc 'jk'	kg/s
W_{jk}	Flowrate at the connection of node 'j' of arc 'jk'	kg/s
L_{jk}	The length of arc 'jk',	m
P_{jk}	Pressure at the connection of node 'j' with arc 'jk'	N/m^2
P_{kj}	Pressure at the connection of node 'k' with arc 'jk'	N/m^2
$Farc_{jk}$	The sum of the external forces acting on arc 'jk'	N
$Fturbine_{jk}$	Represents the force exerted by the turbine on the	

Subscripts:

j	Node j
k	Node k
jk	arc jk

Chapter-1

INTRODUCTION

1.1 General

Hydro power conserves our fossil fuel reserves, is abundant & self renewing supply, is non polluting and produces no waste streams. World installed capacity of small hydro is around 50,000 MW against an estimated potential of 1,80,000 MW. Hydropower is not only environmentally friendly, but also cost effective. Hydro power has the highest operating efficiency of all known generation systems. They are largely automated and their operating costs are relatively low. Hydro power plants also play an important role in water resources management in preventing flooding, making rivers navigable, solving irrigation problems and creating recreation areas.

India with population more than one billion people, living is the second most populous country in the world after china. With respect to energy, India is the net importer of the energy and consumes roughly 3% of the world's total energy. The total installed capacity in India as on 31st March 2009 was 1,49,391.91 MW, out of which 64.6% from Thermal,24.7% from Hydro, 2.9% from Nuclear and 7.7% from Small Hydropower, Biomass Gasfier, Biomass Power, Wind Energy [1].

Hydropower is considered to be an attractive source as it avoids the pollution associated with burning of fuels; however most of the large hydro scheme involves massive dams' impounding enormous volume of water in manmade lakes in order to provide year round power by smoothing out fluctuations in the river flow. In many cases, such schemes are far from in exhaustible because the lakes gradually silt up and will function effectively. There are also numerous environment problems that can result from interference with river flows. Many of larger schemes have had adverse effect on the local environment and gestation period is quite long. On the other hand small hydro is one of the most environmentally benign energy conservative option enhance the main advantages comparing with electricity sources, namely saving consumption of fossil fuels or fire wood, being self sufficient without the need of important component. The term hydropower refers to generation of shaft power from falling water. The power could then be used for direct mechanical purposes or, more frequently, for generating electricity. Hydropower is the most established renewable resource for electricity generation in commercial investments.

Although, hydroelectric generation is regarded as a mature technology, there are still possibilities for improvement [2].

1.2 Small Hydro Power

An installation for the production of hydro electricity, with a capacity less than 25 MW, is generally referred as small hydro power (SHP) plant. The power generated from a hydro power plant is given by:

$$P = \eta g Q H. \quad (1.1)$$

Where,

η = Overall efficiency of the plant,

g = Gravitational Constant in m/sec^2,

Q = Discharge (flow rate) in m^3/sec,

H = Head in m,

P = Power in kW.

There is a general tendency all over the world to define Small Hydropower by the power output. Different countries follow different norms, the upper limit ranges between 5 to 50 MW, as given in the Table 1.1.

Table 1.1: World wide definition of SHP [3].

Country	Capacity (MW)
UK	≤ 5
UNIDO	≤ 10
Sweden	≤ 15
Australia	≤ 20
India	**≤ 25**
China	≤ 25
New Zealand	≤ 50

In India, out of 150,000 MW hydropower potential, 15,000 MW potential is estimated as small hydro, of which about 12% has been tapped so far. The present status of SHP is given in Table 1.2.

Table 1.2: SHP Status in India [2].

Overall potential	15,000 MW
Identified potential	10,477 MW (4,404 sites)
Installed capacity	1937 MW (581 projects)
Under construction	561 MW (207 projects)
Capacity addition during 2002-2007	Over 500 MW
Target capacity addition – 11^{th} Plan (2007-2012)	1400 MW

1.2.1 Advantages of SHP plants

Following are advantages of Small Hydro Power Plants

- Hydropower is a no-inflation power as Water- the 'raw material' for power generation is free of inflation,
- Environment friendly, it does not produce greenhouse gases or other air pollution, renewable source of energy,
- Hydropower projects support socio economic development of remote areas as the project site is developed,
- It has additional benefits like irrigation, flood control, tourism etc,
- Flexibility of installation and operation in an isolated mode and also in a localized or regional grid system [4].

1.2.2 Disadvantages of SHP plants

Following are disadvantages of Small Hydro Power Plants

- Time consuming process for project clearances,
- Until recently, the national focus has been on thermal generation,
- Highly capital intensive and absence of committed funds,
- Poor financial health of State Electricity Boards (SEBs),

- Technical constraints due to complex geological nature of the projects,
- Inter-state disputes as Water is a state subject,
- Absence of long tenure loans makes it difficult for private investors,
- Advance against depreciation is disallowed [4].

1.3 Classification of SHP Schemes

In India Small hydro power is classified broadly as follows [3]:

1.3.1 Classification based on Head

On the basis of net head available at plant site the classification is made as

- Ultra Low Head – Below 3 meters
- Low Head – Less than 40 meters
- Medium/High Head – Above 40 meter

1.3.2 Classification based on SHP plant Capacity Rating

On the basis of SHP plant capacity rating the power plants are classified as

- Up to 100kW – Micro Hydro Power
- 101Kw to 2000kw – Mini Hydro Power
- 2001Kw to 25000kw – Small Hydro Power

1.3.1 Types of SHP Schemes

Small Hydropower can also be broadly categorized in three types as follows:

1.3.2 Run-Off River Scheme

Run-of-River hydroelectric schemes are those, in which water is diverted towards power house, as it comes in the stream. Practically, water is not stored during flood periods as well as during low electricity demand periods, hence water is wasted. Seasonal changes in river flow and weather conditions affect the plant's output. After power generation water is again discharged back to the stream. Generally, these are high head and low discharge schemes. The typical run-off river scheme is shown in Fig. 1.1.

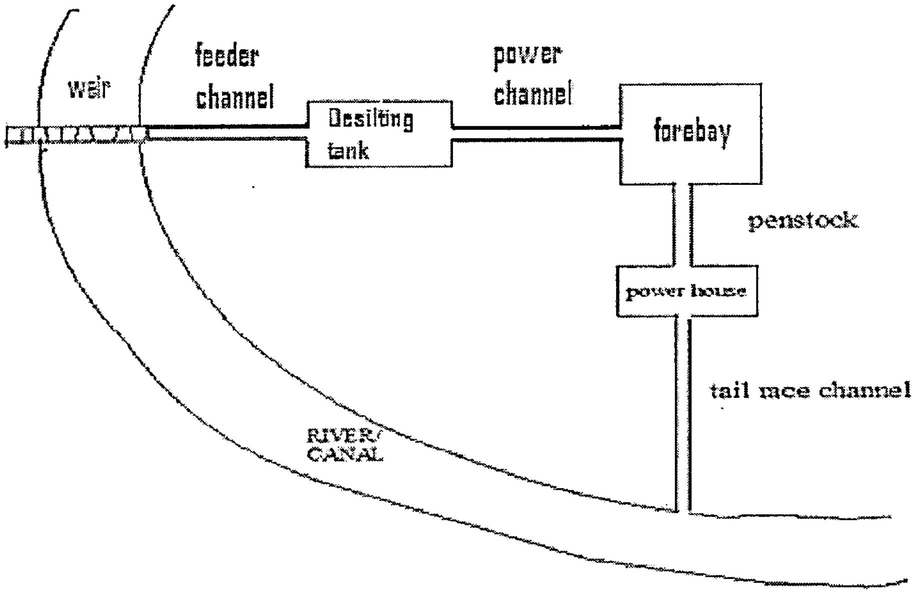


Fig. 1.1: Typical arrangement of run-off river scheme [5].

1.3.3 Canal Based Scheme

Canal based small hydropower scheme is planned to generate power by utilizing the fall in the canal. These schemes may be planned in the canal itself or in the bye pass channel. These are low head and high discharge schemes. These schemes are associated with advantages such as low gestation period, simple layout, no submergence and rehabilitation problems and practically no environmental problems. The typical canal based scheme is shown in Fig. 1.2.

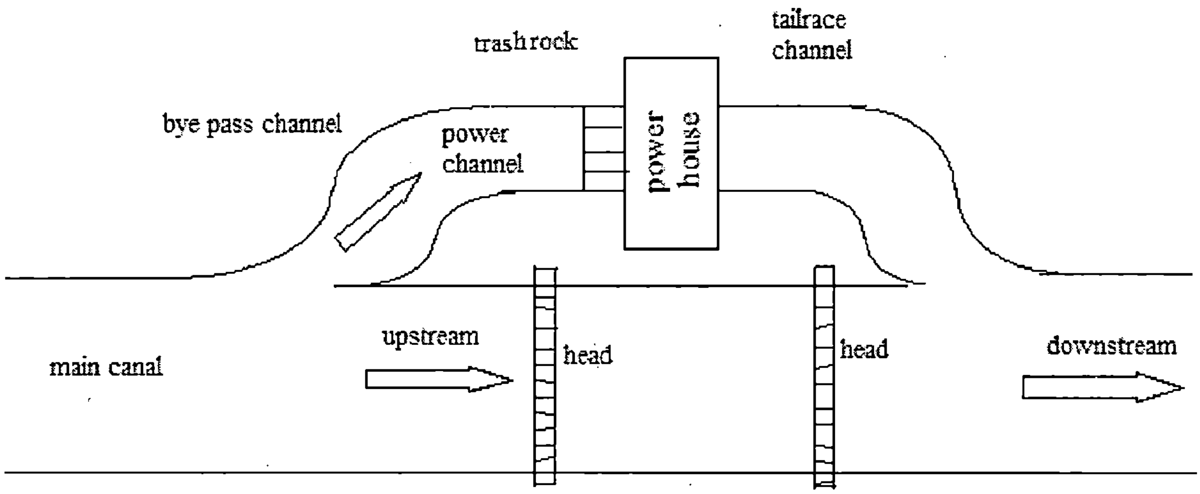


Fig. 1.2: Typical arrangement of canal based scheme [5].

1.3.4 Dam Toe Based Scheme

In this case, head is created by raising the water level behind the dam by storing natural flow and the power house is placed at the toe of the dam or along the axis of the dam on either sides. The water is carried to the powerhouse through penstock. Such schemes utilize the head created by the dam and the natural drop in the valley. Typical dam toe based scheme is shown in the Fig. 1.3.

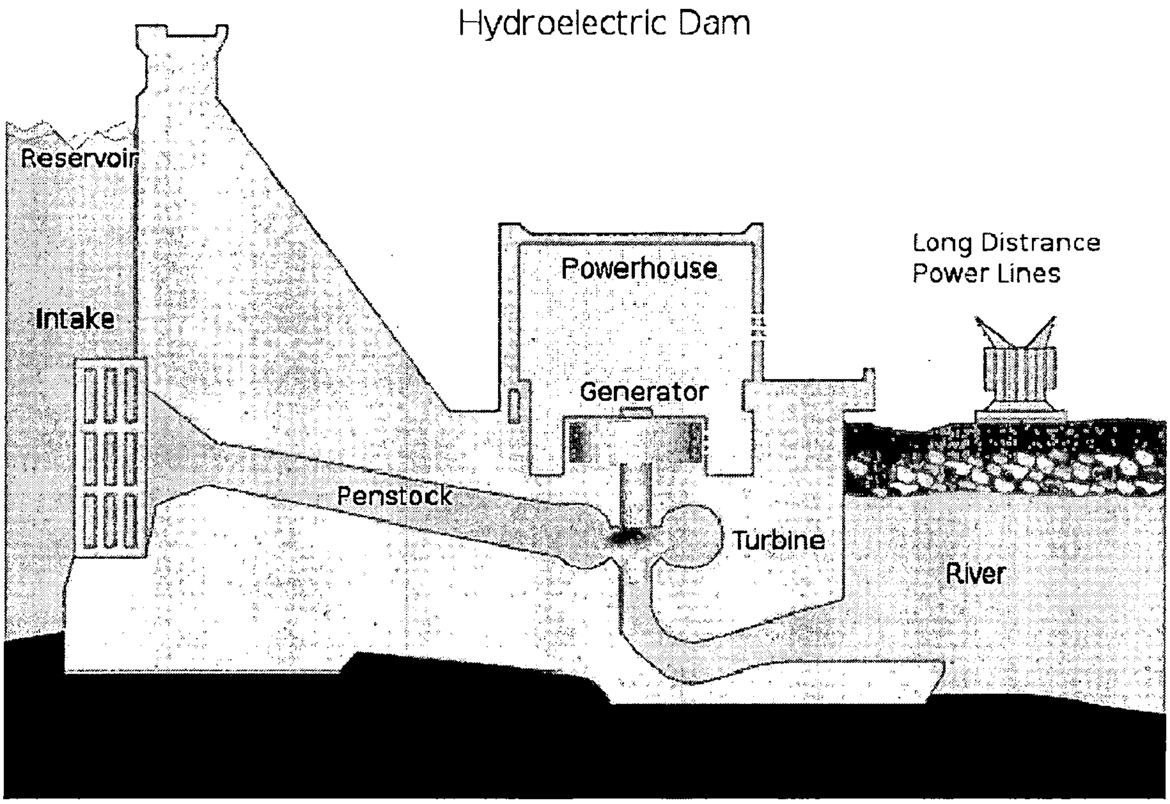


Fig. 1.3: Typical arrangement of dam toe based scheme [6].

1.4 Simulation

Simulation in general sense is "To copy the behaviour of a system or phenomenon understudy". The process of imitating a real phenomenon with a set of mathematical formulas is called simulation. In theory, any phenomena that can be reduced to mathematical data and equations can be simulated on a computer. In practice, however, simulation is extremely difficult because most natural phenomena are subject to an almost infinite number of influences. One of the tricks to developing useful simulations, therefore, is to determine which the most important factors are [7].

Simulation is used in many contexts, including the modelling of natural systems or human systems in order to gain insight into their functioning. Other contexts include simulation of technology for performance optimisation, safety engineering, testing, training and education. Simulation can be used to show the eventual real effects of alternative conditions and courses of action. Key issues in simulation include acquisition of valid source information about the referent, selection of key characteristics and behaviours, the use of simplifying approximations and assumptions within the simulation, and fidelity and validity of the simulation outcomes [7].

1.4.1 Need for Simulation

A simulator is a collection of hardware and software systems which are used to mimic the behaviour of some entity or phenomenon. Typically, the entity or phenomenon being simulated is from the domain of the tangible -- ranging from the operation of integrated circuits to behaviour of a light aircraft during wind shear. Simulators may also be used to analyse and verify theoretical models which may be too difficult to grasp from a purely conceptual level.Such phenomenon range from examination of black holes to the study of highly abstract models of computation. As such, simulators provide a crucial role in both industry and academia [8].

1.4.2 Advantages of Simulation

The advantages to performing a simulation rather than actually building the design and testing are:

1. One of the primary advantages of simulators is that they are able to provide users with practical feedback when designing real world systems. This allows the designer to determine the correctness and efficiency of a design before the system is actually constructed.
2. The user may explore the merits of alternative designs without actually physically building the systems.
3. By investigating the effects of specific design decisions during the design phase rather than the construction phase, the overall cost of building the system diminishes significantly.
4. Simulators permit system designers to study a problem at several different levels of abstraction.
5. By approaching a system at a higher level of abstraction, the designer is better able to understand the behaviours and interactions of all the high level components within the system and is therefore better equipped to counteract the complexity of the overall system.

6. Simulators can be used as an effective means for teaching or demonstrating concepts to students. This is particularly true of simulators that make intelligent use of computer graphics and animation. Such simulators dynamically show the behaviour and relationship of all the simulated system's components, thereby providing the user with a meaningful understanding of the system's nature.
7. Most of the time the simulation testing is cheaper and faster than performing the multiple tests of the design each time [8].

1.4.3 Limitations of Simulation

Despite of the aforesaid advantages of simulation, simulators, like most tools, do have their limitation.

1. The big disadvantage in performing a simulation as well is simulation errors. Any incorrect key stroke has the potential to alter the results of the simulation and give you the wrong results.
2. In order for the simulation to be accepted in the general community you have to take experimental results and simulate them. If the two data sets compare, then any simulation you do of your own design will have some credibility.
3. The delays in the simulation are due to an exceedingly large number of entities being simulated or due to the complex interactions that occur between the entities within the system being simulated.
4. Simulators are restricted by limited hardware platforms which cannot meet the computational demands of the simulator. However, as more powerful platforms and improved simulation techniques become available, this problem is becoming less of a concern [8].

1.4.4 Types of Simulation

There are two different types of simulation:

1. Deterministic simulations;
2. Statistical simulations.

In a deterministic simulation, a system is simulated under well determined conditions. This kind of simulation is useful to observe the behaviour of system in certain particular cases, to discover errors in the design or in the implementations, to build examples, etc. In this kind of simulations, only one run is needed and there is no truly random variable involved. To see the behaviour of the system we need to "trace" the output on a file and later to see and analyse it in a textual or in a graphical form.

In a statistical simulation, we measure the system performance. This is useful to see if the system has good response time under average conditions, to compare different implementations of the same system, or totally different systems that have the same output [7].

1.4.5 Computer simulation

Computer simulation is the discipline of designing a model of an actual or theoretical physical system, executing the model on a digital computer, and analysing the execution output.

Within the overall task of simulation, there are three primary sub-fields:

1. Model design;
2. Model execution;
3. Model analysis.

Computer simulations vary from computer programs that run a few minutes, to network-based groups of computers running for hours, to ongoing simulations that run for days [9].

1.4.6 Simulation Languages

A computer Simulation Language describes the operation of a simulation on a computer. There are two major types of simulation: continuous and discrete-event though more modern languages can handle combinations. Most languages also have a graphical interface and at least simple statistical gathering capability for the analysis of the results. An important part of discrete-event languages is the ability to generate pseudo-random numbers and variants from different probability distributions. Examples are [10]:

1.5.6.1 Discrete-event simulation languages

In these languages, the model is viewed as a sequence of random events each causing a change in state. Following are the languages used for Discrete-event simulation-

1. AutoMod
2. eM-plant
3. Arena

4. GASP
5. GPSS
6. Simula
7. Java Modeling Tools, an open-source package with graphical user- interface.

1.5.6.2 Continuous simulation languages

In these languages, model is viewed as a set of differential equations. Following are the languages used for Continuous simulation:

1. Advanced Continuous Simulation Language (ACSL), which supports textual or graphical model specification
2. Dynamo
3. Sim App, Simple Simulation of Dynamic systems and Control systems
4. Simulation Language for Alternative Modeling (SLAM).

1.5.6.3 Hybrid and Other

1. Simulink – Continuous and discrete event capability
2. SPICE – Analog circuit Simulation
3. XML lab – Simulations With XML.

1.6 Real Time Digital Simulator

Real Time Digital Simulator is an imitation of operational characteristics or behaviour of selected SHP plant. It is a modular system can easily be updated. It is an open system so that new tools and third party or external models codes can easily be added [11].

1.7 Real Time Digital Simulator for SHP Plant at AHEC

Real Time Digital Simulator (RTDS) for Rajwakti SHP plant having capacity 2 x 1800 kW was established at Alternate Hydro Energy Centre (AHEC), Indian Institute of Technology (IIT) Roorkee in the year 2007 under UNDP funding of MNRE, Govt. of India. In RTDS, mathematical models of different components of SHP plant have been used to simulate the SHP plant under the environment of ALICES, an integrated software workshop for the design and study of simulators.

Real Time Digital Simulator for SHP Plant provides a realistic simulation of hydropower plant and control centre environments. It provides efficient initial and advanced training to operators and engineering staff of different types of small hydroelectric plans, by creating training conditions very close to real operating conditions. Real time simulator based training bridges the gap between the theoretical background and required practically performed actions [12].

Following are the some of the benefits:

1. Reduce Operation and Maintenance cost
2. Reduce damage to plant
3. Increase plant life
4. Reduce training time.

1.7.1 General Features of Simulator

The SHP Simulator has three main subsystems (Fig 1.4)

1. SHP Model
2. Instructional System and
3. Control room Model.

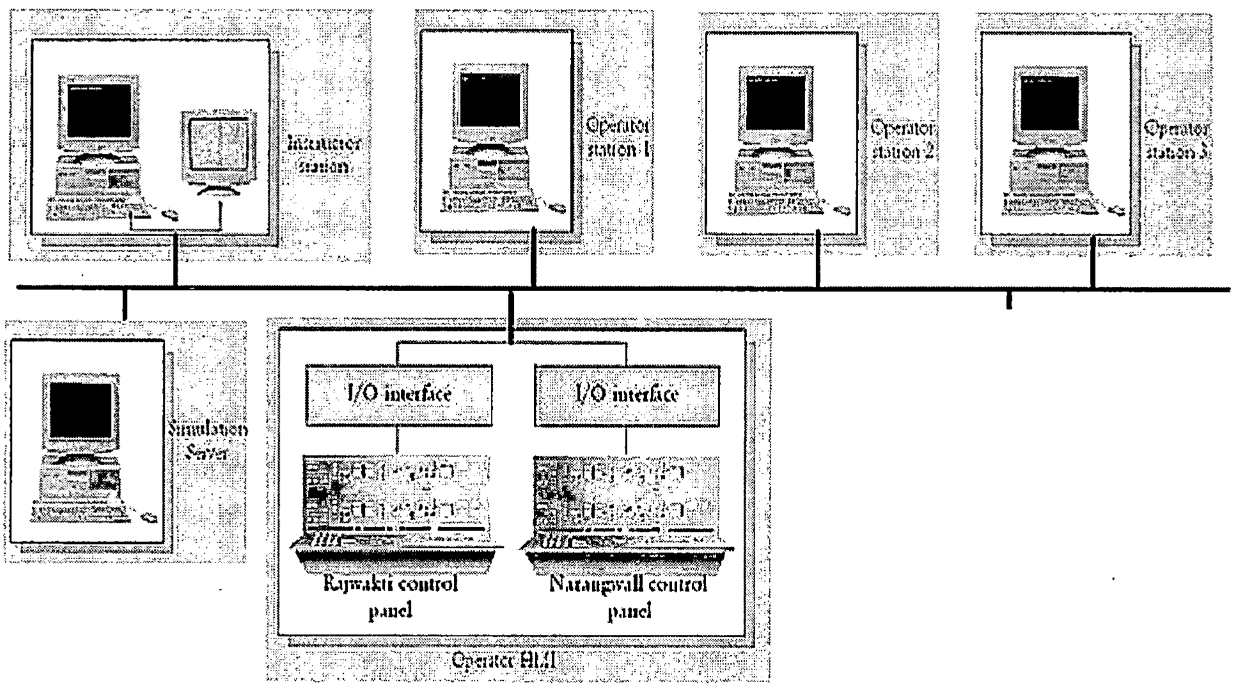


Fig. 1.4: Layout of hardware of Simulator [12]

(A). Features

The main features have been provided as below:

1. It is a modular system and updating of the Simulator is possible
2. It is an open system so that new tools and third party or external models and codes can easily be added
3. Supports various training configuration, from single operating console to a complete replica of a control centre
4. Respond in real time just as the small hydro power plant
5. Use long-term dynamic models to simulate prime movers, generators, governors, excitation systems and relays, so the system is represented under a wide range of frequency and voltage conditions
6. Uses training consoles and controls identical to those used for day-to-day operations so the simulated environment and real-time systems share the same look and feel.

1.7.3 Simulator Operations

The Simulator covers the following Operations:

1. Start/Stop of unit
2. Synchronization unit with grid
3. Load variation
4. Turbine and generator protection
5. Loss of generators, motors, due to internal problems
6. Breakers failures
7. Operation log trend chart
8. Power channel, forebay and penstock draining
9. Loss of auxiliary supply
10. Valve blocking in position
11. Sensors defects
12. Inflow variations in river / canals.

1.8 Modelling and Simulation of SHP plants

Modelling and Simulation of a small hydro power plant is a valuable tool for planning operations and judging the value of physical improvement by selecting proper system parameters .This study helps in verifying costs and safety conditions, in selecting the best alternatives in the early phase of design and to determine the requirements of special protection devices. It also helps in finding parameters of control equipments like water level regulator, governor, exciter etc. and in determining the dynamic forces acting on the system which must be considered in structural analysis of the penstock and their support.

Dynamic response of the hydraulics, governor and electrical system associated with small hydro plants can also be obtained with this simulation, which provides information about the performance of the entire system following system disturbances such as turbine start up, turbine loading, load rejection and movement of wicket gates. It provides the effect of interaction between hydraulics system, the governor and the electric system. It helps in studying the stability problem associated with the system.

In brief, simulation studies provide answers to many questions to designing and planning engineers such as:

1. The analysis of the stability and operational problems and their remedies
2. Co-ordination of governor parameters with those of the hydraulics and electrical systems and selection of optimal governing parameters.
3. Detailed assessment regarding the dimension of penstock and the necessity of a surge tank, when considering the effect of water hammer.
4. Questions based on cost, operational and environmental considerations [13].

1.9 Organization of the report

In chapter-1 small hydro power (SHP), different schemes of SHP development, introduction of simulation, real time digital simulator for SHP plant, modelling and simulation of SHP plants have been presented.

In chapter-2 literature review on modelling and simulation of SHP has been presented.

The chapter-3 describes mathematical modelling of various components of SHP plant has been presented.

The chapter-4 includes the development of simulation for SHP plant under ALICES software.

The chapter-5 deals with the results and discussion.

The chapter-6 includes the conclusion and future scope of work.

Chapter- 2

LITERATURE REVIEW

This chapter presents a review of previous works related with modelling and simulation of small hydropower plants.

Kristian Tuszynski et al. [14] presented a library for simulation of hydro power plants. The library is designed to be an effective tool for commissioning, testing of new control strategies and verifying complete hydro plants or selected plants system only. The library structure builds on four main groups of models: hydro components, electrical power system, and mechanical machinery and control components. In this they covered mainly hydro components and hydro turbine exemplifying mechanical machinery.

Yin Chin Choo et al. [15] conducted a research on modelling of hydraulic turbine for dynamic studies and performance analysis. In this, they presented a hydraulic turbine model with long penstock is represented where the water hammer effects and friction are taken in consideration. A detailed hydraulic turbine-penstock utilised for governing stability studies is used to analyse the transient response when subject to a load disturbance. Frequency response analysis as well as transient response analysis is performed to evaluate the effects of the detailed modelling of the turbine-penstock to the stability analyses and the dynamic performances.

Nand Kishor et al. [16] conducted a research on dynamic simulations of hydro turbine and its state estimation based linear quadratic (LQ) control and concluded that the effect of the elasticity of the water column in the penstock of a hydro power plant represents an irrational mathematical function and this function is reduced to a lower order using the H-infinity approximant method. The gate position-turbine power non-linear steady state characteristic is modelled by this reduced order function, and then, the time domain and frequency domain simulations of turbine power are presented and compared with the widely known Pade′ approximant method for order reduction of irrational functions. State estimation of the inelastic and elastic fifth order state space model of the hydro plant is also performed. The method adopted for state estimation is based on second order polynomial approximations of a multi-dimensional interpolation formula. It is found that the state estimation of the plant by this method outperforms the linear Kalman filter in terms of estimation. Then, a state estimation based linear quadratic (LQ) control approach for the hydro turbine speed control is also presented. The simulated results are compared to the linear quadratic regulator that assumes all the states are measurable.

Xianshan LI et al. [17] presented the full scope real-time simulation model of a hydropower plant simulator for training and research should be developed whole plant, full process and whole zone of plant oriented. Whole plant oriented means that the simulation model of hydro plant simulator (HPS) must include all the generating sets in a hydropower plant; whole process oriented indicates that the simulation model can reflect the complete energy conversion procedure of hydropower plant from hydraulic energy to mechanical energy and to electrical energy under any operating conditions; and whole zone of plant oriented means that the simulation model base should include not only all generating components that directly take part in the energy conversion process, but also such auxiliary systems which are related to the energy conversion process as the supervisory and control system, protection system, external equivalent system, etc.. According to the structural characteristics of a large-scale hydropower plant, the full scope simulation model can be decomposed into several subsystems that can be calculated independently in every time step. Thus, the simulation time is reduced considerably. Examples are given to demonstrate the efficiency of this method.

S. Tesnjak et al. [18] developed a digital simulator for transient condition analyses in hydroelectric power plants. In this, they presented a basic non-linear mathematical for investigation of normal and transient operations in high pressure hydroelectric power plants. On the basis of this model an original digital simulating model has been developed by using software-hardware XANALOG system and the MATRIXx software package because they are suitable as a training simulator for the operators in hydroelectric power plants as well as in real operating conditions. Theoretical results have been verified in hydroelectric power plants in Croatia (75 MW and 480 MW).

O. H. Souza Jr. et al [19] conducted a research on study of hydraulic transients in hydropower plants through simulation of non-linear model of penstock and hydraulic turbine model. In this context, they analysed the discrete hydraulic systems with emphasis on hydraulic parameter analysis. The simulation used was developed based on analog mathematical models of transient phenomenon equations and on a hydro turbine model. The results were obtained by using a non-linear analog-digital simulation method. They compared the results of a theoretical simulation of a literature example using the characteristics method and the result obtained with present method.

D. Lindenmeyer et al. [20] developed simulation of the start-up of a hydro power plant for the emergency power supply of a nuclear power station and described the derivation of generator, turbine, exciter, and induction motor models, and their individual validation through field measurements. They verified the complete power system model by comparing simulation results to measurements, as obtained during an Engineered Safeguards Functions (ESF) test of the emergency power system of Oconee nuclear power plant.

M. Mahmoud et al. [21] conducted a research on design and simulation of a non-linear fuzzy controller for a hydropower plant. In this, they presented a a fuzzy controller simulated exclusively to control a hydropower plant with several hydraulically coupled turbines under non-linear process conditions and compared the performance of this fuzzy controller with conventional PID controller . It may replace a commonly used control arrangement of several independent PID turbine governors.

C. Nicolet et al [22] developed new tool for the simulation of transient phenomena in francis turbine power plants. In this, they modelled transient phenomena in pipes, valves, surge tanks and francis turbines based on impedance method. These models are implemented in asoftware called "SIMSEN", which simulates the behaviour of complex applications in the domain of adjustable speed drives and electrical power networks. This program is based on a modular structure, which enables the numerical simulation of transient modes of systems exhibiting arbitrary topologies. The numerical simulation for transient phenomena in hydropower plants with "SIMSEN" has the benefit of an algorithm that generates and solves an integrated set of differential equations. This algorithm solves simultaneously the electrical, hydraulic and control equations ensuring a proper interaction between the three parts of the system. The case of a Francis turbine power plant is studied. The model of the turbine is based on measured steady state characteristics. The simulation of the dynamic behaviour of the power plant under load variation is investigated.

Chandra Sekhar Kolli [23] developed simulator for SHP plant. In this thesis work, simulation of a small hydroelectric plant has been performed to study its behaviour under various conditions. The various components of small hydropower plant like penstock, valve, surge tank, Francis turbine, Synchronous generator, PID governor and exciting system for generator have been considered for simulation. The simulation of small hydro power plant has been performed in SIMULINK/MATLAB. Using the developed simulation model, the dynamic and transient behaviour of small hydro power plant can be studied when subjected to disturbances like load addition, load reduction and different fault conditions(1-phase,2-phase,3-phase short circuit).

Nikhil Kumar [24] developed simulator for high head SHP plant to study behaviour of plant. In this thesis work, presented the modelling of different components high head SHP plant like weir, power channel, pelton turbine, governor and generator. These models used to simulate the high head SHP plant under the environment of ALICES. The developed simulator has been tested under various operating conditions such as: starting of generating units, synchronizing of generating units with grid, loading of generating units, shut down of generating units, Auxiliary power supply operation and load rejection.

Chapter- 3

MATHEMATICAL MODELLING OF VARIOUS COMPONENTS OF SMALL HYDRO POWER PLANT

This chapter deals with the mathematical modelling of various components of small hydro power plant (SHP).

3.1 Important Components of SHP plant:

Fig 3.1 represents the schematic diagram of a SHP plant with its important components.

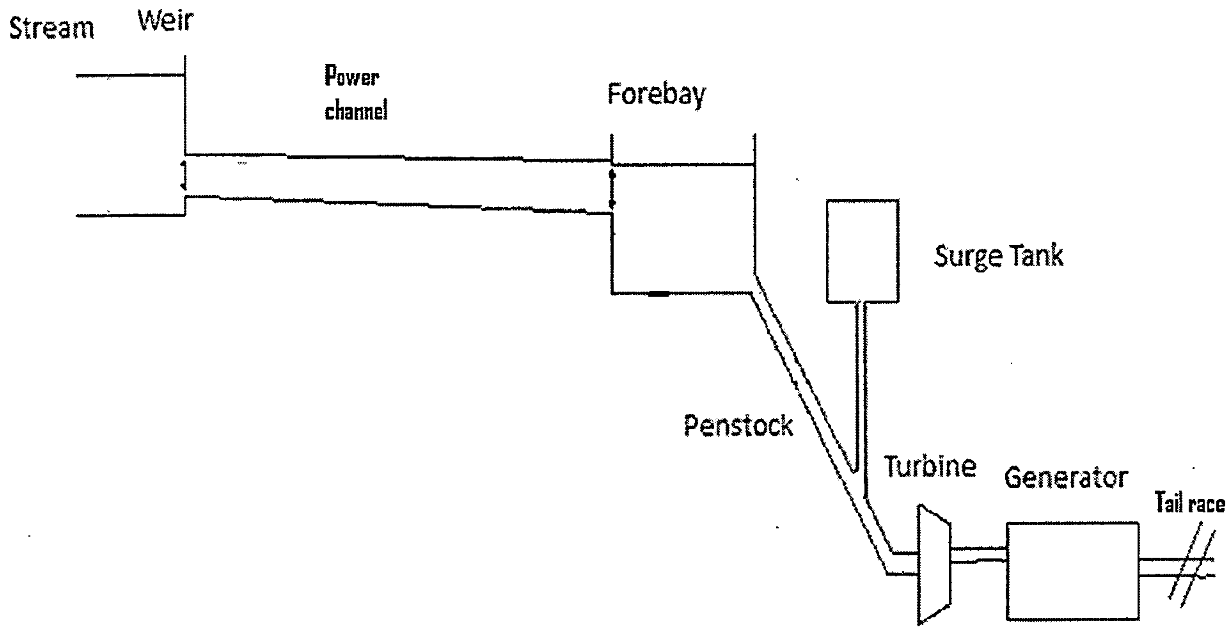


Fig. 3.1: schematic diagram of a SHP plant with its important components.

3.2 Mathematical Modeling of Various Components of SHP plant

3.2.1 Weir Model

A weir is a notch of regular form through which water flows. The primary function of weir is to measure the flow rate or discharge estimation. Weirs are classified in accordance with the shape of the notch, e.g. V notch, rectangular, trapezoidal and parabolic. The equation for the discharge over a weir cannot be derived exactly because: (1) The flow pattern of one weir differs from another of a different shape, and (2) The flow pattern varies with the discharge [26]. The discharge is expressed by (3.1).

Discharge flow: $Q = \left(\frac{2}{3}\right)^{1.5} \times Cd \times Cv \times b \times \sqrt{2 \times g \times h1^3}$ (3.1)

Where,

Discharge Flow: Q

Velocity Coefficient: $C_d = 1.163 \times \left(1 - \frac{0.0003}{h_1}\right)^{1.5}$

3.2.1 Channel Model

One is placed before the forebay called as power channel and the other one after forebay called the feeder channel. Power channels terminate in forebay (head pond) feeding water to the hydraulic turbine-penstock. Feeder channel may be open channel or the closed conduit. Fig 3.2 shows the channel model. The modeling of a scheme is given by (3.2) – (3.12).

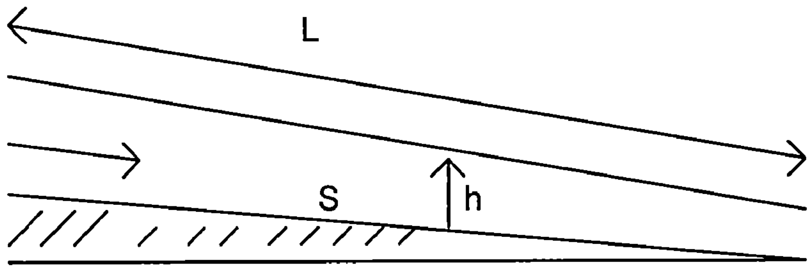


Fig. 3.2: Channel model [25].

Discharge flow: $Q = \frac{1}{n} \times R^{\frac{2}{3}} \times d \times b \times \sqrt{\frac{\Delta H}{L}}$ (3.2)

Where,

Hydraulic radius: $R = \frac{d \times b}{2 \times d + b}$

The important equations used for implement the channel model are listed below.

Inertia Equation: $M \times \frac{\partial V}{\partial t} = \sum_i F_i$ (3.3)

Time acceleration term: $M \times \frac{\partial V}{\partial t} = L \times \frac{\partial Q_m}{\partial t}$ (3.4)

Simplified sum of forces: $\sum_i F_i = \rho \times g \times b \times d \times (\Delta H - \Delta H_{fric})$ (3.5)

Gravity force and hydrostatic forces: $F_g = \frac{\rho \times g \times b \times d \times \Delta H}{L}$ (3.6)

Friction forces: $F_{fric} = \rho \times g \times b \times d \times \Delta H_{fric}$ (3.7)

Friction head loss: $\Delta H_{fric} = \max\lfloor \Delta H_{fric\_t}; \Delta H_{fric\_l} \rfloor$ (3.8)

Turbulent friction loss: $\Delta H_{fric\_t} = L \times \left[\frac{V \times n}{R^{\frac{2}{3}}} \right]^2$ (3.9)

Laminar friction head loss: $\Delta H_{fric\_l} = \frac{L \times 64}{\Re e \times 4 \times R} \times \frac{V^2}{2 \times g}$ (3.10)

Reynolds number: $\Re e = \frac{V \times 4 \times R}{\nu}$ (3.11)

Mass Flow: $Q_m = \rho \times Q = \rho \times b \times d \times V$ (3.12)

3.2.3 Penstock Model

In high head power plant closed conduits (penstock) are used. Open channels are un pressurized one and closed conduits are pressurized channel. Closed conduits may be of different materials, they may be concrete pressure shaft or steel penstock or of some other materials. Fig 3.3 shows the penstock model. The modeling of penstock is given by (3.13) – (3.19).

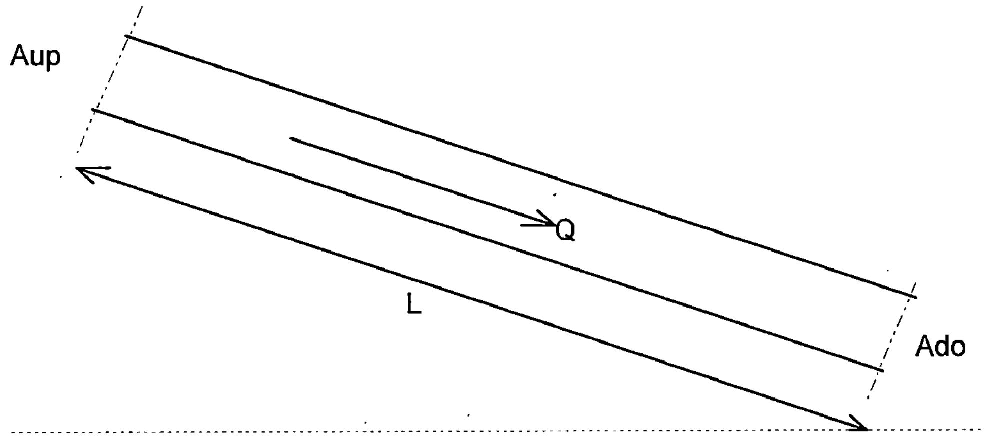


Fig.3.3: penstock Model [25].

The important equations used for implement penstock model are listed below.

Inertia equation: $$M \times \frac{\partial V}{\partial t} = \sum_i F_i \qquad (3.13)$$

Time acceleration term: $$M \times \frac{\partial V}{\partial t} = L \times \frac{\partial Q_m}{\partial t} \qquad (3.14)$$

Simplified sum of forces: $$\sum_i F_i = A \times \left(\Delta Pg + \Delta P_s - \Delta P_{frot}\right) \qquad (3.15)$$

Gravity head: $$\Delta P_g = \rho \times g \times \left(Z_{up} - Z_{do}\right) \qquad (3.16)$$

Hydrostatic head: $$\Delta P_s = A \times \left(P_{up} - P_{do}\right) \qquad (3.17)$$

Friction head losses: $$\Delta P_f = A \times V^2 \times \left(coeff_{fric} \times \frac{L}{D} + coeff_{dif} \right) (3.18)$$

Mass flow: $$Q_m = \rho \times Q = \rho \times A \times V \qquad (3.19).$$

3.2.4 Francis Turbine model

Francis turbines are reaction turbines i.e. they convert both kinetic energy and potential energy of the fluid into mechanical work. This is an inward flow turbine that combines radial and axial flow concepts. They are used for medium head and medium discharge. Fig 3.4 shows the Francis turbine model. This turbine is modeled by (3.20) – (3.23).

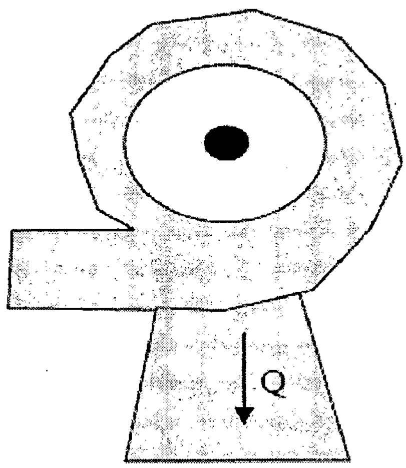


Fig.3.4: Francis turbine model [25].

Turbine Discharge Flow: $$Q = q_{50}[p_v, N] \times \sqrt{\frac{H}{H_{50}}} \qquad (3.20)$$

Turbine efficiency: $\eta = \eta[Q]$ (3.21)

Turbine input power: $Pw = Q \times H \times g \times \rho$ (3.22)

Turbine output power: $Pt = \eta \times Pw$ (3.23).

3.2.5 Governor Model

The basic function of a governor is to control speed and /or load. The primary speed/load control Function involves feeding back speed error to control the gate position. In order to ensure satisfactory and stable parallel operation of multiple units, the speed governor is provided with a droop characteristic. The purpose of the droop is to ensure equitable load sharing between generating units. Typically the steady state droop is set at about 5% [28].

3.2.5.1 Electro Hydraulic Governor Model

The dynamic characteristics of electro-hydraulic governors are usually adjusted to be essentially similar to those of the mechanical-hydraulic governors. Their operation is very similar to that of mechanical-hydraulic governors. Speed sensing, permanent droop, temporary droop and their measuring and computing functions are performed electrically. The electric components provide greater flexibility and improved performance with regard to dead bands and time lags. Fig. 3.5 shows the model of governors for hydraulic turbines.

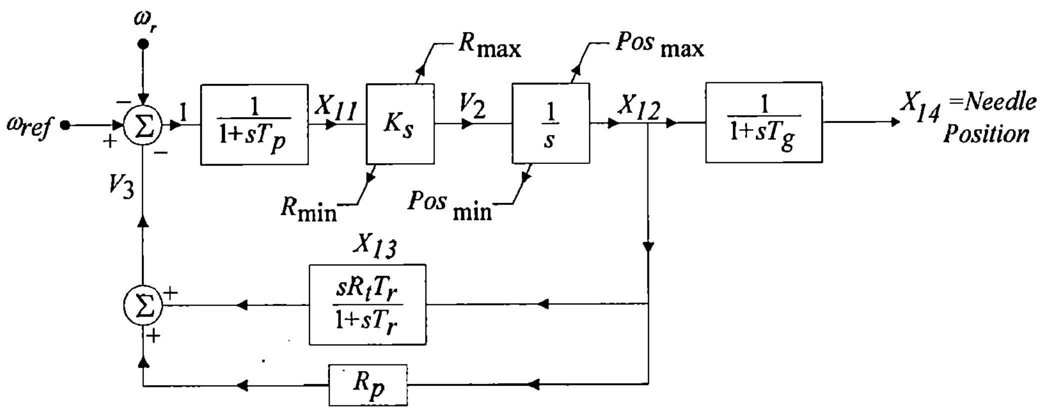


Fig. 3.5: Model of governor for hydraulic turbine [27].

3.2.5.2 PID Governing Model

Fig 3.6 shows the proportional-integral-derivative (PID) model. Electro hydraulic governors are provided with three-term controllers with PID action. The derivative action is beneficial for isolated operation, particularly for plats with large water starting time ($T_W = 3$ s r more). Typical values are $K_P = 3.0$, $K_I = 0.7$ and $K_D = 0.5$. Without derivative action, it is equivalent to hydraulic governor. The proportional and integral gains can be adjusted to obtain desired temporary droop and reset time.

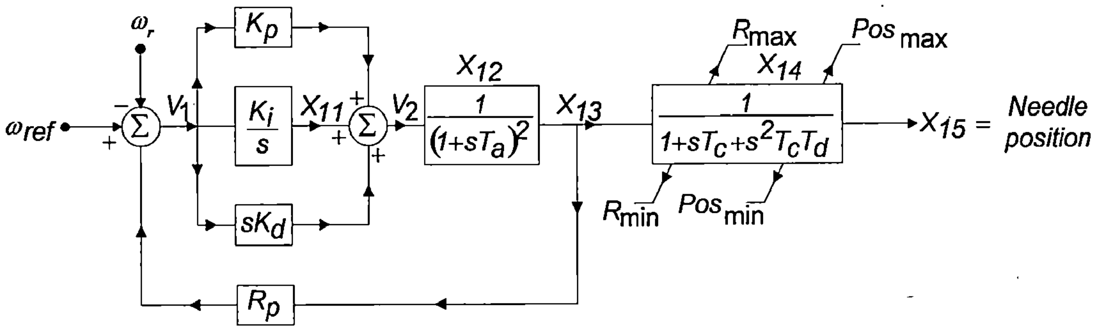


Fig. 3.6: PID governor model [27].

3.2.6 Synchronous Generator Model

The Synchronous generator model, considers both the electrical and mechanical characteristics of the machine. The model takes into account the dynamics of the stator, field, and damper windings. The equivalent circuit of the model is represented in the rotor reference frame (dq frame). All rotor parameters and electrical quantities are viewed from the stator. They are identified by primed variables in Fig.3.7. Synchronous generator model is given by (3.24) – (3.37).

The electrical model of the machine is with the following equations.

$$V_d = R_s i_d + \frac{d}{dt}\Psi_d - \omega_R \Psi_q \tag{3.24}$$

$$V_q = R_s i_q + \frac{d}{dt}\Psi_q - \omega_R \Psi_d \tag{3.25}$$

$$V'_{fd} = R'_{fd} i'_{fd} + \frac{d}{dt}\Psi'_{fd} \tag{3.26}$$

$$V'_{kd} = R'_{kd} i'_{kd} + \frac{d}{dt}\Psi'_{kd} \tag{3.27}$$

$$V'_{kq1} = R'_{kq1} i'_{kq1} + \frac{d}{dt}\Psi'_{kq1} \tag{3.28}$$

$$V'_{kq2} = R'_{kq2} i'_{kq2} + \frac{d}{dt}\Psi'_{kq2} \tag{3.29}$$

$$\Psi_d = L_d i_d + L_{md}(i'_{fd} + i'_{kd}) \tag{3.30}$$

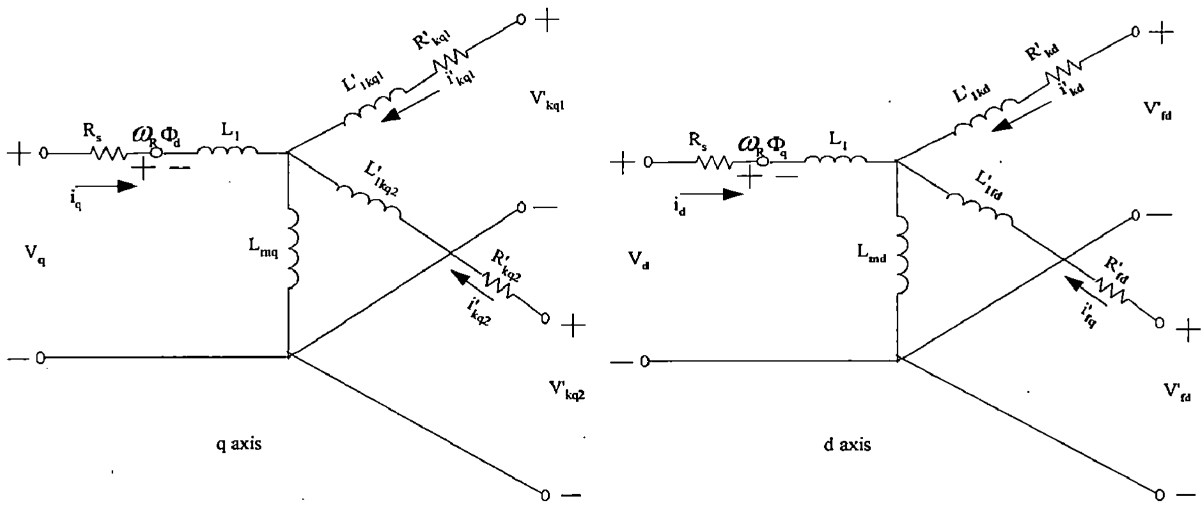
$$\Psi_q = L_q i_q + L_{mq} i'_{kq} \tag{3.31}$$

$$\Psi'_{fd} = L'_{fd}\, i'_{fd} + L_{md}\,(i_d + i'_{kd}) \quad (3.32)$$

$$\Psi'_{kd} = L'_{kd}\, i'_{kd} + L_{md}\,(i_d + i'_{fd}) \quad (3.33)$$

$$\Psi'_{kq1} = L'_{kq1}\, i'_{kq1} + L_{mq} i_q \quad (3.34)$$

$$\Psi'_{kq2} = L'_{kq2}\, i'_{kq2} + L_{mq} i_q \quad (3.35)$$



(a) q axis (b) d axis

Fig. 3.7: Synchronous generator (a) q axis equivalent model, (b) d axis equivalent model [28]

The Synchronous Generator swing behaviour is described by

$$\Delta\omega(t) = \frac{1}{2H}\int_0^t (T_m - T_e)dt - Kd\Delta\omega(t) \quad (3.36)$$

$$\Delta\omega(t) = \Delta\omega(t) + \omega_0 \quad (3.37)$$

3.2.7 Exciter Model

The basic function of an excitation system is to provide direct current to the synchronous machine field winding. In addition, the excitation system performs control and protective functions essential to the satisfactory performance of the power system by controlling the field voltage and thereby the field current [27].

3.2.7.1 Type DC1A Exciter Model

The type DC1A exciter model represents field-controlled dc commutator exciters, with continuously acting voltage regulators. The exciter may be separately excited or self-excited, the latter type being more common. When self excited, K_E is selected so that initially V_R =0, representing operator action of tracking the voltage regulator by periodically trimming the shunt field rheostat set point. Fig 3.8 shows the IEEE type DC1A excitation system model.

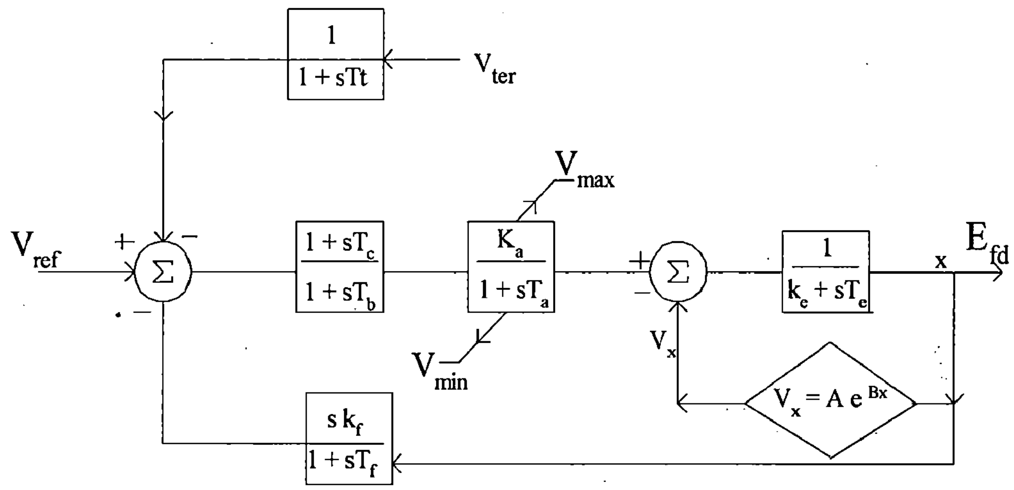


Fig.3.8: IEEE type DC1A excitation system model [27].

3.2.7.2 Type AC1A Exciter Model

The type AC1A exciter model represents a field-controlled alternator excitation system with non-controlled rectifiers, and is applicable to brush less excitation systems. Fig. 3.9 represents the IEEE type AC1A excitation system model.The diode rectifier characteristics impose a lower limit of zero on the exciter output voltage. The exciter field is supplied by a pilot exciter, and the voltage regulator power supply is not affected by external transients.

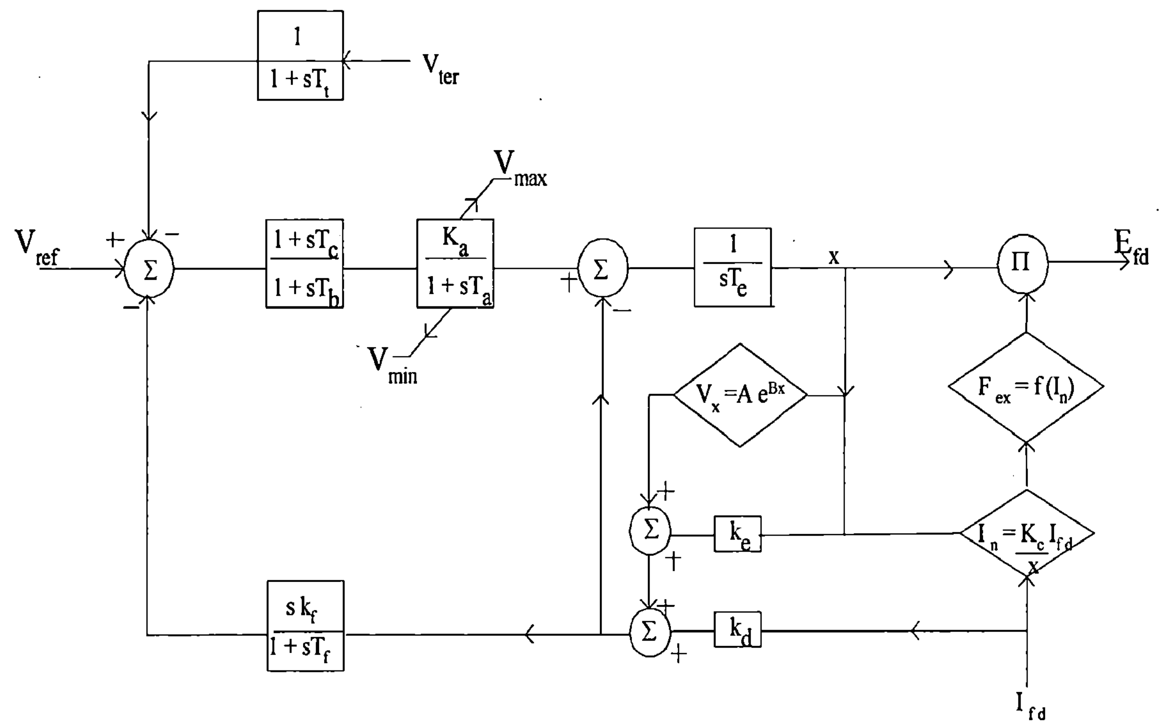


Fig. 3.9: IEEE type AC1A excitation system model [27].

Chapter- 4

DEVELOPMENT OF SIMULATION FOR SHP PLANT UNDER ALCIES SOFTWARE

Real Time Digital Simulator (RTDS) for Rajwakti SHP plant existing at AHEC, Indian Institute of Technology (IIT) Roorkee. This RTDS for Rajwakti SHP plant was developed under the environment of ALICES.

This chapter deals with development procedure of simulation for other SHP plants with different specifications. A simulation for Pacha SHP plant, located in East Kameng, Arunachal Pradesh has been taken for simulation under the environment of ALICES software. A brief description of ALICES software is present in Appendix- A.

Table 4.1 shows the salient features comparison between existing Rajwakti (2 x 1.8 MW) SHP plant and Pacha (2 x 1.5 MW) SHP plant [30 & 31].

Table 4.1: Salient features comparison between Rajwakti SHP plant and Pacha SHP plant.

S.No.	Item		Rajwakti SHP plant	Pacha SHP plant
I	Civil works	Diversion weir	Length-68 m Width - 12 m Height- 4.5m	Length-45 m Width -12 m Height - 8 m
		Intake channel	Length-105 m Width - 3.0 m Height - 3.0 m	Length-564 m Width -3.20 m Height-2.39 m
		Desilting tank	Length-63.5 m Width - 6.5 m Height - 3.0 m	Length- 90 m Width - 3.2 m Height- 2.39 m
		Power channel	Length-1235 m Width - 3.0 m Height - 2.0 m	Length-3921 m Width - 3.20 m Height - 2.25 m
		Forebay tank	Length- 20 m Width -4.5 m Height -6.0 m	Length- 35 m Width-10.5 m Height- 3.5 m
		Penstock	Number - 2 nos Length - 980 m Diameter- 2.2 m Speed - 600 rpm	Number - 2 nos Length - 147 m Diameter-1.275 m Speed - 600 rpm
		Tail race channel	Length - 100 m Width - 5.0 m Height - 2.0 m	Length - 25 m Width -2.80 m Height -1.40 m

II	E & M Works	Horizontal Francis Turbine	Speed - 600 rpm Net head-51.5 m Discharge-9.0 m^3/s	Speed-600 rpm Net head-43.0 m Discharge-9.16 m^3/s
		Synchronous Generator	Rating-2250 kVA Voltage- 3.3 kV p.f - 0.9 lag Frequency- 50 Hz Speed - 600 rpm.	Rating-1875 kVA Voltage- 3.3 kV. p.f - 0.8 lag Frequency – 50 Hz Speed - 600 rpm.
		Main transformer	Rating-5000 kVA Voltage-3.3/66 kV Frequency – 50 Hz	Rating – 2000 kVA Voltage-3.3/66 kV Frequency – 50 Hz
		Auxilary trans former	Rating-100 kVA Voltage- 433/3.3 kV Frequency- 50 Hz	Rating – 250 kVA Voltage- 415/3.3 kV Frequency- 50 Hz
		Grid	Voltage – 66 kV Frequency-50 Hz	Voltage- 66 kV Frequency-50 Hz
		Power Generation	Capacity- 2 x 1800 kW	Capacity-2 x 1500 kW

4.1 Production Steps

Various steps required for the development of simulation are as follows:

1. Creation of a work session.
2. Creation of a data bank.
3. Creation of LV-2 models.
4. Production of LV-2 documents.
5. Configuration.
6. Execution.

4.2 Creation of a Work Session:

For developing a simulation for Pacha SHP plant " pacha_Lv2.ses " session is created in the session directory. A brief description of each tab is as follows.

4.2.1 Resources Tab

Resources tab allows the users to select the standard libraries of elementary level-1 (LV-1) objects needed for the work session. These objects libraries, loaded as resources are only available in read only mode. All LV-1 libraries have been uploaded under this resource tab.

4.2.2 Environment

This tab is only accessible in read only mode. It displays environment variables set before the ALICES menu bar is started using "alcedt" command.

The **ALC_CBB_PATH** variable contains access paths to libraries.

The **ALC_LIBRARY_PATH** variable contains access paths to dynamic libraries.

4.2.3 Libraries

Under this tab, session libraries are been uploaded that are accessible in read and in write mode in the explorer. These libraries are called level-2 (LV-2) libraries. In this case Hdx_ckt.cbb, Elc_ckt.cbb, logics_pannels.cbb files are available.

4.2.4 Explorer

When a session named **"pacha_Lv2.ses"** is defined, an explorer is opened. The libraries for which the editor is loaded in the editors section are visible. In this case, all LV-1 and LV-2 libraries are visible. The loaded databank is not visible through the explorer. Fig. 4.1 shows Explorer of session "pacha_Lv2.ses".

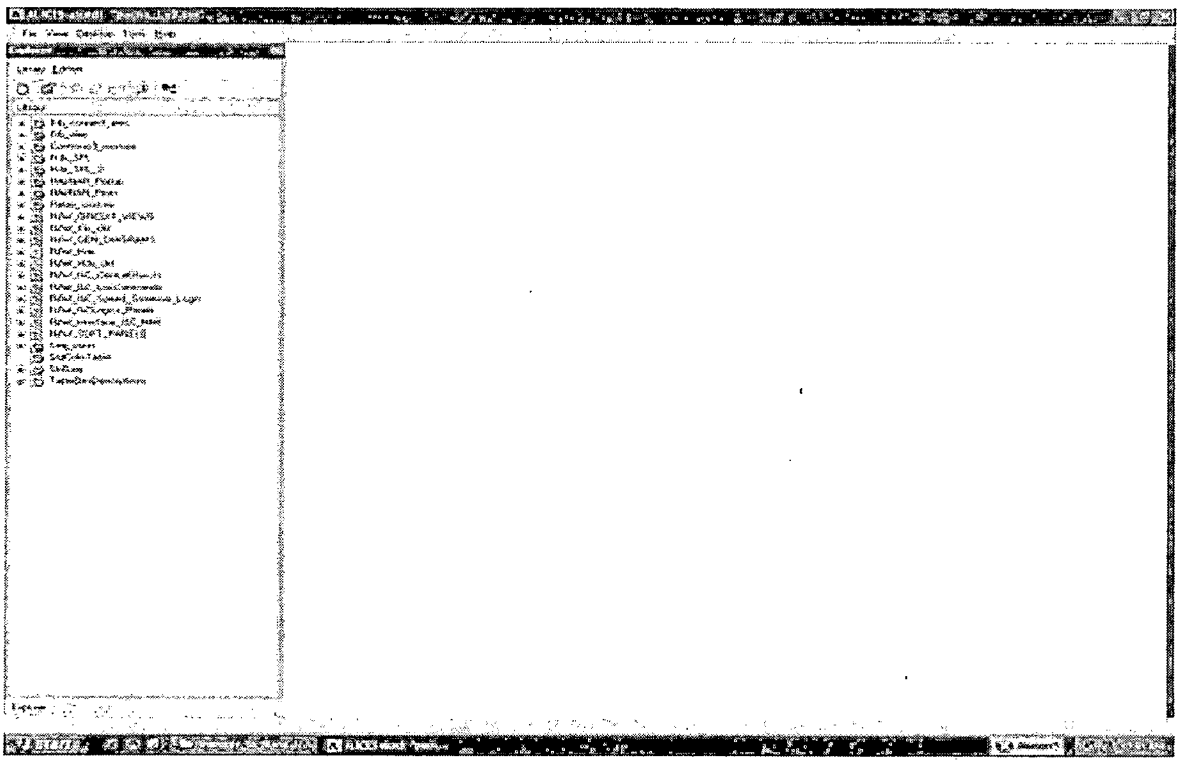


Fig. 4.1: ALICES explorer of session "pacha_Lv2.ses".

4.3 Creation of a Data Bank

The data in the bank is displayed in tables. A table comprises of one or several fields each containing a specific type of data. The decomposition of the table into fields is described in the table scheme. The scheme is defined by the intermediate schemes editor. The content of a table field can come from another table. These two tables are thus linked. When the table scheme has been defined, the table can be filled using the table's editor. Each table line corresponds to a recording.

A data bank (DBK) named **PACHA_HYDRO_DataBank.cbb** is created for the development of simulation for Pacha SHP plant.

Fig 4.2 shows the DBK of Pacha SHP plant. DBK contains all alphanumerical data of Pacha SHP plant to be simulated. The data is spread out in tables whose structure is defined by the scheme of each table.

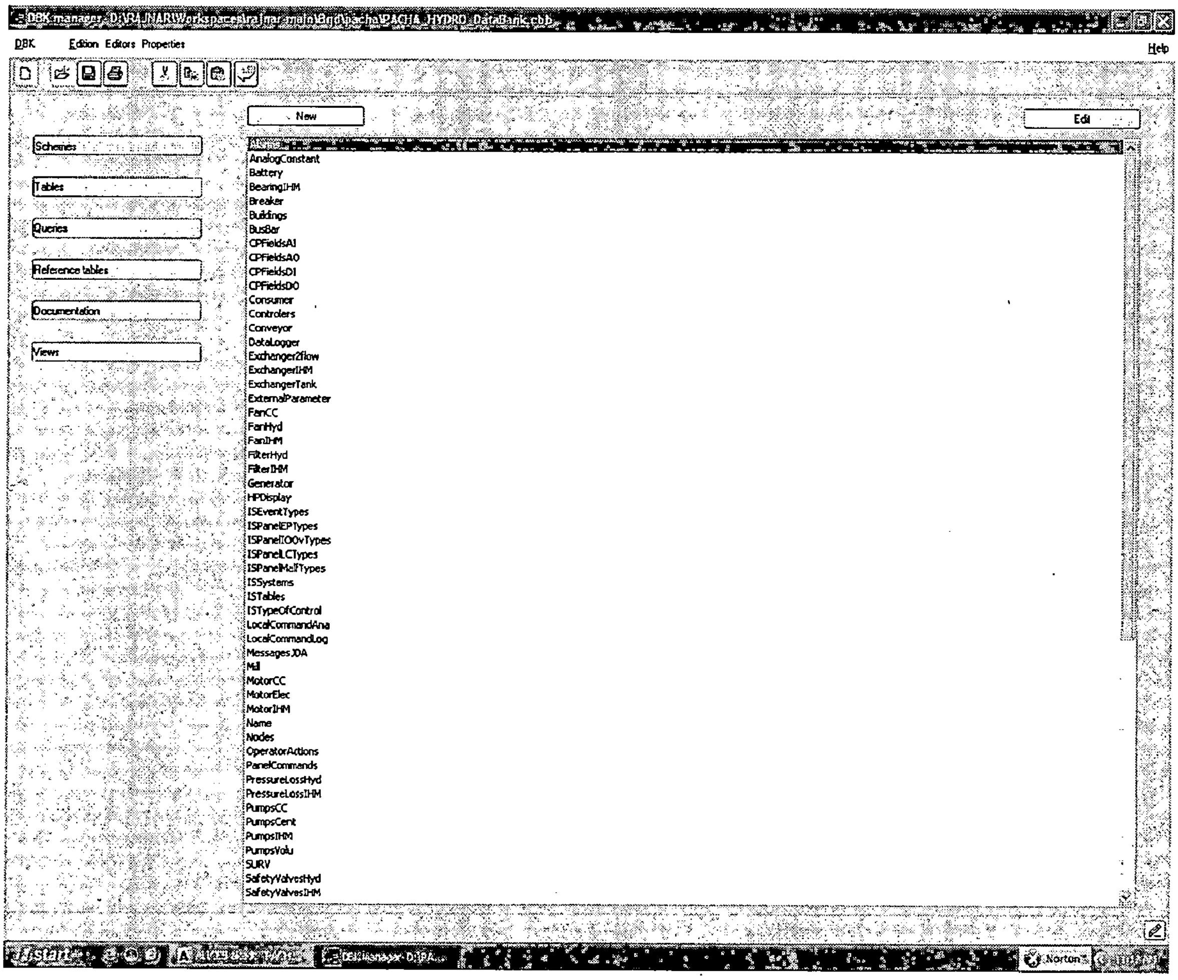
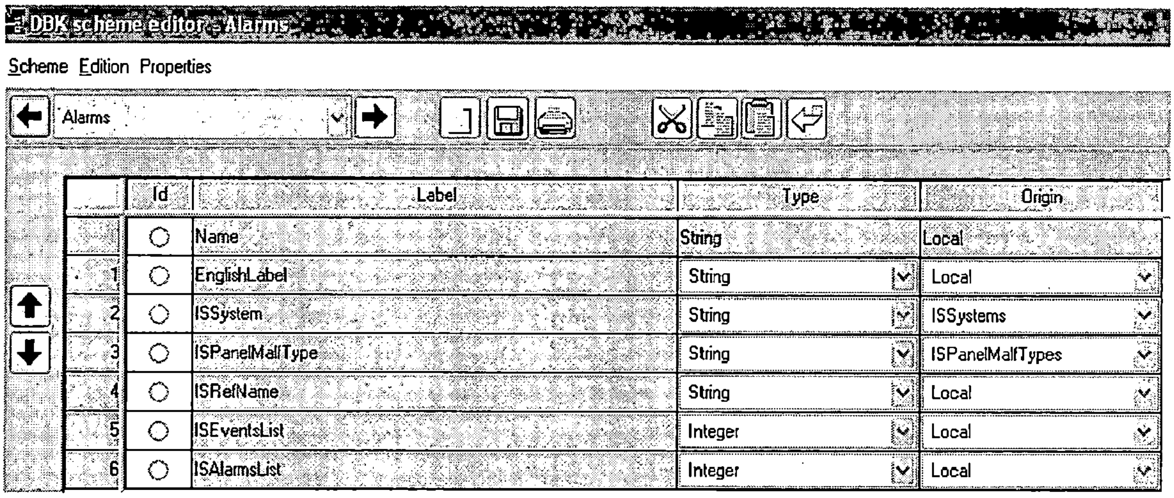


Fig.4.2: Data Bank of Pacha SHP Plant.

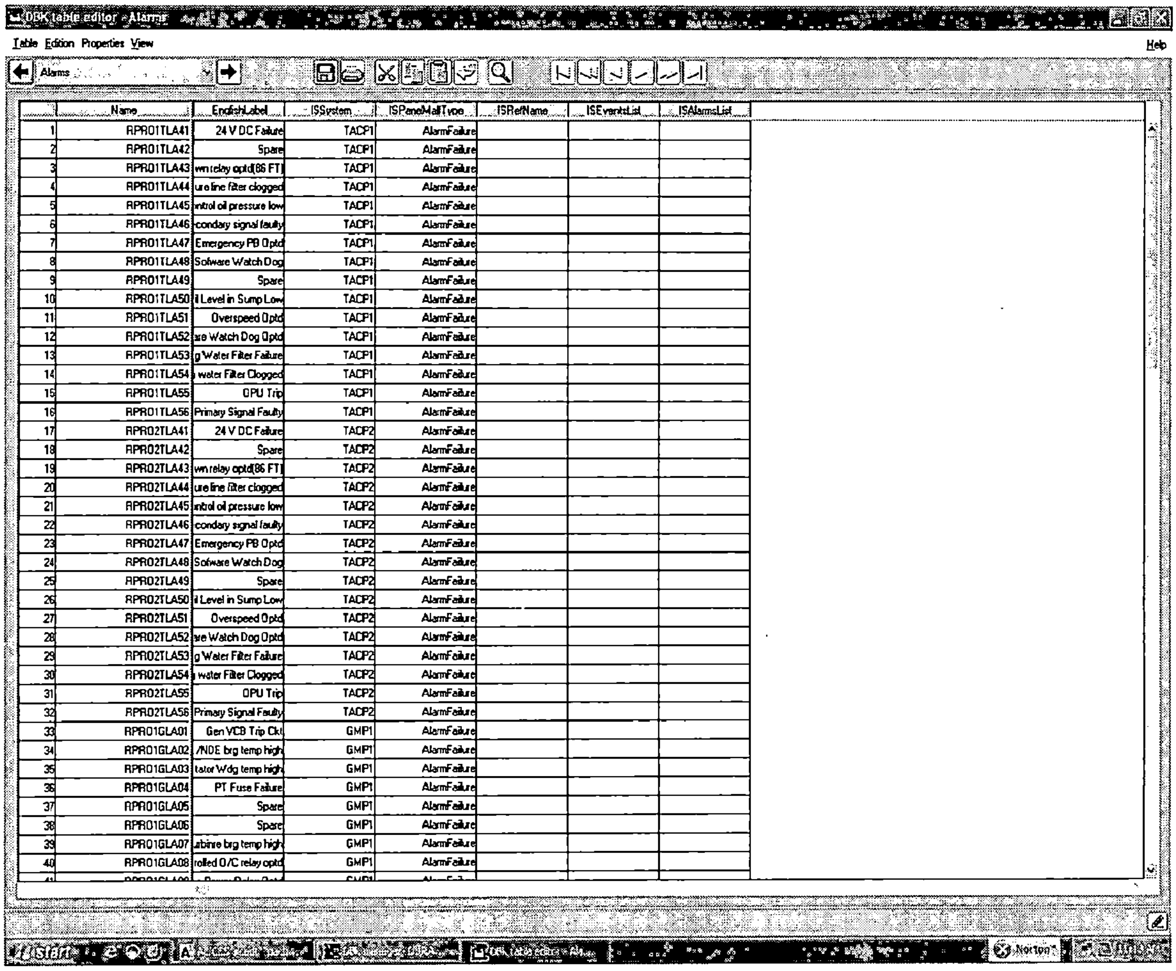
Fig. 4.3 shows the scheme editor of DBK for Pacha SHP plant.



	Id	Label	Type	Origin
	○	Name	String	Local
1	○	EnglishLabel	String	Local
2	○	ISSystem	String	ISSystems
3	○	ISPanelMalfType	String	ISPanelMalfTypes
4	○	ISRefName	String	Local
5	○	ISEventsList	Integer	Local
6	○	ISAlarmsList	Integer	Local

Fig.4.3: Data Bank Scheme Editor.

Fig. 4.4 shows the table editor of DBK for Pacha SHP plant.



	Name	EnglishLabel	ISSystem	ISPanelMalfType	ISRefName	ISEventsList	ISAlarmsList
1	RPR01TLA41	24 V DC Failure	TACP1	AlarmFailure			
2	RPR01TLA42	Spare	TACP1	AlarmFailure			
3	RPR01TLA43	wn relay optd(86 FT)	TACP1	AlarmFailure			
4	RPR01TLA44	ure line filter clogged	TACP1	AlarmFailure			
5	RPR01TLA45	ntrol oil pressure low	TACP1	AlarmFailure			
6	RPR01TLA46	condary signal faulty	TACP1	AlarmFailure			
7	RPR01TLA47	Emergency PB Optd	TACP1	AlarmFailure			
8	RPR01TLA48	Sofware Watch Dog	TACP1	AlarmFailure			
9	RPR01TLA49	Spare	TACP1	AlarmFailure			
10	RPR01TLA50	il Level in Sump Low	TACP1	AlarmFailure			
11	RPR01TLA51	Overspeed Optd	TACP1	AlarmFailure			
12	RPR01TLA52	are Watch Dog Optd	TACP1	AlarmFailure			
13	RPR01TLA53	g Water Filter Failure	TACP1	AlarmFailure			
14	RPR01TLA54	water Filter Clogged	TACP1	AlarmFailure			
15	RPR01TLA55	OPU Trip	TACP1	AlarmFailure			
16	RPR01TLA56	Primary Signal Faulty	TACP1	AlarmFailure			
17	RPR02TLA41	24 V DC Failure	TACP2	AlarmFailure			
18	RPR02TLA42	Spare	TACP2	AlarmFailure			
19	RPR02TLA43	wn relay optd(86 FT)	TACP2	AlarmFailure			
20	RPR02TLA44	ure line filter clogged	TACP2	AlarmFailure			
21	RPR02TLA45	ntrol oil pressure low	TACP2	AlarmFailure			
22	RPR02TLA46	condary signal faulty	TACP2	AlarmFailure			
23	RPR02TLA47	Emergency PB Optd	TACP2	AlarmFailure			
24	RPR02TLA48	Sofware Watch Dog	TACP2	AlarmFailure			
25	RPR02TLA49	Spare	TACP2	AlarmFailure			
26	RPR02TLA50	il Level in Sump Low	TACP2	AlarmFailure			
27	RPR02TLA51	Overspeed Optd	TACP2	AlarmFailure			
28	RPR02TLA52	are Watch Dog Optd	TACP2	AlarmFailure			
29	RPR02TLA53	g Water Filter Failure	TACP2	AlarmFailure			
30	RPR02TLA54	water Filter Clogged	TACP2	AlarmFailure			
31	RPR02TLA55	OPU Trip	TACP2	AlarmFailure			
32	RPR02TLA56	Primary Signal Faulty	TACP2	AlarmFailure			
33	RPR01GLA01	Gen VCB Trip Ckt	GMP1	AlarmFailure			
34	RPR01GLA02	/NDE brg temp high	GMP1	AlarmFailure			
35	RPR01GLA03	tator Wdg temp high	GMP1	AlarmFailure			
36	RPR01GLA04	PT Fuse Failure	GMP1	AlarmFailure			
37	RPR01GLA05	Spare	GMP1	AlarmFailure			
38	RPR01GLA06	Spare	GMP1	AlarmFailure			
39	RPR01GLA07	urbine brg temp high	GMP1	AlarmFailure			
40	RPR01GLA08	rolled O/C relay optd	GMP1	AlarmFailure			

Fig.4.4: Data Bank Table Editor.

4.4 Creation of LV-2 Models

In this step, different subsystems of Pacha SHP plant is developed using elementary objects defined in LV-1.

4.4.1 Creation of Hydraulic Differential Models

The level-1 objects used for the creation of hydraulic differential model are listed in Table B.1 of Appendix-B.

Fig. 4.5 shows the LV-2 model developed for the upstream of river. This model contains weir and intake gates. Fig. 4.6 shows the LV-2 model developed for the intake channel, desilting tank and power channel to the plant. Fig. 4.7 shows the LV-2 model developed for the foebay tank and penstock and their connections to each other. Fig. 4.8 shows the LV-2 model developed for the Francis turbine and its connection to penstock. Fig. 4.9 shows the LV-2 model developed for the tailrace level and down stream of river.

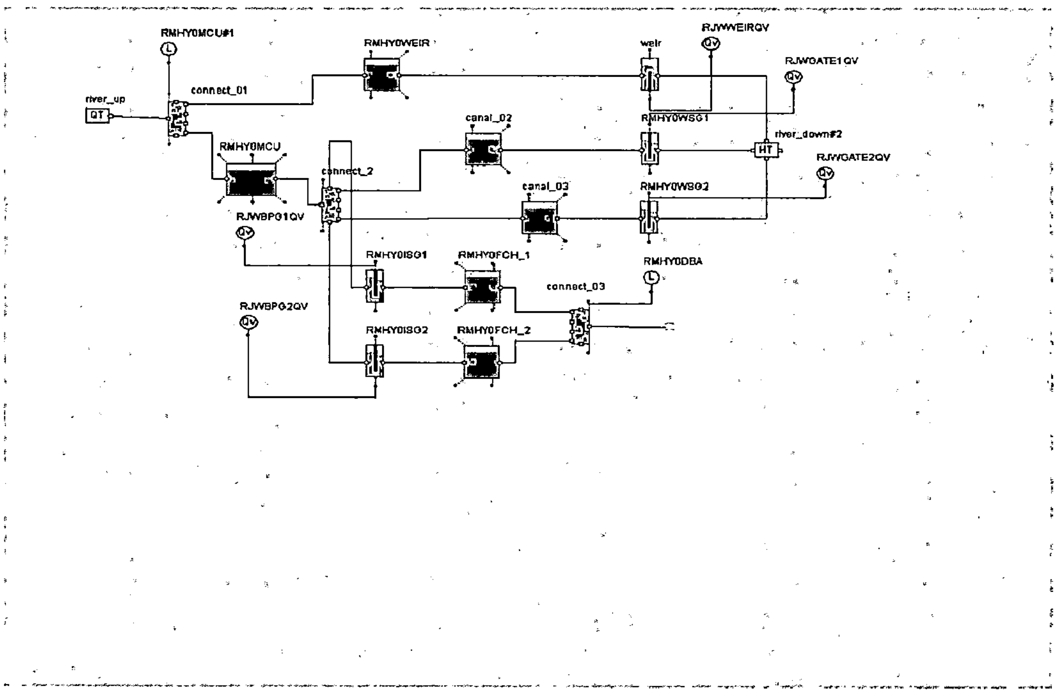


Fig.4.5: Level 2 model for upstream of river for Pacha SHP plant.

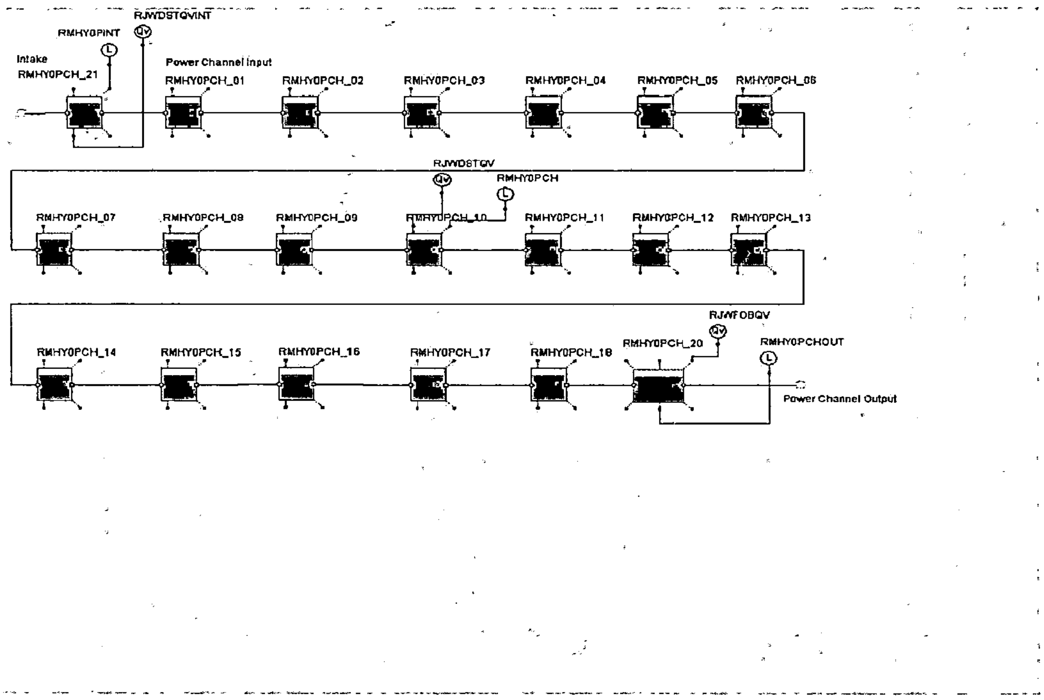


Fig.4.6: Level 2 model for intake channel, deslting tank and Power Channel for Pacha SHP plant.

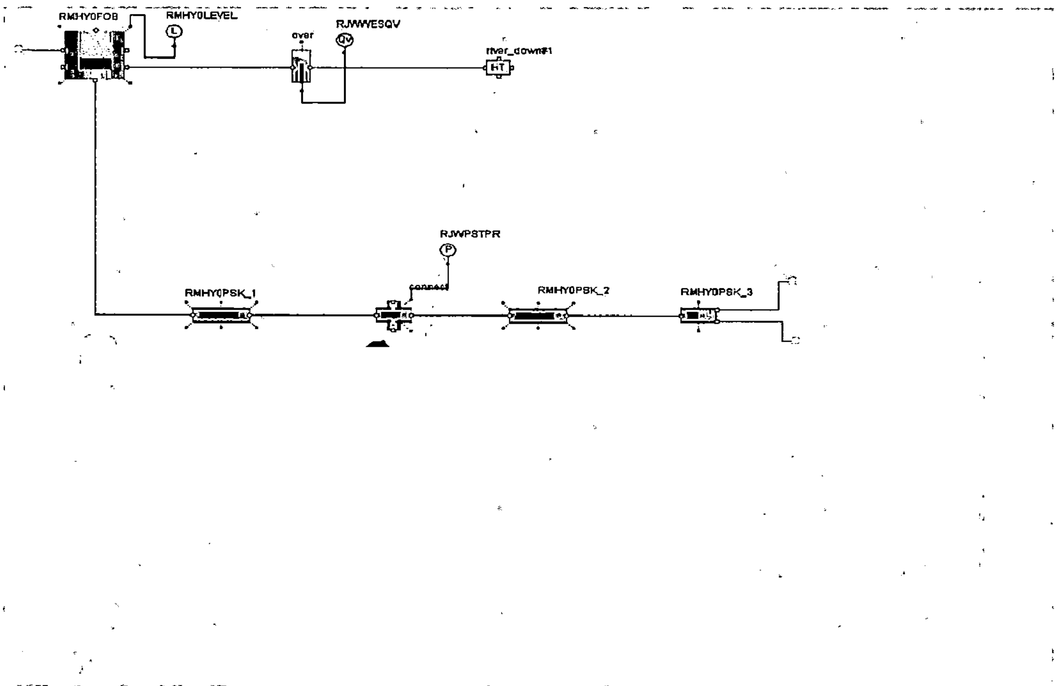


Fig.4.7: Level 2 model for Forebay and Penstock for Pacha SHP plant.

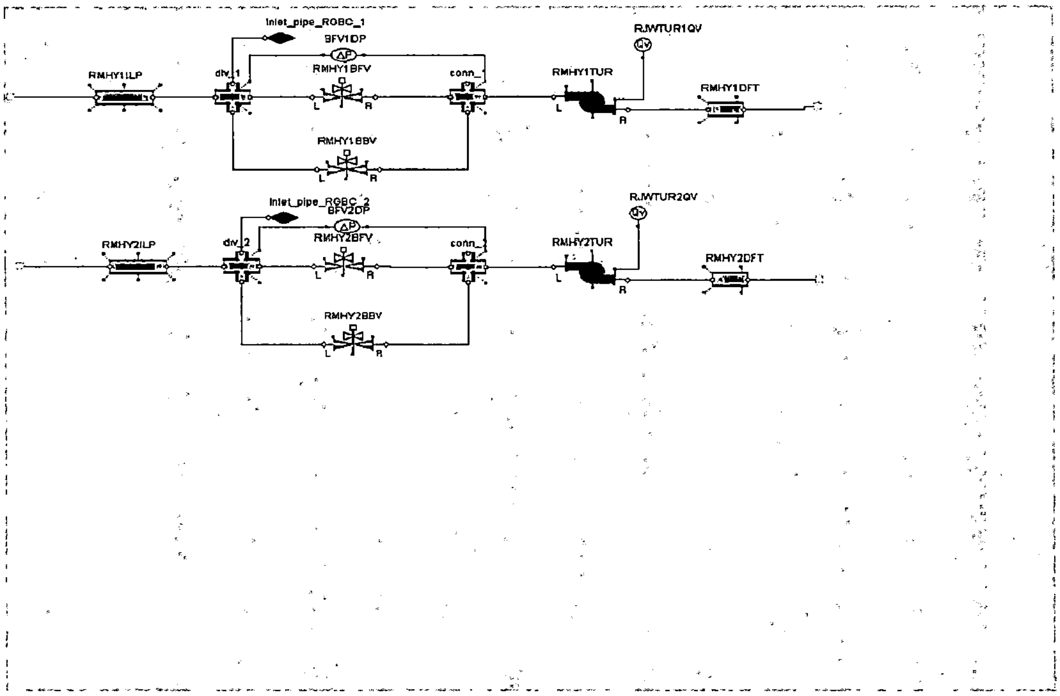


Fig.4.8: Level 2 model for Butter fly valve and francis turbine for Pacha SHP plant.

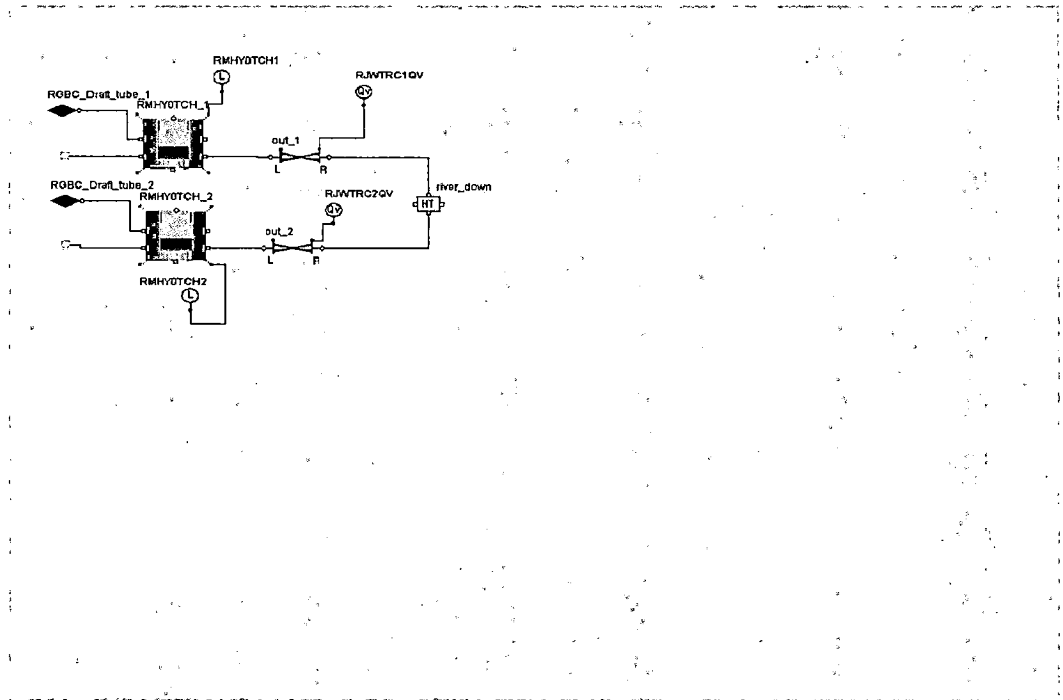


Fig.4.9: Level 2 model of Tailrace and Downstream of river for Pacha SHP plant.

4.4.2 Creation of Electrical Differential and Sequential Models

The LV-1 objects used for the creation of LV-2 models electrical differential and sequential circuits are listed in table B.2 of Appendix-B.

Fig. 4.10 shows LV-2 model developed for the power evacuation circuit of Pacha SHP plant. Fig. 4.11 shows LV-2 model developed for the power production circuit of SHP plant. Figs. 4.12 and 4.13 show LV-2 models developed for the auxiliary electrical circuit of SHP plant.

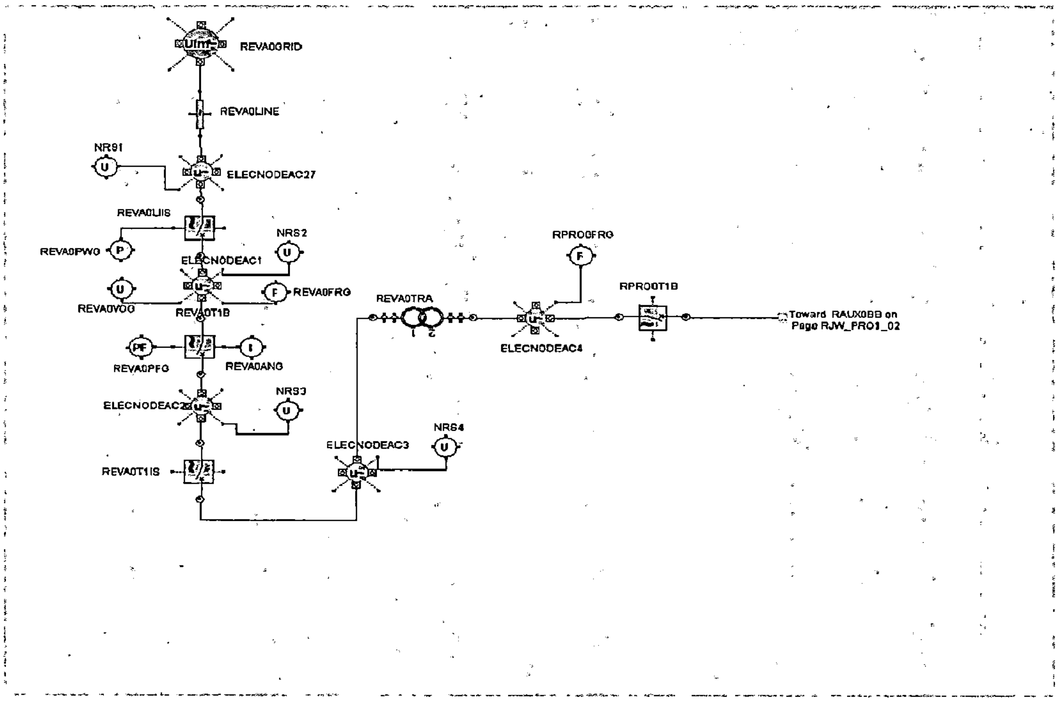


Fig.4.10: Level 2 model of power evacuation Circuit of Pacha SHP plant.

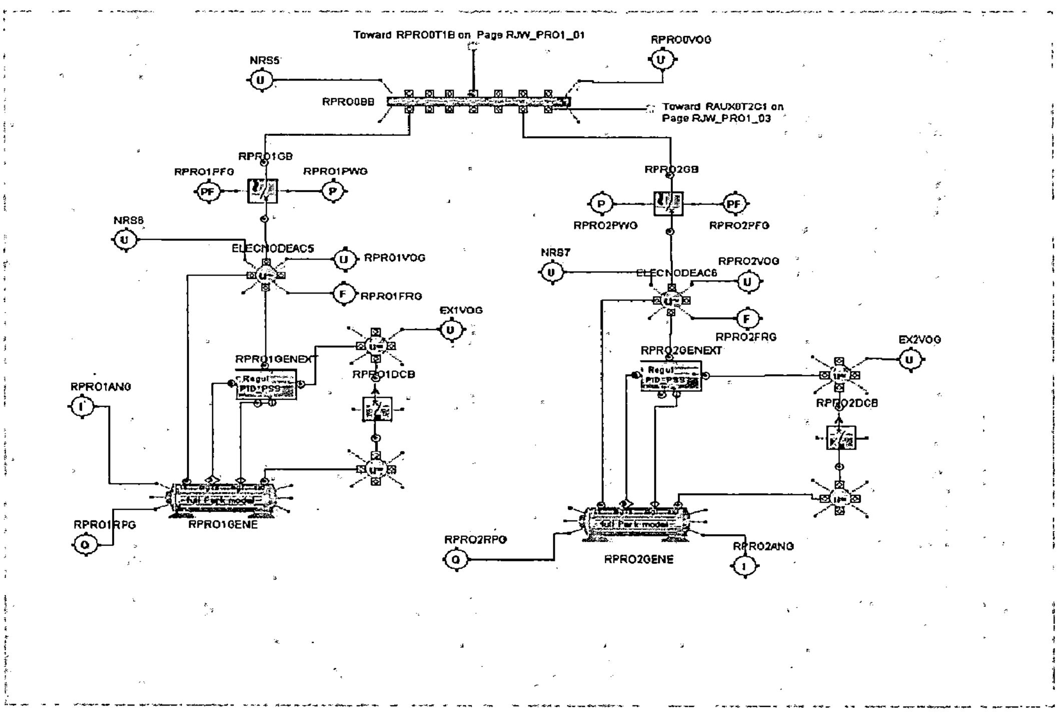


Fig.4.11: Level 2 model of power production Circuit of Pacha SHP Plant.

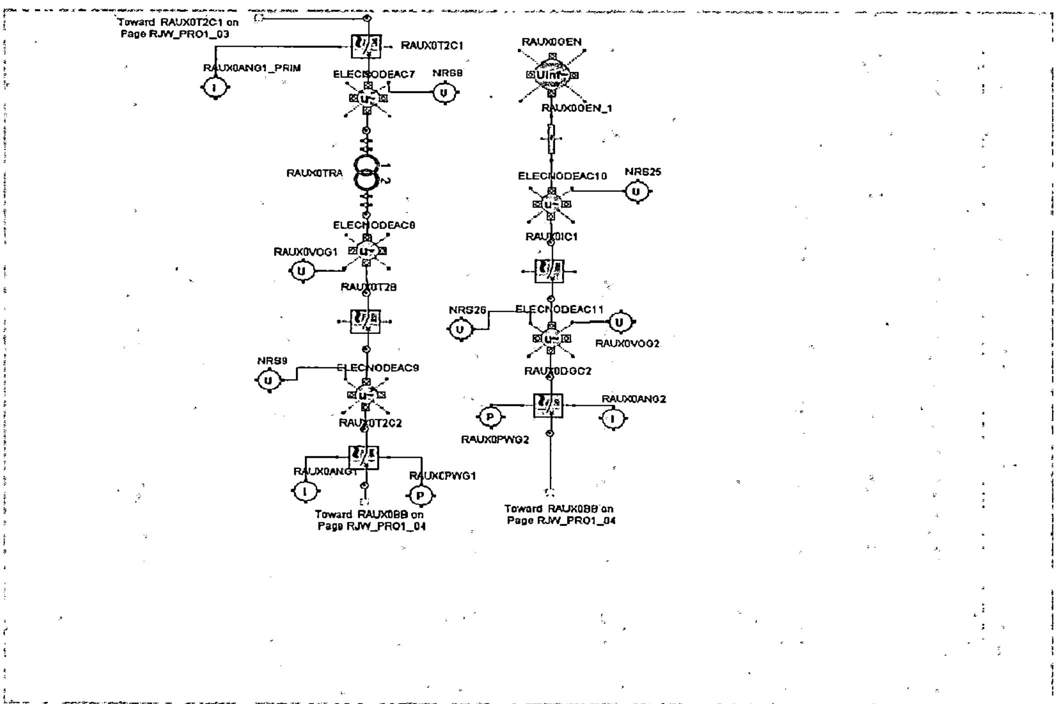


Fig. 4.12: Level 2 model 1 of auxiliary electrical Circuit of Pacha SHP Plant.

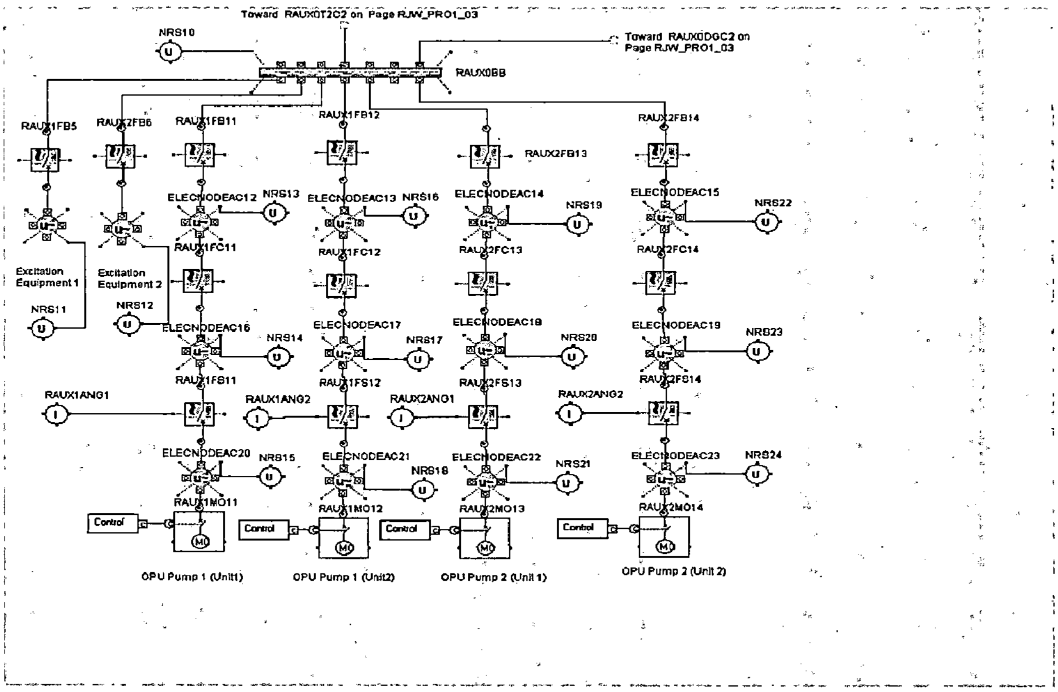


Fig. 4.13 Level 2 model 2 of auxiliary electrical Circuit of SHP Plant.

4.5 Production of LV-2 documents

The following table data are used to develop the Pacha SHP plant hydraulic circuits.

4.5.1 Production of hydraulic circuits

4.5.1.1 Diversion Weir

LV-2 parameter form for diversion weir is ' RMHY0WEIR '. Table 4.2 represents the data for diversion weir.

Table 4.2: Diversion weir data.

Name	Comment	Initialization value	Unit	Type
Cv_th_amb	energy transfer coefficient with ambient	1.0000	W/K	Real
Width	Width	12.000	m	Real
Length	Length	45.000	m	Real
Height_L	Left bottom Height	971.00	m	Real
Height_R	Right bottom Height	971.00	m	Real

Roughness	Roughness	0.010000	m	Real
Depth	Depth	8.0000	m	Real
Coeff_PdC_Singul	singular loss of head coeff	0.00000	-	Real
IND_V2_L	speed on left side (0=no,1=yes)	1	-	Integer
IND_V2_R	speed on right side (0=no,1=yes)	1	-	Integer

4.5.1.2 Intake Channel

LV-2 parameter form for intake channel is ' RMHY0PCH_21'. Table 4.3 shows the data for intake channel.

Table 4.3: Intake channel data.

Name	Comment	Initialization value	Unit	Type
Cv_th_amb	energy transfer coefficient with ambient	1.0000	W/K	Real
Width	Width	3.2000	m	Real
Length	Length	564.00	m	Real
Height_L	Left bottom Height	973.40	m	Real
Height_R	Right bottom Height	973.10	m	Real
Roughness	Roughness	0.0050000	m	Real
Depth	Depth	2.3900	m	Real
Coeff_PdC_Singul	singular loss of head coeff	5.0000	-	Real
IND_V2_L	speed on left side (0=no,1=yes)	0	rpm	Integer
IND_V2_R	speed on right side	0	rpm	Integer

	(0=no,1=yes)			

4.5.1.3 Desilting Tank

LV-2 parameter form for desilting tank is ' RMHY0PCH_10 '. Table 4.4 represents the data for desilting tank.

Table 4.4: Desilting tank data.

Name	Comment	Initialization value	Unit	Type
Cv_th_amb	energy transfer coefficient with ambient	1.0000	W/K	Real
Width	Width	17.000	m	Real
Length	Length	90.000	m	Real
Height_L	Left bottom Height	972.38	m	Real
Height_R	Right bottom Height	972.30	m	Real
Roughness	Roughness	0.010000	m	Real
Depth	Depth	3.5000	m	Real
Coeff_PdC_Singul	singular loss of head coeff	1.0000e-006	-	Real
IND_V2_L	speed on left side (0=no,1=yes)	0	rpm	Integer
IND_V2_R	speed on right side (0=no,1=yes)	0	rpm	Integer

4.5.1.4 Power Channel

LV-2 parameter form for power channel is ' RMHY0PCH_20 '. Table 4.5 shows the data for power Channel.

Table 4.5 Power Channel data.

Name	Comment	Initialization value	Unit	Type
Cv_th_amb	energy transfer coefficient with ambient	1.0000	W/K	Real
Width	Width	3.2000	m	Real
Length	Length	3921.0	m	Real
Height_L	Left bottom Height	971.66	m	Real
Height_R	Right bottom Height	971.50	m	Real
Roughness	Roughness	0.010000	m)	Real
Depth	Depth	2.2500	m	Real
Coeff_PdC_Singul	singular loss of head coeff	1.0000e-006	-	Real
IND_V2_L	speed on left side (0=no,1=yes)	0	rpm	Integer
IND_V2_R	speed on right side (0=no,1=yes)	0	rpm	Integer

4.5.1.5 Forebay Tank

LV-2 parameter form for forebay tank is ' RMHY0FOB'. Table 4.6 represents the data for forebay tank.

Table 4.6 : Forebay tank data.

Name	Comment	Initialization value	Unit	Type
Cv_th_amb	energy transfer coefficient with ambient	1.0000	W.K-1	Real
H_con	height of connections	[4]{ 971.5 , 966.3 , 966.3 , 973.47 }	m	Array1OfReal

Section_res	Section of tank	[3]{ 35 , 10.5 , 3.5}	m^2	Array1OfReal
Height_res	Height of tank	[4]{ 930 , 966.27 , 973.5 , 976.5 }	m	Array1OfReal
D_con	diameter of connections	[5]{ 2.6 , 0 , 0 , 3 , 1.275 }	m	Array1OfReal

4.5.1.6 Penstock

LV-2 parameter form for penstock is ' RMHY0PSK_1 '. Table 4.7 shows the data for penstock.

Table 4.7 : Penstock data.

Name	Comment	Initialization value	Unit	Type	Range
Cv_th_amb	energy transfer coefficient with ambient	1.0000	W/K	Real	
Length	Length	147.00	m	Real	
Height_L	Left bottom Height	930.00	m	Real	
Height_R	Right bottom Height	930.00	m	Real	
Roughness	Roughness	0.0010000	m	Real	
Thickness	Thickness	0.0080000	m	Real	
Diam_L	Left diameter	1.2750	m	Real	
Diam_R	Right diameter	1.2750	m	Real	
Coeff_PdC_Singul	singular loss of head coeff	0.35000	-	Real	

4.5.1.7 Francis Turbine

LV-2 parameter form for francis turbine is ' RMHY1TUR'. Table 4.8 represents the data for francis turbine.

Table 4.8 : Francis turbine data.

Name	Comment	Initialization value	Unit	Type
Height_nom	Nominal net head (m)	43.000	m	Real
Qv_nom	Nominal volumic flow	5.0833	m^3/s	Real
Srot_nom	Nominal rotation speed	600.00	[rpm	Real
Pos_nom	Guide vanes mominal position	80.000	-	Real
Pos_max	Guide vanes maximal position	100.00	-	Real
Pos_min	Guide vane minimal position	0.00000	-	Real
Qv_max	Maximal volumic flow for nominal net head	6.1000	m^3/s	Real
Power_bearings	Energy loss in bearings	0.00000	W	Real
Tm_fric	Minimal friction torque	0.010000	N.m	Real
Diam_L	Left diameter	1.0166	m	Real
Diam_R	Right diameter	1.0166	m	Real
Height_L	Height	926.88	m	Real
Height_R	Height	928.20	m	Real

4.5.1.8 Tail Race Channel

LV-2 parameter form for tail race channe lis ' RMHY0TCH_1 '. Table 4.9 present the data for tail race channel.

Table 4.9 : Tail Race Channel data.

Name	Comment	Initialization value	Unit	Type	Range
Cv_th_amb	energy transfer	1.0000	W/K	Real	

	coefficient with ambient				
H_con	height of connections	[4]{ 926 , 923.593 , 921 , 926 }	m	Array1OfReal	
Section_res	Section of tank	[3]{ 25, 2.80., 1.40. }	m2	Array1OfReal	
Height_res	Height of tank	[4]{ 921., 928.,0., 0. }	m	Array1OfReal	
D_con	diameter of connections	[5]{ 0.0508 , 1.81 , 0 , 5083 , 0 }	m	Array1OfReal	

4.5.2 Production of documents for Electrical Circuts

The following table data are used to develop the Pacha SHP plant elecrtical circuits.

4.5.2.1 Grid

LV-2 parameter form for grid is ' REVA0GRID'. Table 4.10 shows the data for grid.

Table 4.10 : Grid data.

Name	Comment	Initialization value	Unit	Type
Sn	nominal apparent power	2.0000e+006	VA	Real
Un	nominal voltage	66000.	V	Real
Fn	nominal frequency	50.000	Hz	Real
Theta_Uinf	argument of the infinite power node voltage	0.00000	rad	Real
Fizc	Flag of zone current computation	1	-	Integer

4.5.2.2 Main Transformer

LV-2 parameter form for main transformer is ' REVA0TRA '. Table 4.11 represents the data for main transformer.

Table 4.11 : Main Transformer data.

Name	Comment	Initialization value	Unit	Type
B	exponent expressing saturation	1.0000	-	Real
IM	magnetizing current (noload current)	0.40000	pu	Real
Pcu	copper losses	0.020000	pu	Real
Pfe	iron losses	0.0010000	pu	Real
theta_K	transformer ratio phase shift angle	0.00000	degrees	Real
U10	primary noload voltage	66000.	V	Real
U20	secondary noload voltage	3300.0	V	Real
Ucc	short_circuit voltage	0.095000	pu	Real
n1TAP	primary TAP number	0	-	Integer
n2TAP	secondary TAP number	2	-	Integer
DU1_TAP	primary TAP voltage	1000.0	V	Real
DU2_TAP	secondary TAP voltage	100.00	V	Real
Sn	nominal apparent power	2.0000e+006	VA	Real
W0	nominal network angular frequency	314.16	rad/s	Real

4.5.2.3 Busbar

LV-2 parameter form for busbar is ' RPRO0BB '. Table 4.12 shows the data for busbar.

Table 4.12 : Bus bar data.

Name	Comment	Initialisation value	Unit	Type
Sn	nominal apparent power	4.0000e+006	VA	Real
Un	nominal voltage	3300.0	V	Real
Fn	nominal frequency	50.000	Hz	Real
Fizc	Flag of zone current computation	1	-	Integer

4.5.2.4 Generator

LV-2 parameter form for generator is ' RPRO1GENE'. Table 4.13 represents the data for generator.

Table 4.13 : Generator Data.

Name	Comment	Initialization value	Unit	Type
Sn	nominal apparent power	1.8750e+006	VA	Real
Un	nominal voltage	3300.0	V	Real
eKrf	rotor resistance	1.8500	ohm	Real
Ifbase	base excitation current	1.6500	A	Real
W0	nominal network angular frequency	314.16	rad/s	Real
eKpp	number of pair of poles	5	Nms^2	Integer
eKJ	inertia of rotation	1100.0		Real
eKmd	saturation coefficient md	1.0000	-	Real
eKnd	saturation coefficient nd	1.0000	-	Real
eKra	armature resitance	0.016000	Ohm	Real
Rf_pu	normalized excitation resistance	1.8300	pu	Real

eKlf	rotor inductance	5.0000	H	Real
eKld	inductance	0.10000	H	Real
eKrD	resistance D	0.26300	Ohm	Real
eKlD	inductance	1.0000	H	Real
eKrQ1	amortisseur resistance Q1	0.34370	Ohm	Real
eKrQ2	amortisseur resistance Q2	0.034370	Ohm	Real
eKlQ1	amortisseur inductance Q1	5.4450	H	Real
eKlQ2	amortisseur inductance Q2	5.4450	H	Real
eKMd0	mutual inductance	1.0000	H	Real
eKMd	satured value of the d-axis mutual inductance at the nominal point	1.0000	H	Real
eKCf	Friction torque	143.31	Nm	Real
eKCv	Wet friction torque	34.000	Nms	Real
Ftest	flag of synchronism test	0		Integer
Fn	nominal frequency	50.000	Hz	Real

4.5.2.5 Auxiliary Transformer

LV-2 parameter form for auxiliary transformer is ' RAUX0TRA '. Table 4.14 shows the data for auxiliary transformer.

Table 4.14 : Auxiliary Transformer data.

Name	Comment	Initialization value	Unit	Type
B	exponent expressing saturation	1.0000	-	Real
IM	magnetizing current (noload current)	0.40000	pu	Real
Pcu	copper losses	0.076000	pu	Real

Pfe	iron losses	0.0010000	pu	Real
theta_K	transformer ratio phase shift angle	0.00000	degrees	Real
U10	primary noload voltage	3300.0	V	Real
U20	secondary noload voltage	415.00	V	Real
Ucc	short_circuit voltage	0.095000	pu	Real
n1TAP	primary TAP number	0	-	Integer
n2TAP	secondary TAP number	0	-	Integer
DU1_TAP	primary TAP voltage	50.000	V	Real
DU2_TAP	secondary TAP voltage	4.0000	V	Real
Sn	nominal apparent power	2.5000e+005	VA	Real
W0	nominal network angular frequency	314.16	rad/s	Real

4.6 Configuration

A configuration is the description (list of modules and hardware description) of a simulator. The execution of a simulation needs the prior definition of such a configuration.

A configuration consists of :

- **Network:** All machines or workstations connected in the network and capable of exchanging information.
- **Machines:** Work stations from which information relative to the simulation models will be extracted and calculated.
- **Sequences:** A sequence determines the calculation frequency of the entire simulation model or a part of it, depending on the number of sequences created in the configuration tool.
- **Modules:** A processing module is processing program of simulator data.

Networks, Machines and sequences can only be placed in parallel. Modules can be place in series or in parallel. Fig. 4.14 shows the LV-3 configuration.

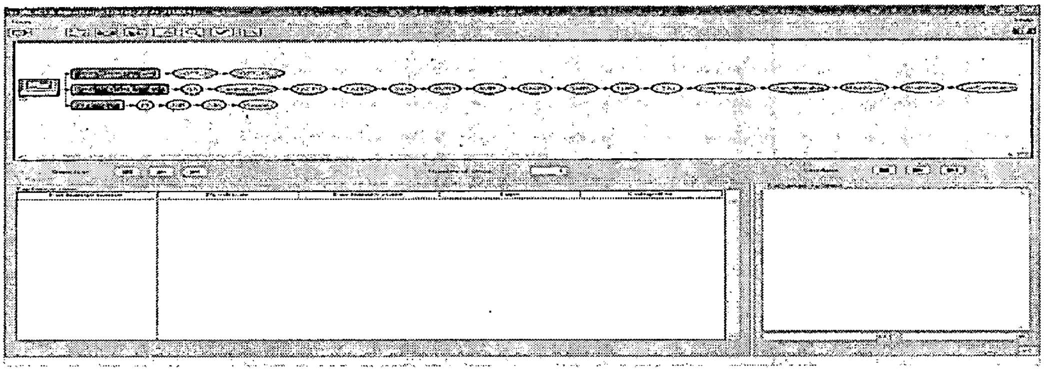


Fig. 4.14 : Level 3 configuration.

4.7 Execution

The execution of a configuration can be done by using instructor station. Fig 4.15 shows the instructor station.

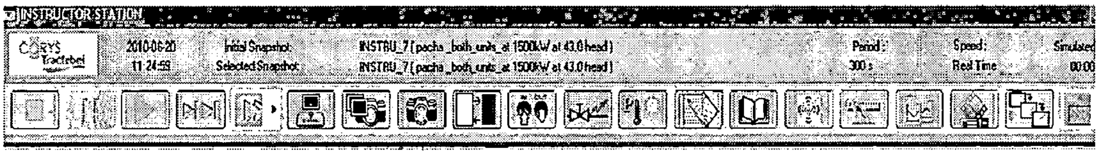


Fig. 4.15: Instructor station.

Following are the execution steps:

1. By using **snapshot management** icon as shown in Fig 5.16, load the required snapshot.

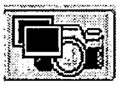
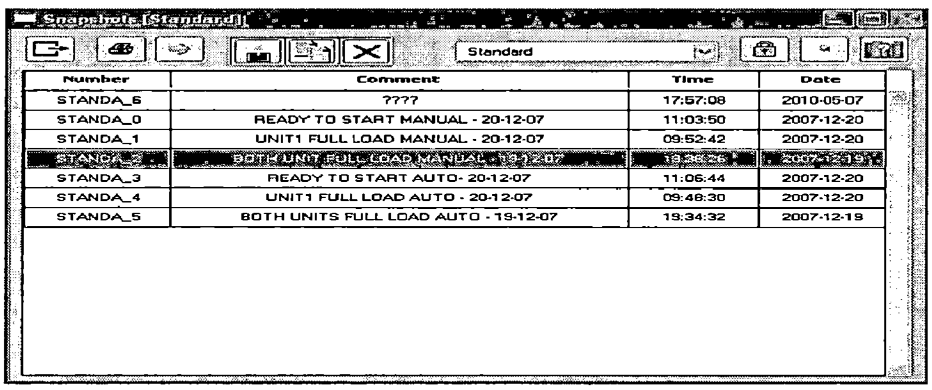


Fig. 4.16 Snapshot management icon.

Fig. 4.17 represents the following standard snapshots available in simulation.



Number	Comment	Time	Date
STANDA_6	????	17:57:08	2010-05-07
STANDA_0	READY TO START MANUAL - 20-12-07	11:03:50	2007-12-20
STANDA_1	UNIT1 FULL LOAD MANUAL - 20-12-07	09:52:42	2007-12-20
STANDA_2	BOTH UNIT FULL LOAD MANUAL - 19-12-07	19:36:26	2007-12-19
STANDA_3	READY TO START AUTO- 20-12-07	11:06:44	2007-12-20
STANDA_4	UNIT1 FULL LOAD AUTO - 20-12-07	09:48:30	2007-12-20
STANDA_5	BOTH UNITS FULL LOAD AUTO - 19-12-07	19:34:32	2007-12-19

Fig. 4.17 Standard snapshots.

2. By using **Init** icon as shown in Fig. 4.18, intialise the required standard snapshot.

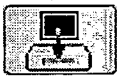


Fig. 4.18 Init icon.

3. After initialising, run the standard snapshot by using **Run** icon as shown in Fig. 4.19.

Fig. 4.19 Run icon.

Chapter- 5

RESULTS AND DISCUSSION

This chapter deals with the results of developed simulation under different operating conditions as follows.

1. Starting of Unit-1
2. Unit-1 Synchronised with Grid and run at partial load
3. Starting of Unit-2 with Unit-1 running at full load.
4. Unit-1 running with full load and Unit-2 Synchronised with Grid.
5. Both the units are running at full load.
6. Unit-1 running with full load and Unit-2 running with Emergency Shut down.
7. Grid Failure.

5.1 Starting of Unit-1:

To simulate the starting of Unit-1, simulation is first initialised and run using "READY TO START MANUAL" snapshot. This snapshot ensures the full fill ment of all pre start conditions necessary to start the units. After this, Unit-1 is started manually.

During starting of Unit-1 the speed of turbine-1 increases slowly with respect to simulation time as shown in Fig. 5.1.

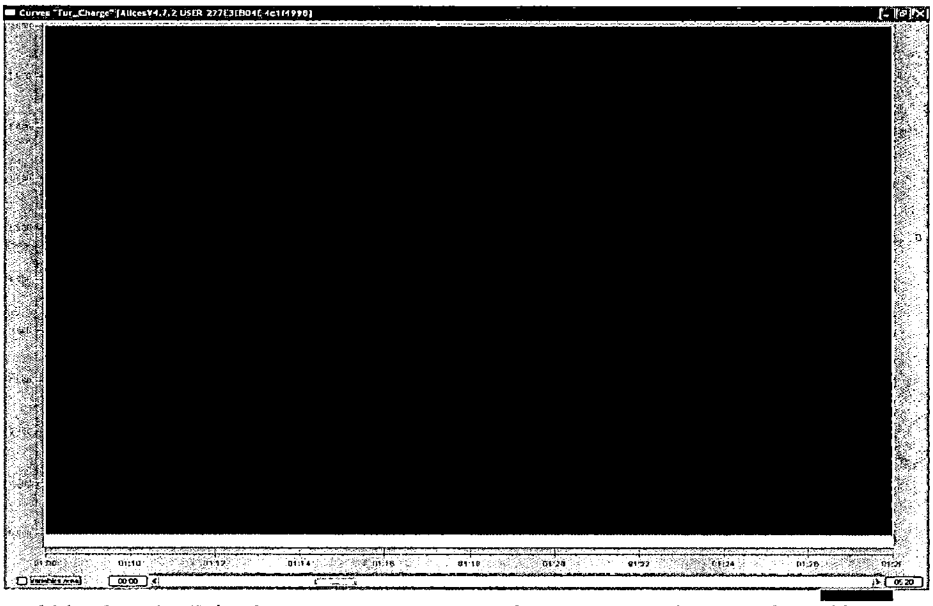


Fig. 5.1: Speed (rpm) of turbine-1 with respect to Simulation time (sec).

Fig. 5.2 represents voltage of Generator-1 with respect to simulation time. Excitation contacts are closed when speed of Generator-1 reaches 90% of rated speed and the voltage of Generator-1 settles down to its rated value with in 8-10 sec.

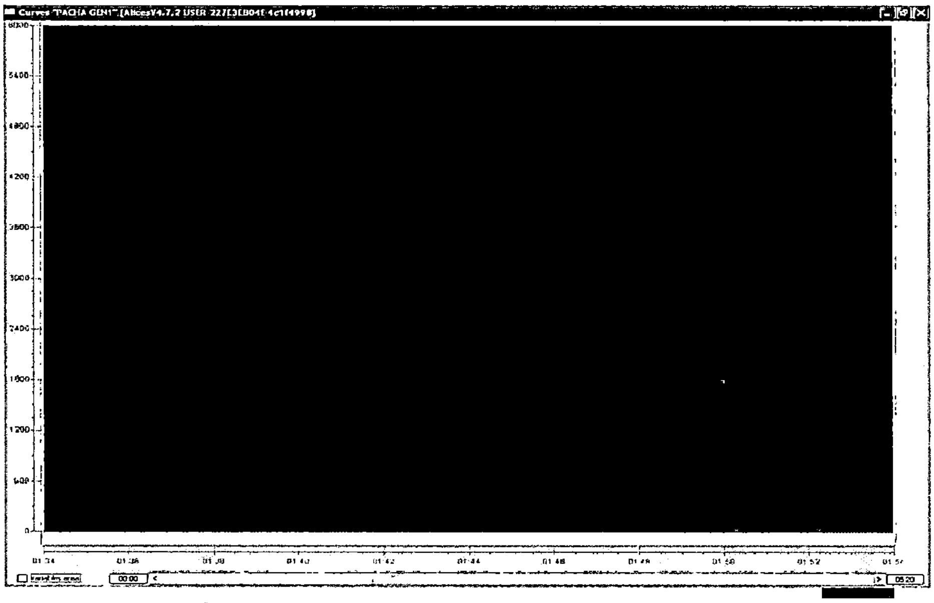


Fig. 5.2: Voltage (V) of Generator-1 with respect to Simulation time (sec).

Fig. 5.3 shows the frequency of Generator-1 with respect to simulation time. The frequency increases as the speed increases and finally at settles at 50 Hz.

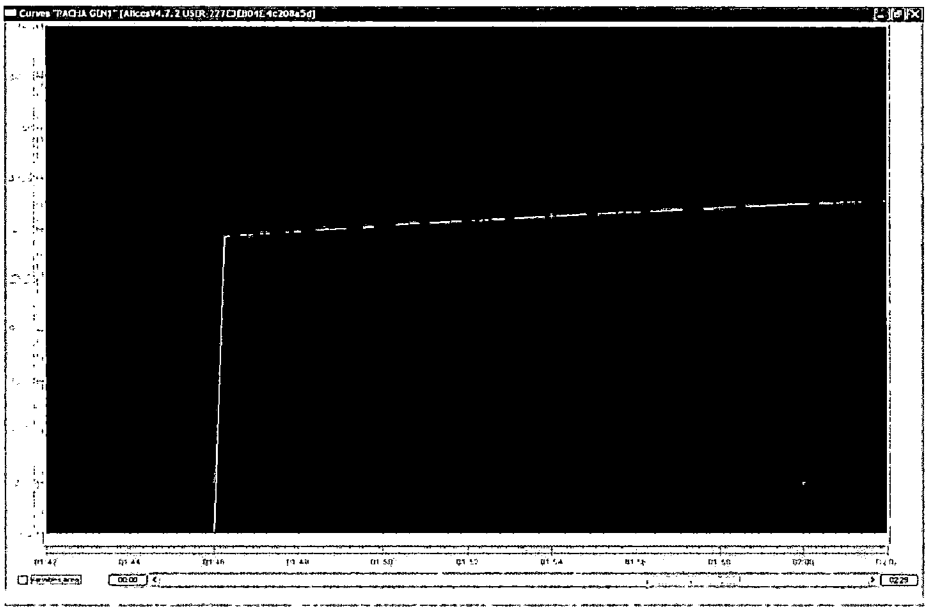


Fig. 5.3: Frequency (Hz) of Genertor-1with respect to Simulation time (sec).

5.2 Unit-1 Synchronised with Grid and run at partial load

After starting the Unit-1 as discussed in previous section, Unit-1 is synchronised with grid and loaded upto minimum load requirement.

Fig. 5.4 represents that the power from Generator-1 starts building up when it is synchronised and loaded upto minimum load requirement. Fig. 5.5 shows the power factor of Generator-1 with respect to simulation time. Due to continuous increment in the load, power factor of Unit-1 keeps on varying and after few transients, it settles down to 0.0635.

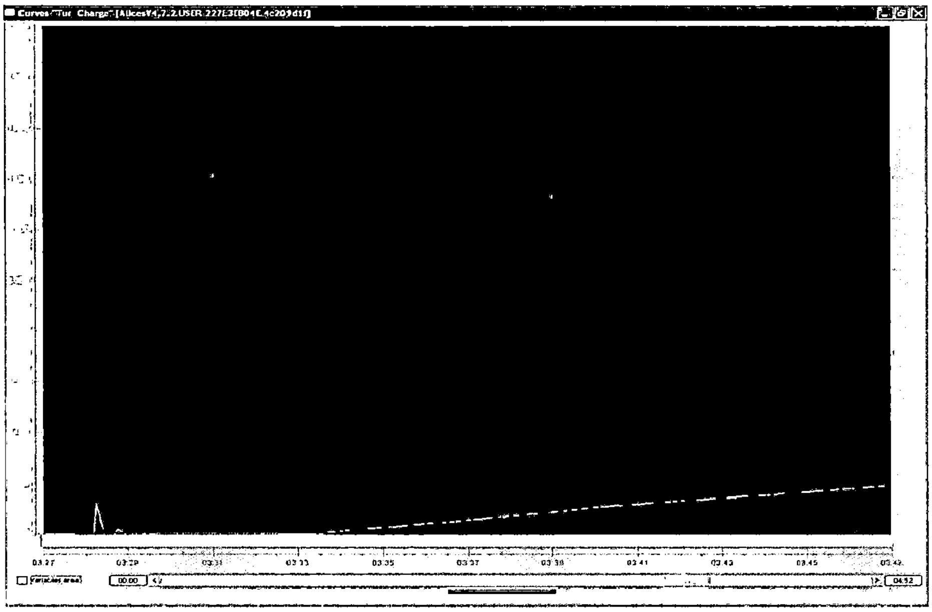


Fig. 5.4: Power (kW) output from Unit-1with respect to Simulation time (sec).

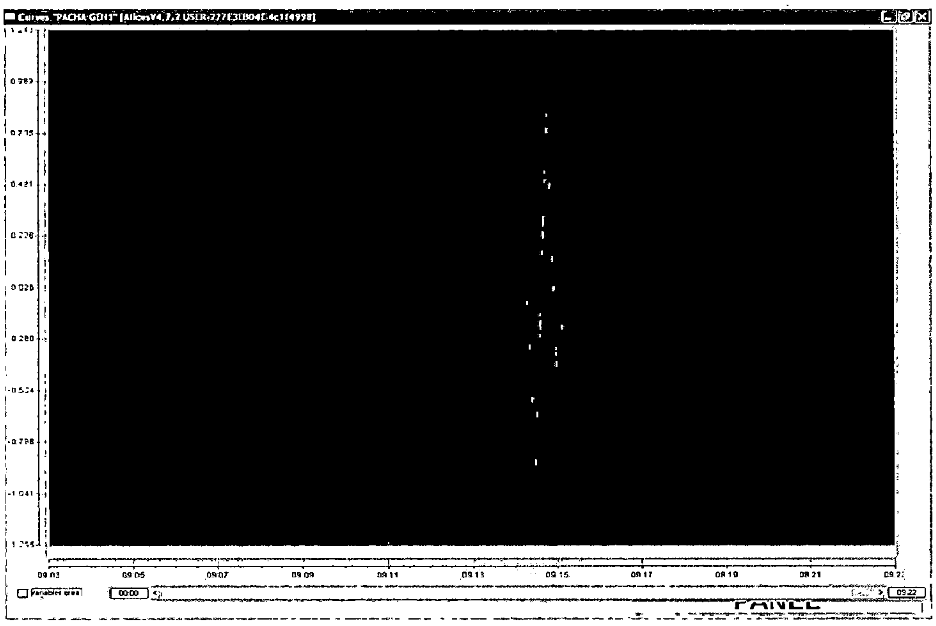


Fig. 5.5: Power factor of Generator-1 with respect to Simulation time (sec).

Similarly, the voltage of Generator-1 also varies continuously due to increment in load and settles down to 3.3 kV, as shown in Fig. 5.6.

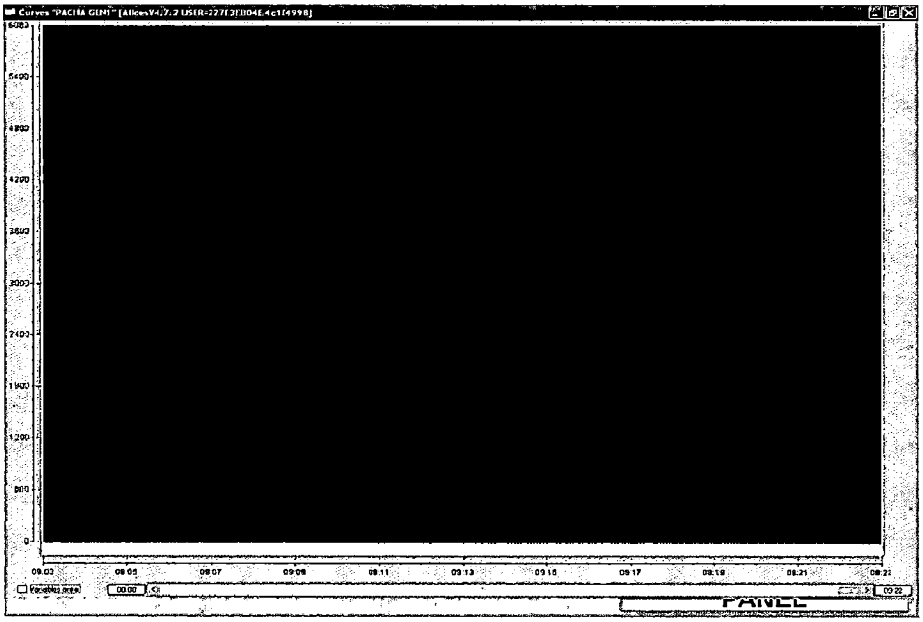


Fig. 5.6: Voltage (V) of Generator-1 with respect to Simulation time (sec).

Fig. 5.7 shows increment in the current of Generator-1 with respect to simulation time.

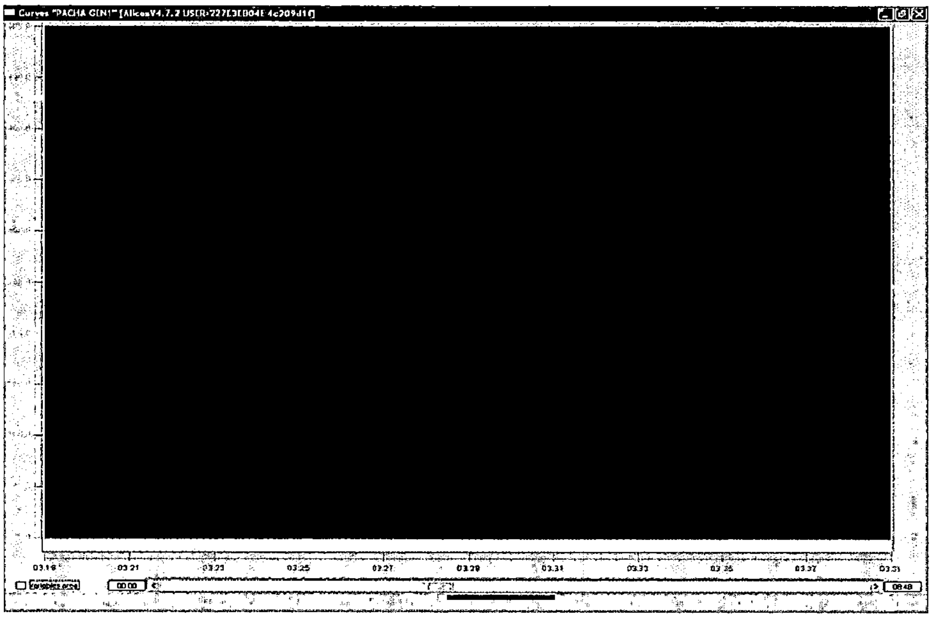


Fig. 5.7: Current (A) from Generaor-1with respect to Simulation time (sec).

Figs. 5.8, 5.9 and 5.10 show the variation of Grid power, power factor and current, respectively with respect to simulation time when the Unit-1 is synchronised with grid and loaded partially. Few disturbances are observed in power, p.f and current when Unit-1 is synchronised with grid. These disturbances die out with 4-5 sec.

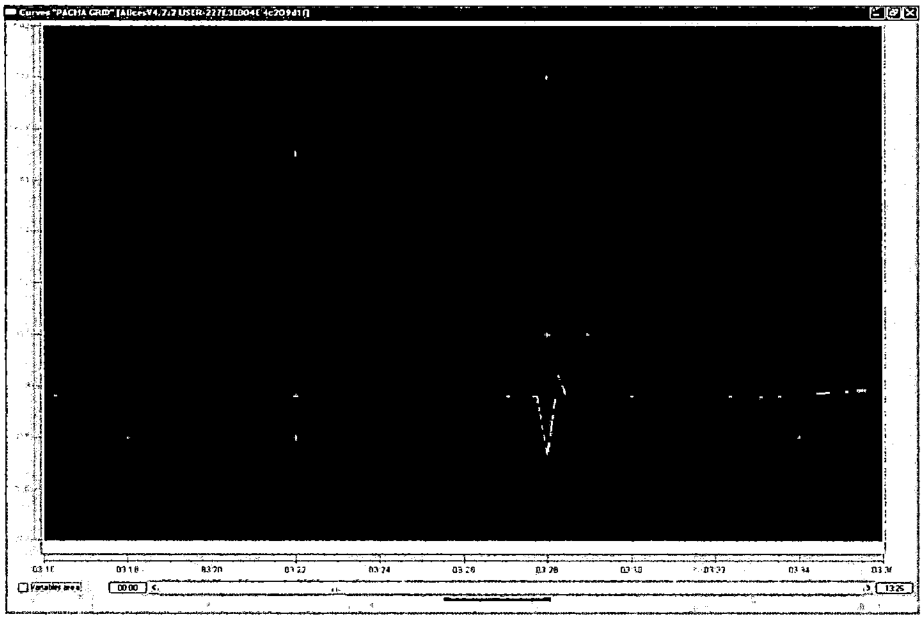


Fig. 5.8 Power (kW) fed to Grid with respect to time Simulation time (sec).

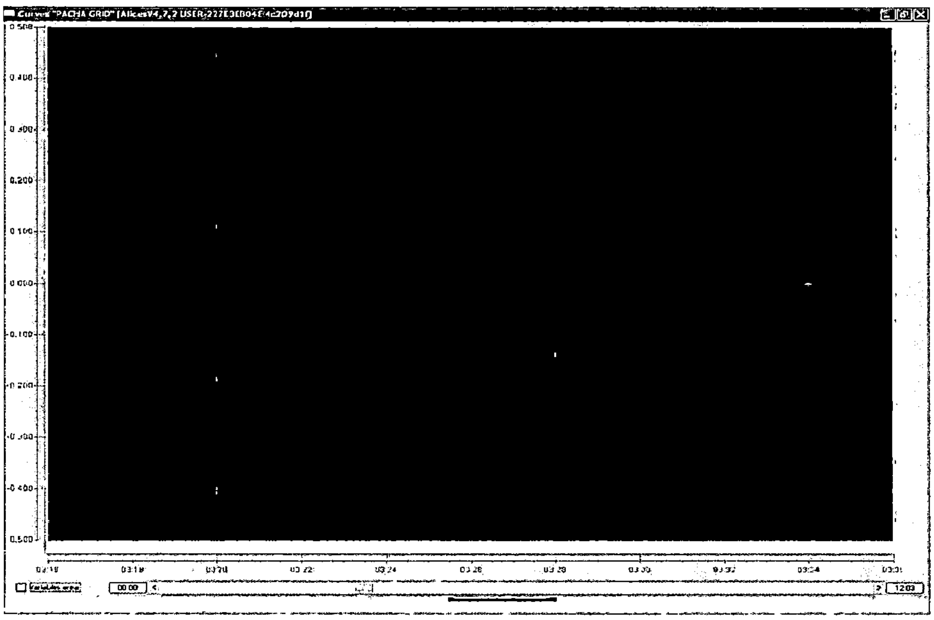


Fig. 5.9: Grid power factor with respect to Simulation time (sec).

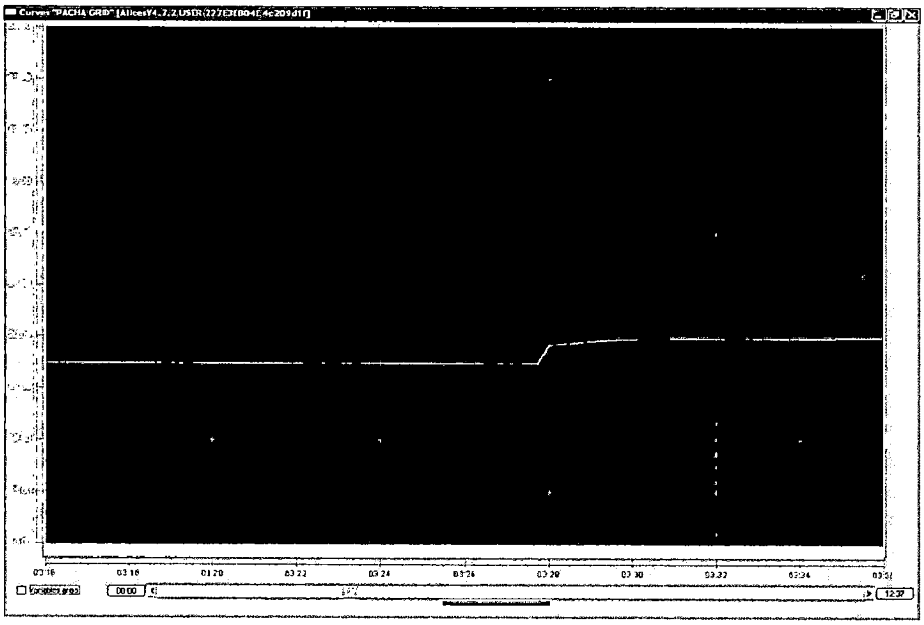


Fig. 5.10: Current (A) fed to Grid with respect to Simulation time (sec).

5.3 Starting of Unit-2 with Unit-1 running at full load

To simulate the starting of Unit-2 with Unit-1 running at full load, simulation is first initialised and run using "UNIT-1 FULL LOAD MANUAL" snapshot. Then Unit-2 is started manually.

During starting of Unit-2 the speed of turbine-2 increases slowly with respect to simulation time as shown in Fig. 5.11.

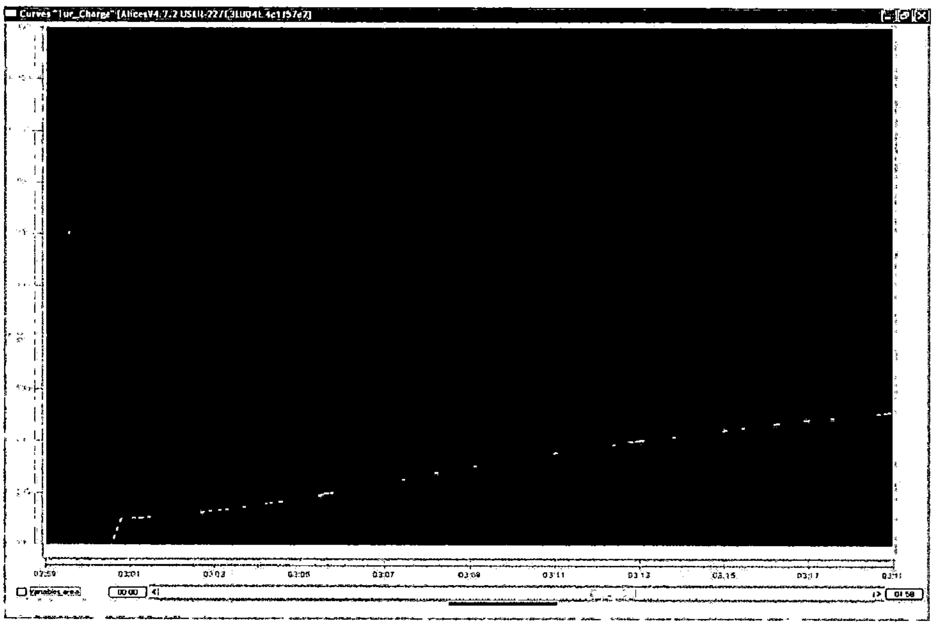


Fig. 5.11: Speed (rpm) of Turbine-2 with respect to Simulation time (sec).

Fig. 5.12 represents voltage of Generator-2 with respect to simulation time. Excitation contacts are closed when speed of Generator-2 reaches 90% of rated speed and the voltage of Generator-2 settles down to its rated value with in 8-10 sec.

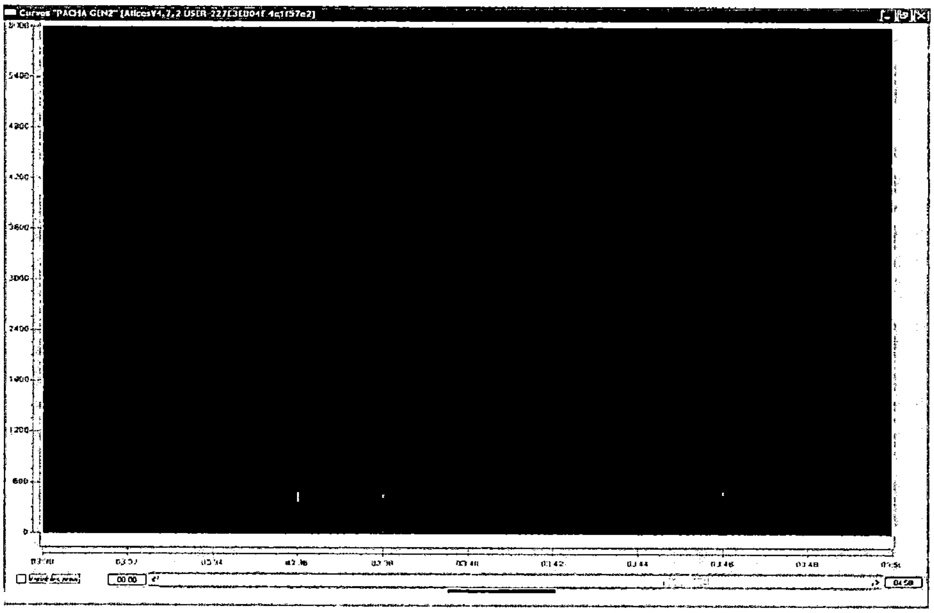


Fig. 5.12: Voltage (V) of Generator-2 with respect to Simulation time (sec).

Fig 5.13 represents the frequency of Generator-2 with respect to simulation time. The frequency increases as the speed increases and finally at settles at 50 Hz.

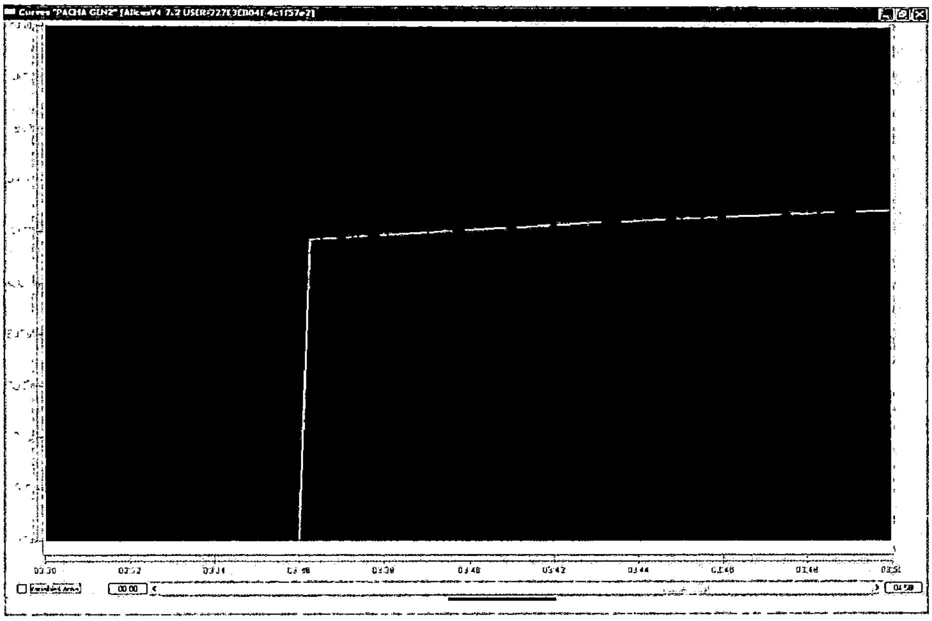


Fig. 5.13: Frequency (Hz) of Generator-2 with respect to Simulation time (sec).

Figs. 5.14 and 5.15 show the variation in power and current of Generator-1 with respect to simulation time when Unit-2 is started.

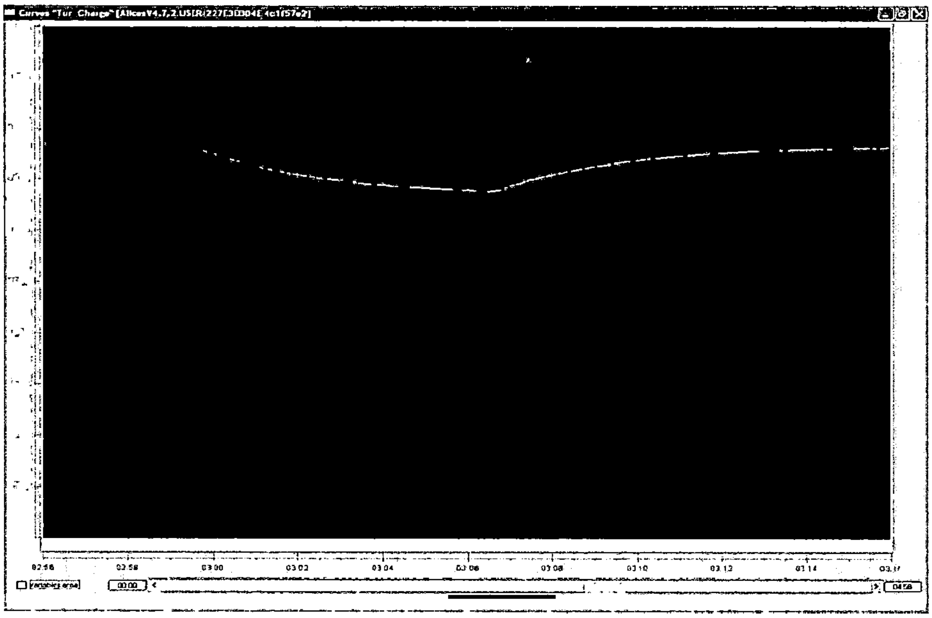


Fig. 5.14: Power (kW) from Generator-1 with respect to Simulation time (sec).

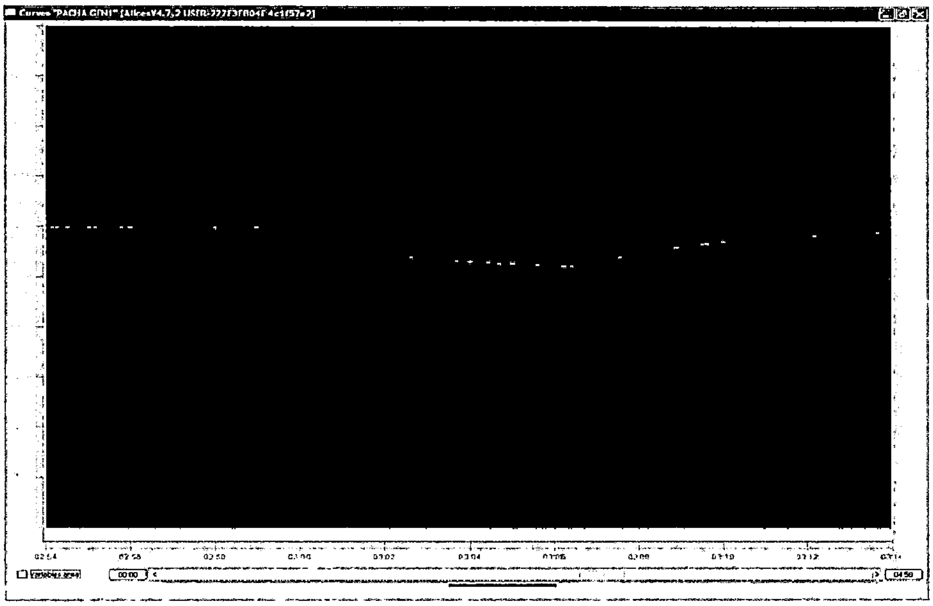


Fig. 5.15: Current (A) from Generator-1 with respect to Simulation time (sec).

Figs. 5.16, 5.17 and 5.18 represent the variation in power, power factor and current fed to Grid respectively, with respect to simulation time.

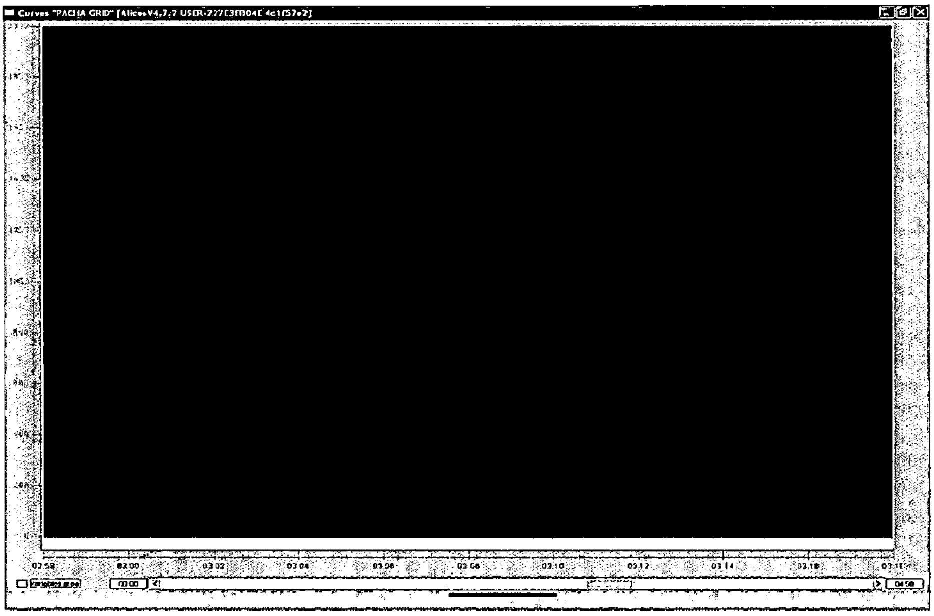


Fig. 5.16: Power (kW) fed to Grid with respect to Simulation time (sec).

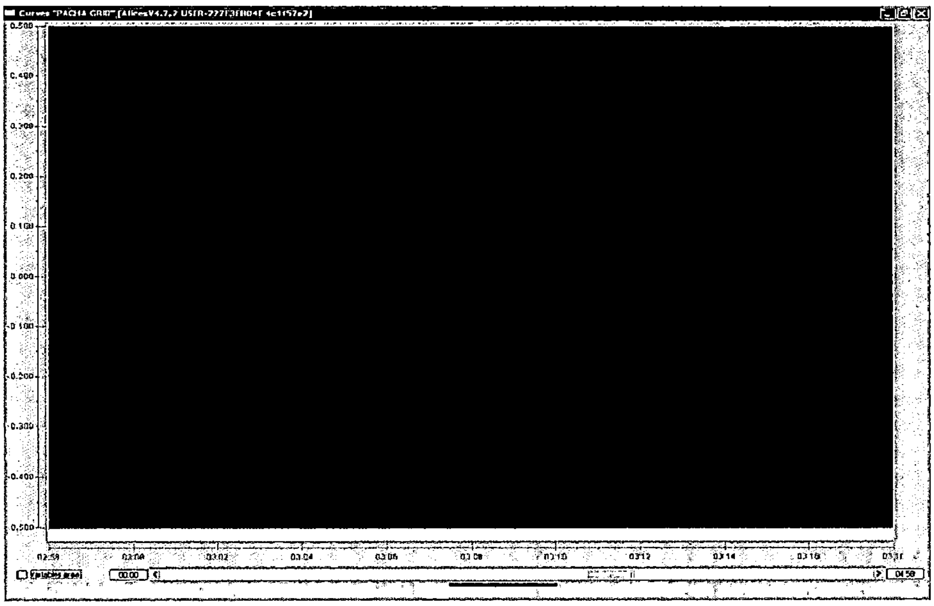


Fig. 5.17: Power factor of Grid with respect to Simulation time (sec).

Fig. 5.18: Current (A) fed to Grid with respect to Simulation time (sec).

5.4 Unit-1 running with full load and Unit-2 Synchronised with Grid:

After starting of Unit-2 as discussed in previous section, Unit-2 is synchronised with grid and loaded upto minimum load requirement.

Fig. 5.19 shows that the power from Genrator-2 starts building up when it is synchronised and loaded upto minimum load requirement. Fig. 5.20 represents the power factor of Generator-2 with respect to simulation time. Due to continuous increment in the load, power factor of Unit-2 keeps on varying and after few transients, it settles down to 0.0635.

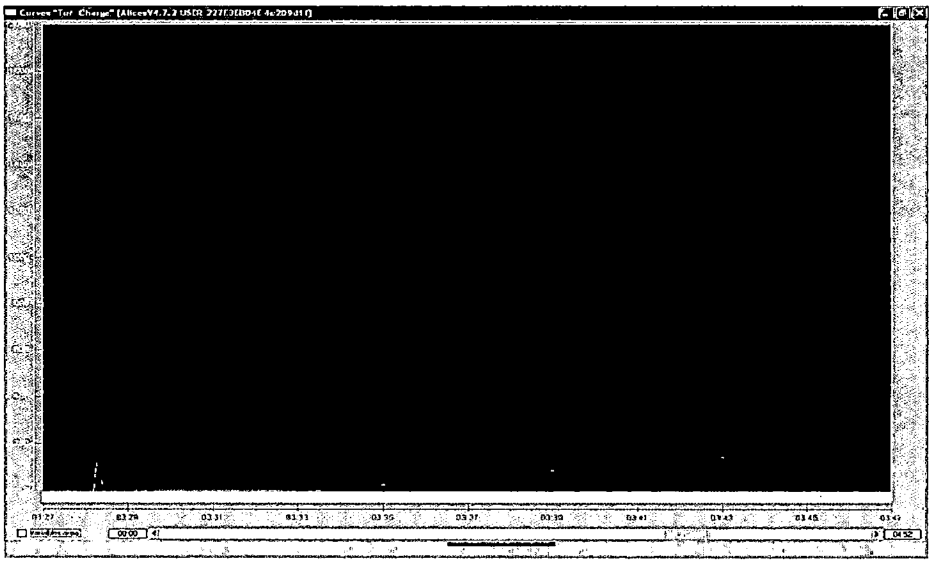


Fig. 5.19: Power (kW) from Generator-2 with respect to Simulation time (sec).

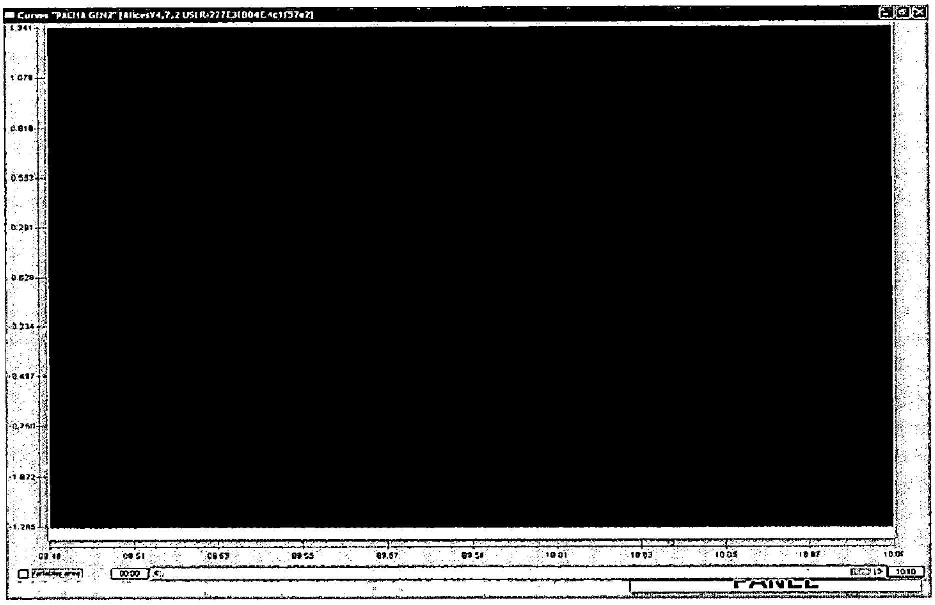


Fig. 5.20: Power factor of Generator-2 with respect to Simulation time (sec).

Similarly, the voltage of Generator-1 also varies continuously due to increment in load and settles down to 3.3 kV, as shown in Fig. 5.21.

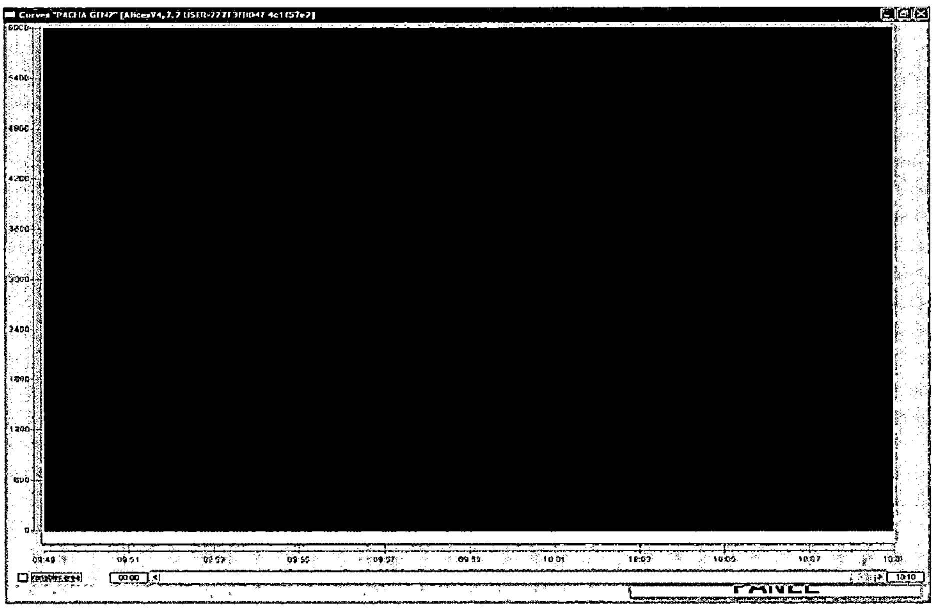


Fig. 5.21: Voltage (V) from Generator-2 with respect to Simulation time (sec).

Fig 5.22 represents increment in the current from Generator-2 increases slowly with respect to simulation time.

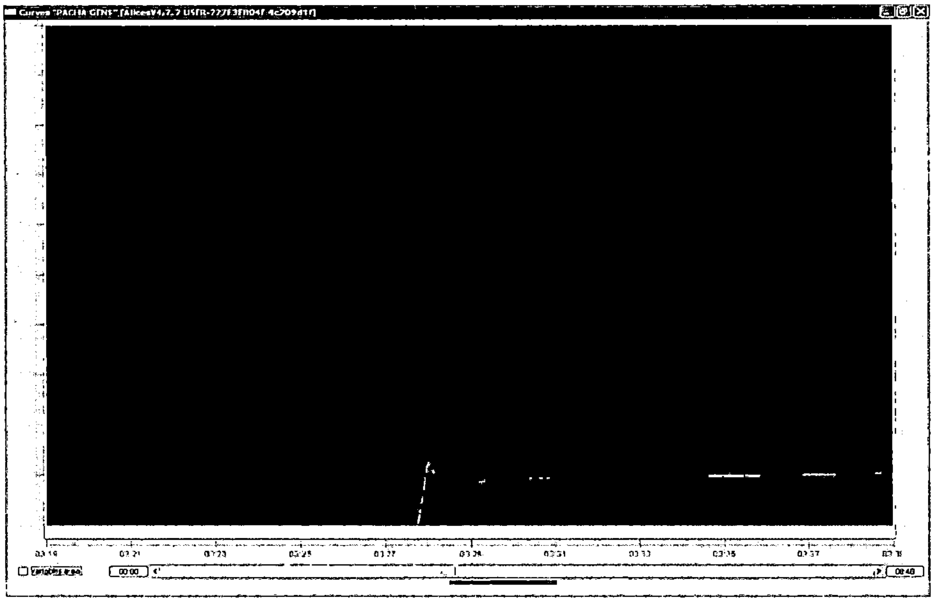


Fig. 5.22: Current (A) from Generator-2 with respect to Simulation time (sec).

Figs. 5.23 and 5.24 show the variation in power and current of Genrator-1 respectively, with respect to simulation time when Unit-2 synchronised with grid.

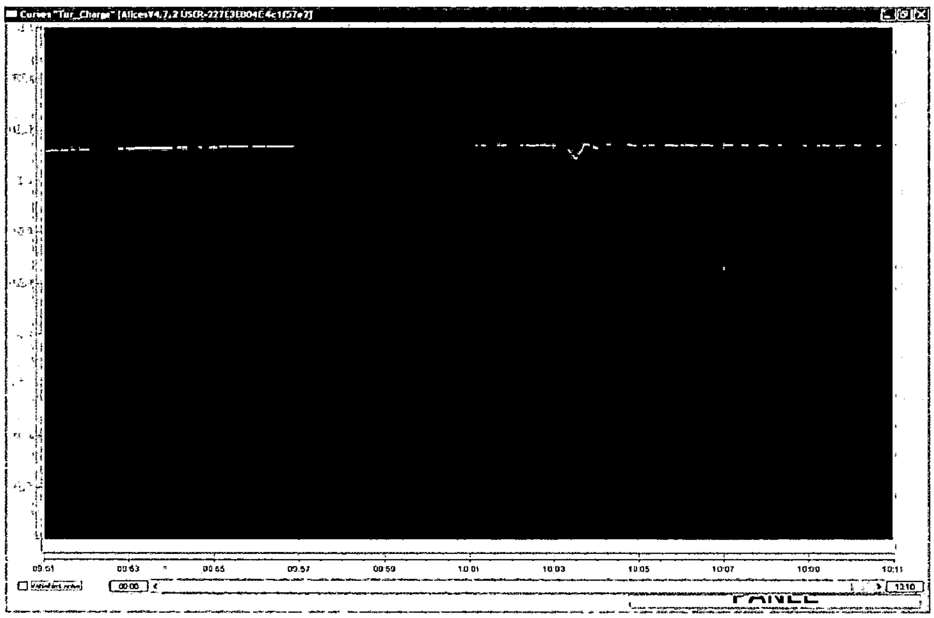


Fig. 5.23: Power (kW) from Generator-1 with respect to Simulation time (sec).

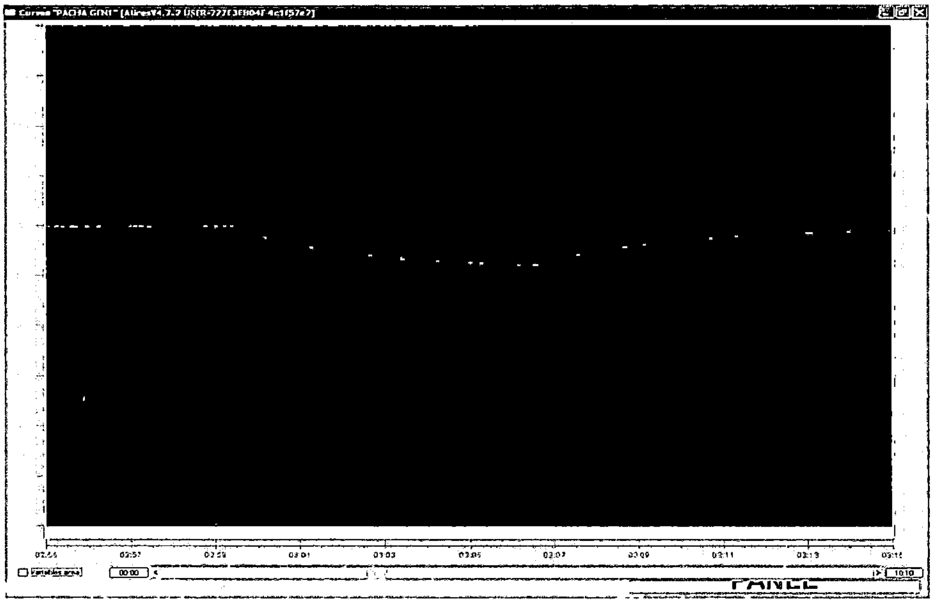


Fig. 5.24: Current (A) from Generator-1 with respect to Simulation time (time).

Figs. 5.25, 5.26 and 5.27 represent the variation of power, power factor and current fed to Grid respectively, with respect to simulation time. Few disturbances are observed in power, p.f and current when Unit-1 is synchronised with grid. These disturbances die out with 4-5 sec.

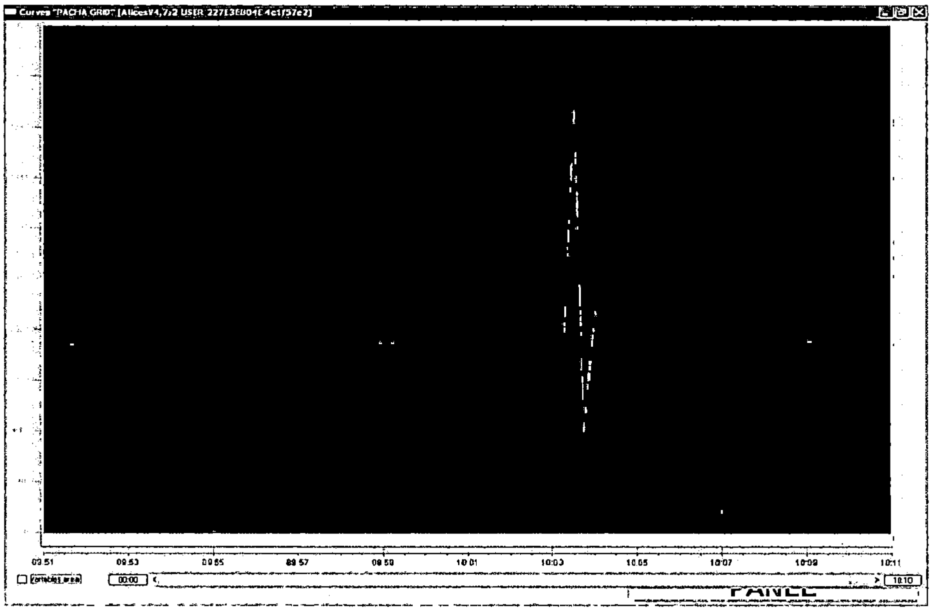


Fig. 5.25: Power (kW) fed to Grid with respect to Simulation time (time).

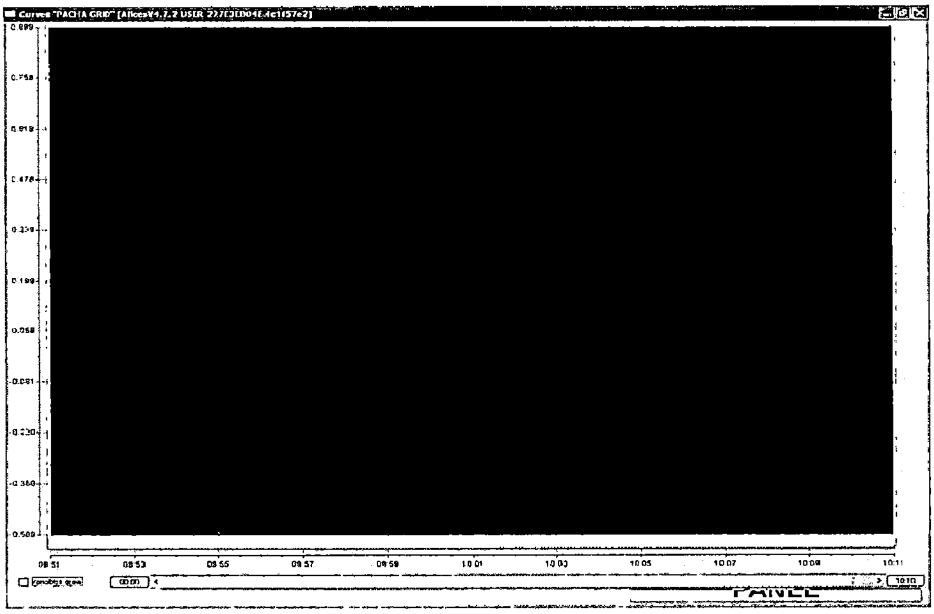


Fig. 5.26: Power factor of Grid with respect to Simulation time (sec).

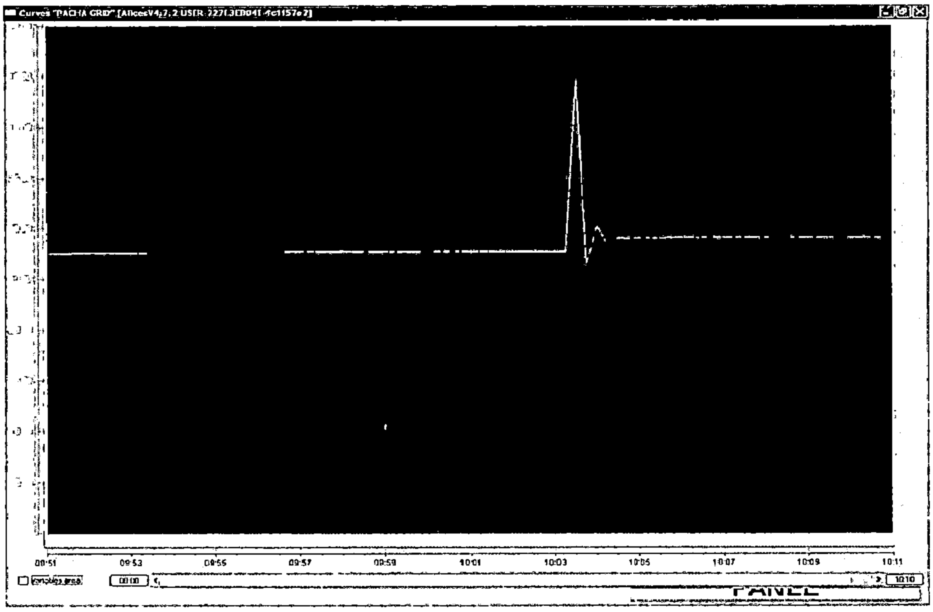


Fig. 5.27: Current (A) fed to Grid with respect to Simulation time (sec).

5.5 Both the Units are running with full load

To simulate the both the units are running with full load, simulation is first initialised and run using "BOTH UNIT FULL LOAD MANUAL" snapshot.

The Pacha SHP plant (2 x 1500 kW) having H= 43.0 m and Discharge = 4.58 cumecs for each unit. Figs. 5.28 and 5.29 show the hydraulic network of unit 1 and 2, respectively of developed Pacha SHP plant simulator.

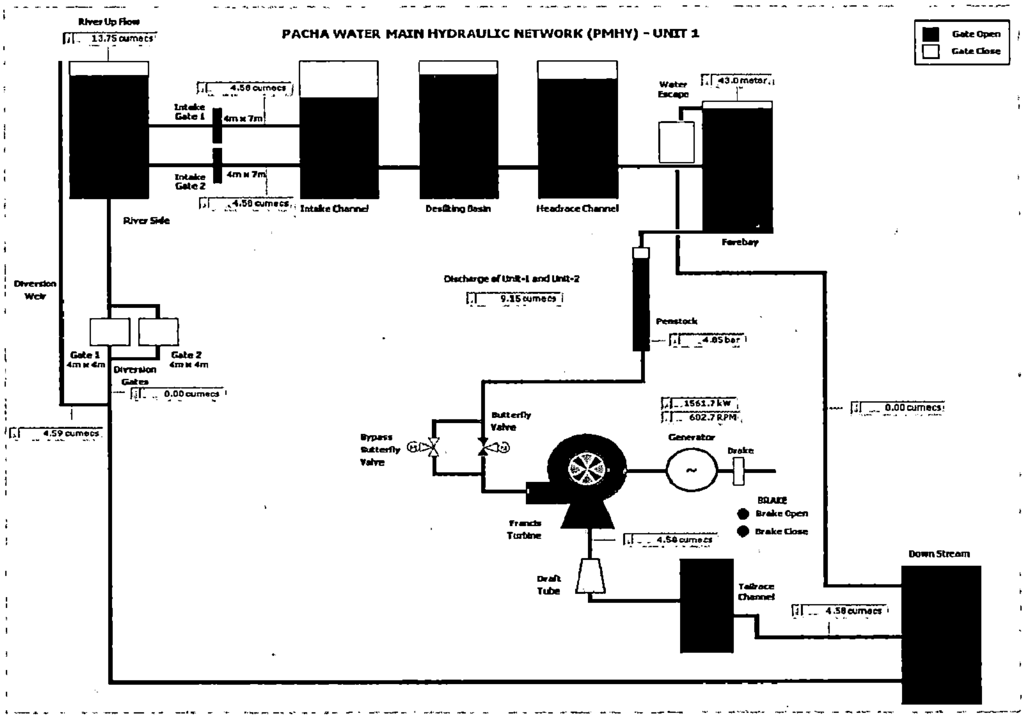


Fig. 5.28: Pacha SHP plant main hydraulic network of unit-1.

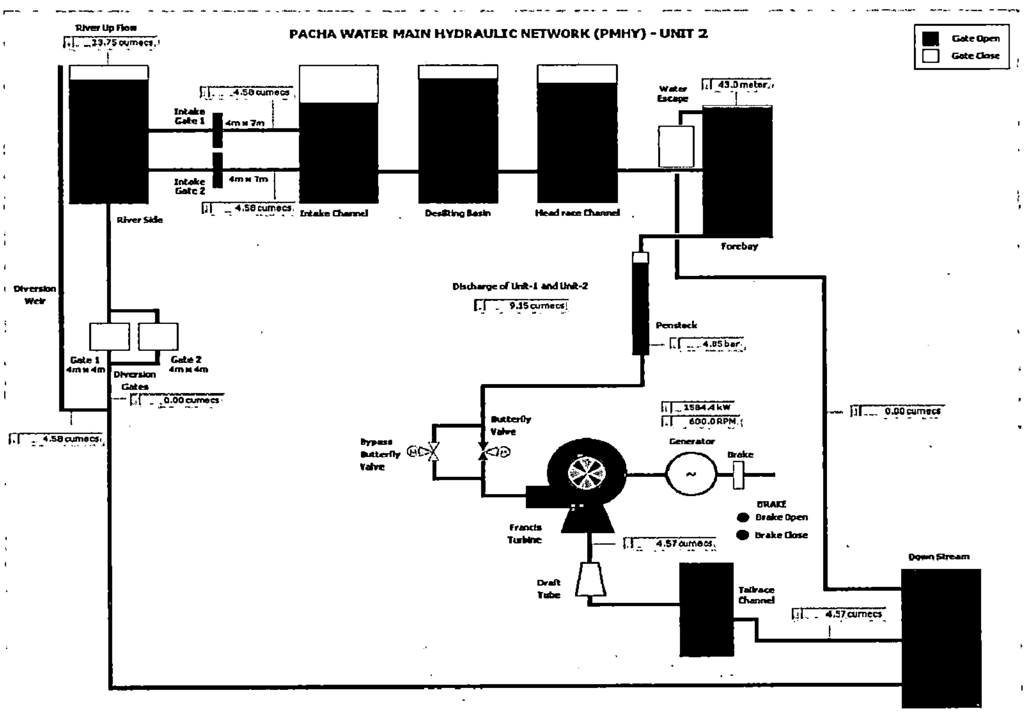


Fig. 5.29: Pacha SHP plant main hydraulic network of unit-2.

Fig. 5.30 shows the main electrical circuit of Pacha SHP plant.

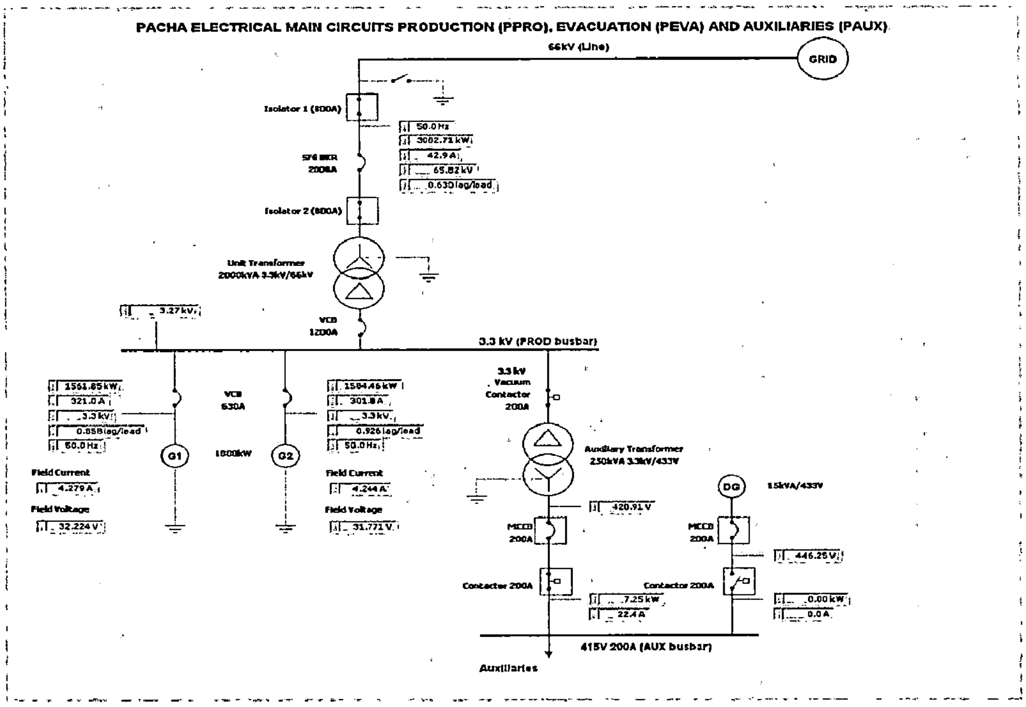


Fig. 5.30: Main electrical circuit of Pacha SHP plant.

When simulator is running under rated operating conditions the output obtained from different parameters are as follows:

For Grid:

Grid Frequency= 50 Hz

Grid Power = 3082.71 kW

Grid Current= 42.9 A

Grid Voltage= 65.82 kV

Grid Power Factor= 0.630

Main Busbar Voltage= 3.27 kV.

For Generator Unit-1:

Power Output= 1561.85 kW

Output Current=321.0 A

Output Voltage= 3.3 kV

Power Factor= 0.858

Frequency= 50 Hz

Field Current= 4.279 A

Field Voltage= 32.224 V.

For Generator Unit-2:

Power Output= 1581.92 kW

Output Current =301.8 A

Output Voltage = 3.3 kV

Power Factor= 0.926

Frequency= 50 Hz

Field Current= 4.244 A

Field Voltage= 31.771 V.

Fig. 5.31 shows the auxiliaries circuit of Pacha SHP plant.

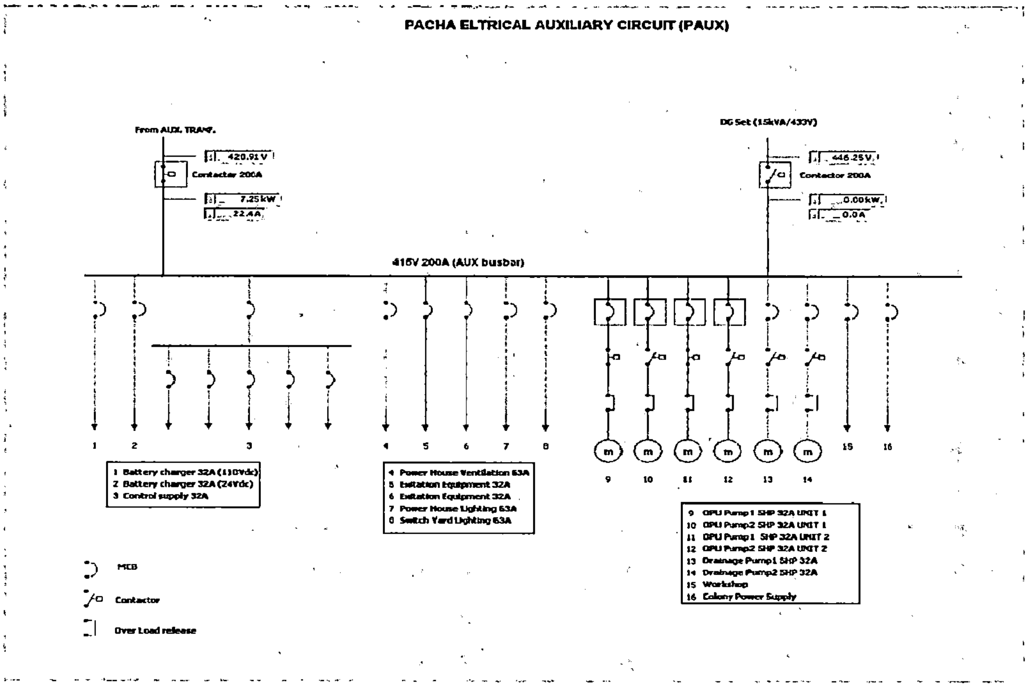


Fig. 5.31: Auxiliary circuit of Pacha SHP plant.

From Auxiliary Transformer:

Voltage = 420.91 V.

Power output = 7.25 kW.

Current = 22.4 A.

5.6 Unit-1 running with full load and Unit-2 running with Emergency shut down

To simulate the Unit-1 running with full load and Unit-2 running with emergency shutdown, simulation is first initialised and run using "BOTH UNIT FULL LOAD MANUAL" snapshot.

Fig. 5.32 shows the speed of turbine-2 with respect to simulation time. After emergency shutdown of Unit-2, its speed rises very fast and reaches to 1.8 times the rated speed.

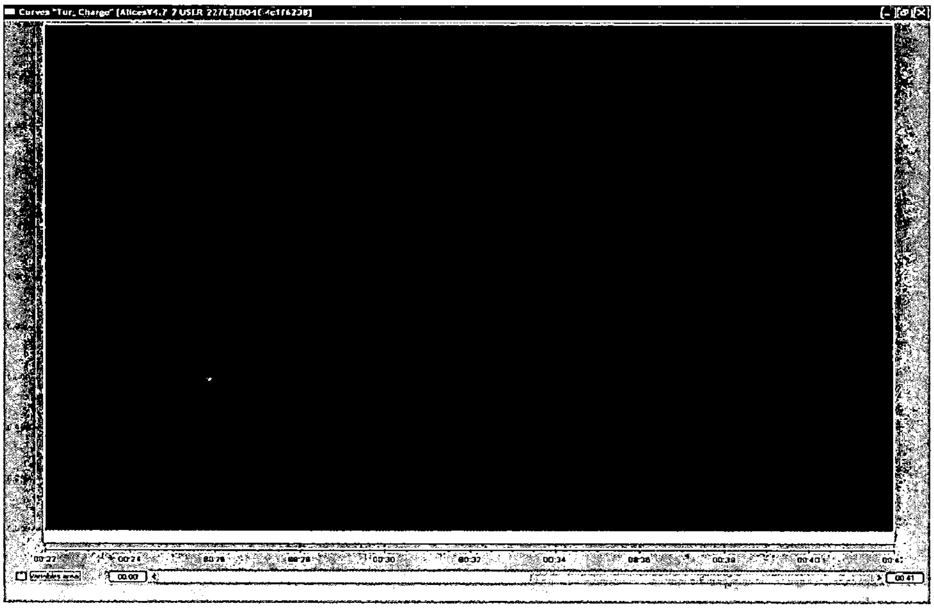


Fig. 5.32: Speed (rpm) of Turbine-2 with respect to Simulation time (sec).

Figs. 5.33, 5.34 and 5.35 represent the power, voltage and current of Generator-2 respectively, with respect to simulation time. Power and current reach to zero with in 1 sec, while voltage takes 5-6 secs to reach the zero.

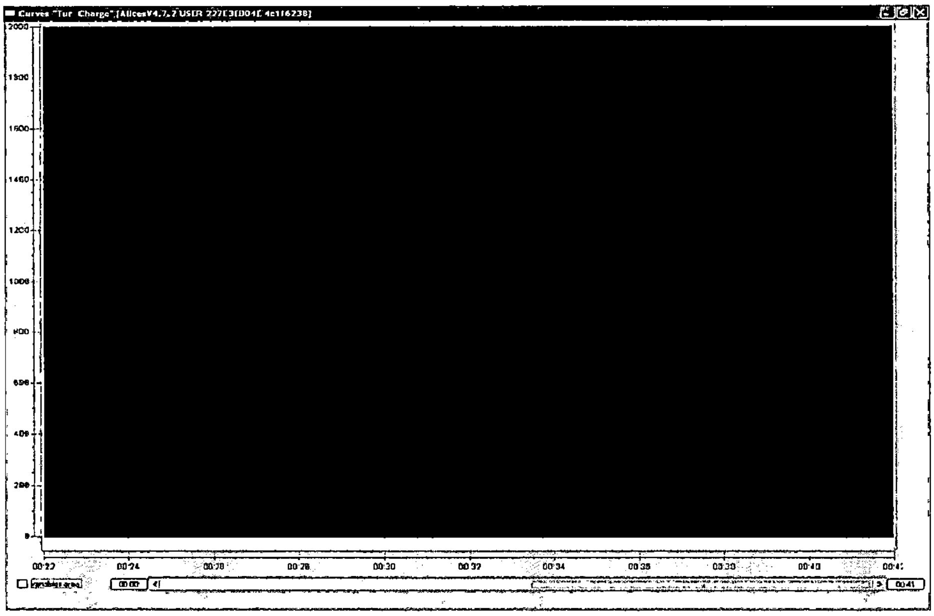


Fig. 5.33: Power (kW) from Generator-2 with respect to Simulation time (sec).

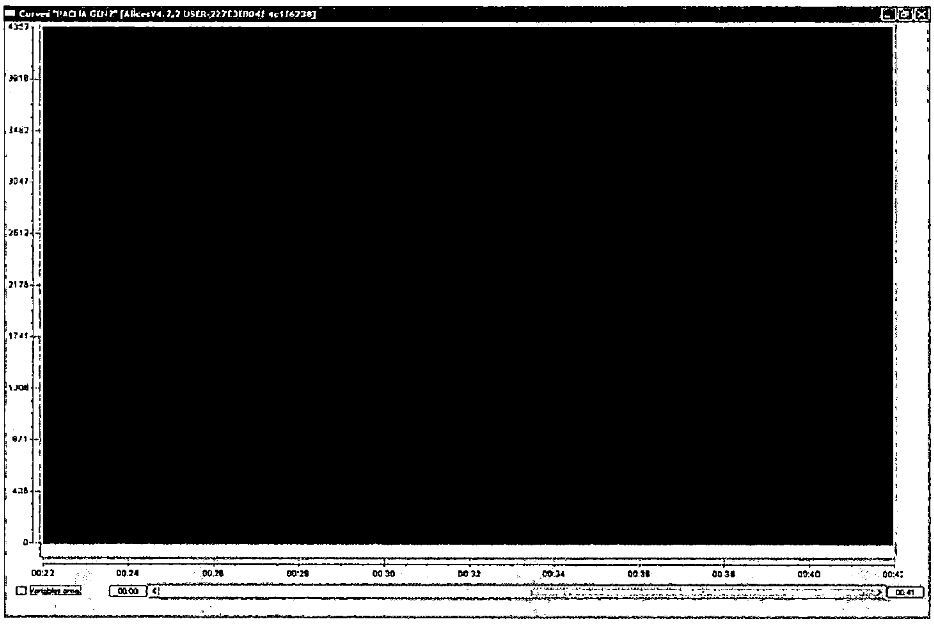


Fig. 5.34: Voltage (V) from Generator-2 with respect to Simulation time (sec).

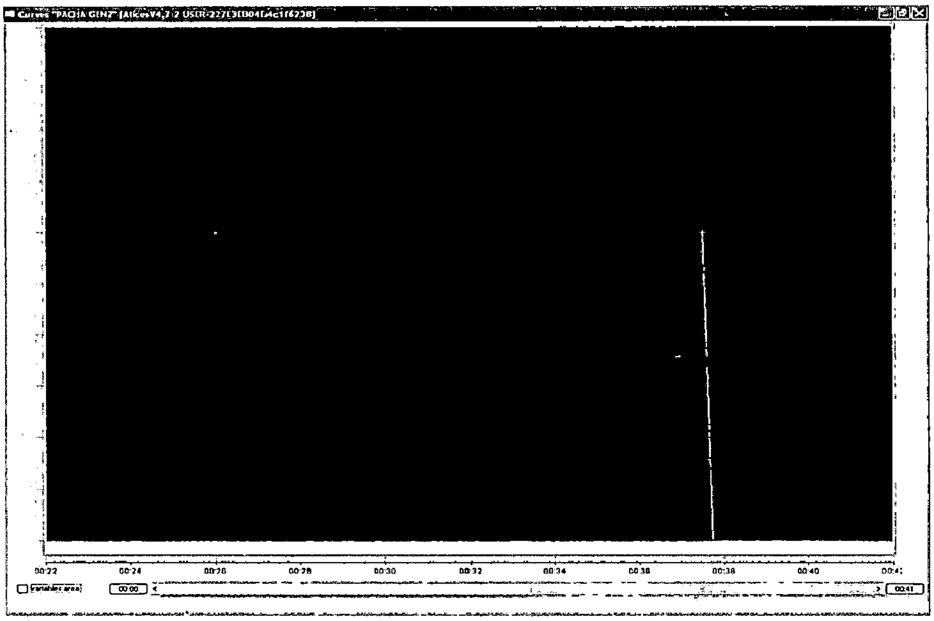


Fig. 5.35 Current (A) from Generator-2 with respect to Simulation time (sec).

Fig. 5.36 shows the impact on Generator-1 voltage with respect to simulation time when Unit-2 running with emergency shut down.

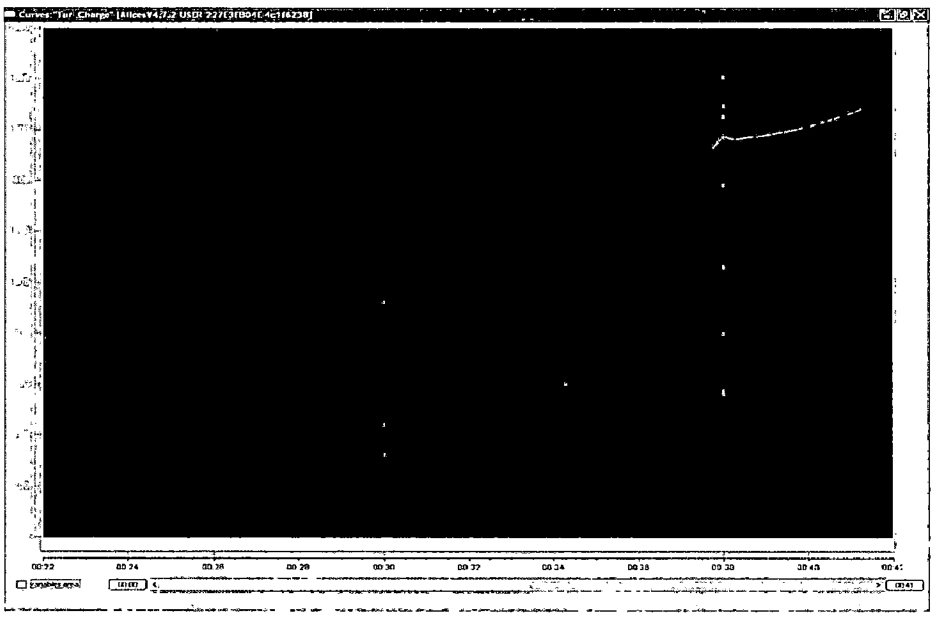


Fig. 5.36: Voltage (V) from Generator-1 with respect to Simulation time (sec).

Figs. 5.37, 5.38 and 5.39 show the variation in power, power factor, voltage and current fed to Grid, respectively, with respect to simulation time.

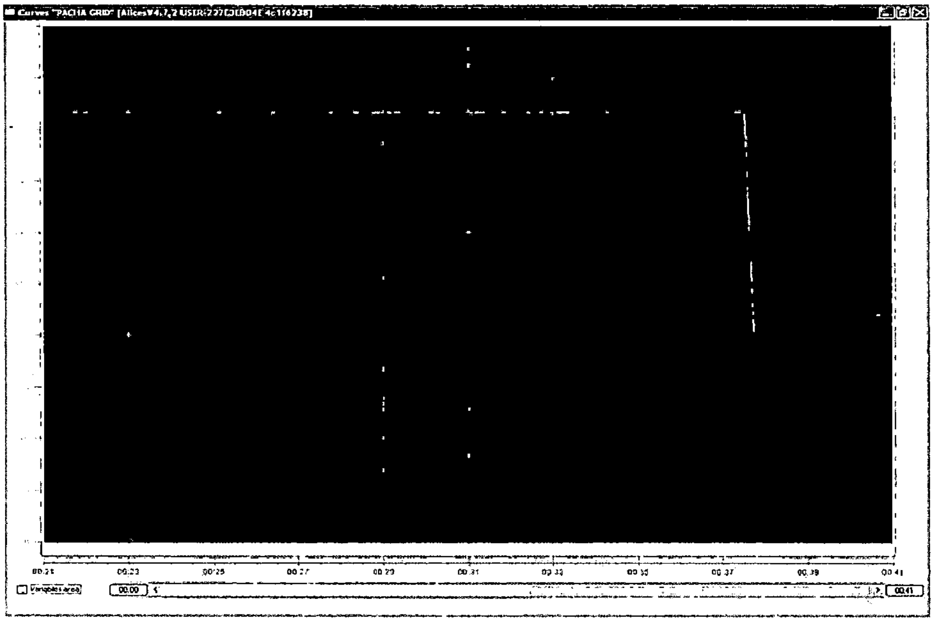


Fig. 5.37: Power (kW) fed to Grid with respect to Simulation time (sec).

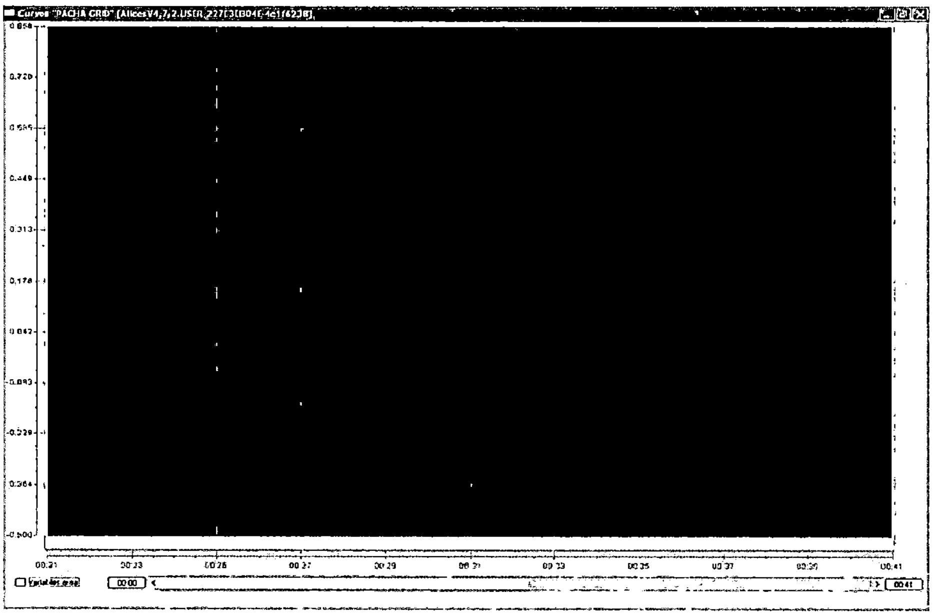


Fig. 5.38: Power factor of Grid with respect to Simulation time (sec).

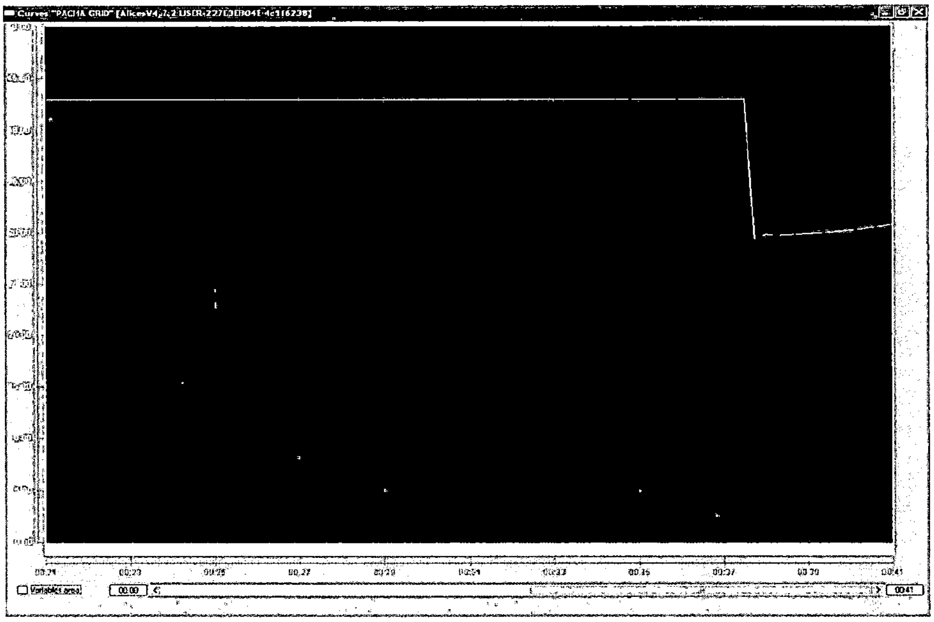


Fig. 5.39: Current (A) fed to Grid with respect to Simulation time (sec).

5.7 Grid failure

To simulate the Grid failure, simulation is first initialised and run using "BOTH UNIT FULL LOAD MANUAL" snapshot.

Fig. 5.40 represents the speed of turbine-1 with respect to simulation time. After grid failure, speed of turbine-1 rises very fast and reaches to 1.8 times the ratio the rated speed.

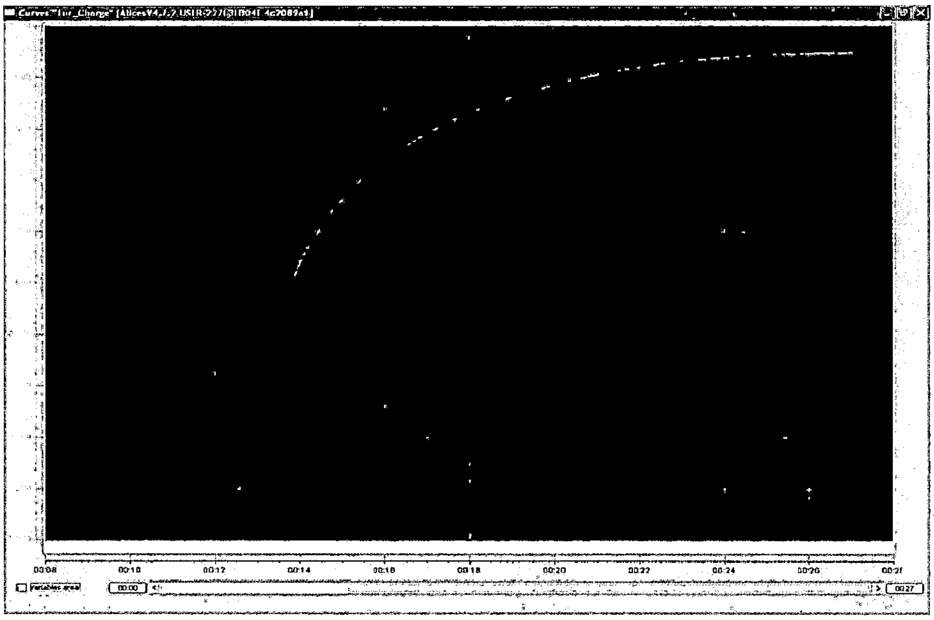


Fig. 5.40: Speed (rpm) of Turbine-1 with respect to Simulation time (sec).

Figs. 5.41, 5.42 and 5.43 show the power, voltage and current of Generator-1 respectively, with respect to simulation time. Power reaches to zero with in 1 sec and Voltage reaches to zero with in 8-10 secs, while current reaches to zero with in 2-3 secs.

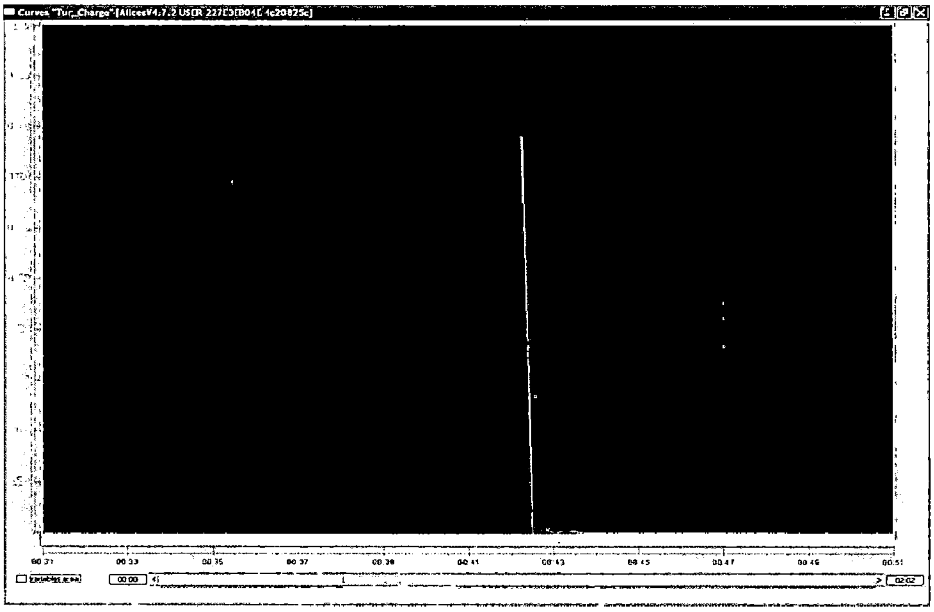


Fig. 5.41: Power (kW) from Generator-1 with respect to Simulation time (sec).

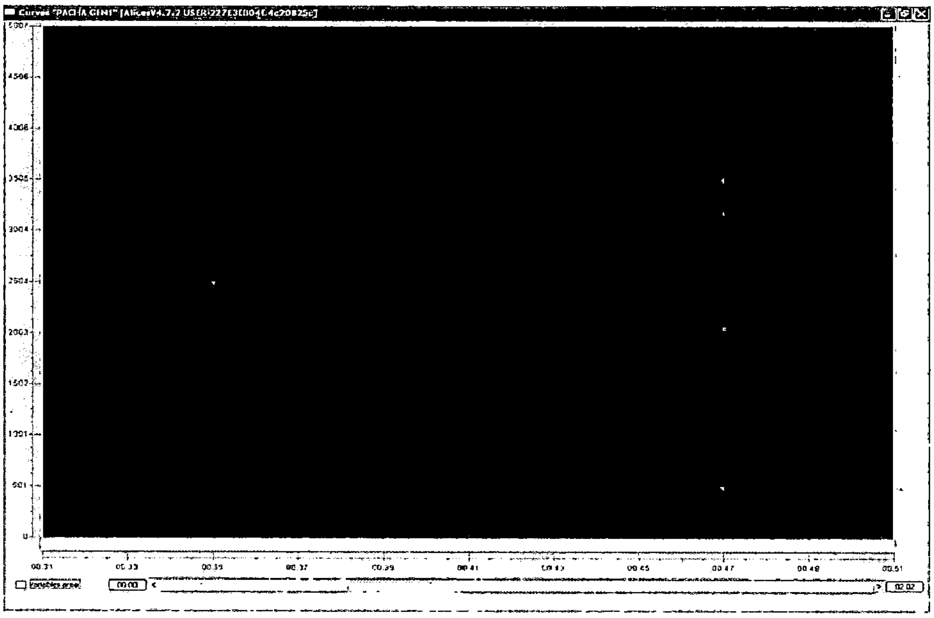


Fig. 5.42: Voltage (V) from Generator-1 with respect to Simulation time (sec).

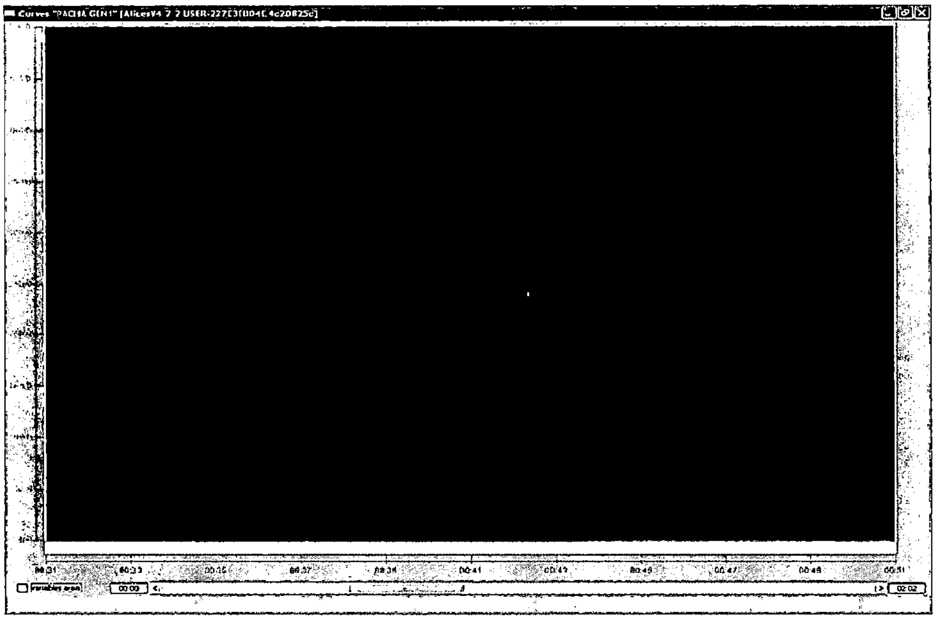


Fig. 5.43: Current (A) from Generator -1 with respect to Simulation time (sec).

Similar observation are also made for Unit-2 .

Figs. 5.44, 5.45and 5.46 show the variation in power, power factor and current fed to Grid respectively, with respect to simulation time.

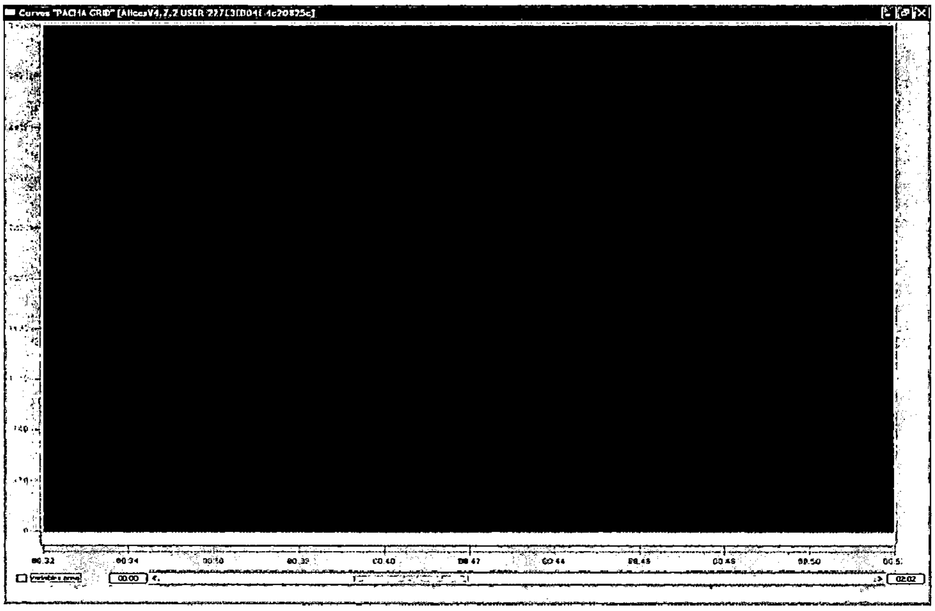


Fig. 5.44: Power (kW) fed to Grid with respect to Simulation time (sec).

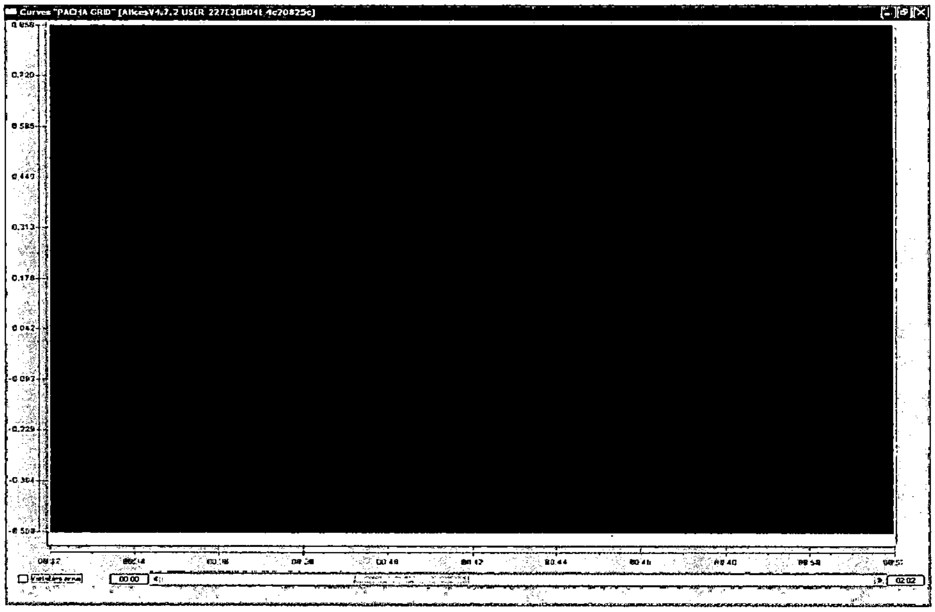


Fig. 5.45: Power factor of Grid with respect to Simulation time (sec).

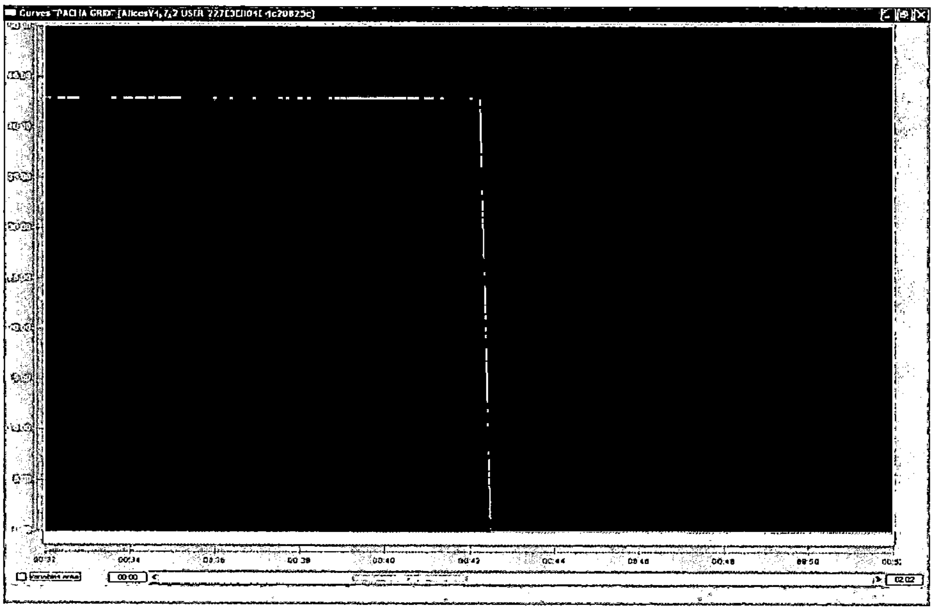


Fig. 5.46: Current(A) fed to Grid with respect to Simulation time (sec).

Figs. 5.47 and 5.48 show the voltage and frequency of Busbar respectively, with respect to simulation time. Voltage and frequency reach to zero with in 2- secs.

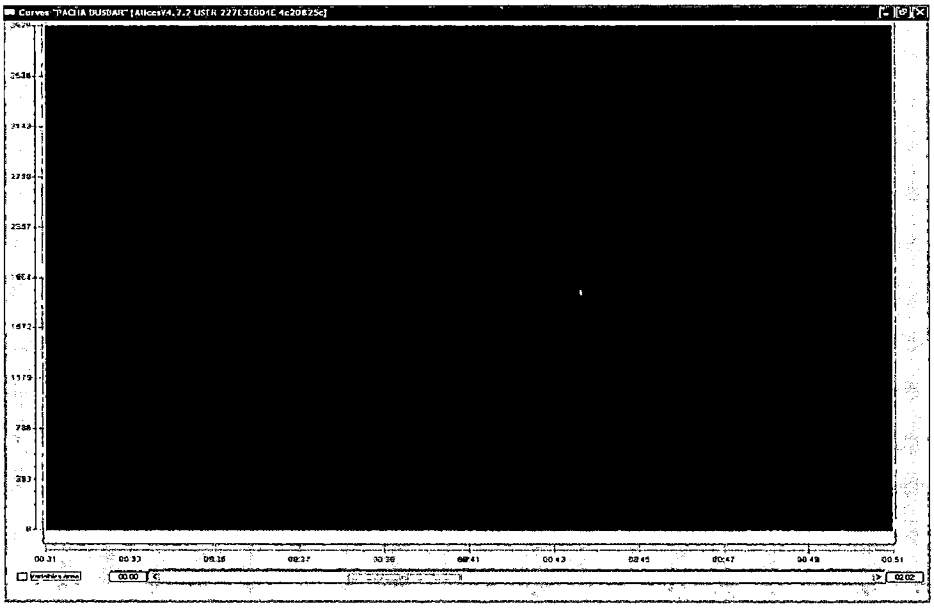


Fig. 5.47: Voltage (V) of Busbar with respect to Simulation time (sec).

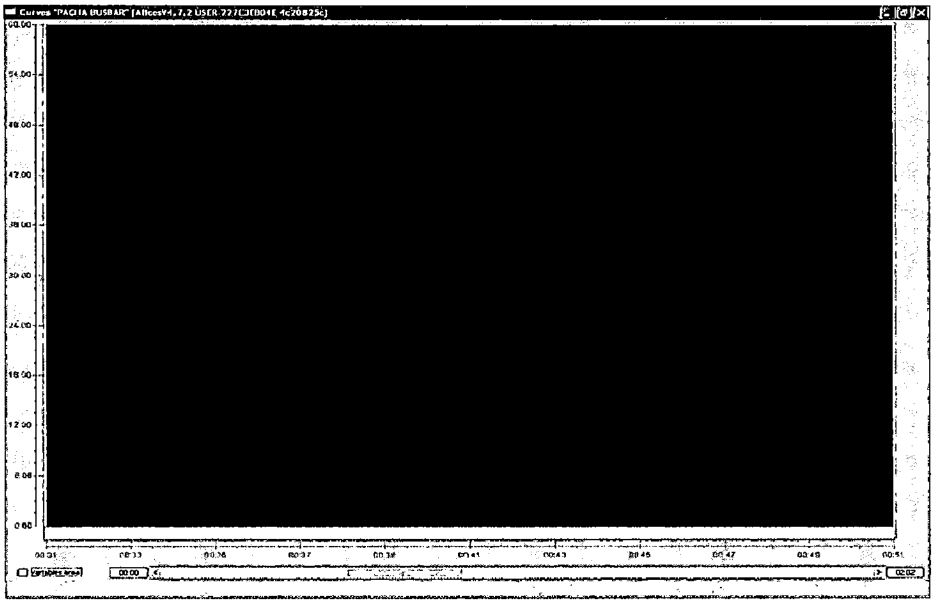


Fig. 5.48: Frequency (Hz) from Busbar with respect to Simulation time (sec).

Chapter-6

CONCLUSION AND FUTURE SCOPE OF WORK

In this chapter, conclusion on the developed Pacha SHP plant simulator and future scope of work is presented.

6.1 Conclusion

In this thesis work, first mathematical modelling of various components of SHP plant have been presented. Then hydraulic differential models and electrical differential and sequential models are developed for Pacha SHP plant under the environment of ALICES software and produced the documents for developed models.

The developed simulation simulates the Pacha SHP plant having capacity 2 x 1.5 MW with operating under 43.0 m net head and 9.16 cumecs rated discharge.

The developed Pacha SHP plant simulatation is tested under various operating conditions such as:

1. Starting of Unit-1
2. Unit-1 Synchronised with Grid and run at partial load
3. Starting of Unit-2 with Unit-1 running at full load
4. Unit-1 running with full load and Unit-2 synchronised with grid
5. Both the units are running with full load
6. Unit-1 running with full load and Unit-2 running with emergency shut down
7. Grid failure.

6.2 Future Scope of Work

The present work can be extended by considering the following points.

1. The developed simulation model is applicable to run-off river based SHP schemes. The simulation model may be developed for Dam toe based SHP scheme.
2. Other types of turbines can be modelled, so that the simulation developed can be used for different power plants.

3. Plant with one unit and more than two units can be implemented.
4. Grid connected mode of SHP plant has been considered. The model can be extended to study the performance of SHP plant in isolation mode also.

REFERENCES

[1]. http://www.powermin.nic.in/JSP_SERVLETS/internal.jsp.

[2]. International course on "Small Hydropower Development", by Alternate Hydro Energy Centre , Indian Institute of Technology Roorkee, February 2004.

[3]. Naidu, Dr. B.S.K (2005), "Small Hydro Highest Density, Non- Conventional, Renewable Energy Source."

[4]. International Course on "Cost Effective Planning and Design for Small Hydro Projects" February 5-14, 2002, AHEC IIT Roorkee.

[5]. International Course on "Planning of Small Hydro Power Projects", March 7–16, 2000, AHEC IIT Roorkee.

[6]. http://en.wikipedia.org/wiki/File:Hydroelectric_dam.svg.

[7]. http://en.wikipedia.org/wiki/Simulation

[8]. http://web.cs.mun.ca/~donald/msc/node5.html.

[9]. http://www.cis.ufl.edu.

[10]. http://en.wikipedia.org/wiki/Computer_model.

[11]. http://www.rtds.com/

[12]. J.D. Sharma, Arun Kumar, and M.K. Singhal, "Real Time Digital Simulator for Small Hydropower Plants", International Conference on Small Hydropower – Hydro Sri Lanka, 22-24 October 2007.

[13]. D.K. Khatod, "Modelling and Simulation of Small Hydro Plant", M.Tech Dissertation, IIT ROORKEE, 2002.

[14]. Kristian Tuszynski, Jan Tuszynski, and Karl Slattorp, "Hydro Plant- a Modelica Library for Dynamic Simulation of Hydro Power Plants", September 4-5,2006.

[15]. Yin Chin Choo, Kashem M. Muttaqi, and Michael Negnevitsky, "Modelling Of Hydraulic Turbine for Dynamic Studies and Performance Analysis ".

[16]. Nand Kishor, S.P. Singh, and A.S. Raghuvanshi, " Dynamic Simulations of Hydro Turbine and its State Estimation based LQ Control ", Energy Conversion and Management, Vol. 47, May 2006.

[17]. Xianshan LI, Chengming WU, and Xiangyong HU, " Full scope Real – Time Simulation of Hydropower Plant for a Training and Research Simulator ", IEEE/PES

Transmission and Distribution Conference & Exhibition: Asia Pacific Dalian, china,pp.1-5, 2005.

[18]. S. Tesnjak, T. Tomisa, and I. Kuzle, " Digital Simulator for Transient Condition Analyses in Hydroelectric Plants ", First International Conference on Digital Simulators,pp.369-374, 1995.

[19]. O. H. Souza Jr., N. Barbieri, and A. H. M. Santos, " Study of Hydraulic Transients in Hydro plants through Simulation of Non-linear model of Penstock and Hydraulic turbine Model ", IEEE Transactions On Power System, Vol. 14, No. 4, November 1999.

[20]. D. Lindenmeyer, A. Moshref, C. Schaeffer, and A. Benge, " Simulation of the Start – Up of a Hydro Power Plant for the Emergency Power supply of a Nuclear Power Station ", IEEE Transactions on Power Systems, Vol. 16, No. 1, February 2001.

[21]. M. Mahmoud, K. Dutton, and M. Denman, " Design and Simulation of a Non-linear Fuzzy Controller for a Hydropower Plant ",Elecrical Power Systems rearch, Vol. 73 September 2004.

[22]. C. Nicolet and P. Allenbach " New Tool For the Simulation of Transient Phenomena in Francis Turbine Turbine Power Plants ", Proceeding of the XX1st IAHR Symposium on Hydraulic Machinery and Systems, September 9-12,Lausanne, 2002.

[23]. Chandra Sekhar Kolli, "Development of Simulator for SHP plant", M.Tech Dissertation AHEC IIT Roorkee, 2009.

[24]. Nikhil Kumar, "Development of Simulator for high head SHP plant", M.Tech Dissertation AHEC IIT Roorkee, 2009.

[25]. "Simulator Detailed Design SHP-MOD-HYD-001", AHEC, IIT Roorkee

[26]. French, R. H. "Open Channel Hydraulics", McGraw-Hill.

[27]. P. Kundur " Power System stability and Control ", Tata Mcgraw Hill edition.

[28]. http://www.mathworks.com/access/helpdesk/help/toolbox/physmod/powersys/synchronous generatormodel.html.

[29]. ALICES User Manual – V1 Edition developed by CORYS T.E.S.S, France, 2005.

[30]. Design Document of Rajwati Hydroelectric Power Preject (2 x 1800 kW), owned by

M/s Him Urja, New Delhi.

[31]. Tender document of Pacha SHP project (2 x 1500), owned by Department of Hydro Power Development, Arunachal Pradesh.

LIST OF PUBLICATIONS

1. D. Lakshman Kumar, M.K. Singhal, D.K. Khatod, "SIMULATION OF SMALL HYDRO POWER PLANTS", published in International Conference on Advances in Renewable Energy, "ICARE- 2010", June 24 – 26, 2010 organised by Maulana Azad National Institute of Technology, Bhopal, M.P, India.

APPENDIX-A

A.1 General

A software named ALICES (Atelier Logiciel Intégré de Conception et d'Etude de Simulateurs - Integrated Software Workshop for the Design and Study of Simulators) has been used to develop the Real-Time Simulator for SHP Plant.

A.2 Advantages of ALICES

The ALICES structure and methodology make up a design tool for simulators due to the following advantages [29]:

- **Modular:** ALICES is structured in basic software components and these components can be individually modified without interfering with the structure of the whole,
- **Adaptable:** ALICES can be used for the upgrading of an existing simulator or can be gradually integrated into the maintenance process of the simulator,
- **Progressive:** New components can be easily added to ALICES according to the client needs and specific characteristics of the simulated process,
- **User friendly:** a graphic interface enables the user to carry out all operations in a natural manner.

A.3 Hierarchial levels of ALICES

ALICES is organised in **three hierarchical levels**, which correspond to the different stages of simulator development. Fig 4.1 shows the hierarchial levels of ALICES workshop.

Level 1 of ALICES workshop allows creation or modification of simulation elementary objects. Elementary objects are provided in order to modify models or graphic interfaces, the objects are classified in different libraries according to its domain. Third party codes can be integrated in an ALICES level 1 object, which are as follows:

1. Designing new object models based on the third party codes libraries,
2. Electrical objects (batteries, breakers, generators etc.),
3. Hydraulic objects (valves, pumps, turbines, tank etc.)

4. Instrumentation & Control (relays, logical operators, analogical operators, controllers etc.),
5. Man machine interfaces (alarm, lamp, push button, indicator etc.).

Level 2 of ALICES workshop allows assembly of elementary objects defined at level 1 for the creation or the modification of the models or of the interfaces (level 2 documents) useful to build a simulator. ALICES allows implementation of different kinds of physical models and interfaces such as:

1. Electrical system
2. Hydraulic systems
3. Man machine interfaces (MMI).

Level 3 of ALICES workshop allows integrating the different documents, which have been developed at level 2, to configure (software architecture) and to execute the simulation. It comprises two main parts:

1. Configuration, which defines the level 2 documents which make up the simulator. In the test phases, a single or a small number of documents are thus assembled, whereas in the simulator operating phases, all the documents forming the process to be simulated are assembled. Configuration also determines certain parameters of the simulation, such as the duration of a computing cycle for a given document. Configuration enables the choice to be made between several documents to simulate a given system, providing the choice of the degree of complexity of simulation, while using the particularly simple "plug and play" metaphor.

2. Execution, which corresponds to operation of the simulator created by the configuration. Execution also manages write and read of **snapshots,** which constitute a real "photo" of the state of the simulator at a given moment of the simulation. The execution phase is used for tuning and testing modelled object or document models.

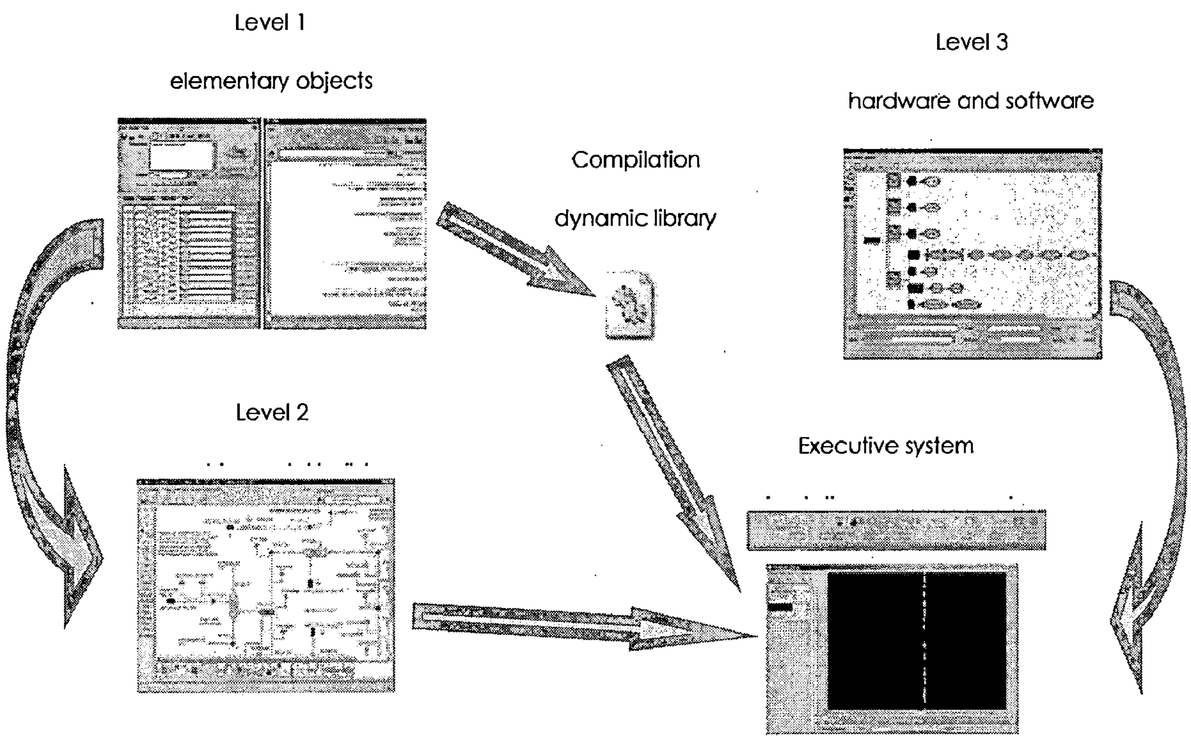


Fig. A.1: Hierarchial levels of ALICES workshop [29].

A.4 Complementary Tools

ALICES complementary tools are as follows [29]:

1. Data bank
2. Operating tool
3. Library manager

A.4.1 Data Bank

The data bank (DBK) is a relational data base system of the customer/server type managing structured information. The different ALICES tools (customers) access the centralised data by means of a **server** responsible for management of the data. The DBK contains all alphanumerical data of the installation to be simulated. The data is spread out in tables whose structure is defined by the scheme of each table. The levels 1, 2 and 3 are connected to the peripheral tool constituted by the relational DBK. The objects of DBK are:

1. To enable raw documents to be organised (the data package of the process to be simulated, supplied by the client) and follow-up of modifications to these documents;
2. To store in structured manner the raw data necessary for development of the simulator;

3. To enable the value of the simulation parameters to be computed using these raw data;
4. To ensure consistency between the raw data and the values used by the simulator;
5. To enable data sharing between various clients.

DBK is linked to all the hierarchical levels of the software workshop. It has specific functionalities enabling the data to be entered manually or from a file external to the workshop [29].

A.4.2 Operating Tool

This tool enables:

- Creation and definition of a project (including work **sessions** relating to the project),
- Personal user work **sessions** (not connected to a project).

A **session** regroups **tools** and **libraries** that the user has to produce for an already determined task.

A.4.7 Library Manager

Modelling elements produced at **levels 1 and 2** are arranged in **libraries**. The **library manager** enables the management of libraries and their content [30]. Fig. 4.2 shows the development and exploitation stages of simulator.

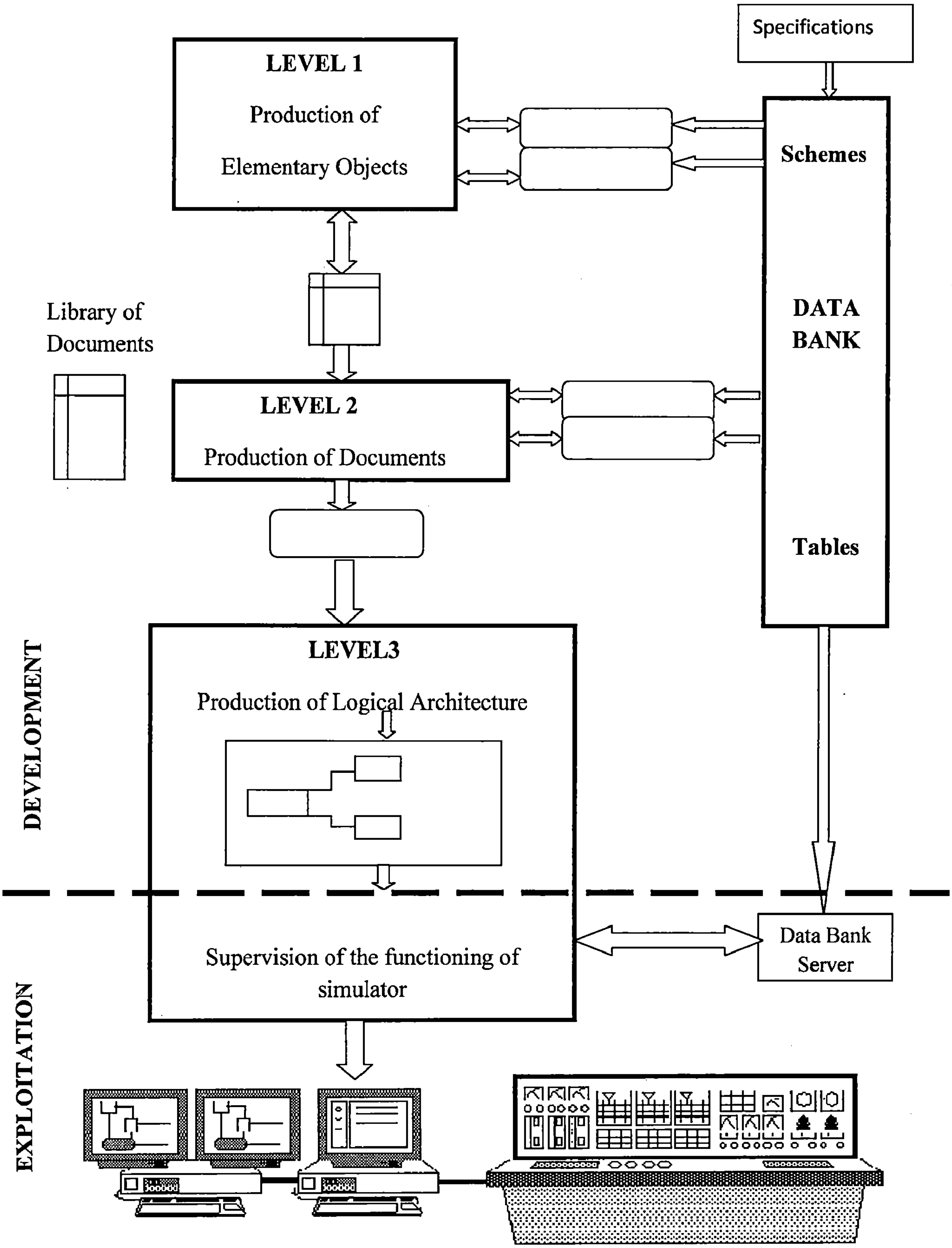


Fig. A.2: Development and Exploitation Stages of simulator [29].

A.5 Modelling in ALICES

A.6 Basic Equations

The equations used to model the phenomena characterizing are derived from the following basic fluid mechanics equations [25]:

1) Mass conservation equation

$$\frac{dM}{dt} = \sum W_{ext} \tag{A.1}$$

2) Dynamics equation

$$\frac{d(M.U)}{dt} = \sum Fext \tag{A.2}$$

3) Energy conservation equation

$$\frac{d(M.(E + U^2/2)}{dt} = \sum \phi ext \tag{A.3}$$

The following external forces are taken into account for the dynamics equation:

a) Friction forces,
b) Pressure forces,
c) Gravity,
d) The forces exerted by the devices (turbine etc).

The power supplied by the external forces taken into account for the energy conservation equation are as follows:

a) The power delivered by the pressure forces,
b) The power delivered by the gravitational forces,
c) The power supplied by the devices (turbine, etc.).

The additional equations connecting the variables to one another are:

Mass: $$M = \rho.V \tag{A.5}$$

Flow rate: $$W = A.\rho.V \tag{A.6}$$

A.7 Discretisation of continuous Media

Hydraulic systems are represented by a network model with concentrated parameters. The system is broken down into a series of objects which concentrate all the system's mass and energy. The mass and energy conservation equations are written for each object making up the system. The dynamics equation is written for each junction connecting the neighboring objects [25].

A.8 Modelling

Discretisation of hydraulic systems takes place by means of arcs, nodes and devices. The (arcs + nodes + devices) assembly models the behavior of the hydraulic systems. A node and an arc can be defined as:

1) A node models a volume inside which mass and energy conservation equations are computed for a variety of homogeneous phases, the main unknown quantity being pressure.
2) An arc models the flux transfer relationship (mass, energy) between the nodes. The dynamics equation and the energy transfer equations are computed in the arcs, the main unknown quantity being the flow-rate [25].

Fig. A.3 shows flow rate between two nodes, node j and node k through an arc jk.

Inlet energy $$W_{jk}\left(h_j+\frac{U^2{}_{jk}}{2}\right) \qquad \text{(A.7)}$$

Outlet energy $$W_{jk}\left(h_j+\frac{U^2{}_{jk}}{2}\right)+\phi arc_{jk} \qquad \text{(A.8)}$$

Inlet flow-rate W_{jk}

Outlet flow-rate W_{kj}

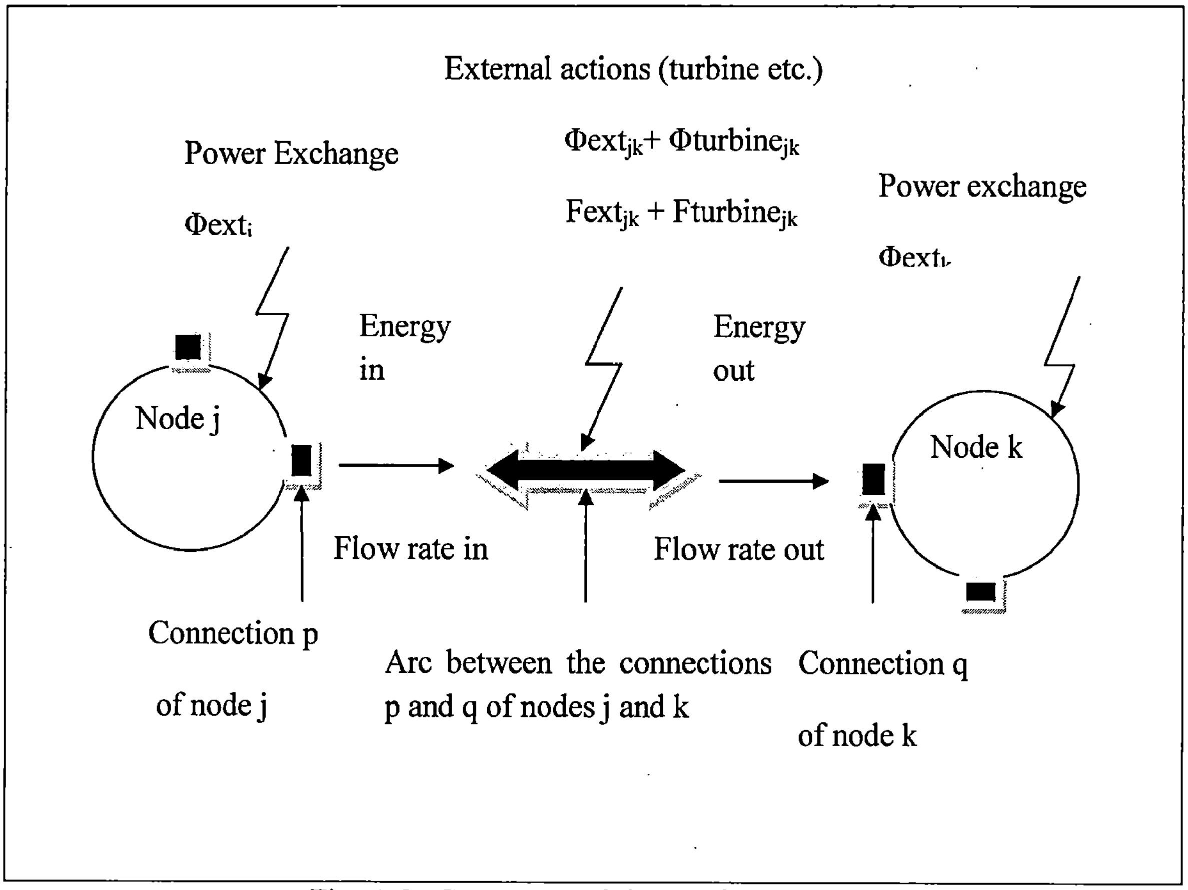


Fig. A.3: System Breakdown Diagram [25].

A device object models a system component. A device is associated either with an arc, or with a node, or with an arc and a node, or with several arcs and nodes. A number of different devices can be associated with the same arc or the same node, for example:

a) A pipe is associated both with an arc and a volume.

b) The pipe length, diameter and surface area characteristics enable its contributions to be computed in the dynamics equation and in the energy conservation equation of the arc.

c) Pipe volume enables its contribution to be computed in the global volume of the node, which appears in the mass and energy conservation equations.

The main assumptions used to adapt the equations to discretisation are:

a) Node volume is assumed constant,

b) Phase volume in a node is considered variable,

c) The arcs do not store mass or energy.

A. Application of basic equations at node ' K '

1. Mass conservation equation

$$\frac{dM_k}{dt} = \sum W_{jk} - \sum W_{kl} \qquad \text{(A.9)}$$

2. Dynamics equation

In most cases (forebay), velocity is not conserved:

$$Ukj = 0 \qquad \text{(A.10)}$$

$$Ulk = 0 \qquad \text{(A.11)}$$

In certain cases (turbines etc.), velocity is conserved:

$$Ukj = Ulk \qquad \text{(A.12)}$$

3. Energy conservation

$$\frac{d(M_k.h_k)}{dt} = \sum\left(W_{jk}.\left(h_j + \frac{U^2{}_{jk}}{2}\right) + \phi arc_{jk}\right) - \sum W_{kl}.\left(h_k + \frac{U^2{}_{kl}}{2}\right) + \phi ext_k + V_k.\frac{dP_k}{dt} \qquad \text{(A.13)}$$

B. Application of basic equations at arc 'jk'

1. Mass conservation, where mass is ignored in the arc.

$$W_{kj} = W_{jk} \qquad \text{(A.14)}$$

2. Dynamics equation applied to arc 'jk'

$$L_{jk}.\frac{dW_{jk}}{dt} + W_{jk}.(U_{kj} - U_{jk}) = A_{jk}.(P_{jk} - P_{kj}) + Farc_{jk} \qquad \text{(A.15)}$$

and

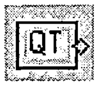
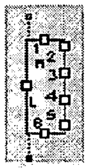
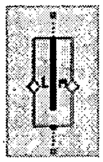
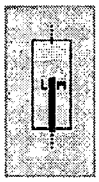
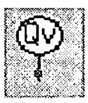
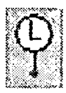
$$Farc_{jk} = Fturbine_{jk} + ... \qquad \text{(A.16)}$$

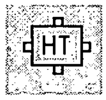
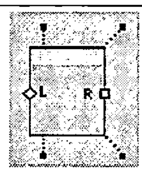
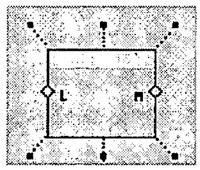
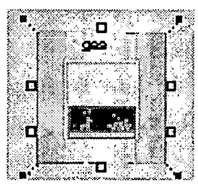
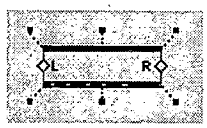
3. Energy conservation applied to arc 'jk'

$$\frac{L_{jk}}{2}.\frac{d(W_{jk}.U_{jk})}{dt} + W_{jk}.\left(h_{kj} + \frac{U^2{}_{kj}}{2} - h_{jk} - \frac{U^2{}_{jk}}{2}\right) = Fext_{jk} + Fturbine_{jk} + ... \qquad \text{(A.17)}$$

APPENDIX-B

Table B.1: Level 1 objects used to develop hydraulic circuit of Pacha SHP plant

S. NO.	Level 1 Object Name	Symbol	Function of the object in document
1	Bound_canal_flow_SPL		This Boundary object represents an imposed mass flow. The positive (direct) flow direction is the output direction.
2	Node_canal_connect_SPL		This Node object represents the end of a canal (left connection) which can be connected to 6 other canal (right connections 1- >6)). It is used to link canal objects with direction change.
3	Arc_gate_SPL		This object represents a hydraulic gate.
4	Arc_weir _SPL		This object represents a weir.
5	Sens_Qv_SPL		This Equipment object represents a sensor measuring the volumic flow.
6	Sens_level_SPL		This Equipment object represents a sensor measuring the liquid real level.

7	Bound_canal_level_SPL		This Boundary object represents an unlimited homogeneous fluid volume. This object is used to represent downstream of the river.
8	Node_canal_AN_SPL		This Node object represents a canal with one volume (right).
9	Node_canal_ANA_SPL		This Node and Arc object represents an open canal. The volume shape is limited to rectangular form. The width is the same along the canal object. Loss of head along the canal is computed. The speed energy at inlet and outlet is taken in account. The inertia is taken into account.
10	Node_res_closed_SPL		This Node object represents an open tank(Forebay). The volume shape is limited to vertical cylinders. The top connection is used only for liquid overflow. The pressure above the tank is a fixed pressure.
11	Node_pipe_ANA_SPL		This object represents a pipe (Penstock). The volume shape is a conical cylindrical form.

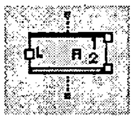
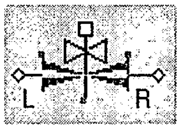
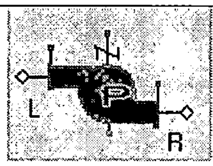
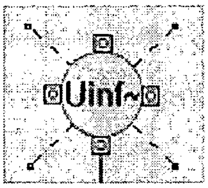
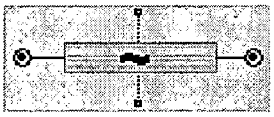
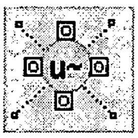
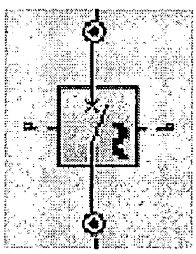
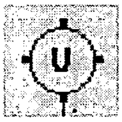
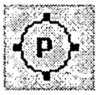
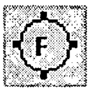
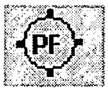
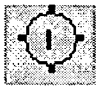
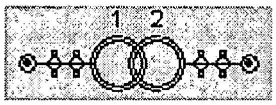
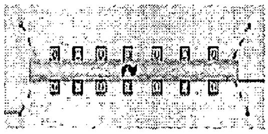
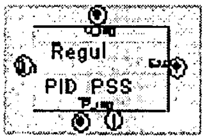
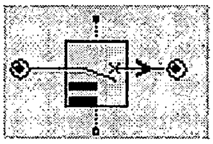
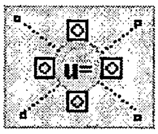
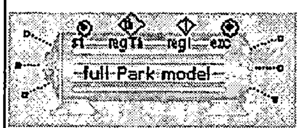
12	Node_pipe_sepa_SPL		This represents a pipe connection node without mass. The volume shape is a conical cylindrical form. The left diameter can be different from right diameter with a continuous variation along the pipe object.
13	Arc_valve_SPL		This Arc object represents a pipe with a valve characterised only by a pressure loss (no height difference). The positive (direct) flow direction is taken from Left to Right. The pressure loss is the same for a direct or a reverse flow direction. The pressure difference in the Arc object is determined by the object parameters and the valve position.
14	Arc_turbine_francis_SPL		This Arc object represents a Francis Turbine. The positive (direct) flow direction is taken from Left to Right. There is no transformation between inlet and outlet, only the transported energy of water is modified between inlet and outlet.

Table B.2 : Level 1 objects used to develop main and auxiliary electrical circuit of pacha SHP plant.

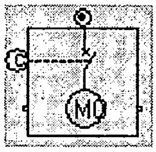
S.No.	Level 1 Object Name	Symbol	Function of the object in the Document
1	ElecNodeInf		Infinite voltage source: This object is a boundary condition with four connections, modelled by a generator outputting an alternating voltage V at constant frequency F.
2	ElecArcAC		Series impedance line: This object is a conservative arc modelled by a series resistance and/or inductance There is thus no representation of the transverse elements of the model in "pi" which simulate line capacitive leakages. The object must be connected to 2 nodes (AC).The object can be connected to 2 sensors.
3	ElecNodeAC		AC Node: This object is the equivalent of a AC node. Electric node in the sense of a junction between several arcs (e.g. top of busbar) the object must be connected to 4 arcs (AC) sensors and can be connected to 4 sensors.
4.	ElecDisj		AC circuit Breaker: This object is a non-impedant arc represent-ting a circuit-breaker. The circuit-breaker representation allows breaking of all power transmissions whatever their value. The operation is performed at the start of the model time

			step. The logical calculation determines the different frequency zones and the potential.
5.	ElecSensorU		This is a sensor which gives the voltage value. The object has 4 connections.
6.	ElecSensorP		This is a sensor which gives the active power value. The object has 4 connections.
7.	ElectSensorF		This is a sensor which gives the frequency value. The object has 4 connections.
8.	ElecSensorCos_ Phi		This is a sensor which gives the value the power factor.
9.	ElecSensorInt		This is a sensor which gives the current value.
10.	ElectTransf		The object is an impendent arc representing a two windings transformer with a complete model. This model is a detailed transformer adjustable in the load-flow and whose taps can be changed during the simulation. In this equivalent model, the iron losses, the magnetic losses are simulated. A parameter allows to choose between different types of coupling: star/star, delta/delta, delta star or star/delta. The parameter which makes this transformation is the angle theta_K. The object must be connected to 2 nodes (AC).

11.	ElecBusBar		AC busbar: The busbar object is equivalent to a busbar with 14 connections.
12.	ElectRegulPIDPSS		The object represents the excitation system with a voltage regulation. Its aim is to supply the rotor windings of the generator by a continuous current in order to create the electromagnetic field that will induce the stator field and thus generate electrical power.The model has the following characteristics :- 1. An automatic voltage regulation that includes a setpoint regulation done by a proportional integral derivative (PID) regulator that measures the generator stator voltage deviation, a power stabiliser system (PSS) that is actived when additional damping is required. It is based on the survey of the power variations and reduces the rotor oscillations duean electrical or a mechanical transient, an over-excitation limiter to avoid the rotor windings damages an under-excitation limiter to stabilise the generator and avoid when possible the asynchronous mode functioning. 2. A manual voltage regulation that includes a first order filtered output using directly the setpoint tuned by the

			operator,it allows a variation that do not introduce a over the output of the regulator is a rheostat position used for the computation of the rotor current of voltage.
13.	ElectDisjDC		DC circuit-breaker: This object is a non-impedant arc representing a circuit-breaker. The circuit-breaker representation allows breaking of all power transmissions whatever their value. The operation is performed at the start of the model time step.The object must be connected to 2 nodes (DC).The object can be connected to 2 sensors
14.	ElectNodeDC		DC Node: This object is the equivalent of a DC node. Electric node in the sense of a junction between several arcs (e.g top of busbar). The object must be connected to 4 arcs (DC).The object can be connected to 4 sensors.
15.	ElecGen		Synchronous machine (Park model): The object is a generator realised by using the Park model synchronous machine (with dampers).When in out-of-balance conditions, the magnetomotive forces created by the windings of the three phases of the stator have different values or directions. The resulting mmf can be

			broken down into two mmf, corresponding to projection of the resulting mmf on two axes : - the direct axis d (rotor axis) -the quadrature axis q (axis perpendicular to the rotor) In Park modelling, these two mmf are considered to be created by two fictitious windings fixed on these two axes d and q and supplied by DC currents Id and Iq. These axes rotate at synchronism speed with respect to the stator; the resulting mmf is thus continuous and rotates at synchronism speed with respect to the stator, thus simulating the stator rotating fields. The mechanical power transmitted by the shaft is fixed by the turbine. Part of this power is consumed (joule, mechanical and iron losses) in the rotor and stator. The rest is transmitted in the form of electricity to the network. The generator can be connected to a separated or an infinity network. The object must be connected to a DC node (excitation), an AC node (stator) and a voltage regulation (internal angle and stator current) the object can be connected to 6 sensors.
16.	ElectControl		This object is used to give the information to the motor that the breaker is closed, that is to say the motor is running

17.	ElecMotorLoad		This object is an AC boundary which represents a motor of low power , it is modelled by a PQ load and gives a speed value according to its state. This speed can be used by the hydraulic system. The object must be connected to an AC node. The object must be connected to a control box which orders the feed breaker. The object can be connected to 2 sensors.