A SIMULATION MODEL FOR STAGE –IV KOYNA HYDROPOWER PLANT

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ABSTRACT

Hydroelectric power contributes around 12.45 percent of the electricity supply in India. It is considered to be the most vital, unpolluted, emission-free and an inexpensive renewable source of energy. Hydroelectric power-plants operating all over the world aims to have high electric output with minimum maintenance cost. It's very different with Koyna Hydropower Plant (KHPP) stage IV which generates lower electric output than the installed capacity with higher maintenance. This project aims to build a simulation model which can simulate the regular operation of Koyna Hydropower Plant with Arena®. The study involves to evaluate dynamic response of the system and plant performance under various operating conditions such as head height, quantity of water flow penstock and operating gates. Also to determine and identify the optimum parameters required for maximum power generation. The outcomes of the model helped to analyse the power generation capacity against the required quantity of water flow and head height. The developed simulation model was validated and used as an apparatus to determine the optimal operating parameters that maximise power generation of stage –IV at Koyna Hydropower plant.

KEYWORDS: *Hydropower Plant, turbine, Penstock, Head, Flow rate, simulation modelling.*

I. INTRODUCTION

Energy is one of the essential element for our world. It play a key role in development like health, education, infrastructure, transportation, economic development and employment to. In the last decade, increasing in population worldwide resulting in oil crises and high Consumption of electric energy. These problem will rise in future, which suggest the need of alternative technology to assure the solution. Generating energy with use of renewable sources like wind, solar, tidal and hydro which do not cause environment pollution. Electricity generated by hydropower is called hydroelectricity, in which the gravitational force of the flowing water helps in production of electricity. Hydroelectric power is generated with help of potential energy of water in the dams using operating gates which allow the water to flow into the penstock, "Penstock is an enclosed pipe that delivers water to hydro turbines" which drives the turbines and a rotational force is generated. This rotational force produces a torque on the shaft. The turbine shaft is attached to a generator, where electricity is produced. There are four generating method to produce hydro-electric power. [3]

1. Conventional Method: In this method, the potential energy of dam water is used to generate power. It is used on a large scale across the world.
2. Pumped Storage: Pump turbines transfer water back to the reservoir after power generation, to utilize it during the peak period.
3. Run of River: Natural flow of water is used and the turbine is placed along the stream. It is often used for low head heights.
4. Tide: It uses rise and fall of ocean water levels to generate power.

The above methods use the kinetic energy of flowing water to generate power. Hydropower is an extremely flexible technology for power generation. Hydropower is a renewable energy source with relatively low generation and maintenance cost. Hydropower Plants are used to generate electricity in more than 150 countries, 32 percent of which is generated in the Asia Pacific region, in which China's and India's contribution is high.[2] The key elements in hydro power generation are, Operating Gates, Penstock, Reaction turbine namely Francis turbine and the Generator. "An electric generator is any machine that transforms mechanical energy into electricity for transmission and distribution." The generator works by spinning a rotor that is turned by Francis turbine. "The rotor is a shaft that has field windings. These copper windings are supplied with an excitation current or voltage. As the rotor rotates, the excitation current creates a magnetically induced current onto a stator."

A hydro power plant has the following constituents; [9]

- Hydraulic unit.
- Mechanical unit.
- Electrical unit.

These components are combined to represent the Hydro Power Plant model. The simulation of the model can be used to study the performance of a plant under various operating conditions.

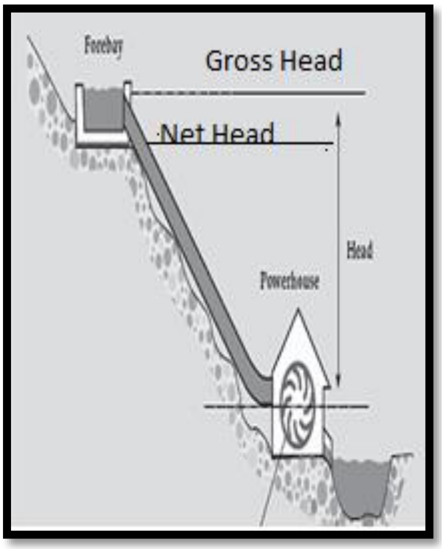

Fig 1: Head Height.

The Net height "which is the pressure at the bottom of the penstock when water is actually flowing to the turbine, and will always be less than the Gross Head", "Gross head is the difference of height between the water surface of fore bay and the tail race under specified conditions measured**"** and the quantity of water flow through the penstock play a vital role in power generation in Hydro Power Plants. [4]

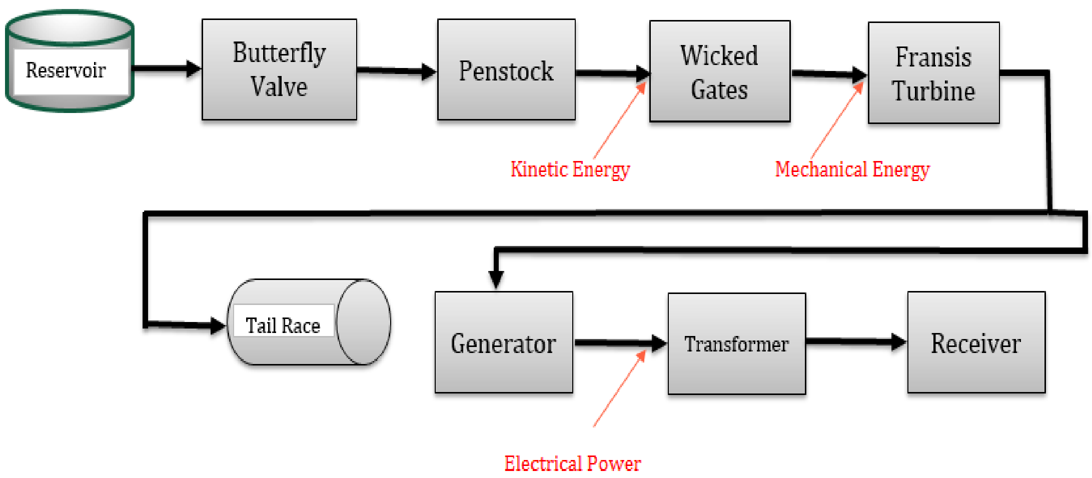

Fig 2. Schematic View of a Hydro Power Plant.

The different elements and the conversion of energy during the process is shown in the flow process chart below. The Butterfly Valve is used to regulate the flow of water from the reservoir and the penstock carries water with a constant flow rate. Wicket gates are used to avoid the wear and tear of the turbine blades and release some pressure of the flowing water.

Koyna power plant is one of the largest in India. It generates a total of 1920mw of electrical power in four stages. My research focus only on the stage –IV. A simulation model was built to study the technical aspect and find the key input parameters of the real system. The developed model help to simulate the static and dynamic behaviour of system with different scenarios. The developed simulation model show the same behaviour as the real power plant. The simulation model can be used to study dynamic behaviour of overall system, performance of the system with change in input parameter and reduction of losses of energy during energy conversion.

II. KOYNA HYDRO POWER PLANT (KHPP)

Koyna Hydropower Plant, constructed across Koyna River, a branch of Krishna Basin, is a concrete dam, 103.2 m above the foundation, in Satara District, Maharashtra State, India. It is the second largest Hydro-electric project in the country and impounds water (initially 2797.4 M.cum) to generate 1960 MW in four stages, listed in the table below with each stage of power generation. The power plant was established in the year 1966 with the first two stages; due to the increase in demand, the power plant was extended with a new stage with a capacity of 1000 MW, called "STAGE-IV". The Power Plant uses the impending of water from the Koyna River for stages I, II and IV. The water from the tailrace of stage I and II is utilized by stage–III for power generation. All the generators are located in the underground power house, excavated deep inside the surrounding mountains of the Western Ghats. A dam foot powerhouse also contributes to the electricity generation. Koyna River is considered as the life-line of the state of Maharashtra due to the KHPP generating capacity. This plant supplies power to nearly twenty percent of the state's population.

Table-I. Power Generation of Koyna Hydro Power Plant in Stages. [4]

Stage	Units	Installed Capacity
I	4 X70 MW	280 MW
II	4 X 80MW	320 MW
III	4 X 80 MW	320 MW
IV	4 X 250 MW	1000 MW
KDPH	2 X 20 MW	40 MW
	Total	1960 MW

III. KOYNA POWER PLANT SPECIFICATIONS

The technical specification with a constant head and flow rate in each stage of Koyna Hydro Power Plant (KHPP) are listed below in the table.

Table-II. Basic Data of Koyna Hydro Power Plant. [4]

	Stage I & II	**Stage III**	**Stage IV**
1. Dam			
Catchment Area	891.78 km^2	25.04 km^2	891.78 km^2
Capacity	2797.00 mm3	36 mm3	2797.mm3
Max. Height above foundation	103.02 m	63.30 m	103.02 m
Length	807.72 m	497.00 m	807.72 m
2. Intake Works			
Head Tunnel Length	3748 m	4551 m	4230 m
Intake Tunnel Diameter	6.4 m Circular	7.4 m 'D' Shape	7 m * 9.50 m
Discharge	164m3 /sec	170 m3 /sec	175 m3 / sec

3. Pressure Shafts			
Number	4	4	4
Length	616 m	192 m	590 m
Tail Race Tunnel Length	2215 m	4543 m	2314 m
Installed Generation capacity	640 MW	320 MW	1000 MW

IV. POWER AND FLOW CALCULATIONS

Hydroelectric power plants capture the energy released by water falling through a vertical distance, and transform this energy into useful electricity. The amount of electricity, which can be generated at a hydroelectric plant, is based on two main factors.

1. The vertical distance through which the water falls, called the "Head",
2. Flow rate of water passing through the penstock.

The electricity produced is related to the product of the Head and the rate of flow. The following is an equation used to calculate the amount of power generated. The following are the equation used to calculate the different energy transformation during the power generation process at Koyna hydropower plant.

4.1 Electric Power

$$\boxed{P = \eta \rho g Q H} \tag{1}$$

Where:

- P is the Electrical power produced at the turbine shaft (Mega Watts),
- η is the hydraulic efficiency of the turbine
- ρ is the density of water (1000 kg/m3),
- g is the acceleration due to gravity (9.81 m/s2),
- Q is the volume flow rate passing through the turbine (m3/s),
- H is the effective pressure head of water across the turbine (m).

4.2 Flow Rate

The amount of Water flow is calculated by

$$\boxed{F.R = \frac{\pi}{4} d^2 \sqrt{2gz}} \tag{2}$$

Z is the specific head height in Meters. The model will read the input parameters and calculate the flow rate of the system and power achieved with the above input values.

4.3 Capacity Factor

"It is the ratio of actual output to its potential output over a period of time".

$$\boxed{C.F = \{ \frac{((\text{Energy generated per year (kWh/year)})}{(\text{Installed capacity kW}) \times 8760 \text{ hours/year})} \}} \tag{3}$$

4.4 Potential energy of water

$$\boxed{P.E = M*g*H} \tag{4}$$

4.5 Kinetic energy of water

$$\boxed{\text{Kinetic Energy (K.E)} = \frac{1}{2} * M * C2} \tag{5}$$

Where,

- M is the mass of water (kg),

• g is the acceleration due to gravity (9.81 m/s²),
• H is the Effective Pressure Head of water across the turbine (m).
• C is the jet velocity of water at the intake of the turbine blade (m/s).
Where, jet velocity $C = \sqrt{(2gH)}$, mass = Density * Volume

V. SIMULATION MODEL OF KHPP

The amount of energy available from water depends on the amount of water flowing and the height of the water surface above the turbine. This height is called the 'Head' and greater the head, more energy per cubic metre of water is available to spin a turbine, which in turn drives a generator which produces electricity. Greater the quantity of water, greater the number and size of turbines that may be spun and greater the power output of the generators. Water is collected and stored in the dam above the power station, to be used when it is required

The simulation model consists of two tanks with a capacity of 100,000 Gallon. Tank 1 is divided in four stages to fill according to the requirement, which is connected with four regulators to seize water with a constant speed of 170 m/s (KHPP Data). Tank 2 act as a tail race. Sensors are used to determine the specific level of water in the Tank. Positive sensor gets triggered when the desired level of water flow is achieved in the tank, Negative sensor is triggered when water level is at a desired low level i.e. 100 Gallons, and the tank needs to be refilled.

The model is used to simulate the stage-IV of KHPP. It is mainly simulating the intake water from the reservoir (huge tank) which is in the stored form, (i.e. potential energy) with help gate valves (regulators). In this model, the entity (water) which is flowing through a specific head height, seizes the gate valves from the regulator set. Different variables have been given in assign modules. Here the gate valves act as regulator check which not only regulates the valve but also ensure its active state. The potential energy of the stored water gets converted into kinetic energy when water flows through the penstock.

When the water flow hits the turbine the total kinetic energy gets converted into mechanically energy which in turn transforms into electrical energy by generation of electrical output thorough the generator. The free water move out through tank 2 in to the river.

5.1 Simulation Setup.

The simulation model works very similar to the original koyna power plant stage -IV model right from the intake of water flow to the exit through tail race. All the operational parameter used in the simulation model are listed in table-II except the following parameters as they were optimized and selected for higher electric output (Table – III). A newer component which ensures the desired flow rate in between the turbine and seize regulator called "Flow check" has been included and verified. The component automatically sends the signals to 'regulator set' which makes certain changes within the flow rate depending upon the final electrical output. The simulation model was made to run for a day with a warm-up time period of 45 minutes and a 50 number of replications.

Table – III Optimum values Stage –IV KHPP

Head Height	120 meter
Flow Rate	190 m^3/sec
Turbine Efficiency	0.70
Operational Setup	Triangular (10,15,20) Min

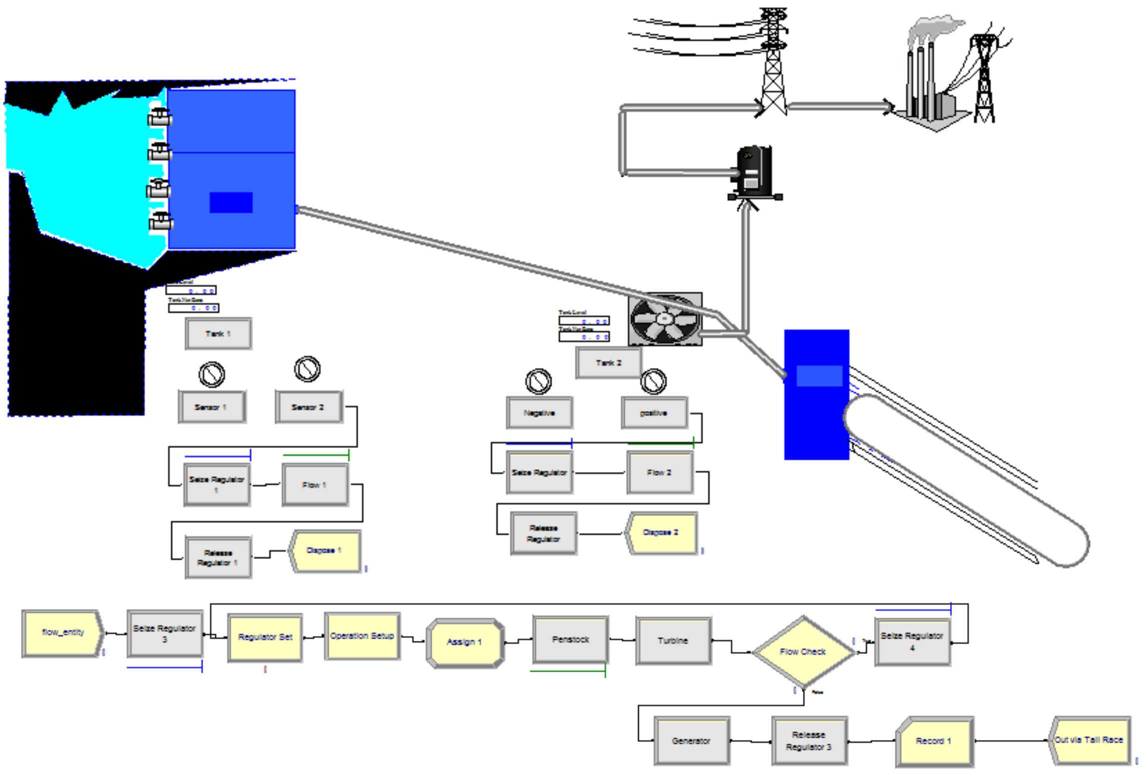

Fig.3: Main Model KHPP

VI. SIMULATION RESULTS

The table below show the results of the simulation model for Koyna Hydro Power Plant. The result for the current head (103Ft) generates a power of 710.32 MW/day, with optimum head (120Ft) produces 896.68 MW/day.

Table – IV Simulation Model Result with varying head height.

Head Height	Quantity of Water Flow (M3/sec)	Speed (Rpm)	Efficiency	Kinetic Energy (KJ)	Mechanical Power(MW)	Electrical Power(MW)
90	158	440	0.55	5.246934	1090.473	599.76
100	161	565	0.61	5.829926	1092.459	696.4
103	175	598	0.61	6.004824	1125.115	710.32
110	182	625	0.67	6.412919	1160.433	789.6
120	190	750	0.70	6.995912	1195.4	896.68

The installed capacity of Stage-IV of Koyna Hydro Power Plant is 1000MW and the plant can generate 896.68 MW of electric power with optimum operation set up. The key elements such as Head and quantity of water flow boost the turbine speed, efficiency to generate more power. Here its linear increment in speed of turbine as kinetic energy of water flow changes with respect to head height .The electrical power generation is increase by 186 Mw to reach 896.68 Mw with rise in head height of 17 meter and flow rate of 20 M3/Sec compared with actual factor.

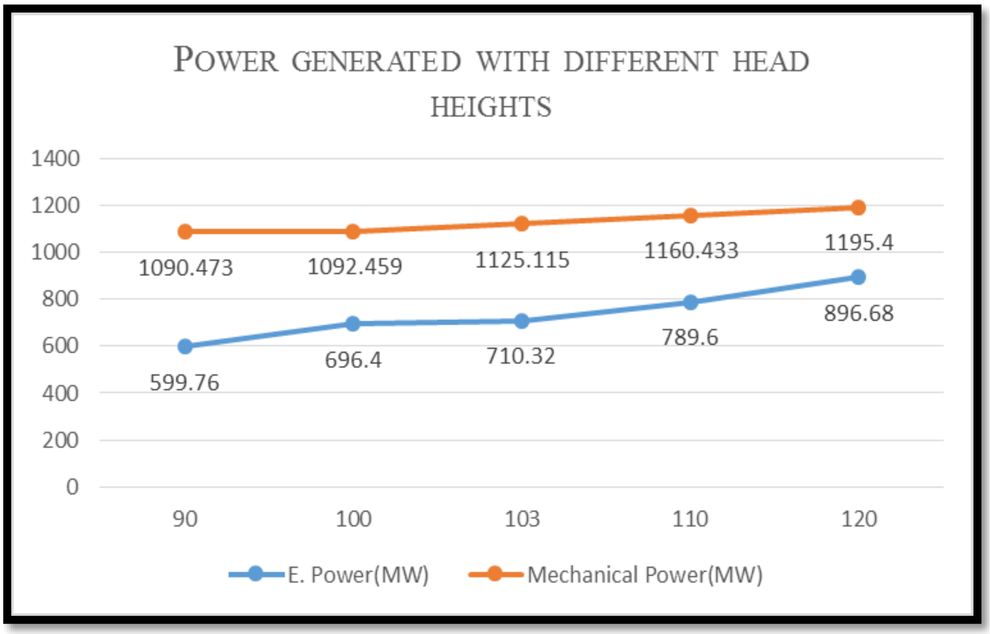

Fig 4: Power generated with different head height

The loss in energy conversion from mechanical to electrical energy shown in the figure with respect to the head height. With the optimum head height (120 M) the energy loss is reduced by 7 percent compared with actual head (103 M).

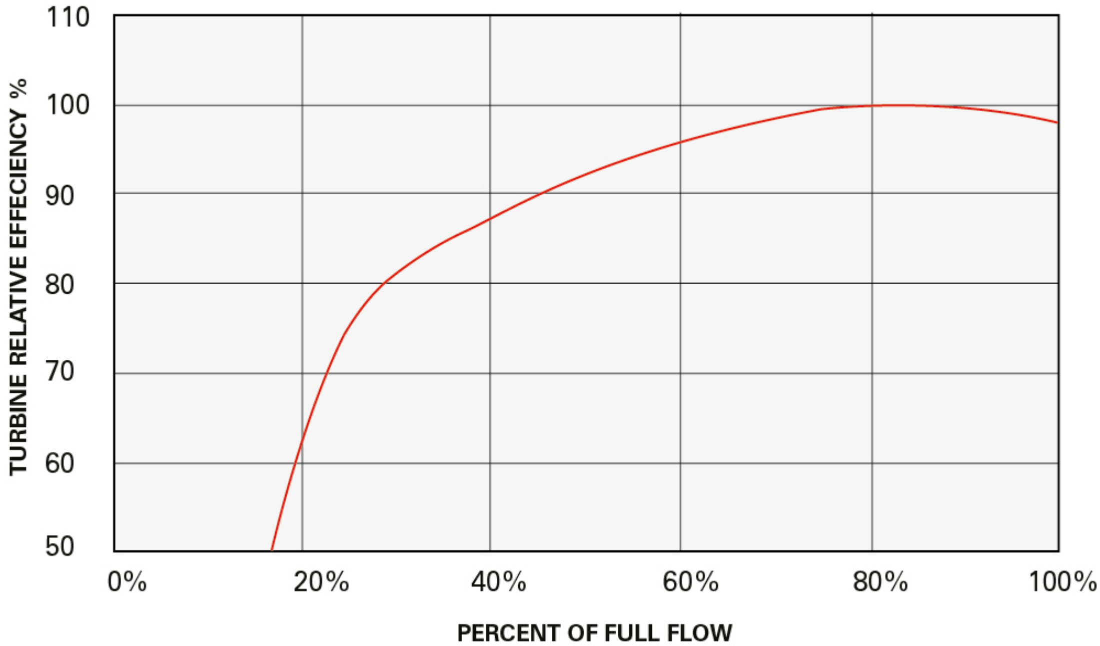

Fig. 5 Turbine Efficiency with full flow

The figure give the direct relation of efficiency of turbine with the quantity of water flow which is channelled through the penstock to rotate the turbine. As the percentage of water flow is increased the speed of turbine increases which in turn increases the efficiency and help to generate more electric power.

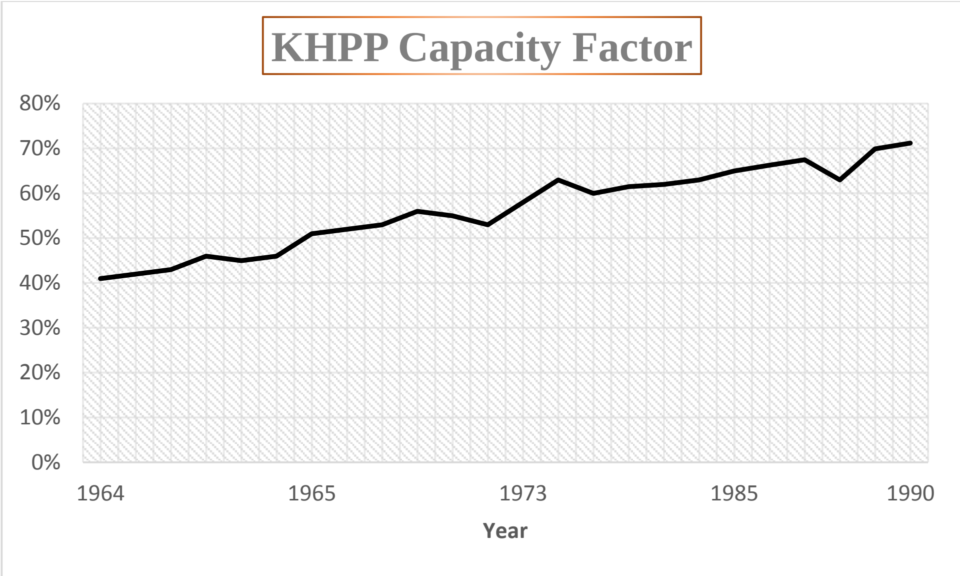

Fig. 6 KHPP Capacity Factor

The Capacity factor of the plant increases with optimum output and proper utilisation of resources. This will help to boost the base load of the plant, base load are designed for the maximum efficiency and high output. The model shows that the plant gives an optimum output at a head height of 120 m. The optimum output of the plant at this head height is:

- Electrical Power: 896.8 megawatt
- Mechanical Power generation before conversion into electric power: 1195.4 megawatt Intake Flow of water: 190 m^3/sec
- The Speed: 750 Revolution per minute
- Kinetic Energy of Water flow: 6.995912 Kj.

VII. CONCLUSION

- The speed of the turbine depend upon the quantity of water flow and head height. The sudden change in water flow with help of operating gates, effects the speed, results in low electric output. In this model, the turbine speed is maximised with optimum water flow, this in turn helps to generate maximum electricity.
- The model helped to identify the optimal values of different input parameters namely head, flow rate & turbine efficiency which are key elements to maximize power generation. For example, if the head height is adjusted to 120 ms, with flow rate 190 m3/second has actually helped the plant to cope with the energy supply in peak time (summer) by efficiently managing the energy.
- Based on the measurement in the koyna hydro power plant stage-IV, the data collected routed to build a dynamic model. It is identified that obtained results are almost similar to the real power plant.
- The important findings are that the power generation capacity of koyna hydro power plant stage-IV shows a linear increment with increase in head height, approximately 21 percent with respect to current steady state condition.
- Also it was observed that the energy dissemination during the transformation of energy from mechanical to electrical was very less giving higher power output approximately 36 percent more when compared to the real power plant.
- The results obtained have encouraged us to experiment the same simulation model using different tool like MATLAB, GOLDSIM.
- As a future work, experimenting with different tools will be beneficial and can give promising results outfacing critical information such as electrical, mechanical and hydraulic components which could not be the key findings in ARENA model.

ACKNOWLEDGEMENT

I would like to thank Dr. Hisham Alidrisi chairman, Industrial engineering department, college of engineering, King Abdulaziz University for all the technical support throughout the research.

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