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A Sustainable Decision Support System for Scheduling of Cascaded Hydropower Plants

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Abstract*—Effective utilization of renewable source of energy from hydro power has been found to be most promising for proposing energy solutions. The most challenging and upcoming methodology is to form cascaded hydro power plant which can fulfill multifaceted objectives. Optimum electricity generation from water flowing system lies in proper scheduling and dispatch in order to fulfill the commitment of energy generation. A sustainable decision support system for scheduling of hydro power generation is required which is proposed by system modeling approach. System dynamics (SD) approach can be applied for development of HPP, covering stages from concept to commissioning which can influence decisions and hence set up a block diagram for co-ordination between each operation for better project management. Modeling of HPP is a complex process and there is no uniform modeling for each plant since every plant has its unique physical operational scenario. The concept becomes more complex when modeling of cascaded HPP is to be done. Proper scheduling of hydro electric plant means judicious utilization of available parameters in such a way that water discharge in upstream is converted into electric power in the downstream side in an efficient manner without much losses. Proper modeling of these factors along with scheduling process will contribute in increasing power generation. Decision is done for various variables under restrictions/constraints for meeting objective/criterion. If there are n numbers of variables, then number of combinations can be 2^n. System dynamics approach can be used to handle and optimize these factors.*

Keywords:*—Decision Support System [DSS], Scheduling, Cascading, System Dynamics (SD). Hydro Power Plant (HPP).*

1. INTRODUCTION

There are many types of Hydro power plant schemes like micro, mini, small and large power plants which make its wide spectrum of application for power generation. Huge opportunity of growth is present in this sector and the efficient utilization of resources is to be used to obtain the goal [1].Hydro power is by far the single largest renewable source of energy in India. While most of this energy is from large HPP, small HPP have also started making its presence. In terms of small/mini/micro HPP, potential is much more. There are many problems associated with large HPP such as its construction, operation and managing it [2]. Considering the investment in HPP, generation cost is less as compared to thermal power plant [3]. Major advantages of Hydro Power lies in no CO_2 emission, no fuel cost and low operation cost. For meeting socio-economic energy demand, need for integrated assessment, formulation of system design is necessary. As we know that there are many dams, irrigation canals and HPP in our country, a systematic modeling of which can support the development of small/mini/micro HPP in the downstream side of reservoir [4]. Policy planning is required which can help authorized decision makers so that they can initiate a action plan for development of unexplored energy potential in downstream side.

When more than one plant is installed in a same river system then power production can be multiplied that number of times. Along with this installing plant in canals can make reach of electricity to rural areas. Prior to the development of these plants if design and modeling is done for optimum scheduling of the plants, then increased amount of energy generation can be obtained. Generation of power through HPP depends on the amount of water in the upstream side which is coming from downstream side of some other dam/plant or canal, this concept can be developed for the construction of HPP in a cascaded manner for optimum utilization of renewable source of energy. Loss of water from one hydel plant is gain to other plant in the downstream side, this should be considered in market share model [5]. Scheduling of more than one plant is to be done whose performance is interrelated and interdependent, then the system becomes more complex. To obtain proper regular power generation both in rain and other seasons, it becomes necessary to prepare and perform modeled study so that factors affecting the power production can be regulated accordingly. By working in this direction uniformity of energy production can also be improved by providing unit commitment to plant through economic dispatch. Research work leading to decision support system for scheduling of cascaded hydro power plant is done using different approaches, but there is lot of scope via system dynamics approach. In the present literature a System Dynamics (SD) model for scheduling (Meeting the unit commitment of HPP generation in terms of various factors) of Cascaded (Installing more than one HPP serially or parallel in the same river system) Hydro Power Plant (HPP) is presented.

2. OBJECTIVES OF RESEARCH

Policy makers have the technical, financial and social responsibility when any power plant setup planning is done. So the broad objectives of the research to assist decision makers to develop system dynamics model for sustainable decision support system (DSS) for setup of cascaded hydro power system. Feedback loop system is developed which will help in better alteration acceptance [H6]. Parameters for planning include socio economic, techno commercial, strategic planning, tactical planning, operational planning, corporate management planning and integration of all planning for optimization [H6/8]. This is done to minimize investment risks including 25 year projections and 10 year forecast which requires a detailed framework [5], consists of planning and implementation of micro/mini hydro power plant in the vicinity of large SHP or thermal power plant by SD approach can be done to address short term and long term hydrothermal generation scheduling problem Wood et. al. 1996.

Thus the overall objective is to minimize the production cost of the energy needed to satisfy the load.

3. PHYSICAL AND OPERATIONAL CONSTRAINTS

In hydro power system, mainly there are two types of constraints exists which are equality and inequality constraints. Scheduling of cascaded HPP requires information such as hill chart, area capacity curve of reservoir, water transport delay. Model has to be developed considering specific situations uncertainties and constraints as per availability [5], which can be applied to competitive energy market [H8/8], these constraints are:

(i) Inflow water discharge ($Q_{min}<Q<Q_{max}$) available to the prime mover and energy demand correlation to cover long term/ short term uncertainty of water quantity

[5], Water inflow in upstream side, downstream discharge [6], hydro potential available ($P_{min}<P<P_{max}$) and turbine capacity.

(ii) Reservoir size, upper and lower limits levels of the reservoir ($U_{min}<U<U_{max}$), [if reservoir is big then variation of head will be less but if reservoir is small then variation of head will be more, reservoir filling depend upon the difference of inflow and outflow]

(iii) Other characteristics like spillage limits, costing criteria, environmental impacts and diversion channel path, hydraulic losses, turbine-generator efficiencies, working zones, tail race levels, gainers/ losers from the project and costs benefit analysis [7].

4. BRIEF LITERATURE REVIEW

Objectives for fulfilling energy gaps are done by scheduling of cascaded HPP system. So there should be flexibility in energy generation which can be obtained on hourly, daily, weekly, monthly or yearly basis, hence a feedback loop is created [9] A typical concept adopted for cascaded hydro power generation system is shown in the figure 1, installing more than one HPP in the same river or canal system. Simultaneous operation of two cascaded HPP (A and B) is shown in the figure indicating the relationship between water flow, storage in upstream and downstream side. This level of head storage finally passes to tail storage after passing through turbine. A crucial component in the hydro power generation system is generator which is coupled directly to the turbine and its performance depends upon the level of head storage and discharge available. So an approach through which optimum generation facility can be obtained depends on combination of factors and its relationships in a complex system under prevailing constraints (like minimum storage, level/height requirement of head storage will decide the type of generator and turbine to be used for power generation). Level of water depends upon rainfall, water released from dam and randomness of weather conditions.

For efficient and continuous operation of hydro electric plant generation, scheduling is an important objective. Scheduling becomes more important when Tail Race Level (TRL) in downstream becomes Full Reservoir Level (FRL) in the upstream for HPP in a continuous water flowing system. In such case discharge and spillage becomes important point of concern. Model is prepared for turbine, TRL, reservoir etc. so that maximum power is generated in a cascaded system like Narmada river covering Omkareshwar, maheshwar and Indira-sagar HPP[H3]. Optimal scheduling of a HPP is demanding, complex and challenging task on a real time basis in the present competitive market. Most complicating factor meeting above goal in the present scenario is that inflow and demand do not remain constant over a period of time and hence remain uncertain. Depending on the requirements short term, medium term or long term generation scheduling is desired. For this many approaches are presented like linear programming methods, dynamic programming, simulations etc. (Yeh et. al. 1985). Successive linear programming methods were applied for solving hydro electric plant generation scheduling in Aswan dam for reservoir operation (Tao et. al .1991).

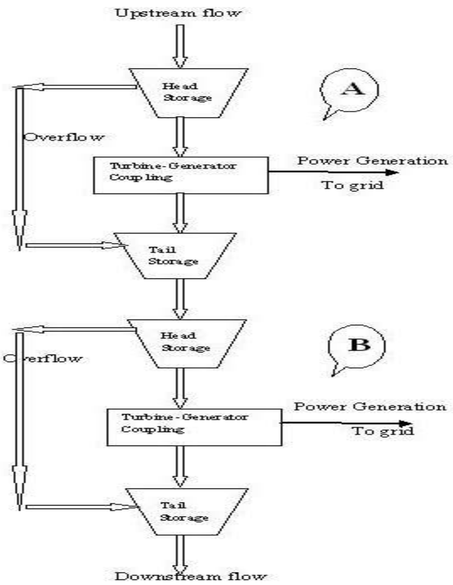

Figure 1: Typical Arrangement of Cascaded Hydro Power Plant Generation System.

Amita M. et. al. 2010 [28] investigated short term scheduling of cascaded hydro energy system present in Narmada river, to find out water discharge, water storage and water spillage for each reservoir for all scheduling time periods in 24 hours. Error between demand and generation is tried to minimize during scheduling horizon. This is done by using particle swarm optimization (PSO) and mathematical modeling. Author described how to match scheduling in a cascaded hydro electric system. Decision support system for HPP should be made so that a layman can obtain data required for optimizing HPP operation i.e. optimum discharge, optimum power etc. Beauty of HPP is that during heavy demand period like winter season availability of water is more (Ray et. al.).

Various traditional methods like non-linear programming [8,10], mixed integer programming [11], dynamic programming [12], quadratic programming [13], lagrange relaxation [14], network flow method [15], bundle method [16] are a few research work in the field of solving scheduling problem. Basic drawback in above approaches is that non-linearity of problem is not handled due to sensitivity to initial estimates and stuck to local optimal solution. Modern heuristic optimization techniques based on operational research and artificial intelligence concepts such as evolutionary programming [17], hybrid chaotic genetic algorithm [18], simulated annealing [19], ant colony optimization [20], tabu search [21], neural network [22,23] & PSO [24,25,26] provide better solution. Each method has its own advantage and disadvantage but none approach provide the solution of hydro scheduling problem in totality.

In past work has been done in this direction by many researchers for solving the power generation optimization problem by traditional techniques like integer programming (IP, Dillon 1978 & Graver 1963), Dynamic programming (DP, Lowery1996 & Snyder 1986), Bender decomposition (Baptistella & Geromel 1980), lagrangian relaxation (Bard 1988, Zhuang & Galiana 1988). In the recent past some advanced methods have been used like heuristic approach like simulated annealing (Zhuang & Galiana 1990), Genetic algorithm (Kazarlis 1996, Orero & Irving 1998). A major task in the scheduling problem is to optimize the process for short term or long term basis, hourly basis (Martin, 1995). Work done by Wurbs, 1993 made a approach to solve the problem on hourly and daily basis. Formulation on a non linear real time basis for optimization model of hydro thermal power generation is given by Tajada & Guibert 1990. Turgeon, 1981 developed progressive optimality technique for making optimal operating curve for HPP arranged serially on the same river. Uhr Markus 2006. Process followed while designing model for subject is shown in following steps (figure 2) for deciding inflow to reservoir and load at step 1 & T.

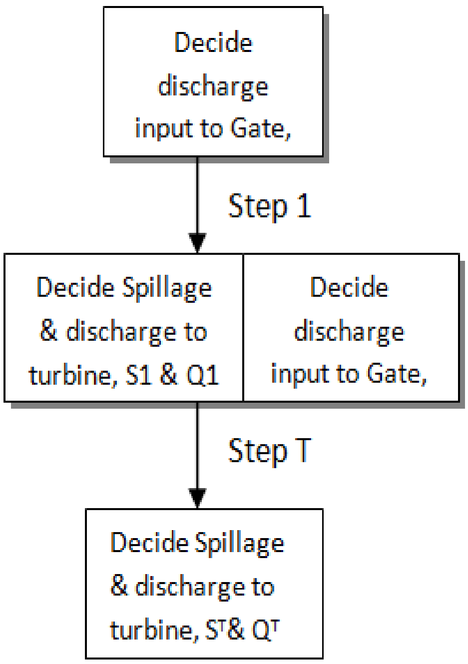

Figure 2: Decision of inflow and load over a time horizon T for scheduling

In receding horizon control, the optimization problem is solved for a time horizon *T*, Then, the optimization is repeated for time steps t = 1…….. (T+1).

5. THE SCHEDULING PROBLEM

Elements such as water inflows in the system and production constraints make it difficult to find a scheduling policy. Combining the goal of the electricity producer to minimize production cost with the operating constraints over the considered time horizon results in an optimization problem. Thus the minimizing arguments of the objective function, subject to the constraints, will be the optimal scheduling decisions. The following two sections describe in detail the objective and constraints of the optimization problem.

6. PROPOSED METHODOLOGY

A model is a substitute for real system, models are used when it is easier to work with a substitute than with the actual system [Ford 1999]. The model in this research is designed to serve as a tool to make easier learning about the implication of different policies on scheduling and cascading of SHP/mini/micro HPP. SD concerns itself with the dynamic behavior of the real systems. Wolstenholme 1990, defined the methodology of SD as "A rigorous model for qualitative description, exploration and analysis of complex system in terms of their processes, information, organizational boundaries and strategies; which facilitates quantitative simulation modeling and analysis for the design of system structure and control". SD approach offers building dynamic simulation model for such complex system as in hydro power operation. The summary of methodology of SD is enumerated below [NR-H11]; SD is based on four foundations:

First: The theory of information feedback system, i.e. circumstances leads to decisions and decisions results to action. The action creates a new circumstance which leads to future decisions and thus cycle continues. The central feature of information feedback systems are: time delays, structures and amplification.

Second: The knowledge of decision making process. Importance of this arises when decisions are to be taken for long term like strategic decisions, planning and policy making. The ground rules aims at eliminating the shortcomings which is characterized by bounded relations [Simon, 1979].

Third: The experimental approach to complex systems. This process is aimed at building mathematical simulation model to portray the structure of system under consideration. Experiments are then conducted to test management policies and strategies.

Fourth: The computer as a means to simulate the model

The SD was invented by Forrester from MIT in 1950s. The approach is based on the feedback control theory, variables and equations equipped with computer simulation technology and used in quantitative researches in complicated fields. The feedback loop is defined as a closed chain of causes and effects. The variables include :

(i) level variable

(ii) rate variable and

(iii) auxiliary variable.

The three kinds of variables are linked by equations taking the form of integral, differential or other types.

The model is needed to be formulated in a way that can be translating the model structure into mathematical equations. In system dynamics, this can be greatly facilitated by using stocks and flow diagram. Statistical analysis and system dynamics modeling will be used for validating the objectives.

Forecasted and historical data are used for modeling and optimizing at different levels of planning. Optimal operation of hydroelectric generation can be divided into various levels of computational manageable levels with each level explaining the solution of different aspect of total problem. The different levels can be explained as given below [5]:

- Long term on monthly time steps

basis for 1-4 years.

- Medium term on weekly time steps basis for 1years.
- Short term on daily or hourly time steps basis for one week.
- Real-time over hourly time steps basis for several hours.

We have to check the consistency of scheduling whether it is short term, medium or long term hydroelectric operation scheduling planning. Inflow to reservoir can be natural or modified by the operation from the upstream side of the river flow path. Several set of combination can be obtained indicating discharge, inflows in and out of the reservoir. Upper and lower levels of storage constraints can also be indicated in equation. Power generation from a plant is a function of gross head available and discharge coming to the turbine. Gross head is a function of forebay level and tail water level. The tail water level depends upon the total discharge from the turbine and downstream water level [NR-H10].

Meeting the required demand of water inflow, discharge, net head and other relevant factors for hydro power plants is proposed by methodology which will require past history data along with forecasted information. Interpretation of interrelated data is done for obtaining a decision support system. For presenting a systematic approach for scheduling of cascaded hydro power system modeling is required considering different constraints of hydropower system [5]. Final objective depend upon the right combination of these constraints. Data series is collected for SD software, these data are reservoir level, evaporation rate, reservoir inflow, energy production capacity, turbine discharge, spillage, tail water level. Scheduling will done on the basis of above model. For cascaded system scheduling each plant is correlated and interpreted as per model shown in the figure 3.

- Reservoir/canal model
- Forebay model
- Penstock model
- Turbine/Generator model
- Tail water level model

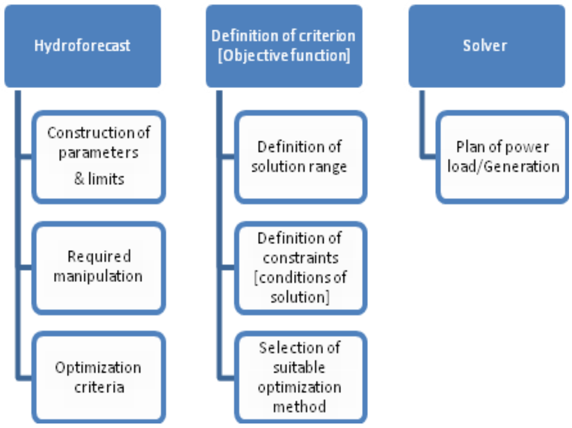

Figure 3: Hydro Power Plant Modeling

7. CONCLUSION

Present study focus on the scope of system dynamics for the management and policy planning/decision making system for producing maximum energy from flowing water. Model is used to address policies for setup of more SHP, canal head based hydro power plants and scheduling of cascaded hydro power system which is dynamic, multi-loop and has non-linear character of feedback system along with flows and stocks. Formulation is done by SD software (Power Sim, Stella). By conducting this study, it is expected to be able to recommend SHP/Mini/ Micro HPP developers a decision support system. The study will address the gap between the exploited HP and potential available of HP. Integrated sustainable decision support system for HPP is presented here for setup of cascaded hydro power plant fulfilling the constraints and uncertainty analysis. Establishing reliable relationship and perfect correlation start-up procedures for successful operation of the plant is essential to consider potential fluctuations in input quality and quantity, optimizing the plant design for given constraints feedback type, inflow content and other factors as per site specific variables.

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