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Power Grid Frequency Based Scheduling for Pumped Storage Hydro-Electric Unit to Maximise the Gross Revenue Margins

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ABSTRACT: This paper presents a methodology which determines as operational criteria for the scheduling of hydro-electric generating units of pumped storage plant (PSP), by making the energy used for pumping most beneficial. Scheduling of PSP is done based on frequency, where Pumped Storage Hydro-Electric (PSHE) units are proposed to operate in a selected range of frequency for pumping and another range for generating. The mode (Generating/pumping) of units is selected depending on the cost of energy which is related to the frequency of the grid, according to UI charges of Available based tariff (ABT). To optimize this process, gross revenue margins of PSP have been maximized using Genetic algorithm.

KEYWORDS: Pumped storage plant, Available Based Tariff, Genetic algorithm, GeneHunter.

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I.INTRODUCTION

PHES is currently the only commercially proven large scale (>100 MW) energy storage technology with over 300 plants installed worldwide with a total installed capacity of over 95 GW[1].The Pumped storage capacity in India would become quite substantial 5,804 MW, in which about 3,350MWpumped storage capacities from different projects are under active construction [2]. In a large power system network with large variation between peak demand and off peak demand, pumped storage units are required to bridge the gap between these two. To smoothen the load curve in the power system, one of the solution is to setup an energy storage device which stores energy in off peak hours and supply the stored energy back to grid at peak hours. PSPs are one of the best suited energy devices to do so. In the case of PSPs, energy storing process is done by converting large quantities of Electrical energy to potential energy by pumping water to higher level reservoir and then released water through turbines for generating electrical energy. The principle equipment at PSP is the pumping-generation Unit. The machinery is reversible and is used for both pumping and generating. It is designed to function as a motor and pump in one direction of rotation and as turbine and generator in opposite rotation. One of the disadvantages of PSP is efficiency, since the conversion of energy taking place twice and this is affecting the over efficiency of the plant. The loss of energy must be taken into account while operations of unit. Generally the overall efficiency of PSP ranges in between 65-75%. Therefore we can say that energy generated is of energy consumed while pumping water or storing energy in potential form. Apart from improving the characteristics of load curve and fulfilling the requirement of the power system, loss due to efficiency play equal and important role in scheduling the operations of PSP.

Although study and research has been done in this area, in the references paper [3] optimization done fore scheduling Hydrothermal system based on Lagrange relaxation technique where system wide constraints are relaxed by Lagrange multipliers, the problem is then converted into the scheduling of individual units. Minimising overall generation costs was aimed. In other case, PSP operating in interconnected power system [4] a mathematical model is developed to determine the power flows between the different power system and the PSP as well as the water flows inside the plant are considered.

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In the present study optimization of PSP operations is done by scheduling the PSHE units based on the frequency of power in gird. Under ABT based energy pricing system, UIcharges in ABT is a factor based on frequency. Therefore by maximizing the Gross revenue margins of plant we can select the optimal frequency range for running PSHE unit in concerned mode (Pumping/ Generation).In a studyby *Ikudo Akina*, optimization of hydro facility is done by integrating uncertainty in the market price of electricity as well as the uncertainty in the inflow rate [5].A study performed for identifying optimal operating strategies of a major pumped storage facility. A new probabilistic production costing algorithm, which included stochastic representation of generating units as well as transmission system, was used in this study. Use of minimum spread for developing operating rules is described [8].

II.FORMULATION OF PROBLEM

Gross revenue margins of plant are the difference of revenues gained by supplying the stored energy from generating electricity and the cost of energy used for pumping certain. It is important to consider that volume of water pumped is equal to that of volume used to generate power. Revenues/cost of generations/ pumping is determined by the product of price of energy per unit which dependent on frequency of grid, power generated/ consumed by PSHE unit while operating, time period for which cost of units is revised, the mode of unit (is expressed as binary variable).

$$\text{Gross Revenue margin} = \sum_i (G \times t \times C_i \times X_i) - \sum_j (G \times t \times C_j \times Y_j) \quad \text{.......(i)}$$

Subjected to,

A PSHE unit cannot run as generator and pump at same time,

$$X_i \times Y_j = 0 \text{ any point of time} \quad \text{........(ii)}$$

Time to operate PSHE unit as generator or pump depends on volume of water available in lower reservoir V_l and upper reservoir V_h respectively.

$$G \times t \times X_i \propto V_l$$

$$P \times t \times Y_j \propto V_h \text{......(iii)}$$

Volume of water used for pumping Vp is equal to volume of water used for generating V_g in a time interval

$$V_p = V_g$$

$$V_g = \left(\sum (t \times G \times X_i)\right) \times K$$

$$V_p = \left(\sum (t \times P \times Y_j)\right) \times K \quad \text{......(iv)}$$

G	MW rating of PSHE unit while Generating
P	MW rating of PSHE unit while Pumping
t	time interval between revised cost of unit energy
C_i	Cost of unit energy at i^{th} frequency
C_j	Cost of unit energy at j^{th} frequency
X_i	Binary variable for PSHE as generator
Y_j	Binary variable for PSHE as Pump

j → is j^{th} frequency for Generation &

i → is i^{th} frequency for pumping

say, j= 1 at frequency= 48.5Hz

j=2 at frequency= 48.6Hz

III.OPTIMIZATION METHODOLOGY

Genetic Algorithm (GA) is directed search algorithm based on the mechanics of biological evolution. This provides efficient, effective technique of optimization. Step-by-step approach of GA and its relations with present problem/ objective function is as follows,

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1) Starting with a set of randomly chosen solutions from the search space (i.e. Chromosomes) this is also called as population. Xi and Yj are the chromosomes, as we need to search best combinations of these binary values with maximum revenue margins.
2) This Population is used to produce a next generation of individuals of reproduction.
3) Individuals with a higher fitness have more chance to reproduce. Evaluation stops when fitness remains unchanged for specified number of generations. Highest fitness represents the optimal condition.

In an article from University of Exter U.K. it is been described about application of Genetic algorithm for scheduling the pump of water supply.The main objective is to minimise the overall cost of the pumping operation, taking advantage of storage capacity in the system and the availability of off-peak electricity tariffs [6].

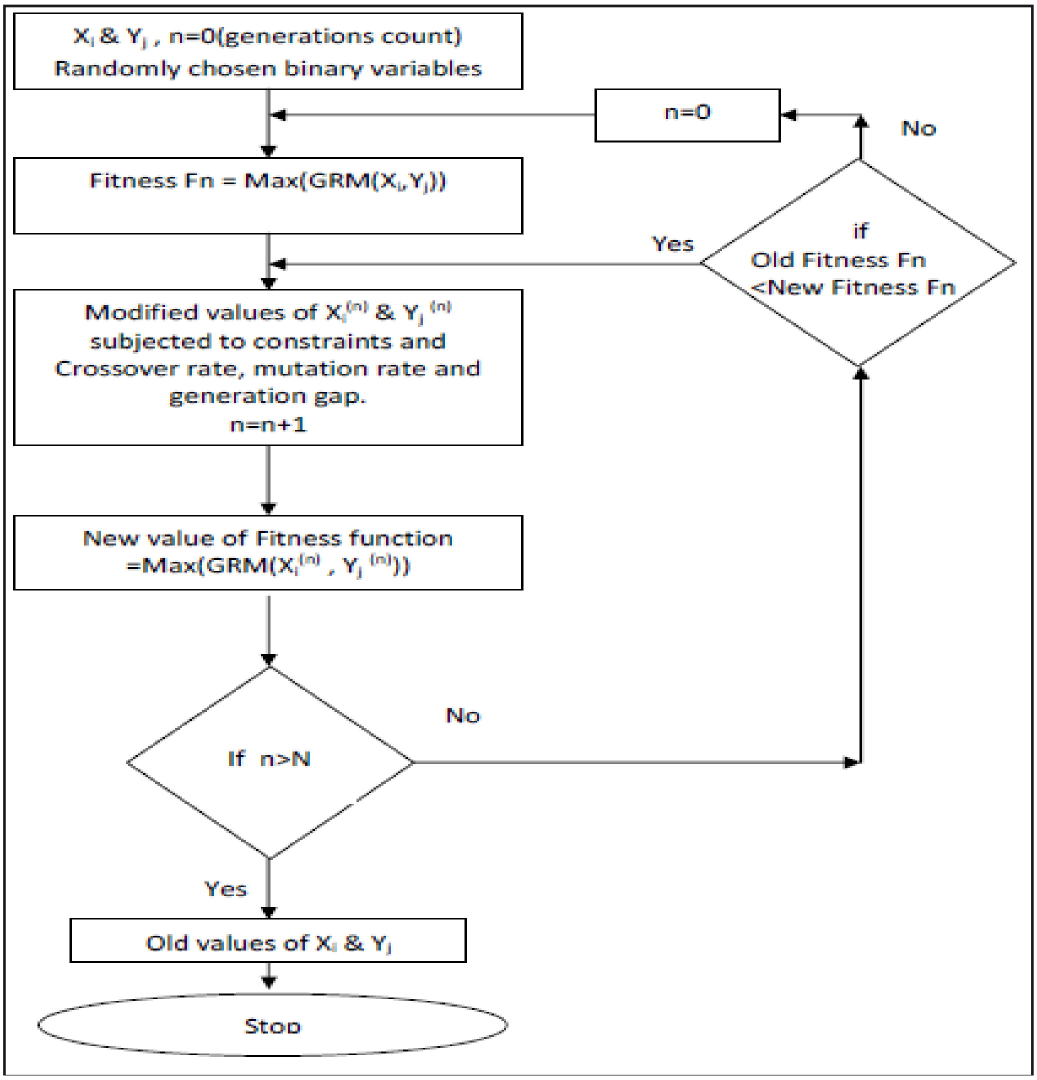

Fig. 1 Computation layout of Genetic algorithm

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IV.SIMULATIONS IN GENEHUNTER

GeneHunter is a powerful software for optimization problem which utilizes a state-of-the-art genetic algorithm methodology.Creating a problem solving model in GeneHunter requires that the entry of the relevant data into a Microsoft Excel spread sheet and specify problem solving parameters.
Data related to the operations of PSP of are gathered from APGENCO Hyderabad for one week operations of Srisailam PSP (16/11/2008-22/11/2008). Data includes

1) Timing of operation Hydro Electric units in pump mode and generation mode of Left Bank power house and generator operation at Right Bank power house.
2) One week of Frequency analysis to calculate the cost of unit at particular time.
3) Their criteria for operating units as Pump and generator, where selection of frequency range is done based on the frequency duration curve and volume of water available in the reservoir.
4) Pricing of unit energy ABT (Available base tariff), is tariff structured for bulk power and is for more responsibility and accountability in power generation and consumption. ABT is the splitting energy charge structure into three components capacity charges (fixed), energy charges (variable) and UI (unscheduled interchange) charges.

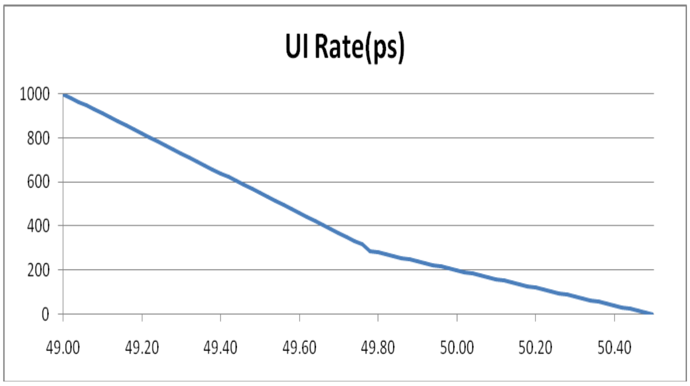

Fig. 2 Price of Unit Energy Vs Frequency

All the data collected are tabulated in an Excel sheet with input data as time, frequency values respective to, cost of energy unit as function of frequency, Rating of PSHE unit while pumping and generating, Volume of water shifted due to operations, Cost/Revenues at that period of time and all these columns are related with concerned formulas and constraints. Two columns are left as a space for binary variable X and Y which determine the mode of operation of PSHE unit. Fitness function comes to be the difference of summation of revenues while unit is generating and summation of costs while pumping.

Table.1 Setting of Gene Hunter Add in

Population size	300
Chromosome length	16 bit
Cross over rate	98%
Mutation rate	0.1
Generation gap	0.98
Stop evolution when- Best fitness unchanged	75 (Generations)

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V. RESULT AND DISCUSSION

Gross revenue margin for one week of operation of Srisailam PSPis Rs. 3, 23, 70, 633. Total gross revenue margin per MU energy used for pumping is Rs. per MU 12, 81,497. Nearly 25.26 MU of energy was spent on pumping water with 6 X 150 MW PHE connected to reversible turbine and generations have taken place in generating units 7X110 MW of Right bank power house of Srisailam dam utilizing the energy from the pumped water. Since the present simulated model gives optimal value of GRM by selecting the mode of PHE unit, it is considered as if only one unit is running. Therefore, comparison GRM is done per MU used for pumping. The following shows the details for GRM of simulated model,

Table.2 Daily Gross Revenue Margins

Date	Gross Revenue Margin per day	MU of energy used for pumping
16-11-2008	-7,75,350.00	2.19
17-11-2008	47,54,550.00	1.31
18-11-2008	45,59,100.00	0.86
19-11-2008	64,03,800.00	0.48
20-11-2008	20,71,500.00	1.05
21-11-2008	19,39,350.00	0.88
22-11-2008	34,51,950.00	0.74
Total of RGM	2,24,04,900.00	7.52
Total gross revenue(Rs.) per MU energy of pumping		29,77,791.07

Total of GRM is Rs. 2,24,04,900 and Total gross revenue margin per MU energy used for pumping is Rs. per MU 29,77,791.

GeneHunter implements Genetic Algorithm on the model in Excel sheet to assign the values of the Binary variables $X_i$and Y_j, it is observed that the frequency range for which generation and pumping modes are activated in the binary variables can be allotted as frequency range for operation of Hydro-Electric unit for generation and pumping modes. The frequency ranges for each day of PSP operated calculated from the GA model is shown as follows,

Table.3 Range of frequencies

Date	Frequency suggested for Pumping is above:	Frequency suggested for generation is below :
16-11-2008	49.754Hz	49.139Hz
17-11-2008	49.606Hz	49.00Hz
18-11-2008	49.41Hz	49.025Hz
19-11-2008	49.512Hz	49.062Hz
20-11-2008	49.46Hz	49.1Hz
21-11-2008	49.471Hz	49.08Hz
22-11-2008	49.334Hz	49.12Hz

A basic idea is given for the application of the results which are obtained by solving the optimization problem. The frequency limits can be used in framing function of frequency in the fuzzy controller. Adding more factors like volume a controller is design with basic working principle of operation of PSP. The designing this controller is mainly focused to show the type for response obtained when the frequency limitation with proposed range is given of scheduling of PSP.

Surface view in the MATLAB fuzzy tool box gives us the clear view of output in 3-dimensional view. The yellow region represents the generation mode, light blue represents idle mode and dark blue region represents pumping.

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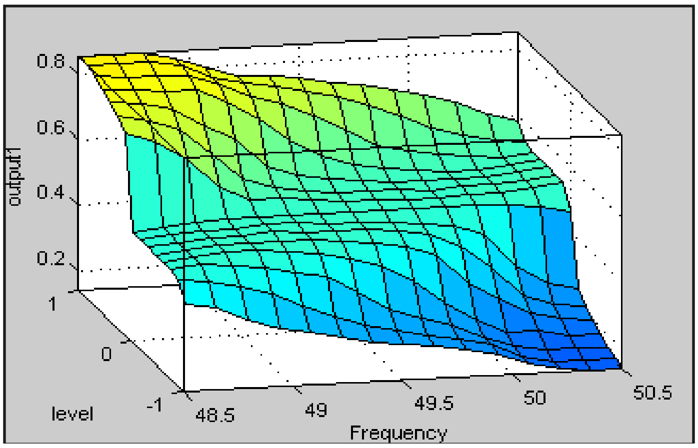

Fig.3Surface view of output result from the fuzzy controller

VI.CONCLUSION

The price of unit energy under ABT is proportional to the demand in the power grid. Optimizing the revenues of a PSP indirectly says the operation of plant is done when there is considerable demand in the grid is met. Optimization is achieved by proposing frequency limits for the operation of PSP and moreover a methodology is described for calculation of frequency limits. Results show that this methodology can improve the performance of the PSP operation better by 2.5 times.

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