Short Term Hydro Thermal Scheduling using Lambda Gamma Iteration Method


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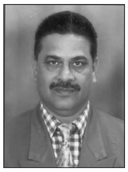
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Abstract: Short term hydrothermal scheduling (STHTS) is a daily planning proposition in power system operation. The main purpose of hydro thermal generation scheduling is to minimize the overall operation cost and to satisfy the given constraints by optimally scheduling the power outputs of all hydro and thermal units under study periods, given electrical load and limited water resource. This paper presents the lambda-gamma iteration method for fixed head hydro-thermal problems. Also, hydro power input-output model with constant head has been developed for Sewa Hydro Electric Power Plant by using the curve fitting techniques by least square method in MATLAB 7.9 version software. From scheduling results, operational decisions can be made for the best performance under changing conditions of load, head, unit availability and other important constraints. Furthermore, these decisions may be used as an effective input to the on-line decision support system for real-time operation of reservoir systems in availability based tariff (ABT) context that results in increased power production and enhanced revenue earnings in the process of planning and management of a water resources project.

Key words: Hydro-thermal scheduling, lambda-gamma iteration method, hydro power input-output model, availability based tariff, Jammu and Kashmir, India

Introduction

This paper presents short term hydrothermal scheduling (STHTS), which can be used for online implementation of Availability Based Tariff (ABT) in which day ahead scheduling is done for 24 hours on 15 minute time intervals (Bhushan, Roy and Pentayya 2004; Geetha and Jayashankar 2008; Deshmukh, Doke and Nerkar 2008). No state or country is endowed with sufficient water sources or abundant coal and nuclear fuel. For minimum environmental pollution and cost considerations, thermal generation should be minimal. Hence, a mix of hydro and thermal power generation is necessary. States with large hydro potential can supply excess hydropower during periods of high water run-off to other states and can receive thermal power during periods of low water run-off from other states. Those states that have a low hydro-potential and large coal reserves can use small hydropower for meeting peak load requirements. This makes the thermal stations to operate at high load factors and to have reduced installed capacity, which results in economy.

In states that have adequate hydropower as well as thermal power generation capacities, power co-ordination to obtain a most economical operating state is essential. Maximum advantage should be taken of cheap hydropower so that coal reserves can be conserved and environmental pollution minimized. The whole or a part of the base load can be supplied by the run-off river hydro plants, and the peak or remaining load is then met by a proper mix of reservoir type hydro and thermal plants. Determination of this by a proper mix is the determination of the most economical operating state of a hydro-thermal system. The hydro plants can be started easily and can be assigned a load in a very short time.

In the case of thermal plants, however, it requires several hours to make the boilers, superheater, and turbine system ready to take the load. For this reason, the hydro plants can handle fast-changing loads effectively. By contrast, thermal plants are slow to respond (Sivanagaraju and Sreenivasan 2009). Hence, due to this, thermal plants are more suitable to operate at base load plants, leaving hydro plants to operate at peak load plants. The operating cost of thermal plants is very high and at the same time its capital cost is low when compared with a hydroelectric plant. The operating cost of a hydroelectric plant is low and its capital cost is high such that it has become economical as well as convenient to run both thermal as well as hydro plants in the same grid.

Short term hydro-thermal co-ordination is concerned with distributing generation among the available units over a day or week, usually on an hourly basis, satisfying the operational constraints, as well as reservoir release targets determined by mid/long-range planning models. In short range scheduling problems, fixed water head is assumed frequently and the net head variation can be ignored for relatively large reservoirs, in which case the power generation is solely dependent on the water discharge (Sivanagaraju and Sreenivasan 2009; Wood and Wollenberg 1984).

Various methods for solving the short term hydrothermal scheduling problems have been reported in the literature, like mixed integer linear programming (Catalao, Pousinho and Mendes 2010; Chang, Aganagic et al 2001), dynamic programming (Shi-Chung, Chen et al 1990), quadratic programming (Oliveira, Soares and Nepomuceno 2005; Anibal, Aurelio and Soares 2008), Lagrange relaxation method (Ngundam, Kenfack and Tatietse 2000; Vo Ngoc Dieu and Ongsakul 2008; Farid and Bendaoud 2010; Nowak and Werner 2000; AI-Agtash and Renjeng 1998; Liang, Ke and Chen 2009), network flow method (Aurelio, Secundino and Leonardo 2005), and others. In addition, a range of other heuristic optimisation techniques such as genetic algorithms, artificial neural networks, simulated annealing, particle swarm optimisation, ant colony optimization, neural-fuzzy approaches, evolutionary programming and various other hybrid techniques are also available for hydro thermal scheduling.

In this paper lambda gamma iteration method for fixed head hydro thermal problem has been employed and tested on a system of one hydro and thermal system. Also, a model for hydro system is developed from the experimental data set taken from Sewa Hydro Electric Plant site of India's Jammu and Kashmir region.

Hydro Power Input-Output Modelling

India's National Hydroelectric Power Corporation (NHPC) has developed various hydroelectric projects in Himachal Pradesh. One of them is Sewa Hydro Electric Project Stage-II (120MW), which is a run-of-river project located in Kathua district of Jammu and Kashmir region. In this section the hydro power input-output model for Sewa Hydro Electric Power Plant is presented.

Electric power is a very important infrastructure in the overall development of a nation. It is a tool to forge economic growth of a country. The utilization of hydro-resources effectively plays an eminent role in the planning and operation of a power system where the hydro power generation plants contribute a significant part of the total installed capacity. There has been, therefore, an ever increasing need for more and more power generation recently in all the countries of the world. Running costs of the hydropower installation are very low as compared to thermal stations or nuclear power stations and hydraulic turbines can be put off and on in matter of minutes.

Modelling of the hydro electric plant is a very complex task and as such there is no uniform overall modelling as each one is unique to its location and requirement. The diversity of these designs makes it necessary to model each one individually. The parameters of modelling are nonlinear and highly dependent on the control variables. Here hydro electric generation is modelled at the plant level by aggregating the hydro units. The generated hydro power (P_H) depends on the specific weight of the water (Ψ), on the flow rate (q) passing through the turbine in m^3/s, on the net head (h), on the turbine in meters (m), and on the efficiency of the plant, considering head loss in the pipeline and the efficiency of the turbine and generator. Power generated by the power plant is presented in the following equation (1), where the numerical factor makes the appropriate unit conversions from (m) and (m^3/s) to MW, taking into consideration both the water density and the acceleration due to gravity (Margeta and Darrell 1989; Masters 2004; Diniz, Esteves and Sagastizabal 2007):

where, $$P_H = \frac{\eta\psi qh}{1000} \quad (1)$$

P_H= Available hydro power (MW)
η= Combined efficiency of turbine and generator set
Ψ = Specific weight of water (N/m^3), and is the product of density of water (kg/m^3) and acceleration due to gravity (m/s^2)
q = Water flow through the turbine (Discharge) in m^3/sec
h= Net head of water in meters (the difference in water level between upstream and downstream of the turbine)

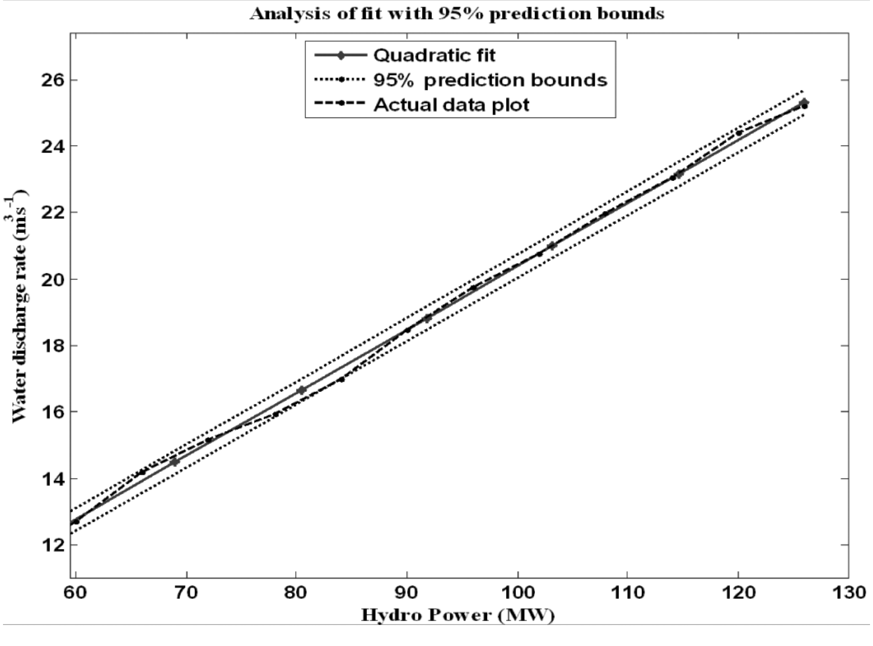


Figure 1. Plot for Actual and Predicted Results for Water Discharge Rate versus Power with Constant Head

To model the input-output curve of the hydro power unit with constant head, experimental data have been obtained from the site of Sewa Hydro Electric Plant of Jammu and Kashmir region. The input is in terms of water discharge rate (m^3s^{-1}) whereas output is in terms of hydro power (MW).

The relationship between water discharge rate and hydro power has been formed by using the curve fitting techniques based on least square method (Belsley, Kuh and Welsch 1980; Cook and Weisberg 1982; Draper and Smith 1998). The second order quadratic equation is very well satisfying the relation of generated power and water discharge rate as per data available from the site, as shown in equation (2). The thick dotted line, shown in Figure 1, represents the actual relationship between the water discharge rate and hydro power. Also, quadratic fit obtained from the experimental data is within the 95% confidence interval.

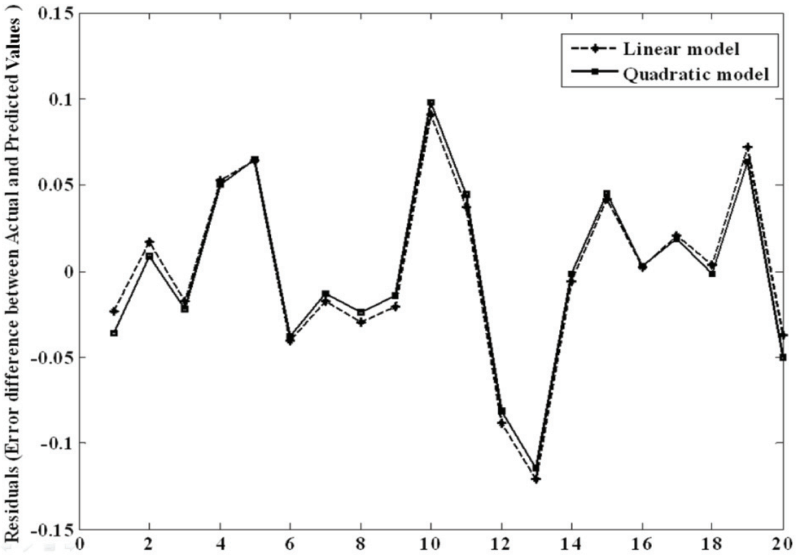
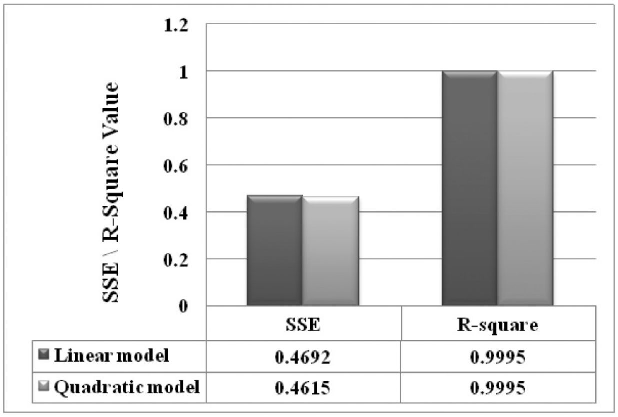


Figure 2. Residual Plot for Linear and Quadratic Regression Models for Water Discharge Rate versus Power (MW) with Constant Head

In Figure 2, residual analyses of different regression models for hydro power versus water discharge rate model with constant head have been plotted and the graphical analysis shows that quadratic model gives less number of residuals. Figure 3, shows plot for R-square value, sum of square due to errors (SSE). For SSE a value closer to zero indicates that the model has small random error component and that the corresponding fit will be useful for prediction. R-square values provide how well the models are close to actual values. In other words, they provide a measure of how well future outcomes are likely to be predicted by the model. Hence it is desired that R-square values to be very high; i.e., close to 1. As per the model, 99% of variation in the dependent variable has been explained by the independent variable. From the graphical results the value of SSE is 0.4615 which was lowest in case of quadratic model and is within acceptable limits. The input-output model, which represents the ideal relationship between generated hydro power (P_H) and water discharge rat for Sewa Hydro Electric Project Stage-II, is:

$$q(P_H) = 0.065844P_H^2 + 675.36\ P_H + 5122.8\ m^3 / hr \qquad (2)$$



	SSE	R-square
■ Linear model	0.4692	0.9995
■ Quadratic model	0.4615	0.9995

Figure 3. Plot for SSE and R-Square Value

Problem Formulation

The main objective of hydro thermal scheduling problem is to determine the optimal schedule of both hydro and thermal plants of a power system in order to minimize the total cost of thermal generation. This overall schedule must meet the given load demand and operational constraints imposed on hydro and thermal plant.

Thermal Model

The objective function is to minimize the total operating cost ($C_{Thermal}$) represented by the fuel cost of thermal generation over the optimization interval (k).

$$C_{Thermal} = \mathrm{Min}\sum_{k=1}^{N_T} t_k C(P_{Tk}); \quad N_T = 96 \qquad (3)$$

where, t_k is number of hours in k^{th} time block.

Here, the problem is to schedule the power generation of hydro-thermal units for k sub interval in order to minimize the fuel cost which is given as:

$$C(P_{Tk}) = \alpha P_{Tk}^2 + \beta P_{Tk} + \theta \quad Rs/hr \qquad (4)$$

where, α, β and θ are cost coefficients of thermal plant.

Hydro Model

In hydro system, there is no fuel cost incurred in the operation of hydro units. According to Kothari and Dhillon (2006), discharge is a function of power output and the head. For large capacity reservoir it is practical to assume that the effective head is constant over the optimization interval. Thus $q(P_H)$ is the rate of discharge of Sewa Hydro Electric Power Plant is represented by the quadratic equation:

$$q(P_H) = aP_H^2 + bP_H + c \quad m^3/hr \qquad (5)$$

where, a, b and c are water discharge rate coefficients of hydro plant.

Water Availability Constraint

The total water discharge is

$$q_{total} = \sum_{k=1}^{N_T} t_k q_k ; \quad k = 1,2,3,\ldots,96 \tag{6}$$

In the current study, constant head operation is assumed and the water discharge rate, q_k is assumed to be a function of the hydro generation, P_{Hk} as in

$q_k = q_k\,(P_{Hk})$

where, $t_k$is number of hours in kth time block and q_k is the water discharge rate for kth time block.

Power Balance Equation

Total generated power is equal to the total demand P_{DK} including losses P_{Lk} in each time interval. Mathematically:

$$P_{Tk} + P_{Hk} = P_{Dk} + P_{Lk} ; \quad k = 1,2,\ldots.,96 \tag{7}$$

where, P_{Dk} is the load demand for kth sub-interval and P_{Lk} are the transmission losses for kth sub-interval. P^{Tk} and P_{Hk} are thermal and hydro power generation for kth sub-interval.

The transmission loss is function of P_{Hk} and P_{Tk}.

Thermal and Hydro Power Limits

Thermal and hydro units can generate power between specified upper and lower limits:

$$P_T^{min} \le P_{Tk} \le P_T^{max} ; \quad k = 1,2,\ldots,96 \tag{8}$$

$$P_H^{min} \le P_{Hk} \le P_H^{max} ; \quad k = 1,2,\ldots,96 \tag{9}$$

where, P_{TK} and P_{Hk} are Power output of the thermal and hydro generating units in MW for kthsub-interval and $P_T^{min}, P_H^{min}, P_T^{max}$ and P_H^{max} represents minimum and maximum power limits of thermal and hydro plant respectively.

Solution Technique

The augmented Lagrangian function (Wood and Wollenberg 1984) for the hydrothermal scheduling problem can be written as:

$$£ = \sum_{k=1}^{N_T} \left[t_k C(P_{Tk}) - \lambda_k \left(P_{Tk} + P_{Hk} - P_{Dk} - P_{Lk}\right)\right] + \gamma \left[\sum_{k=1}^{N_T} t_k q_k (P_{Hk}) - q_{total} \right] \tag{10}$$

Where,

£ =Lagrange function of hydro-thermal problem

γ Fictitious cost of water for hydro plant

λ_k = Incremental cost of received power for kth interval

The co-ordination equation from the above function can be obtained as

$$t_k \cdot \frac{dC(P_{Tk})}{dP_{Tk}} + \lambda_k \frac{dP_{Lk}}{dP_{Tk}} = \lambda_k \tag{11}$$

$$\gamma . t_k \cdot \frac{dq(P_{Hk})}{dP_{Hk}} + \lambda_k \frac{dP_{Lk}}{dP_{Hk}} = \lambda_k \tag{12}$$

Thus using the above equations and given load demand profile, thermal power, hydro power, rate of water discharge in each interval the optimum cost can be calculated.

Algorithm

1. Read the cost coefficients α, β, θ of thermal unit, discharge coefficients a, b, c of hydro unit, demand P_{Dk} for all intervals, loss coefficients, pre-specified available water (volume), maximum and minimum generation limits for both thermal and hydro units.

2. Calculate the initial guess values of P_{Tk} and P_{Hk} by equally dividing the load between the thermal and hydro units for all intervals

3. Calculate guess value of λ_k and γ for k=1 by using the equations given below:

$$\lambda_k = 2\alpha P_{Tk} + \beta \tag{13}$$

$$\gamma = \frac{\lambda_k}{2aP_{Hk} + b} \tag{14}$$

4. Solve the coordination equations

$$t_k \cdot \frac{dC(P_{Tk})}{dP_{Tk}} + \lambda_k \frac{dP_{Lk}}{dP_{Tk}} = \lambda_k \tag{15}$$

$$\gamma . t_k \cdot \frac{dq(P_{Hk})}{dP_{Hk}} + \lambda_k \frac{dP_{Lk}}{dP_{Hk}} = \lambda_k \tag{16}$$

5. Start the iteration counter 1.

6. From the computed values of P_{Tk}, P_{Hk}, γ calculate λ_κ. Then using λ_κ in equations calculate updated values of

P_{Tk} and P_{Hk}. Calculate P_{Lk} using P_{Tk} and P_{Hk}.

7. Calculate power mismatch $\Delta P = P_{Tk} + P_{Hk} - P_{Lk} - P_{Dk}$ then check convergence criteria. If convergence criteria ($\Delta P < 0.01$) is not met then recalculate λ_κ with updated values of P_{Tk} and P_{Hk}.

8. Repeat steps 7 and 8 till convergence criteria is met. Check generator limits such that ΔP =0.

$$P_T^{min} \le P_{Tk} \le P_T^{max} ; \quad k = 1,2,\ldots,96 \tag{17}$$

and $$P_H^{min} \le P_{Hk} \le P_H^{max} ; \quad k = 1,2,\ldots,96 \tag{18}$$

9. After getting P_T, P_H, q and cost of thermal generation for all intervals calculate total volume utilized.

$$\mathbf{\Delta} q = \text{volume} - \sum_{k=1}^{N_T} t_k q_k \tag{19}$$

10. Check for convergence.

11. If convergence criteria ($\Delta P<0.01$) is not achieved update gamma and go to step 6 and increase the iteration counter and repeat. Gamma calculation is done as:

$$\gamma = \gamma((0.000955*(\Delta q / \text{volume}))) \tag{20}$$

12. Print the output schedule, utilized volume of water and cost.

Test System

Normally, short term hydro thermal scheduling is concerned with one day to a week periods of operation with intervals of various lengths (Sivanagaraju and Sreenivasan 2009; Wood and Wollenberg 1984; Kothari and Dhillon 2006). This paper focuses on short term hydro thermal scheduling (STHTS), which can be used for online implementation of ABT in which day ahead scheduling is done for 24 hours on 15 minute time intervals (Bhushan, Roy and Pentayya 2004; Geetha and Jayashankar 2008; Deshmukh, Doke and Nerkar 2008). Total load demand over a 24 hour period for 96 time intervals is shown in Figure 5. The test system is comprised of a Sewa Hydro Power Plant and an equivalent thermal plant that has been adopted from Wood and Wollenberg (1984). The proposed lambda gamma iteration method is applied to hydro-thermal equivalent plant. The algorithm was implemented in MATLAB 7.9 and executed on a PC (Pentium-IV, 512MB, 3.0GHz). The polynomial cost coefficients of the hydro electric system were estimated from experimental data of Sewa Hydro Electric Plant site by a curve fitting technique. The equivalent hydro system obtained with $R^2 = 0.9995$ and SSE=0.4615 is presented in figure 3. The equivalent hydro system obtained is $q(P_H) = 0.065844P_H^2 + 675.36 P_H + 5122.8$ m³/ hr. The lower and upper limits of hydro units for Sewa Hydro Electric Power Plant are 12MW and 126MW, respectively. The equivalent thermal plant with the following characteristics is taken from Wood and Wollenberg (1984):

$F(P_T) = 0.00184P_T^2 + 9.2P_T + 575$ Rs/hr.

The lower and upper limits for the steam units are 20MW and 400MW, respectively. The system electrical losses are associated with the hydro plant and steam plants are expressed as follows:

$P_L = 0.00008P_H^2 + 0.00008P_T^2$

The water reservoir of the hydro plant is limited to a drawdown of 1,555,200m³ over the scheduling period. The results of optimal power generation schedule and interval wise reservoir hydro discharge obtained are shown in Figures 4 and 5, respectively.

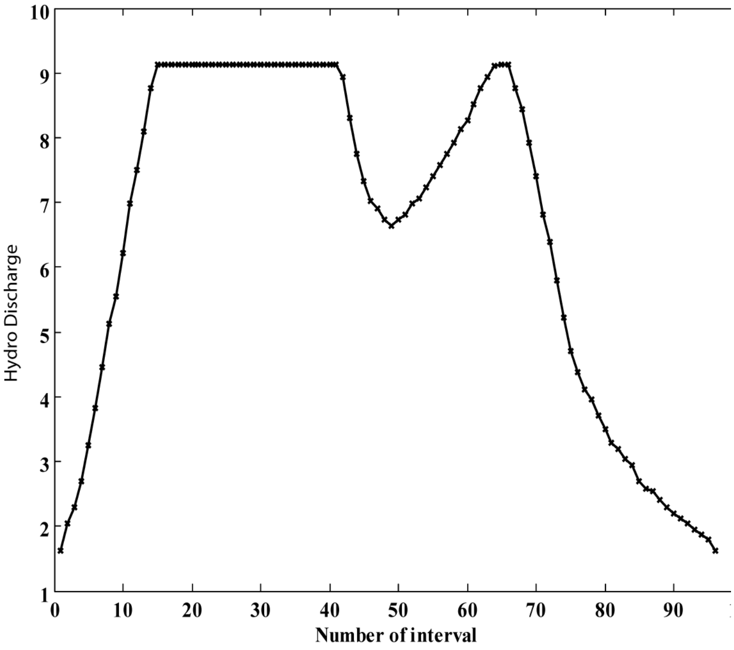


Figure 5. Hydro Plant Discharges (10^4m³/hr)

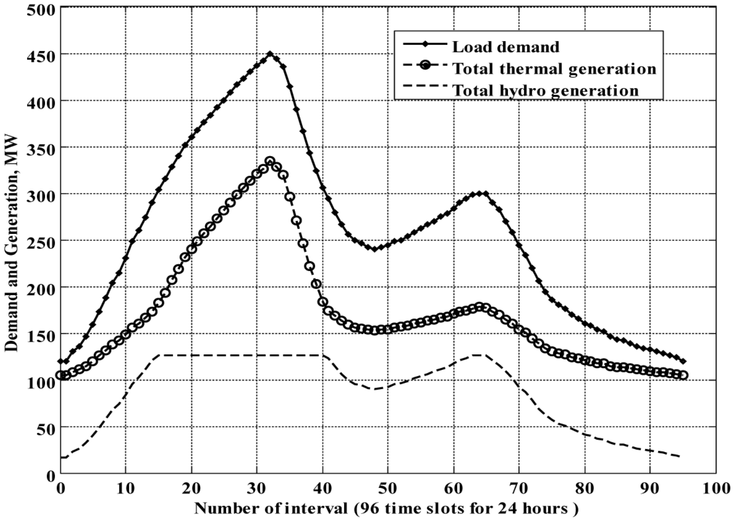


Figure 4. Hourly Hydro and Thermal Generation Scheduling for a Day

As seen in Figure 4, during peak load demand the hydro system works to its full capacity with its maximum limits. In this way, hydro generation replaces the most expensive thermal generation. As per the results obtained with the help of the algorithm explained we get the thermal cost as 215,490 rupees (Rs). The final value of lambda obtained is 9.7475 Rs/MWh, and gamma obtained is $0.0143 m^3 s^{-1}$. The number of iterations for updating gamma comes out to be 28. The mismatch between water used and available water is $0.0047\ m^3\ s^{-1}$.

Conclusion

In this paper short term hydro-thermal scheduling using a lambda-gamma iteration method for fixed head hydro thermal problem under important operating constraints is presented and tested on a test system of hydro and equivalent thermal plant. The model for the hydro system is developed from the experimental data set taken from the Sewa Hydro Electric Power Plant. From the analysis, it is observed that the best model obtained for the water discharge rate versus power (MW) is the quadratic fit model. This developed model and optimal short term hydro thermal scheduling can be used in the future for estimating and predicting the best values of the generated hydro power for online implementation of ABT or for long term hydro power planning.

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In 1999, a group of Non-Resident Nepalese (NRN's) came together with a vision to promote Nepalese hydropower sector with private investments. They began by establishing Sanima Hydropower (P) Ltd. This company then designed and built the 2.5 MW Sunkoshi Small Hydropower Project in 2005. The Sunkoshi Hydropower Plant's implementation brought about the realization for the need of an engineering wing within Sanima Hydropower P. Ltd. Our board concluded that such an engineering wing would go a long way if "Sanima Group" is to continue developing more hydropower projects. Furthermore, this would also retain experienced human resources involved in the Sunkoshi Project. Thus, Sanima Hydro & Engineering P. Ltd (SHE) was registered in 2005. Since its establishment, it has been providing technical services (Feasibility Study, Engineering Design & Construction Supervision) in the hydropower sector for in-house projects, Nepalese Independent Power Producers and as well as for International clients .

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