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A Novel Analysis of Hydrothermal Scheduling Using Genetic Algorithm with Emission Cost

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Abstract: Hydro thermal power plants are one of the most important energy sources in the world which are used most in areas called Niagara Falls in Canada. These power plants attempts to generate the energy from the water by using the equipment called turbines which would be placed in the water source to utilize their potential energy which would then be converted into electricity. Hydro thermal scheduling plays a key role in identifying and fixing the required equipment's to be activated for the production of energy with less cost. This paper presents a novel analysis on differential evolution for short-term hydrothermal scheduling combined economic emission. The optimization technique called genetic algorithm is used for evolution of hydro thermal scheduling the problem which is formulated with economic emission and without economic emission. The genetic algorithm follows biological behavior of chromosomes which would attempt to find the optimized set of resources that requires to be activated for achieving optimal hydroelectric power plant setup. Hence, the proposed method can well be extended for solving the large-scale hydrothermal scheduling. The experimental tests were conducted on the hydro thermal power with varying set of equipment's to be turned, which it is proved that the proposed multi-objective genetic algorithm can provide better and efficient result than the other approaches which has been conducted before.

Key words: Hydrothermal power systems, economic load scheduling, combined economic emission scheduling and differential evolution

INTRODUCTION

Hydrothermal scheduling: The generation of electricity from fossil fuel releases several contaminants, such as sulphur dioxide (SO_2), Nitrogen Oxides (NOx) and carbon dioxide (CO_2) into atmosphere. Atmospheric pollution affects not only humans but also other life-forms such as animals, birds, fish and plants. It also causes damage to materials, reducing visibility as well as causing global warming. Due to increasing concern over the environmental considerations, society demands adequate and secure electricity not only at the cheapest possible price, but also at minimum level of pollution. In particular, since the passage of the Clean Air Act Amendments of 1990, emission control has become one of the important operational objectives.Various methods have been proposed by many researchers to deal with economic emission load dispatch problem of thermal plants with various degrees of success. Some of these methods are goal programming (Nanda *et al*., 1988).

Hydrothermal scheduling is a daily planning task in power system operation and it is the subject of intensive investigation for several decades. Most of the methods that have been used to solve the hydrothermal co-ordination problem make a number of simplifying assumptions in order to make the optimization problem more tractable.Hydrothermal systems are operated by economical scheduling to produce minimum cost for thermal generation, subject to hydraulic and thermal constraints and the demand for electrical energy (Mandal and Chakraborty, 2012).

Hydraulic and thermal constraints may include operational limits on hydro and thermal generation reservoir storage, water discharge and spillage. Hydro-thermal scheduling is concerned with commitment and dispatching of generating units. Short-term hydrothermal scheduling of power systems aims at determining optimal hydro and thermal generations in order to meet the load demands over a scheduled horizon of one day or a week while satisfying the various constraints on the hydraulic and power system network. The goal is to minimize total operation costs of thermal plants. The problem is a complex mathematical optimization problem with a highly nonlinear and computational expensive environment. Hydrothermal scheduling is a complex mathematical optimization

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problem with a highly nonlinear and computational expensive environment. This study proposes an interactive Genetic Algorithm satisfying method based on evolutionary programming technique for short-term optimal scheduling of generation in a hydrothermal system which involves the allocation of generation among the multi-reservoir cascaded hydro plants and thermal plants with non smooth fuel cost and emission level functions so as to minimize the fuel cost and emission level of thermal plants simultaneously while satisfying the various constraints on the hydraulic and power system network.

The main constraints include: the time coupling effect of the hydro sub problem where the water flow in an earlier time interval affects the discharge capability at a later period of time, the varying system load demand, the cascade nature of the hydraulic network, the varying hourly reservoir inflows, the physical limitations on the reservoir storage and turbine flow rate and the loading limits of both thermal and hydro plants. Here the objective functions, (i.e., cost and emission) are modelled with Genetic algorithm sets.

Literature review: Hydro thermal scheduling is one of the earliest known problem in which there has been many researchers conducted to achieve the better solution of production of electricity. The Hydro downside was solved at the first stage to outline the hydro production pattern. The second stage was the thermal production dispatch supportedthe choice of the primary stage. Since, the Hydro downsideand therefore the Thermal downside were solved severally, this 2 stage approach introduced incoherency between the two sub problems. Therefore, the answerwasn'tbest. What is more, the second stage won't have a possibleanswer even though thedownsideis possible. This maysignificantly happen in systems with high share of hydraulic production.As associate degree improvement, the Short-Term Hydro-Thermal Dispatch (STHTD) drawback was resolved by using simplified models each within the hydro scheme and also the thermal scheme (which contains the transmission network) (Dahlin and Shin, 1966; Dandeno, 1960; Drake *et al*., 1962; Brannlund *et al*., 1986; Habibollahzadeh and Bubenko, 1986; Ea and Monti, 1986). These embody ways of neglecting within the hydro scheme has one or a lot of the subsequent effects: couplings of cascaded reservoirs, reservoir head variations and water time delays and on the thermal scheme aspect of exploitation lossless line models or a loss formula model rather than associate degree best Power Flow (OPF). Though the results are unit helpful below specific circumstances. These ways have the common disadvantage that their solutions don't seem to be sure to be possible. This can be thus as a result of some constraints related to a lot of careful models haven't been taken into consideration.

To assure that the ultimateresolutionis possible, elaborated models should be used eachwithin the hydro and therefore the thermal subsystems to formulate the S "D Besides", economicalresolutionstrategiesshould be sought-afteras a result of the high dimension of the STHTD with such elaborated models. One among the triple-crown techniques is to decompose thedrawback into 2 sub-problems: a hydro sub problem and a thermal sub problem, as in references (Duncan *et al*., 1985; Bonaert *et al*., 1972). Since these 2 sub problems aresolved iteratively, the answer technique of every sub problem may be improved individually.

Recently, Network Flow Programming has been accustomedto solve the elaborated hydro sub problem. It'sthe foremost powerful approach compared with alternativeways for determination of hydro dispatch issues. The answer of the thermal sub problem as well as OPF has been given in references. These results represent the analysiswithin thespace. However, additional improvement ought to be sought-afterto beatthe subsequent drawbacks encountered:

- Sophisticated procedure in constructing a hydro tube
- Lack of capability to handle conductor
- Tedious method of breaking the hydro sub problem into a goodvarietyof 1 dimensional improvement problems

The research of this study makes an attemptto granta whole formulation and economical answer of the short Hydro-Thermal Dispatch downside. The formulation of the matter includes the top variations, the impact of cascaded multi chained reservoirs and therefore the time delays of water flow within the hydro system and additionally the consequences obligatory by the load Bow equations and therefore the security constraints. The answer methodology includes most of the benefits of the presentaddthe world and avoids its shortcomings. The matter examined here is predicated on the belief that the unit commitment has been resolved individually, so the up down schedule of the thermal generators is predefined before the matter is being resolved. Supported the on top ofconcerns, a decomposition scheme is adopted. Not solely has it been with successutilized by others however, it can also be rationally derived by mathematical concerns.

Additionally, Network Flow Programming (Duncan *et al*., 1985; Drake *et al*., 1962) been enforced to assure the quick and correctanswer of the hydro sub problem. To hurry up the method, the thermal sub problem is resolved by a mixture of Equations of Coordination (EOC) and OPF. Rather than constructing a hydro tube as in Habibollahzadeh and Bubenko (1986) and performing arts a tedious search as in (Habibollahzadeh and Bubenko, 1986), a line search has between every two iterations is performed to boost the thermal generation objective.

Economic dispatch: The Economic dispatch problem is one of the most important optimization issues in power systems and it is closely related to the UC problem. Finding a bad solution for ED problem might also affect negatively the generation schedule. The objective of the Economic Dispatch is to allocate the power demand among committed generators in the most economical manner while all physical constraints are satisfied. As long as the cost curve of each generator is convex, or what is the same, that it has a monotonically increasing incremental cost the Economic dispatch problem can be easily solved. Methods such as the lambda iteration algorithm, gradient method or the Newton-Raphson are widely employed in solving the Economic dispatch problem.

Nevertheless, these techniques rely on the convexity assumption of cost curves and cannot handle the constraints imposed by some generators. In addition, the presence of restrictions such as ramp rate limits, valve points and prohibited operation zones introduces discontinuities that add additional complexity to the Economic Dispatchproblem. Economic Dispatch will be solved by using the lambda iteration algorithm which is, so far the most popular method for solving the ED problem.

Short term hydrothermal scheduling problem: Short-range hydrothermal scheduling is to determine, optimally, which of the thermal generating units should run as well as the power generated by the hydro and thermal plants so that the total cost is minimized. Minimizing the total cost in this optimization problem is subject to many control and operational constraints. In addition to reliability and security requirements, hydraulic and thermal constraints may include load balance, generation limits, water discharge, starting and ending storage volume of water and spillage discharge rate. Further, in order to solve the hydrothermal coordination problem, thermal unit commitment and economic load dispatch problems should be solved all together with the hydro schedules. Therefore, the short term hydrothermal scheduling is a large-scale non-linear and complicated constrained power system optimization problem.

The following is an outline of the basic short-term hydrothermal scheduling problem. Fundamentally, the problem requires that a given amount of water be used in such a way as to minimize the cost of running the thermal units in the system to meet the load demands in a schedule horizon. The schedule horizon is divided in two number of intervals. The thermal system is represented by an equivalent generator unit. It is assumed that the load in each interval of the schedule horizon is to be supplied from a hydro plant and a thermal system. Mathematically, this minimization problem is set up with an objective function subject to various equality and inequality constraints that are given below.

Parameters:

- j is the the interval in the schedule horizon_1,2,3,…jmax
- $f_j(PT_j)$ is the fuel cost of the equivalent thermal generator operating at generation level Pt_j during the j^{th} interval
- Pt_j is the power generation levelduring the jth interval
- Ph_j is the hydro generation in jth interval
- q_j is the water discharge rate in jth interval
- Pd_j is the total load demand in jth interval
- Pl_j is the total electric loss between the hydro plant and the load in jth interval
- F is the Fuel cost
- r_j is the water inflow rate into the storage reservoir in jth interval
- s_j is the spillage discharge rate in jth interval
- V_j is the volume of water stored in reservoir at the end of the jth interval
- n_j is the number of hours in the jth interval
- K is a constant
- Pt_{min} is the minimum operating limit of the equivalent thermal generator
- P_{max} is the maximum operating limit of the equivalent thermal generator
- Ph_{min} is the minimum operating limit of the hydro plant
- Ph_{max} is the maximum operating limit of the hydro plant
- V_{jmin} is the minimum water volume limit of the reservoir in the jth interval
- V_{jmax} is the maximum water volume limit of the reservoir in the jth interval

The total fuel cost for running the thermal system to meet the load demands in a schedule horizon is given by:

$$f_{total} = \sum_{j=1}^{jmax} n_j f_j \left(PT_j\right) \quad (1)$$

Constraints: Two types of constraints are there, they are equality constraints (power balance constraints) and inequality constraints (operation limits).

Equality constraints: The equality constraints are the power balance constraints, total water discharge constraint and the reservoir volume constraints. The power balance constraints are described as:

$$PD_j = PT_j + PH_j - PL_j for_j = ...,_j max \quad (2)$$

The electric loss between the hydro plant and the load PL_j is given by:

$$PL_j = k(PH)^2_j \quad (3)$$

The constant head operation is considered and the water discharge rate q_j, is assumed to be a function of hydro plant generation (PHj), as described as:

$$q_j = q(PH)_j \quad (4)$$

The total water discharge constraint is given by:

$$q_{total} = \sum_{j=1}^{z} n_j q_j \quad (5)$$

In the case of a storage reservoir with a given initial volume and a given final volume, the reservoir volume constraints are expressed as:

$$v_j = v_{j-1} + n_j\left(r_j - q\left(PH_j\right) - s_j\right) \quad (6)$$
$$for_j = 1,2...,max$$

Inequality constraints: The inequality constraints are the operation limits of the equivalent thermal generator and those of the hydro plant and the reservoir storage limits. These constraints are expressed for_j=1, 2...,$_j$max as below:

$$PT_{min} \le PT_j \le PT_{max} \quad (7)$$

$$PH_{min} \le PH_j \le PH_{max} \quad (8)$$

$$v_{jmin} \le v_j \le v_{jmax} \quad (9)$$

$$q_j^{min} \le q_j \le q_j^{max} \quad (10)$$

Continuity Equation for the hydro reservoir network:

$$v_j = v_{j-1} + I_j - q_j - S_j \quad (11)$$

Thermal system fuel cost equation:

$$F = a + \left(b * P_T\right) + \left(c * P_T^2\right) \quad (12)$$

Hydro plant power generation equation:

$$P_j = C_1 \times V_j^2 + C_2 \times q^2 + C_3 \times V_j \times q_j + C_4 \times V_j + C_5 \times q_j + C_6 \quad (13)$$

The load demand P_D for each interval and the min and max values of discharge of each reservoir and generation limits of each hydro and thermal unit are noted. The starting volume of each reservoir is also taken into account. A discharge (q_j) value for a reservoir for a particular interval is taken at random such that satisfying the min and max limits. By water continuity equation the volume of the reservoir for that interval is derived. The hydro generation (P_H) for the unit for that interval can be obtained from the hydro generation equation. Similarly the generation of each hydro unit for every interval can be obtained.

Thermal generation (P_S) is obtained from power balance equation. This generation limit will be the total thermal power generated for that interval. To find the generation of each thermal unit select a random value of generation for each unit such that it is satisfying the max and min limits and power balance equation as well. The thermal generation of each unit for each interval thus obtained is substituted in fuel cost function. The sum of fuel cost for all the thermal units for every interval gives the total operating cost.

Problem formulation: The hydrothermal scheduling problem is formulated as a multi objective mathematical programming problem which is concerned with the attempt to minimize simultaneously cost and emission of thermal plants. The following objectives and constraints of the hydrothermal scheduling problem are taken into account in the formulation of the Economic Emission Load Dispatch (EELD) problem. The equality and inequality constraints of the system must meanwhile be satisfied.

Objectives

Economy: The total fuel cost in terms of real power output can be expressed as:

$$f1 = M\_m = 1\_Nsi = 1\begin{bmatrix} asi + bsiPsim + csiP2sim + \\ |dsi \sin\{esi(Pminsi - Psim)\}| \end{bmatrix} \quad (14)$$

where asi, bsi, csi, dsi, esi are the cost curve coefficients of ith thermal unit, Psim the output power of ith thermal unit at time m, Pmin si and Pmax si, the lower and upper generation limits for ith thermal unit, Ns the number of thermal generating units, m and M the time index and scheduling period, fq the qth objective function.

Emission: In this study, nitrogen oxides (NOx) emission is taken as the selected index from the viewpoint of environment conservation. The amount of emission from each generator is given as a function of its output which is the sum of a quadratic and an exponential function. The total emission in the system can be expressed as:

$$f2 = M\_m = 1\_Nsi = 1\begin{bmatrix} \alpha si + \beta siPsim + \gamma siP2sim \\ +\eta si \exp(\delta siPsim) \end{bmatrix} \quad (15)$$

where, αsi, βsi, γsi, ηsi, δsi are emission curve coefficients of ith thermal unit.

Power balance constraints: The total active power generation must balance the predicted power demand plus losses, at each time interval over the scheduling:

$$\begin{gathered} \_Nsi = 1Psim + \_Nhj = \\ Phjm - PDm - PLm = 0 m \in M \end{gathered} \quad (16)$$

where, PDm is the load demand at time m, PLm the total transmission line losses at time m, Phjm the output power of jth hydro unit at time m, Nh the number of hydro generating units:

The hydroelectric generation is a function of water discharge rate and reservoir water head, which in turn, is a function of storage:

$$\begin{aligned} Phjm = C1jV2hjm + C2jQ2hjm + \\ C3jVhjmQhjm + C4jVhjm \\ + C5jQhjm + C6j, j \in Nh, m \in M \end{aligned} \quad (17)$$

where, C1j , C2j, C3j, C4j, C5j, C6j are the power generation coefficients of j^{th} hydro unit, Qhjm the water discharge rate of j^{th} reservoir at time m, Vhjm the storage volume of jth reservoir at time m:

Generation limits:

$$\begin{gathered} Pminhj \le Phjm \le Pmaxhj, \\ j \in Ns, m \in M \end{gathered} \quad (18)$$

$$\begin{gathered} Pminsi \le Psim \le Pmaxsi, \\ i \in Ns, m \in M \end{gathered} \quad (19)$$

where, Pmin hj, Pmax hj are the lower and upper generation limits for j^{th} hydro unit.

Hydro constraints: The hydro constraints are shown below in Fig. 1.

Hydro plant generation limits: Limitations on the power generation capacities:

$$P_h(i,t)^{min} \le P_h(i,t)^{max} \quad t \in T \quad (20)$$

Hydraulic network constraints: Physical limitations on reservoir storage volumes and discharge rates:

$$V_h(i,t)^{min} \le V_h(i,t) \le V_h(i,t)^{max} \quad t \in T \quad (21)$$

$$V_h(i,t)^{min} \le V_h(i,t) \le V_h(i,t)^{max} \quad t \in T \quad (22)$$

Where:

$Q_h(i, t)$ = Discharge of ith reservoir in time t

$Q_h(i, t)^{min}$ = Minimum discharge limits of ith reservoir in time t

$Q_h(i, t)^{max}$ = Maximum discharge limits of ith reservoir in time t

$V_h(i, t)$ = Volume of ith reservoir in time t

MATERIALS AND METHODS

Economic load dispatch

Genetic algorithm satisfying method: Genetic Algorithms can identify and exploit regularities in the environment, and converges on solutions (can also be regarded as locating the local maxima) that were globally optimal. This method is very effective at finding optimal or near optimal solutions to a wide variety of problems, because it does not impose limitations required by traditional methods such as gradient search, random search etc. The Genetic Algorithm technique has advantages over traditional non-linear solution techniques that cannot always achieve an optimal solution. The method is very different from "classical" optimization algorithms:

- It uses encoding of the parameters, not the parameters themselves.
- The search is more exhaustive in a given amount of time
- Due to its probabilistic nature rather than deterministic, it yields "different solutions on different runs"

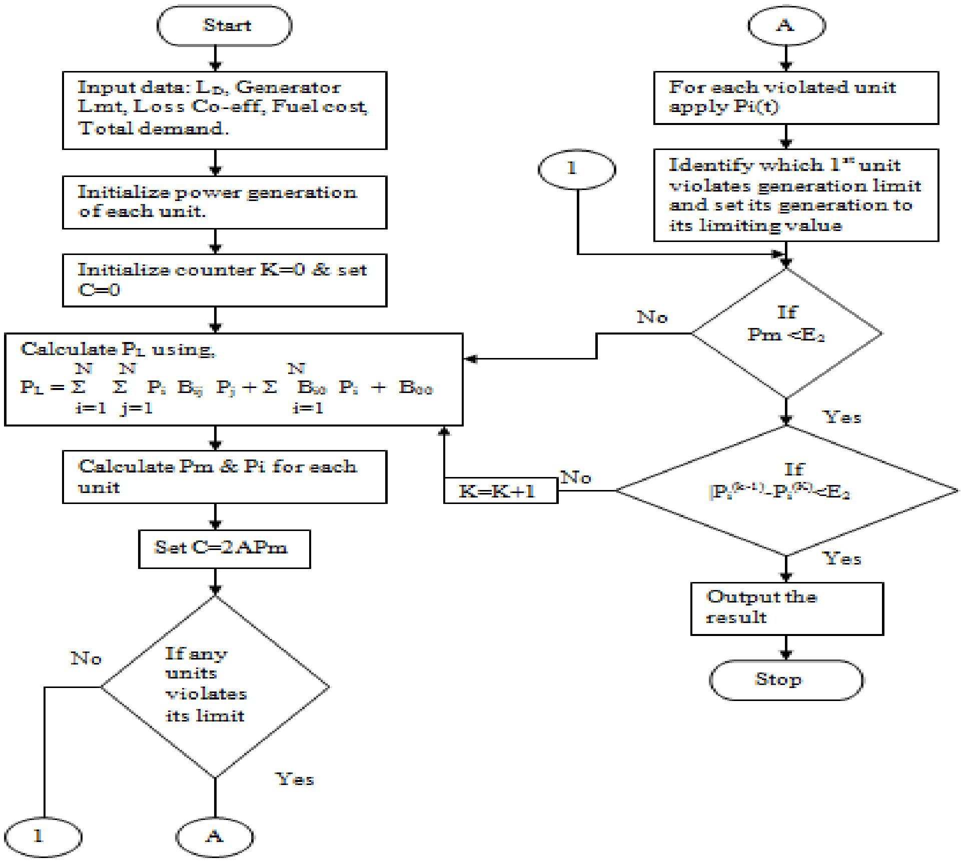

Fig. 1: Flow chart for economic dispatch

- Explores the solution space in multiple directions rather than in single direction

A GA is an iterative procedure which begins with a randomly generated set of solutions referred as initial population. The solving of placement and sizing of DG units problem requires to define the fitness function that can be optimized in the presence of some constraints. The fitness function is selected for reducing power losses and profit maximization in the system. The GA starts the process by automatically proposing different DG sizes within the proposed DG size limits and internally executes the load flow program which is properly linked with GA package till the minimum solution is obtained for the suggested location. This process is repeated for each of the proposed locations (Fig. 2).

In order to determine the best location and size of the DG unit for distribution network, algorithm has been suggested considering the appropriate voltage constraints. The major steps of the proposed algorithm are:

Step 1: Create an initial population vector by randomly generating DG location and DG Size. Each population of initial population vector consists of DG size and corresponding bus location.

Step 2: Apply each population of initial population vector on the network, i.e. DG size generated in population is reinforced in the network at the corresponding generated bus location.

Step 3: Check for the voltage constraints for each population applied on network.

Step 4: If voltage constraints are satisfied, the population is survived population of survived population vector.

Step 5: Calculate the objective function for each population of survived population vector. The population that gives optimum objective function is the optimal population.

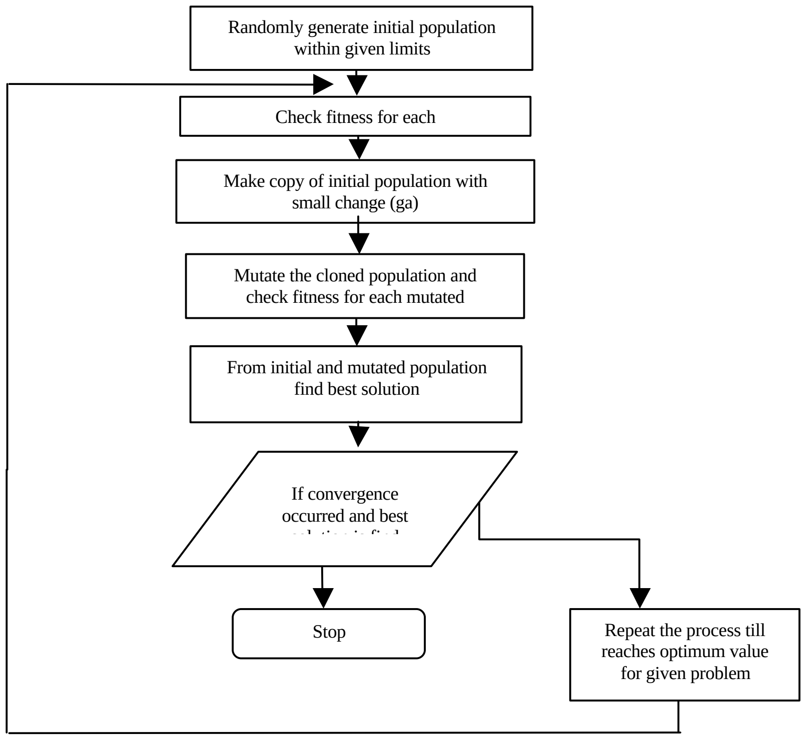

Fig. 2: Flowchart for genetic algorithm

Step 6: If the convergence criterion is satisfied, stop and display the results, otherwise go to step7.

Step 7: Apply the survived population vector from the initial population vector to generate next generation population

RESULTS AND DISCUSSION

Total generation: The experimental tests were conducted in the simulation environment in which different level of varying loads are considered for hydro scheduling process. To prove the performance improvement of the proposed methodology called the Multi-Objective Genetic Algorithm Based Hydro Thermal Scheduling (MOGAHTS) is compared with the existing approach called the Hydro Thermal Based Scheduling (HTBS). From the comparison it is proved that the proposed methodology is improved in terms of our objective parameters called the emission rate and the total generation cost.

In the research work initially the power demand of every hydro thermal power unit would be fixed randomly. These values would be updated by increasing and decreasing the power demand in every iterations based on the performance level of current process. The performance index values of genetic algorithm in terms of varying number of generations are illustrated in the following Fig. 3.

From the above it can be proved that the performance level of the system that is attained would be varying in terms of different generation parameter values. As the numbers of generation are increased in number, the performance index values are decreased linearly. And it starts to maintain its state after some amount of generations. Thus it is proved that the genetic algorithm can perform well than the other approaches in terms of varying power generation loads and can decides the resource level to provide the better function to the hydro thermal power unit. The total generation cost and the total emission rare which was measured in the hydro thermal power unit in case of applying proposed methodology is listed in the following Table 1.

The comparison graph of the total generation cost in different iteration with varying load level is depicted in the following Fig. 4 which is explained in detail as follows. From the above graph, it can be proved that the proposed methodology can plan the resources with reduced total generation cost than the existing system in terms of different power load demand. In X axis varying power load demand is taken whereas in Y axis Total generation cost

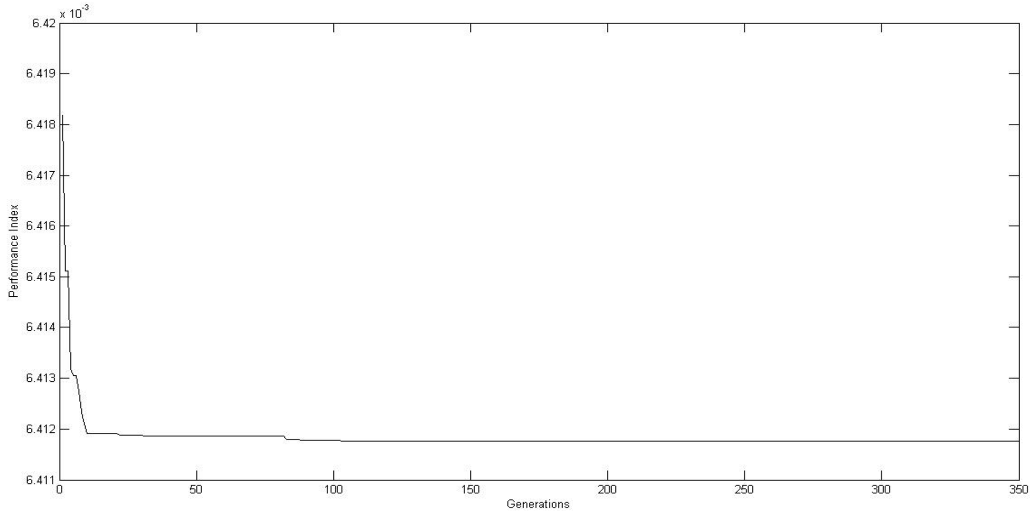

Fig. 3: Performance index level

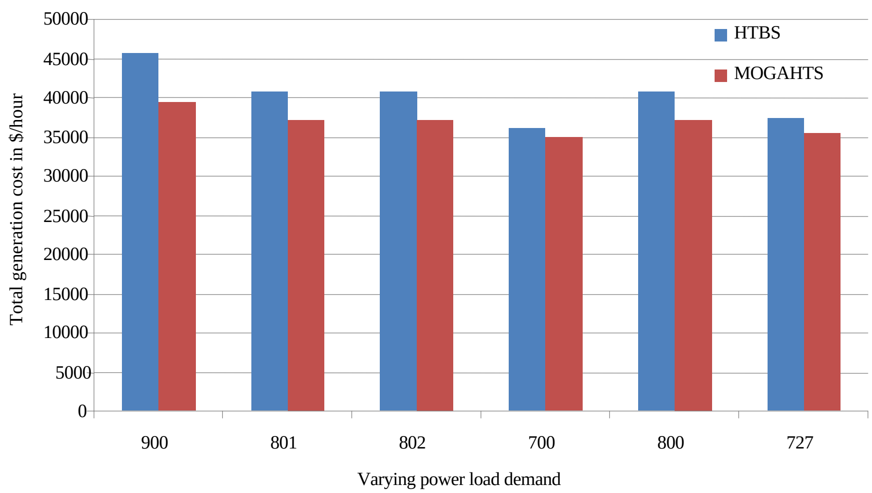

Fig. 4: Total generation cost

Table 1: Parameter values observed in proposed methodology

Total thermal power demand for scheduling period	Pd	Pgen	Tgen	Total generation cost ($ h^{-1})	Total emission (kg h^{-1})
1	900	25.9756	900.0147	39328.6	309.699
2	801	23.5427	801.0220	37081.5	267.080
3	802	23.5671	802.0144	37103.8	267.453
4	700	21.0610	700.0444	34818.7	234.898
5	800	23.5183	800.0296	37059.1	266.708
6	727	21.7244	727.0379	35420.7	242.384

is $ per hour is taken. The performance comparison is made to depict the performance improvement in the hydro thermal power plant.

Total emission rate: Emission rate is the amount of pollutant gases that are emitted from the hydro thermal power plant during generation of thermal power electricity. This pollutant gases would impact the environmental factors in terms of varying power load demands. Thus the emission rate should be less for the proposed methodology which is achieved in the better way using the multi objective genetic algorithm where we considered emission rate as one of the objective for selecting the optimal resource to produce hydro power electricity. The performance measure values which are observed is given in the following Table 2.

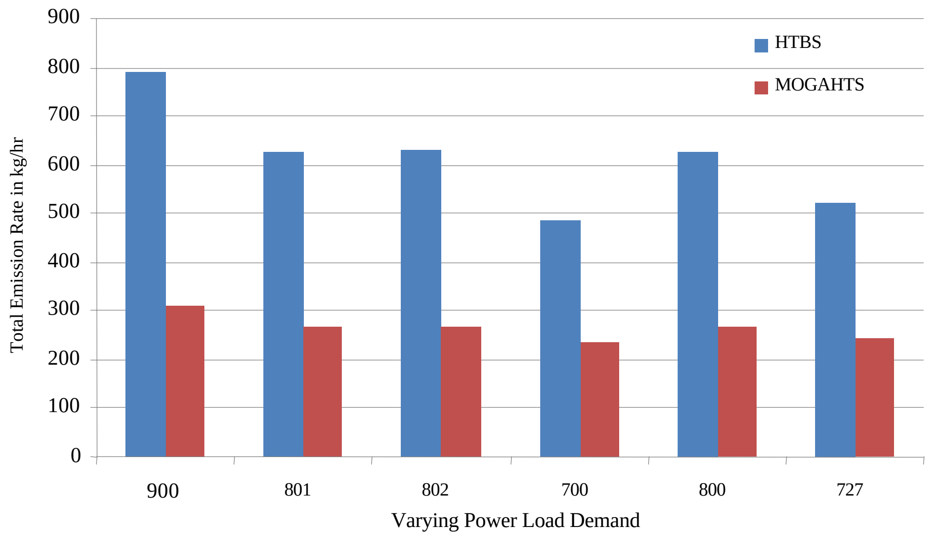

Fig. 5: Total emission

Table 2: Total emission rate values

	HTBS		MOGAHTS	
Thermal scheduling in period	Power demand	Total emission rate	Power demand	Total emission rate
1	900	788.666	900	309.699
2	801	626.749	801	267.08
3	802	628.284	802	267.453
4	700	484.311	700	234.898
5	800	625.201	800	266.708
6	727	519.812	727	242.384

The comparison graph of the total emission rate in different iteration with varying power load level is depicted in the following Fig. 5 which is explained in detail as follows.

From the above graph Fig. 5, it can be proved that the proposed methodology can plan the resources with reduced total emission rate than the existing system in terms of different power load demand. In X axis varying power load demand is taken whereas in Y axis Total emission rate in kg per hour is taken. The performance comparison is made to depict the performance improvement in the hydro thermal power plant.

CONCLUSION

Hydro thermal power plant is the important energy source in world which makes use of potential energy of water resources to generate the electricity to which the user required power demand can be satisfied. Hydro thermal power plant may require spending some resources to satisfy the user demand. However it might lead to the high resource usage cost. In this work multi objective genetic algorithm based resource planning is introduced which is used to schedule the number of resources and the types of resources that should be scheduled for satisfying the user goals. The performance evaluation conducted were proves that the proposed methodology provides better result than the existing approach in terms of improved total generation cost and the emission rate.

REFERENCES

Bonaert, A., A. Elabiad and A. Koivo, 1972. Optimal scheduling of hydro-thermal power systems. IEEE. Trans. Power Apparatus Syst., 1: 263-270.

Brannlund, H., J.A. Bubenko, D. Sjelvgren and N. Andersson, 1986. Optimal short term operation planning of a large hydrothermal power system based on a nonlinear network flow concept. IEEE. Trans. Power Syst., 1: 75-81.

Dahlin, E.B. and D.W. Shen, 1996. Optimum solution to the hydro-stream dispatch problem for certain practical systems. IEEE. Trans. Power App. Syst., 85: 437-437.

Dandeno, P.L., 1960. Hydrothermal economic scheduling-computational experience with co-ordination equations. Trans. Am. Institute Electrical Eng. Power Apparatus Syst., 79: 1219-1228.

Drake, H.H., L.K. Kirchmayer, R.B. Mayall and H. Wood, 1962. Optimal operation of hydrothermal systems. AIEE. Trans. Power App. Syst., 81: 242-242.

Duncan, R.A, G.E. Seymore, D.L. Streiffelt and D.J. Engberg, 1985. Optimal hydrothermal coordination for multiple reservoir river systems. IEEE. Trans. Power App. Syst., 104: 1154-1159.

Ea, K. and M. Monti, 1986. Daily operational planning of the EDF plant mix proposal for a new method. IEEE. Trans. Power Syst., 1: 251-257.

Habibollahzadeh, H. and J.A. Bubenko, 1986. Application of decomposition techniques to short-term operation planning of hydrothermal power system. IEEE. Trans. Power Syst., 1: 41-47.

Mandal, K.K. and N. Chakraborty, 2012. Daily combined economic emission scheduling of hydrothermal systems with cascaded reservoirs using self organizing hierarchical particle swarm optimization technique. Expert Syst. Appl., 39: 3438-3445.

Nanda, J., D.P. Kothari and K.S. Lingamurthy, 1988. Economic-emission load dispatch through goal programming techniques. IEEE. Trans. Energy Convers., 3: 26-32.