A HYBRID OPTIMIZATION TECHNIQUE FOR FIXED AND VARIABLE HEAD SHORT-TERM HYDROTHERMAL SCHEDULING

A Dissertation submitted in fulfillment of the requirements for the Degree
of

MASTER OF ENGINEERING
in
Power Systems

Submitted by

SHASHANK GUPTA
801341024

Under the Guidance of
Dr. Nitin Narang
Assistant Professor, EIED

2015

Electrical and Instrumentation Engineering Department
Thapar University, Patiala
(Declared as Deemed-to-be-University u/s 3 of the UGC Act., 1956)
Post Bag No. 32, Patiala – 147004
Punjab (India)

DECLARATION

I hereby certify that the work which is presented in dissertation entitled, "**A hybrid optimization technique for fixed and variable head short-term hydrothermal scheduling**", in partial fulfillment of the requirements for the award of the degree of **Master of Engineering in Power Systems**, submitted to Electrical & Instrumentation Engineering Department of Thapar University, Patiala is as authentic record of my own work carried under the supervision of **Dr. Nitin Narang**. It refers others researcher's work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other degree to any other university or institute except as reported in text and references.

Shashankgupta

Place: Patiala
Date: 15/07/15

(Shashank Gupta)
Roll No.: 801341024

It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

N Narang

Date: 15-07-15

(Dr. Nitin Narang)
Assistant Professor
Electrical & Instrumentation Engineering Department
Thapar University, Patiala

Countersigned by:

Head
Electrical & Instrumentation Engineering Department
Thapar University, Patiala

Dean (Academic Affairs)
Thapar University, Patiala

ACKNOWLEDGEMENT

Words are often less to revels one’s deep regards. With an understanding that work like this can never be the outcome of a single person. I take this opportunity to express my profound sense of gratitude and respect to all those who helped me through the duration of this work.

I am very thankful to **Dr. Prakash Gopalan**, Director of Thapar University, Patiala for providing the facilities for the completion of M.E. I express my deep sense of gratitude towards **Dr. Ravinder Agarwal**, Head of the Department of Electrical & Instrumentation Engineering, Thapar University, Patiala who has been a constant source of inspiration for me throughout this work.

I would like express my gratitude and thanks to supervisor, **Dr. Nitin Narang**, Assistant Professor, Department of Electrical and Instrumentation Engineering, Thapar University, Patiala, for his patient guidance and support through this work. It was an honour and privilege to work under him as a student. He also provides the help in technical writing and presentation style and I found his guidance to be extremely valuable.

I am also thankful to my batch mates who devoted their valuable time for the successful completion of this dissertation. I extend my gratitude to the researchers and scholars whose hours of toil have produced the papers that I have utilized in my project.

Lastly, I would like to thank my parents for their years of unyielding love and encouragement. They have always wanted the best for me and admire their determination and sacrifice.

Shashank Gupta

Roll No.: 801341024

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

F_T	Total fuel cost of thermal units ($).
$a_{1i}, a_{2i}, a_{3i}, a_{4i}, a_{5i}$	Fuel cost coefficients of i^{th} thermal unit.
P_{ik}	Generated power of i^{th} generating unit during k^{th} subinterval.
P_i^{min}	Lower limits on the i^{th} generating unit.
P_i^{max}	Upper limits on the i^{th} generating unit.
t_k	Time duration of k^{th} subinterval.
NT	Number of thermal units.
NH	Number of hydro units.
T	Total scheduling time.
K_j', K_j	Proportionality constants of j^{th} hydro unit.
y_{1j}, y_{2j}, y_{3j}	Discharge rate coefficients of j^{th} hydro unit.
z_{1j}, z_{2j}, z_{3j}	Head variation coefficients of j^{th} hydro unit.
q_{jk}	Rate of water discharge of j^{th} hydro unit during k^{th} subinterval.
S_j	Surface area of the reservoir of j^{th} unit.
I_{kj}	Inflow rate of j^{th} hydro unit.
h_{jk}	Effective head of j^{th} generating unit during k^{th} subinterval.
h_{j0}	Initial hydraulic head.
P_{Dk}	Power demand during k^{th} subinterval.
P_{Lk}	Transmission loss during k^{th} subinterval.
B_{ij}, B_{i0}, B_{00}	B-coefficients.
q_j^{min}	Lower limit on water discharge rate.
q_j^{max}	Upper limit on water discharge rate.
R_j	Predefined volume of water available for j^{th} hydro unit.
r_p	Exterior penalty factor.
NP	Number of particles in a group.
c_1 and c_2	Acceleration constants.
rand (1), rand (2)	Uniform random numbers between 0 and 1.
IT_1^{max}	Maximum number of iterations for DMSPSO.
IT_2^{max}	Maximum number of iterations for SQP.

NOMENCLATURE (Continued)

$Pbest_{ij}^{t}$	Local best position till t^{th} iteration.
$Gbest_{j}^{t}$	Global best position till t^{th} iteration.
V_{ij}^{t}	Velocity of the j^{th} particle at t^{th} iteration.
w	Inertia weight factor.
$Ibest_{il}^{t}$	Best position achieved by l^{th} sub-swarm till t^{th} iteration.
obj.	Objective function.

ABBREVIATIONS

STHTS	Short-term hydrothermal scheduling
DMSPSO	Dynamic multi-swarm particle swarm optimizer
SQP	Sequential quadratic programming
NR	Newton-Raphson
EP	Evolutionary programming
PSO	Particle swarm optimization
PPO	Predator prey optimization
GA	Genetic algorithm
RCGA	Real coded genetic algorithm
DE	Differential evolution
CFPSO	Constriction factor particle swarm optimization
BFGS	Broyden-Fletcher-Goldfarb-Shanno

ABSTRACT

The optimal short-term scheduling of hydrothermal plants plays an important role in the planning the operation of the power system. In short-term hydrothermal scheduling, the hydro-electric and thermal power generation is optimized to minimize the total operating cost of the thermal plant. The problem of *short-term hydrothermal scheduling* (STHTS) is complex due to consideration of power balance equality constraint, hydraulic constraint of water discharge rate equality constraint and non-linear cost characteristics of thermal units due to valve point loading effect. In this dissertation, a hybrid optimization technique is used to solve the problem of fixed and variable head STHTS. The hybrid optimization technique combines *dynamic multi-swarm particle swarm optimizer* (DMSPSO) and *sequential quadratic programming* (SQP). DMSPSO is a global search technique used for exploration of the search space and the SQP is a local search technique used for fine tuning of results obtained from DMSPSO. The proposed algorithm has been tested on various fixed and variable head hydrothermal test system. The results obtained will proves the effectiveness of the proposed technique.

CHAPTER-1
INTRODUCTION

1.1 OVERVIEW

Electrical power is the most valuable form of energy since last couple decades and its dependency increases day by day. Electric power is most crucial factor in development of economy of various sectors of a country. Now, to fulfill the future electricity demand the trend is to install the new power plants, installation of more transmission lines, expansion of existing power plants, generation should be in most economical form and the losses should be minimized. The basic idea is to develop such a power system which combines various type of generating units such that it minimizes the total operating cost of generated power which satisfies the system load demand and transmission losses [1]. The *short-term hydrothermal scheduling* (STHTS) combines hydro and thermal units for optimum scheduling of generated power. The hydro and thermal units are combined together for STHTS due to their conflicting characteristics. The thermal unit has low capital cost, high operating cost and speed of response is slow. Thermal power plants are used as a base load plants. Hydro power is a renewable, economic and non-polluting source of energy. Hydro power plants have quick starting and stopping ability. The hydro power plant offers flexible load which helps in improving the reliability of power system. Hydro power units are the best choice for meeting the peak load during the high load period [2]. So, it is convenient and economical to have both hydro and thermal units on the same grid. In STHTS the operating cost is associated with only thermal units. The minimization of total fuel cost of thermal units is achieved by the optimization techniques which minimize the operating cost along with satisfaction of all operational constraints. A number of optimization techniques were implemented on different problems which can divided into two categories [3]; conventional and random optimization techniques. Conventional optimization techniques [3] such as mixed integer programming, lagrange relaxation method, interior point method, dynamic programming, *Newton-Raphson* (NR) method, lagrange multiplier method, gradient search technique, newton’s method applied successfully on various problems. The conventional techniques follow a set mathematical procedure to obtain optimal solution. However, most of the conventional optimization techniques use several assumptions to solve their algorithm which may lead to premature convergence and thus the solution may not reach at global minima [4].

In the past decades the use of random search technique was increased rapidly due to their flexibility, versatility and robustness over conventional optimization techniques [4]. The random search techniques such as *evolutionary programming* (EP), *genetic algorithm* (GA), simulated annealing, cuckoo search, *differential evolution* (DE), society civilization algorithm, *particle swarm optimization* (PSO), *artificial immune system* (AIS) and gravitational search algorithm applied by various researchers on different field. However, sometimes the result of random search technique will traps into local minima above which the exploitation process will not occurs. So, to avoid the local minima two optimization techniques will hybridize to obtain the better solution. Generally, the global search optimization technique and local search optimization technique will hybridize together. The global optimization technique is used for exploration of physical search area which gives a feasible solution while the local search optimization technique is used for exploiting the feasible solution achieved by global search optimization technique.

1.2 LITERATURE REVIEW

The objective of hydrothermal scheduling is to determine the generation level for each hydro and committed thermal unit in such a way that the total operating cost is minimized while satisfying various operational constraints [1]. According to the time span, hydrothermal scheduling is divided into 3 categories [1]; long-term hydrothermal scheduling, mid-term hydrothermal scheduling and short-term hydrothermal scheduling. Long-term scheduling interval varies from a year to several years [2]. The advantage of long-term hydrothermal scheduling is to minimization of power generation cost along with fulfilling the irrigational and agricultural requirements. Mantawy [5] successfully determines the optimal long-term scheduling of hydrothermal plant. The scheduling problem having range between a week to a year is termed as mid-term hydrothermal scheduling. Short-term scheduling interval varies from a day to a week which is normally divided into subintervals [2]. STHTS can further divided in the following categories [2]; pumped-storage STHTS, multi-chain STHTS and fixed and variable head STHTS. Chen [6] used pumped-storage short-term hydro model to determine optimal power generation of STHTS problem. Various researchers applied multi-chain hydro model to obtain the optimal generation of STHTS [7, 8].

Depending on the reservoir capacity, the hydro plants can be divided into two categories [2]; fixed head hydro plants and variable head hydro plants. The fixed head hydro plants are associated with large capacity reservoir while for small capacity reservoir variable head hydro plants are used. Various conventional techniques have been applied in literature related to fixed head short-term hydrothermal scheduling such as lagrange multiplier method [9], dynamic programming [10], lagrangian relaxation method [11], mixed integer programming method [12]. EI-Hawary applied NR method [13] to solve fixed head STHTS problem however they used powell's method to eliminate the divergence problem of NR method. The NR method has difficulty in computation of inverse of large matrix and has large computation time [9]. Various conventional techniques applied by researchers on the variable head STHTS problem such as lagrange multiplier method [14], NR method [15] and interior point method [16], however first paper is presented by Ricard [17]. Ricard neglects the transmission losses occurs in the system. Later, Glimn *et.al* [18] applied the same problem including transmission losses. Among all the conventional techniques the DP appears as one of the most popular technique but computational time and dimension of parameters in DP grow drastically with increasing system size [19].

Recently, the trend is to apply the random search techniques on the STHTS problem which seem to be more realistic models for hydro and thermal units. The hydrothermal model has non-convex characteristics which create a complex STHTS problem and cannot be effectively handled by mathematical methods. Such problem requires random search techniques which gives robust, fast and accurate solution. Various researchers applied random search techniques on fixed head STHTS problem such as artificial immune system [19], simulated annealing [20], Hop-field neural network [21], GA [22], improved GA [23], EP [24], *predator prey optimization* (PPO) [4]. Nguyen *et al.* applied cuckoo search algorithm on fixed head STHTS [25]. The Hop-field neural network has slow convergence rate and it required linear constraints before applying in the problem [26]. GA produces good results but sometimes it cannot produce better offspring and hence it has slow convergence near global solution [27]. Optimal gamma based GA [28] was the advancement of GA for improving the results of fixed head STHTS. The various random search techniques applied on variable head STHTS are GA [29], enhanced bacterial foraging algorithm [30], PPO [4]. Dhillon *et al.* applied *real coded genetic algorithm* (RCGA) [31] to determine optimal scheduling of variable head hydro and thermal plants.

PSO is a meta-heuristic optimization technique and its concept is quite simple. It requires only few parameters to be set by user and it does not require conditions like continuity and differentiability of objective function and constraints [32]. Samudi *et al.* [33] applied PSO based optimization technique for optimal generation of STHTS problem. Binghui *et al*. [34] applied PSO on the multi-chain STHTS. After introducing the PSO, the researchers apply different variants of PSO to maintain the balance between global exploration and local exploitation to avoid premature convergence [35]. Different variants of PSO which were applied on different problems are enhanced leader PSO [36], self-organization hierarchical PSO [37], Multi-strategy adaptive PSO [38]. Hinojosa and Leyton [39] presented mixed binary evolutionary PSO technique for determine the optimal generation of hydrothermal scheduling. Lu *et al*. [40] applied a quantum-behaved PSO on the STHTS problem. Improved PSO [41] is applied by Padmini *et al.* for short-term hydrothermal generation scheduling. Zadeh *et al.* [42] applied parallel PSO on the hydrothermal wind energy system scheduling. Ying *et al.* [43] applied improved self-adaptive PSO technique for STHTS problem. Coelho *et al.* [44] applied chaotic and gaussian PSO approach to solve economic load dispatch problems in power systems. Basu [45] applied modified PSO to solve non-convex economic dispatch problem. Chaturvedi *et al*. [46] presented economic load dispatch problem using PSO with time varying acceleration coefficients. A PSO embedded evolutionary technique [47] applied by Sinha *et al*. for economic load dispatch problem. Chuntian *et al*. [48] applied two stage PSO to solve long-term hydrothermal scheduling. Liang *et al*. [49] introduced and applied the *dynamic multi-swarm particle swarm optimizer* (DMSPSO) technique whose neighborhood topology is dynamic and randomized. DMSPSO gives a better performance on multimodal problems than some other PSO variants [50]. Zhao *et al*. [50] applied DMSPSO technique for large scale global optimization problem. Further, Liang *et al*. [51] applied DMSPSO technique to solve multi-objective optimization problem. Meng-xin *et al*. [52] applied DMSPSO technique to the optimal dispatch of loads of thermal units.

The results of random search technique may trap into local minima and not reaches near the global minima. The hybridization of local search and global search techniques avoids any local minima and hence better solution may obtain. Some of the examples of local search techniques [53] are powell method, tabu search and *sequential quadratic programming* (SQP) etc. Sivasubramani *et al*. [54] applied hybrid DE-SQP on the STHTS problem. Narang *et al*. [55] applied integrated PPO and powell method for STHTS problem. Basu [56] presented hybridization of bee colony optimization and SQP for dynamic economic dispatch problem. Attaviriyanupap *et al*. [57] applied hybrid EP and SQP for dynamic economic dispatch problem. Nallasivan *et al*. [58] hybridize an evolutionary algorithm and a conventional optimization technique to solve STHTS problem. Nayak *et al*. [59] presented hybrid EP and tabu search technique to determine short-term optimal generation scheduling of hydrothermal plants.

The intent of this dissertation is to determine the optimal scheduling of fixed and variable head STHTS by hybrid DMSPSO-SQP optimization technique. DMSPSO is a global search technique used for the exploration of the search space while the SQP is a local search technique is used for the exploitation of the results obtained from global search technique.

1.3 OBJECTIVE OF THE WORK

The objective of the dissertation is to apply a hybrid optimization technique on STHTS problem to obtain optimal power generation of the hydrothermal units along with the satisfaction of constraints. The hybrid optimization technique constitutes the DMSPSO and SQP techniques in which DMSPSO technique helps in exploring the search area for optimal solution and SQP leads to exploitation of the explored area for fine tuning of results. In this research work, constraints are handled by generating error whenever they violate. Proposed technique produce satisfying results and prove to be better as compared to other optimization methods.

1.4 ORGANIZATION OF DISSERTATION

The proposed dissertation work entitled as “A hybrid optimization technique for fixed and variable head short-term hydrothermal scheduling” has been summarized in six chapters. **Chapter one** provides a brief introduction, literature review associated to problem and objective of the work done. **Chapter two** deals with the individual structure of PSO, DMSPSO and SQP along with the hybrid DMSPSO-SQP optimization technique. **Chapter three** highlights STHTS in detail and problem formulation of fixed and variable head STHTS. **Chapter four** highlights the solution methodology for fixed and variable head STHTS problem using hybrid optimization technique. **Chapter five** covers the results concluded from various test systems. **Chapter six** concluded the dissertation work and summarizes the scope for future work followed by list of publications and reference section.

CHAPTER-2

SHORT-TERM HYDROTHERMAL SCHEDULING

2.1 NEED OF HYDROTHERMAL SCHEDULING

In the present scenario, a large power system with thermal and hydro units has a great importance. The power station needs an optimal scheduling of units so as to reduce the production cost and for efficient utilization of available resources. The hydrothermal system forms a complex problem compare to all thermal units problem because the hydrothermal system not only works electrically but also mechanically [1]. This means the system has to meet load demand as well as it has to maintain the balance of water availability. The objective of hydrothermal scheduling is to determine the generation level for each hydro and thermal unit in such a way that the total operating cost is minimized while satisfying all equality and inequality operational constraints. The thermal and hydro unit has own advantages and disadvantages. The characteristics of thermal and hydro units [2] are given in table (2.1).

Table 2.1 characteristics of thermal and hydro units

	Thermal Unit	**Hydro Unit**
Capital cost	Low	High
Operating cost	Very high, depends on output power	Negligible, independent of output power
Speed of response	Slow	Fast
Preferred as	Base load plant	Peak load plant
Environmental effects	Pollute the environment	Eco–friendly towards environment

The table (2.1) shows the nature of thermal and hydro units are conflicting in nature. In some point, the hydro units are better while for any other point of view it may possible that the thermal units are better. Now, to integrate the advantages of both hydro and thermal units in the same grid it is necessary to have both types of plants in that grid.

2.2 CLASSIFICATION OF HYDRO PLANTS

The hydro plants are classified [2] in a number of ways such as on the basis of type, on the basis of availability of water head, on the basis of nature of load and on the basis of location. On the basis of type hydro plants can be of two types; pumped storage plants and conventional plants. The pumped storage hydro plant is designed with upper and lower reservoirs while the conventional plants can be of run-of river plants or storage type plants. The water head of the hydro plants can be of low head (less than 30 m), medium head (30-300 m) and high head (greater than 300 m). On the basis of nature of load hydro plants can be divided into base load plants or peak load plants. A base load power plant operates on the steady state and generates constant power regardless of the power demanded by the grid. The run-off river plants without pondage and reservoir plants are considered as base load plants. At the time of peak demand period, the power is also supplied by peak load plants to equalize the supply and load demand. The run-off river plants with pondage and gas turbine plants can be used as peak load plants. The efficiency of peak load plants is around 60-70%. The hydro plants can be located on the different stream or on the same stream. The hydro plants located on different stream are independent of each other while in hydro plants situated on the same stream, the downstream plant dependent on the upstream hydro plant.

2.3 HYDRO TURBINE MODELS

In hydro-electric plant the hydro turbines are used to convert energy of falling water into mechanical energy, which is further utilized for driving the electrical generators. Hydro turbine can be either reaction type or it may be impulse type. The active power output of a hydro turbine [60] can be expressed as

$$P_h = \left(\frac{q_h}{102}\right)\eta_t\eta_g \tag{2.1}$$

where,

P_h is active power generated (MW).

q_h is rate of water discharge (m^3/sec).

h is effective water head (m).

η_g is generated efficiency.

η_t is turbine efficiency.

Due to the variation in installation characteristics, several different models [60] were exists, although all the models are based on above equation. Some of the models are Glimn-Kirchmayer model, Hildebrand model, Hamilton-Lamont’s model and Arvanitidis-Rosing model. Although all the models has a little difference but Glimn-Kirchmayer model is the most important model in which the rate of water discharge is depends upon the bi-quadratic function of active power and net water head. Mathematically,

$$q = K\Phi(P_h)\,\psi(h) \tag{2.2}$$

Where, the function $\Phi(P_h)$ and $\psi(h)$ are quadratic functions of hydro power and effective head, respectively.

$$\Phi(P_h) = y_1 P_h^2 + y_2 P_h + y_3 \tag{2.3}$$

$$\psi(h) = z_1 h^2 + z_2 h + z_3 \tag{2.4}$$

where,
y_1, y_2 and y_3 are discharge rate coefficients.
z_1, z_2 and z_3 are head variation coefficients.

2.4 CLASSIFICATION OF HYDROTHERMAL SCHEDULING PROBLEM

The hydrothermal scheduling is very complex problem. To reduce the complexity for the scheduling of a generating plant, the problem is solved for three different time spans and the output of one may be used for the remaining two, if needed. The three types of scheduling are as follows

2.4.1 LONG-TERM SCHEDULING

The long-term scheduling interval varies from a year to several years. The long-term hydrothermal scheduling involves the long-term forecasting of power demand and water availability and the scheduling of reservoir water release [61]. The long-term hydrothermal scheduling includes the optimization of power generation cost along with fulfilling the irrigational and agricultural requirements with the unknowns like, hydraulic inflows, load demand and availabilities of thermal and hydro units. The purpose of the long-term scheduling is to provide a good feasible solution that is close to the long-term cost minimization of the whole system.

2.4.2 MID-TERM SCHEDULING

The mid-term scheduling problem makes a relation between short-term scheduling problem and the long term scheduling problem [62]. The length of the scheduling period can be a week to one year. However, the modeling of the generation requirements and hydro constraints is handled separately for the first week and the remaining weeks of the medium-term scheduling period. For the first week of scheduling sequential load model is used while for the remaining weeks a load duration curve model is used.

2.4.3 SHORT-TERM SCHEDULING

The short-term scheduling interval varies anywhere from 1 day to 1 week. The scheduling period of short-term scheduling is divided into a number of subintervals, generally the subinterval having duration of 1 hour [62]. Hence, the short-term scheduling involves the hourly scheduling of power generation in order to optimize the production cost. In short-term hydrothermal scheduling problem the load demand, water inflow rate and unit availabilities are always known. The amount of water to be utilized for the short-range scheduling problem is known from the solution of the long-term or mid-term scheduling problem.

The long-term scheduling, medium-term scheduling and short-term scheduling problem is interconnected with each other. In terms of marginal water values [61] the long-term scheduling is the starting conditions of the medium-term scheduling and the medium-term scheduling results are input to the short-term scheduling.

The short-term hydrothermal scheduling can be divided into three categories, as:

1) **Pumped storage STHTS** – The pumped storage STHTS use the pumped storage hydro plants for generating the hydro powers in which water is pumped from lower to upper reservoir during light load period and during the peak load period this water is released to generate the hydro power.
2) **Multi-chain STHTS** – In multi-chain STHTS the hydro plants are located on the same stream as well as on the different streams.
3) **Fixed and variable head STHTS** – The available water head for the hydro unit depends upon the topography of the area. Availability of head of water has considerable effect on the cost and economy of power generation. An increase in

effective head reduces the quantity of water to be stored and handled by the turbines and hence the capital cost of the plant is reduced. In order to determine the most effective and economical head it is necessary to consider all possible factors which affect it. Depending on the reservoir capacity, the hydro plants can be divided into two categories [2]; fixed head hydro plants and variable head hydro plants. The fixed head hydro plants are associated with large capacity reservoir while for small capacity reservoir variable head hydro plants are used.

2.5 SHORT-TERM HYDROTHERMAL GENERATION SCHEDULING

The problem considered in this section is the short-term optimal economic operation of hydrothermal systems with fixed and variable head reservoirs. These fixed head reservoirs are large enough so that they have large amount of water while the variable head reservoir are associated with small amount of water. The objective of the STHTS problem is to minimize the total operating cost by minimizing the total fuel cost associated with the thermal generating units. This minimization of the fuel cost objective function is subject to various operational thermal and hydraulic constraints.

The hydrothermal generating station consists of NT thermal generating units and NH hydro units. The solution to the problem is to determine the optimal active power generation level of each generating unit over the total scheduling period T.

2.5.1 THERMAL MODEL

The generating cost of thermal units is generally given by the quadratic function of thermal powers. The fuel cost is mathematically modeled as [4]:

$$F = \sum_{k=1}^{T} \sum_{i=1}^{NT} t_k (a_{1i} P_{ik}^2 + a_{2i} P_{ik} + a_{3i}) \qquad (2.5)$$

The more realistic model of thermal unit is achieved when the effect of valve point loading is consider, this is given by adding a sinusoidal function to the quadratic function of thermal powers

$$F_T = \sum_{k=1}^{T} \sum_{i=1}^{NT} t_k \left(a_{1i} P_{ik}^2 + a_{2i} P_{ik} + a_{3i} + a_{4i} \sin\left\{ a_{5i} \left(P_i^{min} - P_{ik} \right) \right\} \right) \qquad (2.6)$$

2.5.2 SHORT-TERM HYDRO MODEL

The Glimn-Kirchmayer model [20] model is use for calculating the water discharge rate. The water discharge rate of j^{th} hydro unit at k^{th} subinterval is given by such as:

$$q_{jk} = K_j' \Phi(P_{mk}) \quad : \text{ Fixed head} \quad (\text{j} \in \text{NH}; m \in j + \text{NT}; \text{k} \in \text{T}) \tag{2.7}$$

$$q_{jk} = K_j \Phi(P_{mk})\, \psi(h_{jk}) \quad : \text{ Variable head} \quad (\text{j} \in \text{NH}; \text{m} \in j + \text{NT}; \text{k} \in \text{T}) \tag{2.8}$$

The functions Φ and ψ are the quadratic function of hydro power and effective head, respectively and can be represented as:

$$\Phi(P_{mk}) = y_{1j} P_{mk}^2 + y_{2j} P_{mk} + y_{3j} \quad (\text{j} \in \text{NH}; \text{k} \in \text{T}) \tag{2.9}$$

$$\psi\left(h_{jk}\right) = z_{1j} h_{jk}^2 + z_{2j} h_{jk} + z_{3j} \quad (\text{j} \in \text{NH}; \text{k} \in \text{T}) \tag{2.10}$$

The effective water head is determined by considering that j^{th} hydro unit's reservoir has vertical sides and also having small capacity and if the reservoir storage limit is exceeded, spillage occurs. The Effective head continuity equation is given as

$$h_{j(k+1)} = h_{j(k)} + \frac{t_k}{S_j}\left(I_{kj} - q_{jk}\right) \quad (\text{j} \in \text{NH}; \text{k} \in \text{T}) \tag{2.11}$$

The net water head for a given time interval is determined as

$$h_{jk} = h_{j0} + \frac{1}{S_j}\left[\sum_{k=1}^{T} t_k I_{jk} - \sum_{k=1}^{T} t_k q_{jk}\right] \quad (\text{j} \in \text{NH}; \text{k} \in \text{T}) \tag{2.12}$$

2.5.3 SHORT-TERM HYDRO THERMAL SCHEDULING PROBLEM

The objective of STHTS is to determine the optimal power generation of hydrothermal units so as to minimize the total fuel cost of thermal units while satisfying several equality and inequality constraints.

Objective:

$$\text{Minimize } F_T = \sum_{k=1}^{T} \sum_{i=1}^{NT} t_k\left(a_{1i} P_{ik}^2 + a_{2i} P_{ik} + a_{3i} + a_{4i} \sin\left\{a_{5i}\left(P_i^{min} - P_{ik}\right)\right\}\right) \tag{2.13}$$

Subject to constraints

1) load demand constraint during each subinterval

$$\sum_{i=1}^{NT+NH} P_{ik} = P_{Dk} + P_{Lk} \qquad (k \in T) \qquad (2.14)$$

2) Water discharge of each hydro unit over a period should balance the available volume

$$\sum_{k=1}^{T} t_k q_{jk} = R_j \qquad (j \in NH) \qquad (2.15)$$

3) Water discharge rate limits on hydro units are

$$q_j^{min} \leq q_{jk} \leq q_j^{max} \qquad (j \in NH; k \in T) \qquad (2.16)$$

The bounds on hydro and thermal power generators are

$$P_i^{min} \leq P_{ik} \leq P_i^{max} \qquad (i \in NH + NT;\ k \in T) \qquad (2.17)$$

Transmission loss (P_{Lk}) during each subinterval k is given by Kron's loss formula using B-coefficients [20] is:

$$P_{Lk} = \sum_{i=1}^{NT+NH} \sum_{j=1}^{NT+NH} P_{ik} B_{ij} P_{jk} + \sum_{i=1}^{NT+NH} P_{ik} B_{i0} + B_{00} \qquad (k \in T) \qquad (2.18)$$

CHAPTER-3

HYBRID OPTIMIZATION TECHNIQUE

3.1 INTRODUCTION

PSO is a population based meta-heuristic algorithm introduced by Kennedy and Eberhart [63] in 1995. PSO is inspired by swarm intelligence theory such as bird flocking and fish schooling in which the particles fly around the physical multi-dimensional search space. PSO have a number of advantages [35] compare to other optimization technique, some of which are

1) It requires only few parameters to be set by user.
2) The mathematical calculation is much easier compare to any other optimization technique.
3) PSO is characterized by its fast convergence behaviour.
4) PSO has high accuracy.
5) PSO has an in-built ability to adapt a changing environment.
6) Its behaviour is not highly influenced by increase in dimension.

Although PSO has several advantages, it also suffers from the following disadvantages [37] [41]

1) The solution of PSO sometimes traps into local minima.
2) The PSO having the premature convergence.
3) The solution highly depends on the initial random solution.
4) Sometimes PSO cannot maintain the balance between the global exploration and local exploitation.

To overcome the shortcomings of the PSO technique, the dynamic multi-swarm technique was introduced by Liang and Suganthan [49]. DMSPSO is the local version of PSO in which whole population is divided into small number of sub-swarms. The particles in a sub-swarm will search the best position by considering the historical information of the own group. To provide the better exploration, the sub-swarms are regrouped frequently by using a regrouping schedule [49]. In this way, a much better solution can be obtained by DMSPSO compare to classical PSO. However, the complex optimization problem needs more attention for determine a better solution. Since the STHTS problem is very complex problem, sometimes DMSPSO technique cannot effectively handle the problem and provide a local optimal solution. To handle the complex optimization problem hybridization of two optimization techniques are found very effective. *Sequential quadratic programming* (SQP) is use here for hybridization with DMSPSO. The SQP is one of the best nonlinear programming for practical optimization problems in terms of accuracy, efficiency and convergence rate [56]. SQP is a conventional optimization technique which used a set mathematical procedure for optimization. The method is closely related to newton's method for constrained optimization problems. In each iteration hessian matrix is updated then a quadratic program is solved to find the search direction. These search directions are used to update the decision variables.

3.2 CLASSICAL PSO

PSO is a population based meta-heuristic algorithm introduced by Kennedy and Eberhart [63] in 1995. PSO is inspired by swarm intelligence theory such as bird flocking and fish schooling in which the particles fly around the physical multi-dimensional search space. During flight, each particle updates its position according to its own history and history of other particles. PSO provides the global exploration and local exploitation to find the optimum solution. Exploration is the ability to expand the search space while exploitation is the ability to found global optima near local optima obtained from global exploration [35]. PSO starts with random initialization of particles position and velocity within search space which subsequently updates the velocity and position to minimize the objective. Each particle in PSO considers the current position, current velocity, distance to local best position (Pbest), and distance to global best position (Gbest) to modify its position. PSO was mathematically formulated as:

$$V_{ij}^{t+1} = w \times V_{ij}^{t} + C_1 \times rand(1) \times \left(Pbest_{ij}^{t} - x_{ij}^{t}\right) + C_2 \times rand(2) \times (Gbest_{i}^{t} - x_{ij}^{t}) \quad (3.1)$$

$$x_{ij}^{t+1} = x_{ij}^{t} + V_{ij}^{t+1} \qquad (\mathrm{i} \in \mathrm{NT} + \mathrm{NH};\ j \in NP) \qquad (3.2)$$

V_{ij}^{t} is limited between minimum and maximum value of velocity, as given below

$$V_{i}^{min} \le V_{ij}^{t} \le V_{i}^{max} \qquad (3.3)$$

V_i^{max} is set to 15-20% of the dynamic range of the decision variable while V_i^{min} was set to 10-15% of the dynamic range of the decision variable but always with the negative sign [2]. w is continuously decreasing from $w^{max} = 0.9$ to $w^{min} = 0.4$, mathematically given as

$$w = w^{max} - (\frac{w^{max} - w^{min}}{\mathrm{IT}^{max}}) \times \mathrm{IT} \tag{3.4}$$

The updated velocity term in Eq. (3.1) is contains 3 parts. The physical significance [35] of the individual parts is given as

1) The first term is momentum, which is used for previous velocity term having tendency to carry the particle in the direction it has travelled so far;
2) The second term is cognitive component or self-knowledge, it having the tendency to return to the best position achieved so far;
3) Last term is social component or cooperation; it has the tendency to be attracted towards the best position achieved by its neighbourhood particles so far.

3.3 DYNAMIC MULTI-SWARM PARTICLE SWARM OPTIMIZER

Dynamic multi-swarm particle swarm optimizer (DMSPSO) is the local version of PSO in which whole population is divided into small number of sub-swarms [50]. The particles in a sub-swarm will search the best position by considering the historical information of the own group.

$$V_{ij}^{t+1} = w \times V_{ij}^t + C_1 \times rand(1) \times \left(Pbest_{ij}^t - x_{ij}^t\right) + C_2 \times rand(2) \times (Ibest_{il}^t - x_{ij}^t) \tag{3.5}$$

The velocity and the position of the swarm are update by the Eq. (3.5) and (3.2), respectively. However, to exchange the information between the sub-swarm they were regrouped frequently by using a random regrouping schedule. Particles from different sub-swarms are regrouped to form a new configuration by using the random regrouping schedule. In this way, the physical search space of each small sub-swarm is expanded and better solutions are possible to be found by the new small sub-swarm [52]. The regrouping period R is a key factor which has the major effect on the result obtained. If R is too small, the sub-swarms are not able complete the adequate search procedure in given number of iterations. If R is set too high, the evaluation procedure will be wasted after some iteration if the sub-swarms could not improve the results further. So, to save the time and to obtain a good solution the R should neither be too small nor too large. This procedure is shown in Fig. (3.1).

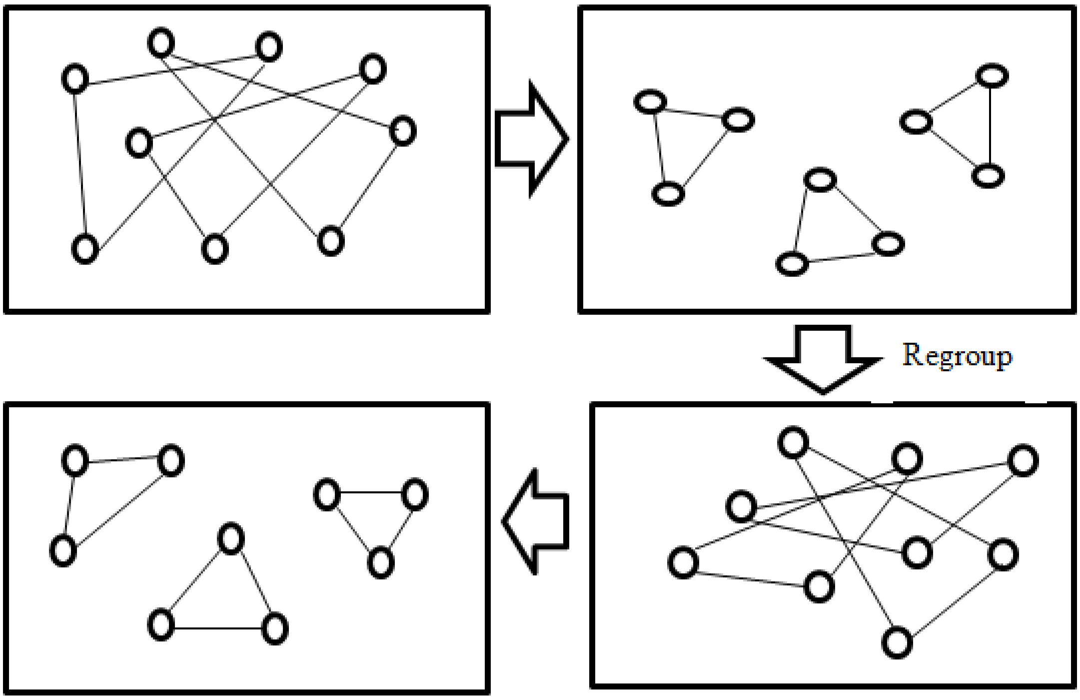


Figure 3.1 DMSPSO's search process

The total iterative process is divided into two phases. The top eighty percent of the iterations run as the above sub-swarm strategy. The process is mostly used to conduct an extensive search. The remaining iterations run as the global version PSO which can be used as a targeted search procedure.

3.3.1 ALGORITHM: DMSPSO

Step 1: Randomly initialize the velocity of particles and position of particles within the search space.

Step 2: For each particle calculate the objective function.

Step 3: If iteration count IT $< 0.8 * IT_1^{max}$, go to next step, otherwise go to step 8.

Step 4: Randomly divide the particles into l no. of sub-swarm.

Step 5: Update velocity and position of each particle according to Eq. (3.5) and (3.2), respectively.

Step 6: Update the Pbest for each particle and choose the particle with minimum objective function for each l^{th} sub-swarm as$lbest_l$.

Step 7: Recombine the swarms in a single group and go to step 3.

Step 8: Update velocity and position of each particle according to Eq. (3.1) and Eq. (3.2), respectively.

Step 9: Update the Pbest for each particle and choose the particle with minimum objective function as Gbest.

Step 10: If maximum number of iteration reached, go to next step, otherwise go to step 8.

Step 11: The value of Gbest obtained is the final result.

3.4 SEQUENTIAL QUADRATIC PROGRAMMING

Sequential quadratic programming (SQP) is widely used to solve practical optimization problems. The SQP is one of the best nonlinear programming for optimization problems in terms of accuracy, efficiency and convergence rate [54]. The method is closely related to newton's method for constrained optimization problems. At each iteration, the hessian matrix is updated and then a quadratic programming sub-problem is solved to find the search direction. This search direction is used to update the decision variables.

The SQP can be described as [57]

Minimize the following

$$\frac{1}{2}(d^t)^T H^t d^t + \nabla f(x^t)^T d^t \qquad (3.6)$$

Subjected to

$$g_i(x^t) + [\nabla g(x^t)]^T d^t = 0 \qquad (i \in m_c) \qquad (3.7)$$

$$g_i(x^t) + [\nabla g(x^t)]^T d^t \leq 0 \qquad (i \in m) \qquad (3.8)$$

where,

H^t is the hessian matrix of the lagrangian function defined by

$$L(x, \lambda) = f(x) + \lambda^T g_i(x) \qquad \text{at, } x = x^t \qquad (3.9)$$

d^t is search direction at t^{th} iteration.

λ is lagrange multiplier.

f(x) is objective function.

g(x) is constraints.
m is number of inequality constraints.
m_c is number of equality constraints.

SQP consists of three main stages as follows-

(1) Update the hessian matrix
The *Broyden-Fletcher-Goldfarb-Shanno* (BFGS) Quasi-Newton method is used to update the hessian matrix at each iteration, given as

$$H^{t+1} = H^t + \frac{q^t(q^t)^T}{(q^t)^T(x^{t+1}-x^t)} - \frac{(H^t(x^{t+1}-x^t))(H^t(x^{t+1}-x^t))^T}{(x^{t+1}-x^t)^T H^t(x^{t+1}-x^t)} \tag{3.10}$$

where, q^t is the difference of gradient of objective function at x^{t+1} and x^t.
for any non-differentiable function, the gradient is computed by the first principle i.e. finite difference method.

(2) Quadratic programming problem
At each iteration t, a search direction d^t can be calculated by solving the quadratic programming sub-problem given in Eq. (3.6).

(3) Calculation of line search
The search direction d^t is used to find a new iteration

$$x^{t+1} = x^t + \alpha d^t \tag{3.11}$$

The step length α calculated so as to produce a significant decrease in the objective function.

3.5 HYBRID OPTIMIZATION TECHNIQUE

The hybrid optimization technique combines the DMSPSO technique with the SQP optimization technique. Due to hybridization, the better exploration and exploitation is available. The DMSPSO is a global search optimization technique used for exploration of search space and the exploitation is provided by local search optimization technique SQP. The flowchart of the hybrid DMSPSO-SQP optimization technique is given in Fig. (3.2).

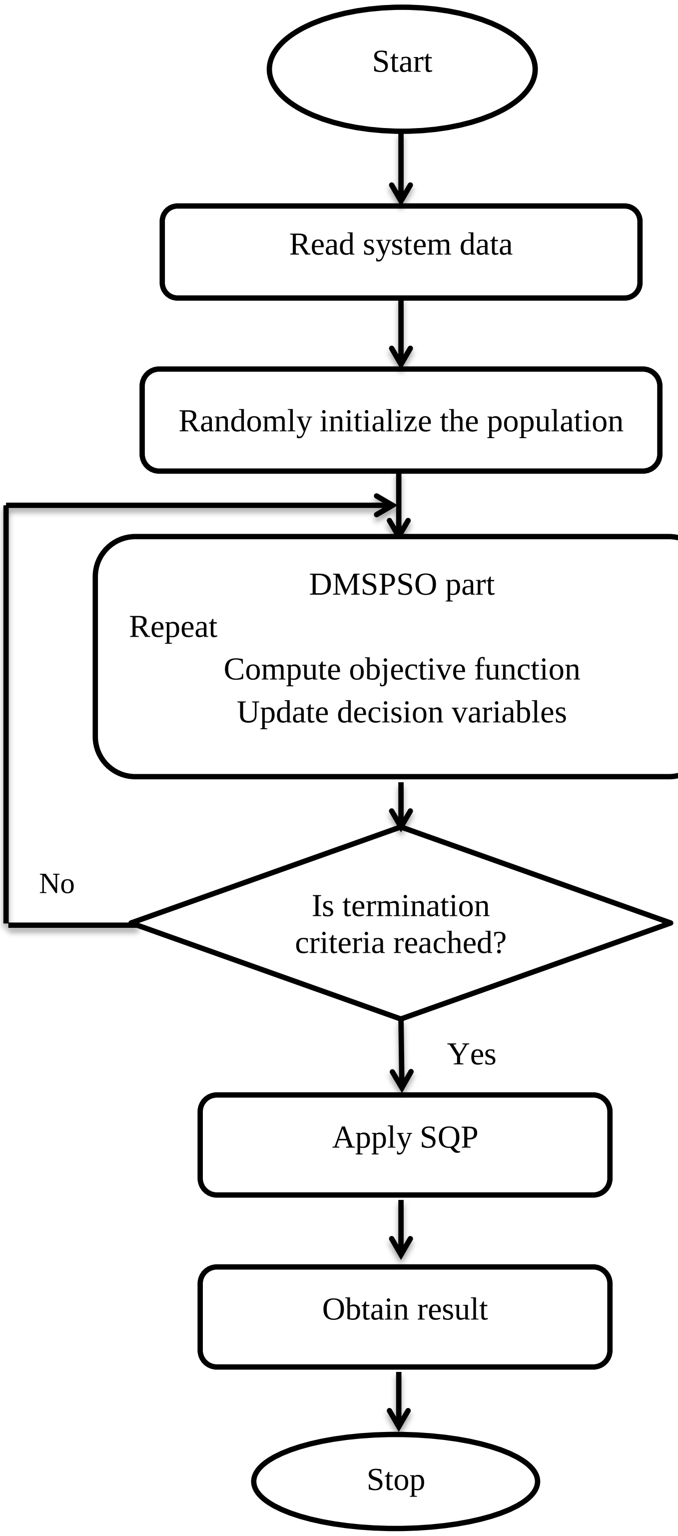


Figure 3.2 Flowchart of hybrid optimization technique

CHAPTER-4

SHORT-TERM HYDROTHERMAL SCHEDULING USING HYBRID OPTIMIZATION TECHNIQUE

4.1 INTRODUCTION

The scheduling problem of fixed and variable head short-term hydrothermal generating plants can be considered as minimization of total fuel cost associated with the all thermal units with simultaneously satisfaction of equality and inequality constraints. In fixed and variable head STHTS, power demand equality constraint and water discharge rate equality constraint are two equality constraints along with one inequality constraint on lower and upper limits of water discharge rate. A hybrid optimization technique of DMSPSO and SQP is implemented to determine the optimal scheduling of fixed and variable head short-term hydrothermal scheduling. DMSPSO is used as a global search optimization technique for exploration of the search space while the SQP is used as a local search optimization technique for fine tuning of the results obtained from DMSPSO technique.

4.2 FORMULATION OF OBJECTIVE FUNCTION

The scheduling of fixed and variable head short-term hydrothermal plants associated with cost function which includes the quadratic function of thermal power and cost due to the valve point loading effect for fossil-fuel based unit. Mathematically, the operating cost of thermal unit is expressed as

$$F_T = \sum_{k=1}^{T} \sum_{i=1}^{NT} t_k \left(a_{1i} P_{ik}^2 + a_{2i} P_{ik} + a_{3i} + a_{4i} \sin\left\{ a_{5i} \left(P_i^{min} - P_{ik} \right) \right\} \right) \tag{4.1}$$

subject to constraints as discussed in Eq. (2.14) to (2.16) in chapter 2.

4.2.1 EQUALITY AND INEQUALITY CONSTRAINTS

During the search of decision variables i.e. thermal power and hydro power, the equality and inequality constraints may violate. The hybrid DMSPSO-SQP optimization technique is an unconstraint optimization technique. To consider the effect of various constraints in the fixed and variable head STHTS problem, the constraints handling method must be incorporated externally to the hybrid DMSPSO-SQP technique.

In the present power system the load demand is very fluctuating; hence the mismatch between generated power and power demand is much common. Now, it is necessary to take care of this mismatch so as to satisfy the power demand equality constraint as discussed in Eq. (2.14). The error generated from the mismatch of power is calculated as:

$$E_1 = \sum_{i=1}^{NT+NH} P_{ik} - P_{Dk} - P_{Lk} \tag{4.2}$$

Due to the hydro units, the available water for each hydro unit is also fixed which is to be met by each hydro unit at the end of scheduling period as given in Eq. (2.15). So, the error generated from the mismatch from the available water is computed as:

$$E_2 = \sum_{k=1}^{T} t_k q_{jk} - R_j \tag{4.3}$$

The water discharge rate inequality constraint may violate, if the updated water discharge rate falls outside the given range. So, water discharge rate inequality constraint can violate either by exceeding the upper limit or by falls below the lower limit. The error generated, if the limits of water discharge rate is violated can be calculated as:

$$E_3 = \begin{cases} q_j^{min} - q_{jk} & \text{, if } (q_{jk} < q_j^{min}) \\ q_{jk} - q_j^{max} & \text{, if } (q_{jk} > q_j^{max}) \end{cases} \tag{4.4}$$

4.2.2 OBJECTIVE FUNCTION

For determination of optimal scheduling by the proposed technique on the STHTS problem, the objective function needs to be evaluated. The objective function is formed in such a way that it minimizes the total fuel cost associated with thermal units along with proper handling of all the constraints. Mathematically, the objective function is formed by adding the total fuel cost function discussed in Eq. (4.1) with the summation of square of all the computed errors as given in Eq. (4.2) to (4.4) multiplying with exterior penalty factor as:

$$\text{obj.} = F_T + r_p \times (E_1^2 + E_2^2 + E_3^2) \tag{4.5}$$

4.3 PROPOSED TECHNIQUE ON THE STHTS

In this section, the proposed hybrid DMSPSO-SQP optimization technique is discussed for fixed and variable head STHTS problem. The algorithm starts with random initialization of decision variables; thermal power and hydro power. The initialization must be within the search space. For a hydrothermal system having NT+NH generating units (NT thermal and NH hydro units), the position of each particle is initializes randomly with in the search space as described in Eq. (2.17) which can be represented as

$$X_j^0 = (P_{j1}^0, P_{j2}^0, \dots \dots \dots \dots \dots \dots, P_{jNT+NH}^0) \qquad (j \in NP) \qquad (4.6)$$

Now, the velocity of particles is also randomly initialize according to Eq. (3.3), which can also be represented as

$$V_j^0 = (V_{j1}^0, V_{j2}^0, \dots \dots \dots \dots \dots \dots, V_{jNT+NH}^0) \qquad (j \in NP) \qquad (4.7)$$

4.3.1 ALGORITHM: PROPOSED TECHNIQUE ON STHTS

The Algorithm steps for the implementation of proposed techniques on the fixed and variable head hydrothermal scheduling is as follows:

Step 1: Parameter selection for DMSPSO

Read data; viz. Maximum iteration for DMSPSO (IT_1^{max}), population size (NP), limits of velocity and other algorithm constants.

Step 2: Initialization of population

Randomly initialize the velocity of particles and position of particles within the search space.

Step 3: Calculation of objective function

For each particle, calculate the objective function using Eq. (4.5).

Step 4: Determination of iteration count

If iteration count IT< 0.8*IT_1^{max}, go to next step, otherwise go to step 9.

Step 5: Sub-swarm formation

Divide the whole particles randomly into l no. of sub-swarm randomly.

Step 6: Update velocity and position of particles

Update velocity of particles according to Eq. (3.5) and check

If ($V_{ij}^{new} < V_i^{min}$), then $V_{ij}^{new} = V_i^{min}$

If ($V_{ij}^{new} > V_i^{max}$), then $V_{ij}^{new} = V_i^{max}$

Update position of each particle according to Eq. (3.2) and check

If ($P_{ij}^{new} < P_i^{min}$), then $P_{ij}^{new} = P_i^{min}$

If ($P_{ij}^{new} > P_i^{max}$), then $P_{ij}^{new} = P_i^{max}$

Step 7: Update local best and global best for each group

Update the Pbest for each particle and choose the particle with minimum objective function for each l^{th} sub-swarm as$Ibest_l$.

Step 8: Recombine the swarm

Recombine the swarms in a single group and go to step 4.

Step 9: Update velocity and position of particles

Update velocity of particles according to Eq. (3.1) and check

If ($V_{ij}^{new} < V_i^{min}$), then $V_{ij}^{new} = V_i^{min}$

If ($V_{ij}^{new} > V_i^{max}$), then $V_{ij}^{new} = V_i^{max}$

Update position of each particle according to Eq. (3.2) and check

If ($P_{ij}^{new} < P_i^{min}$), then $P_{ij}^{new} = P_i^{min}$

If ($P_{ij}^{new} > P_i^{max}$), then $P_{ij}^{new} = P_i^{max}$

Step 10: Update local best and global best

Update the Pbest for each particle and choose the particle with minimum objective function as Gbest.

Step 11: Termination criteria for DMSPSO

If maximum number of iteration (IT_1^{max}) reached, go to next step, otherwise go to step 9.

Step 12: Initial point for SQP

The value of Gbest obtained is the initial value of decision variables for SQP.

Step 13: Parameter selection for SQP

Read data for SQP; viz. Maximum iteration for SQP (IT_2^{max}), initial hessian matrix and step length.

Step 14: Calculation of search direction

Calculate the search direction by solving quadratic programming sub-problem discussed in Eq. (3.6).

Step 15: Update the decision variables

Update the Gbest using Eq. (3.11).

Step 16: Termination criteria for SQP

If maximum number of iteration for SQP (IT_2^{max}) reached, go to next step, otherwise go to step 14.

Step 17: Final result

The value of Gbest obtained is the final scheduling result.

CHAPTER-5

RESULT AND DISCUSSION

5.1 INTRODUCTION

To check the validity and effectiveness of the proposed hybrid DMSPSO-SQP technique was applied to the various fixed and variable head STHTS test systems. The proposed algorithm has been tested on four standard hydrothermal test systems.

5.2 TEST SYSTEMS

The test systems are divided into two cases.

Case I: Fixed head short-term hydrothermal test systems.
The case I consist of two fixed head short-term hydrothermal test systems:

Test system 1: In this test system, two thermal and two hydro units are considered. The thermal unit is free from valve point loading effect. The total scheduling period is of 24 hrs. which is divided into 3 subintervals of 8 hrs. The data is taken from [64] and listed in appendix A.

Test system 2: This test system consists of two hydro and two thermal units including the valve point loading effect. Total scheduling period is of 24 hrs. which is divided into three equal subintervals of 8 hrs. The data is taken from [19] and listed in appendix B.

Case II: Variable head short-term hydrothermal test systems.
The case II consist of two variable head short-term hydrothermal test systems:

Test system 1: In this test system, two thermal and two hydro units are considered. The total scheduling period is of 24 hrs. which is divided into 24 subintervals. The data is taken from [29] and listed in appendix C.

Test system 2: This test system slightly complex as it consists of 4 hydro and 5 thermal units. The total scheduling period is of 24hrs. which is divided into 24 subintervals of 1hr. each. The data is taken from [31] and listed in appendix D.

5.3 SIMULATION RESULTS

The proposed research work has been carried out in the FORTRAN-90 compiler for the optimal generation scheduling of short-term hydrothermal system. In order to obtain more better and stable solution, a number of trials had been carried for the different values of algorithm parameters. The value of parameters of DMSPSO and SQP techniques for optimal cost are given in table (5.1) and (5.2), respectively.

Table 5.1 Parameter for DMSPSO

Parameter	Case I		Case II	
	Testsystem1	Testsystem2	Testsystem1	Testsystem2
IT^{Max}	100	250	250	350
NP	30	30	45	60
C_1	2	2	1.8	1.6
C_2	2	2	1.8	1.6

Table 5.2 Parameter for SQP

Parameter	Case I		Case II	
	Testsystem1	Testsystem2	Testsystem1	Testsystem2
IT^{Max}	200	150	150	100
α	0.1×10^{-4}	0.1×10^{-4}	0.1×10^{-3}	0.1×10^{-5}

5.3.1 COST COMPARISON OF VARIOUS TEST SYSTEMS

The optimum cost is achieved by DMSPSO technique alone and by using hybrid DMSPSO-SQP for various fixed and variable head short-term hydrothermal test systems. The result obtained of various hydrothermal test systems for both case I and case II are compared with the results pertaining in various literature given in table (5.3) and table (5.4).

Table 5.3 Cost comparison for case I test systems

Test system 1		Test system 2	
Method	Cost ($)	Method	Cost ($)
RCGA [65]	66,603	AIS [19]	66,117
DMSPSO	64,793	DE [19]	66,121
DMPSO-SQP	64,724	DMSPSO	65,166
		DMSPSO-SQP	65,137

Table 5.4 Cost comparison for case II test systems

Test system 1		Test system 2	
Technique	Cost ($)	Method	Cost ($)
CFPSO [29]	69,801	RCGA [31]	4,61,717
DE [29]	69,801	DMSPSO	4,64,287
DMSPSO	69,013	DMSPSO-SQP	4,64,273
DMSPSO-SQP	68,969		

5.3.2 RESULTS OBTAINED OF CASE I (TEST SYSTEM1)

This test system is the simplest test system as it contains only two hydro and two thermal generating units and the fuel cost characteristics is perfectly quadratic i.e. valve point loading is neglected. The optimum value of fuel cost for this test system using DMSPSO is 64,793$. The generated power and transmission losses for this test system using DMSPSO technique is given in table (5.5). The water discharge rate corresponding to obtained hydro power is shown in Fig. (5.1).

Table 5.5 Result obtained of case I (test system1) using DMSPSO

k	Thermal Power (MW)		Hydro Power (MW)		P_{Lk}(MW)
	P_{1k}	P_{2k}	P_{3k}	P_{4k}	
1	168.5629	412.2880	233.9244	113.5758	28.35099
2	190.9703	624.2994	262.9991	173.7158	51.98477
3	211.5532	488.9386	337.1959	105.1933	42.88113

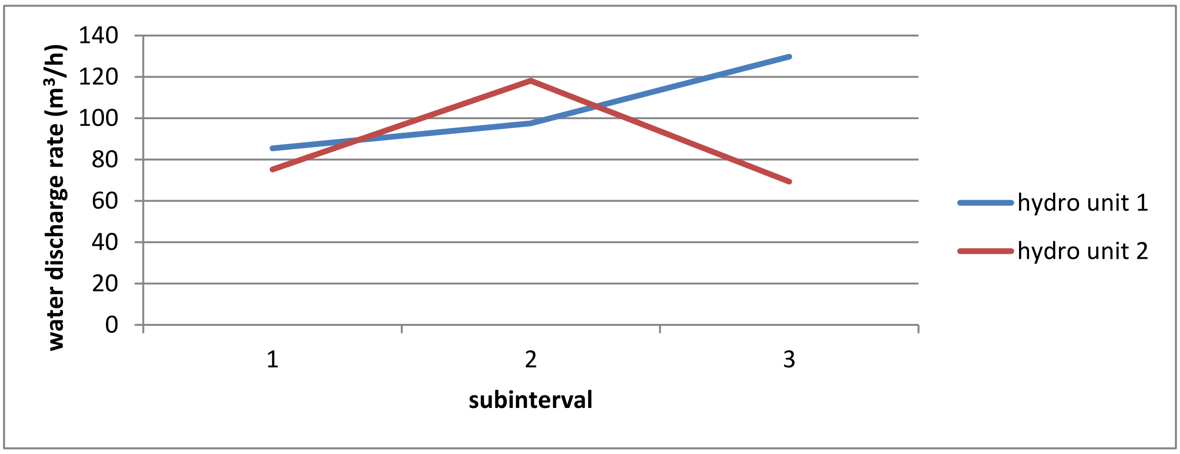


Figure 5.1 Water discharge rate for case I (testsystem1) using DMSPSO

The result of DMSPSO when applied to SQP, the cost reduced to 64724 $. For case I (testsystem1) generated power and transmission losses using hybrid DMSPSO-SQP are shown in table (5.6) and corresponding water discharge rate is given in Fig. (5.2).

Table 5.6 Result obtained of Case I (test system1) using DMSPSO-SQP

k	Thermal Power (MW)		Hydro Power (MW)		P_{Lk} (MW)
	P_{1k}	P_{2k}	P_{3k}	P_{4k}	
1	168.4915	412.2154	233.8888	113.5231	28.3366
2	190.8971	624.2261	262.9627	173.6599	51.96534
3	211.4786	488.8657	337.1568	105.1412	42.86289

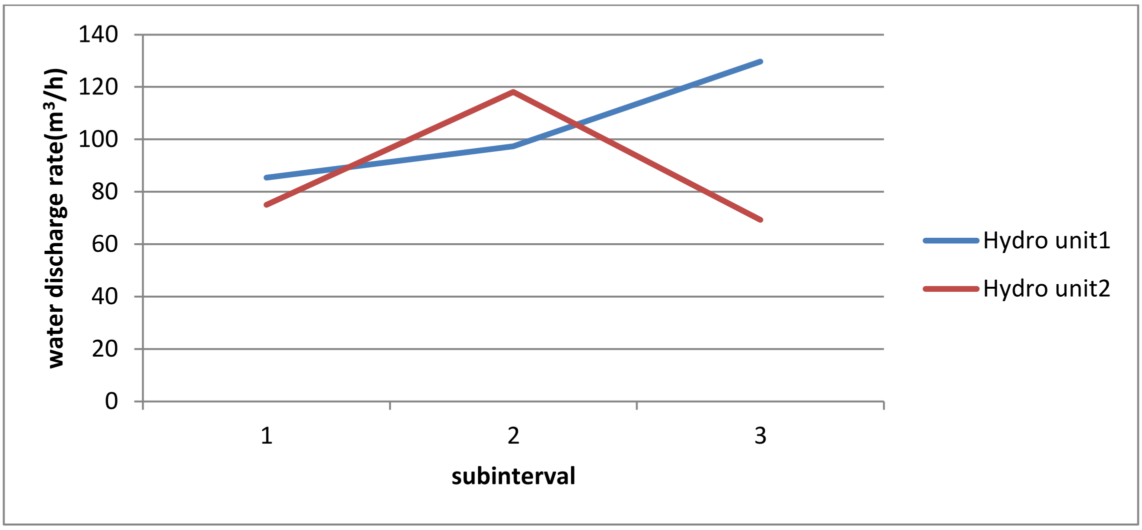


Figure 5.2 Water discharge rate for case I (test system1) using DMSPSO-SQP

5.3.3 RESULTS OBTAINED OF CASE I (TEST SYSTEM2)

This test system also consist of two hydro and two thermal units but the fuel cost of thermal units are also considers the valve point loading effect. The optimal cost for this test system using DMSPSO is calculated as 65,166$. The result obtained for this case using DMSPSO technique is given in table (5.7) and Fig. (5.3).

Table 5.7 Result obtained of Case I (test system2) using DMSPSO

k	Thermal Power(MW)		Hydro Power(MW)		P_{Lk}(MW)
	P_{1k}	P_{2k}	P_{3k}	P_{4k}	
1	122.8349	397.5510	259.5112	148.9398	28.83692
2	276.3527	546.8024	299.7611	129.7674	52.68374
3	173.8371	577.4645	277.3087	114.9050	43.51543

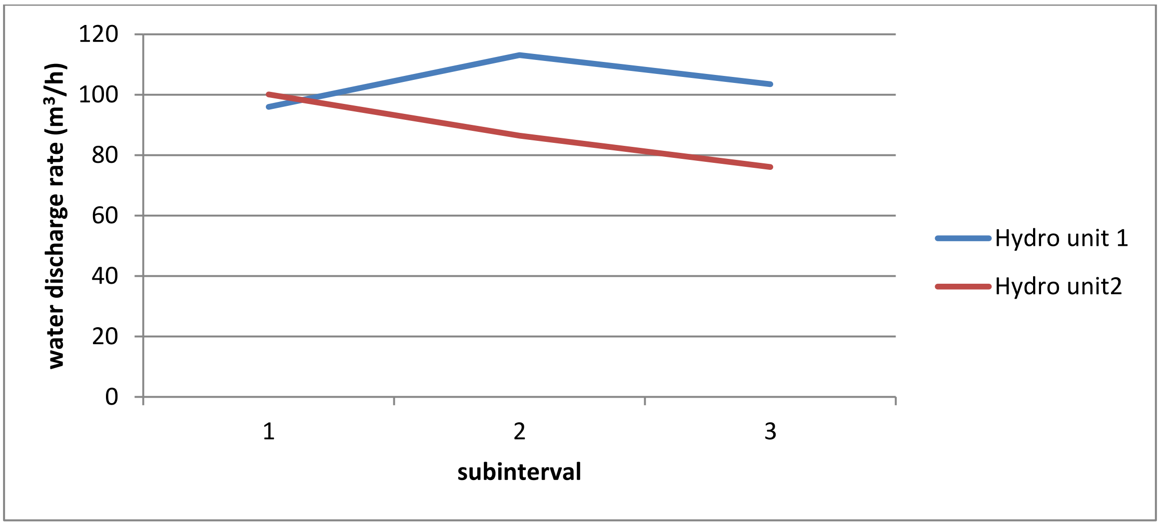


Figure 5.3 Water discharge rate for case I (test system2) using DMSPSO

For this test system the optimal cost obtained using DMSPSO-SQP is 65,137$. The result obtained for this test system using DMSPSO-SQP technique is given in table (5.8) and Fig. (5.4).

Table 5.8 Result obtained of Case I (test system2) using DMSPSO-SQP

k	Thermal Power (MW)		Hydro Power (MW)		P_{Lk} (MW)
	P_{1k}	P_{2k}	P_{3k}	P_{4k}	
1	122.5943	397.4985	259.6037	149.0209	28.67325
2	276.2151	546.7250	299.6774	129.6169	52.23130
3	173.5783	577.4094	277.2975	114.9667	43.25536

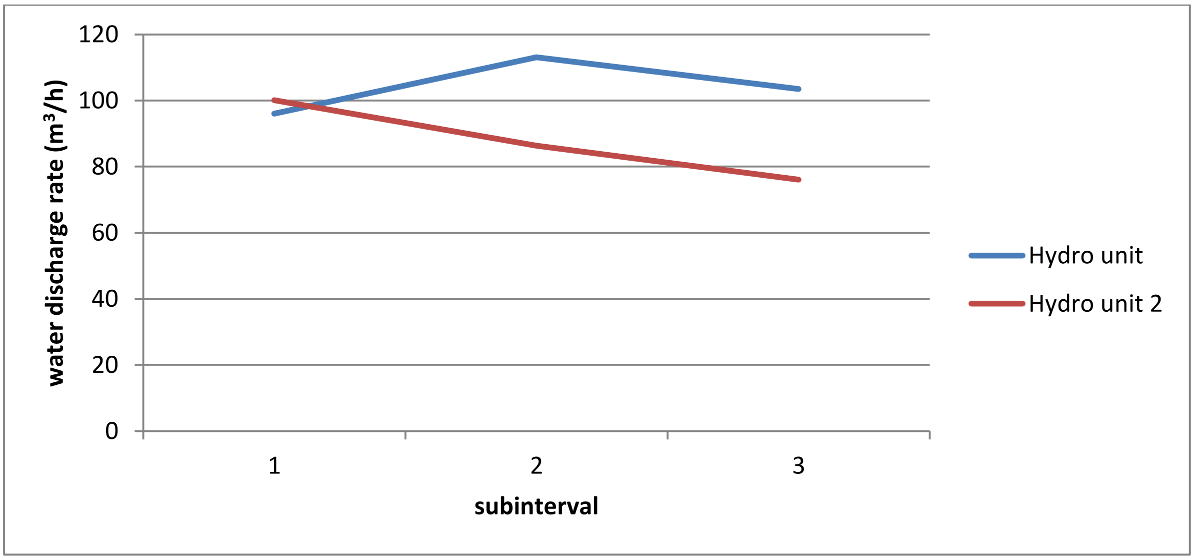


Figure 5.4 Water discharge rate for case I (test system2) using DMSPSO-SQP

5.3.4 RESULTS OBTAINED OF CASE II (TEST SYSTEM1)

This is small variable head hydrothermal system. It consists of two thermal and two hydro units. The optimal cost is calculated as 69,013$ using DMSPSO technique. The generated power and transmission loss for this test system during the period of 24h. using DMSPSO technique is given in table (5.9). The water discharge rate and effective head variation for this test system using the DMSPSO technique are given in Fig. (5.5) and (5.6), respectively.

Table 5.9 Result obtained of Case II (test system1) using DMSPSO

k	Thermal Power(MW)		Thermal Power(MW)		P_{Lk} (MW)
	P_{1k}	P_{2k}	P_{3k}	P_{4k}	
1	118.0411	344.8005	311.7521	47.86581	22.45957
2	50.00000	310.6939	352.1883	5.000000	17.88233
3	50.00000	358.0374	200.0000	5.000000	13.03743
4	50.00000	358.0374	200.0000	5.000000	13.03743
5	50.00000	320.4679	237.2747	5.000000	12.74263
6	50.00000	328.6064	281.4460	5.000000	15.05064
7	50.00000	413.5532	200.0000	160.0623	23.61550
8	160.9235	593.3304	271.0819	11.49116	36.82704
9	300.0000	605.7232	363.7502	125.6052	65.07864
10	300.0000	655.4930	374.1541	87.53142	67.17855
11	300.0000	700.8641	344.5252	182.3486	77.73792
12	300.0000	731.5007	252.4437	300.0000	83.94434
13	135.4119	658.3583	458.3701	110.1458	62.28621
14	280.4546	606.0670	392.1866	137.9549	66.66312
15	239.6890	621.3312	550.0000	5.000000	66.02027
16	300.0000	685.1110	440.8232	13.29110	69.22547
17	87.80025	750.0000	428.6345	265.3518	81.78644
18	300.0000	738.4789	399.9921	223.0376	91.50883
19	300.0000	557.7542	349.1521	300.0000	76.90620
20	300.0000	600.4353	462.3727	54.06188	66.87014
21	300.0000	503.8982	438.4727	87.37184	59.74265
22	269.3467	620.3002	304.8214	5.000000	49.46845
23	50.00000	595.8087	285.7542	106.6378	38.20068
24	129.6184	423.4128	342.4833	32.93286	28.44732

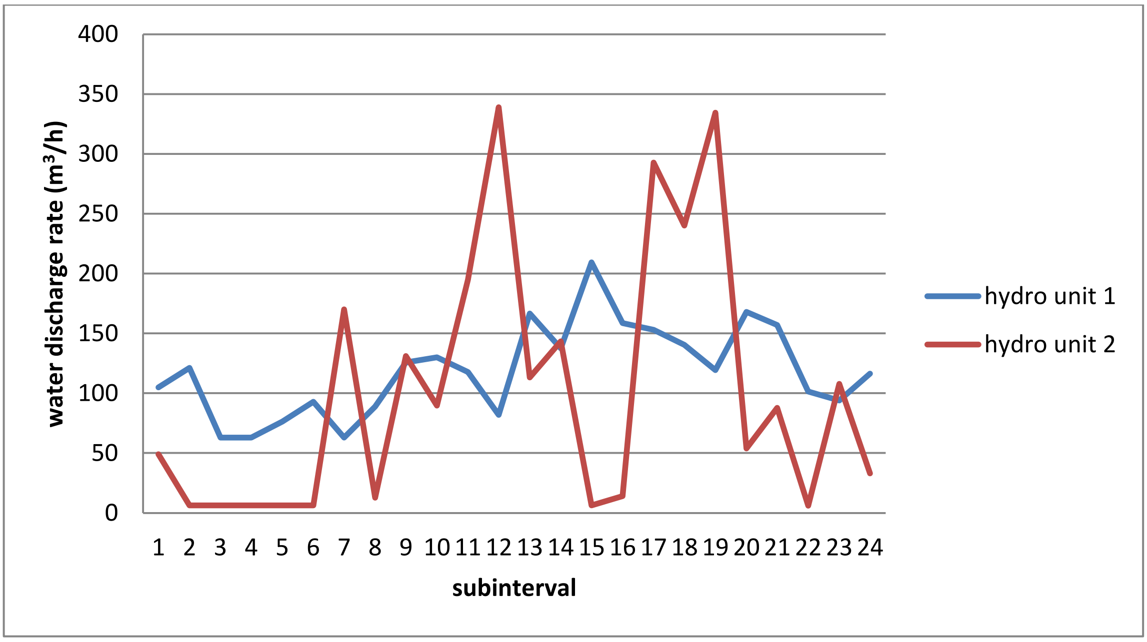


Figure 5.5 Water discharge rate for case II (test system1) using DMSPSO

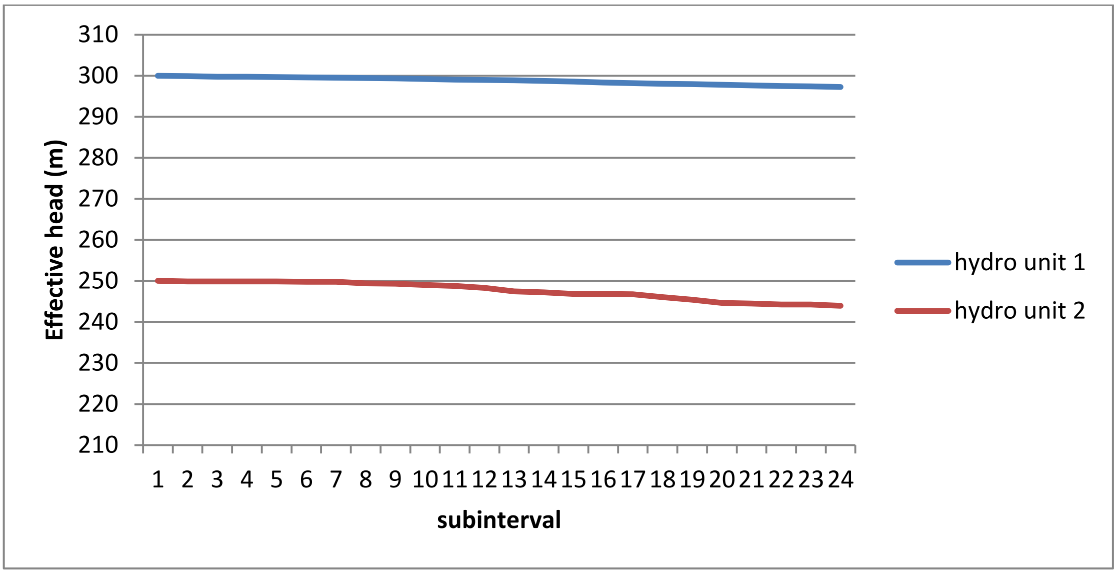


Figure 5.6 Effective head for case II (test system1) using DMSPSO

The hybridization of SQP technique to the DMSPSO technique was reduced the cost for this test system to 68,969$. The generated power and transmission losses for this test system are given in table (5.10). The water discharge rate and effective head variation for this test system using hybrid DMSPSO-SQP technique during the period of 24h. are given in Fig. (5.7) and (5.8), respectively.

Table 5.10 Result obtained of Case II (test system1) using DMSPSO-SQP

k	Thermal Power(MW)		Hydro Power(MW)		P_{Lk}(MW)
	P_{1k}	P_{2k}	P_{3k}	P_{4k}	
1	117.831900	344.556600	311.767700	47.8413700	22.435940
2	50.0000000	310.307500	352.115200	5.02733800	17.862190
3	50.0000000	357.194800	200.059900	5.34034500	13.011900
4	50.0000000	357.313800	200.000000	5.33899700	13.015370
5	50.0000000	320.073100	237.241200	5.00532400	12.723990
6	50.0000000	328.210500	281.404000	5.01074200	15.030980
7	50.0000000	413.179000	200.111600	159.883300	23.589100
8	160.676700	593.093000	271.093300	11.4922200	36.792580
9	299.807100	605.518100	363.746100	125.511400	65.030200
10	299.798000	655.278100	374.132100	87.4920800	67.130570
11	299.800800	700.649400	344.591700	182.207500	77.685870
12	299.841900	731.334700	252.520900	299.733600	83.888530
13	135.221500	658.168600	458.258900	110.139100	62.244380
14	280.270300	605.860900	392.178700	137.853700	66.614700
15	239.508700	621.130600	549.756400	5.13316800	65.974340
16	299.790100	684.898800	440.718700	13.3303900	69.176020
17	87.6210200	749.844100	428.624500	265.183000	81.738380
18	299.822100	738.293600	400.003500	222.880700	91.451580
19	299.850300	557.581200	349.216300	299.743300	76.852260
20	299.806200	600.217800	462.254300	54.0967600	66.821690
21	299.805600	503.674700	438.423900	87.3446500	59.697110
22	269.098100	620.042700	304.813000	5.04214200	49.424350
23	50.0000000	595.350200	285.664400	106.791500	38.168230
24	129.376400	423.193100	342.477500	32.9244100	28.919430

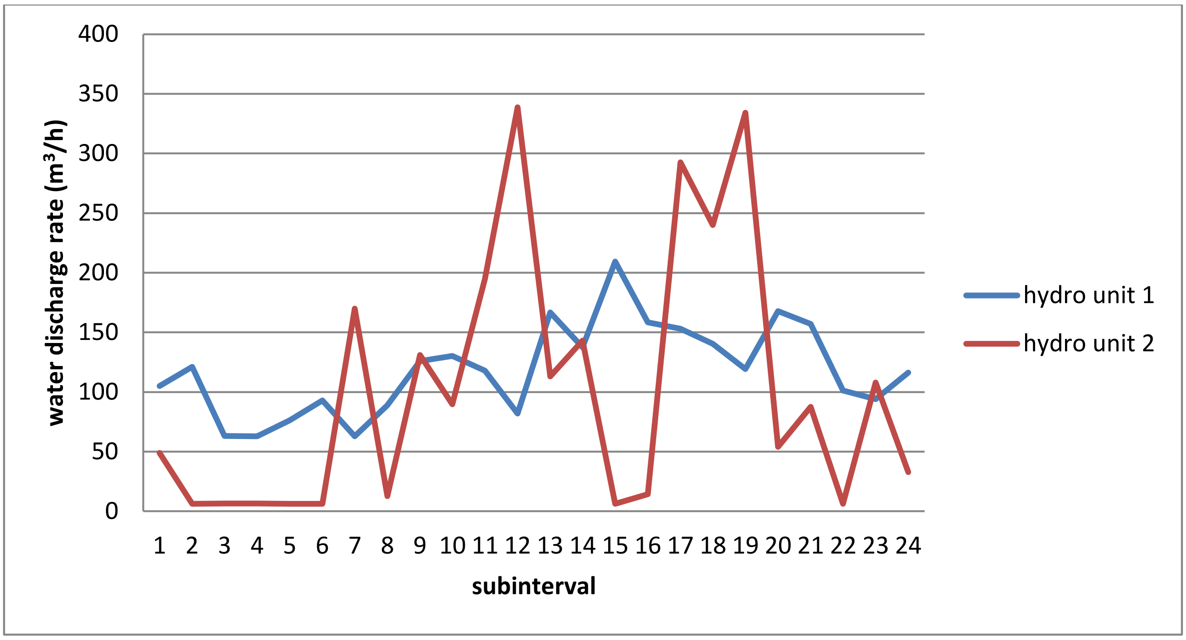


Figure 5.7 Water discharge rate for case II (test system1) using DMSPSO-SQP

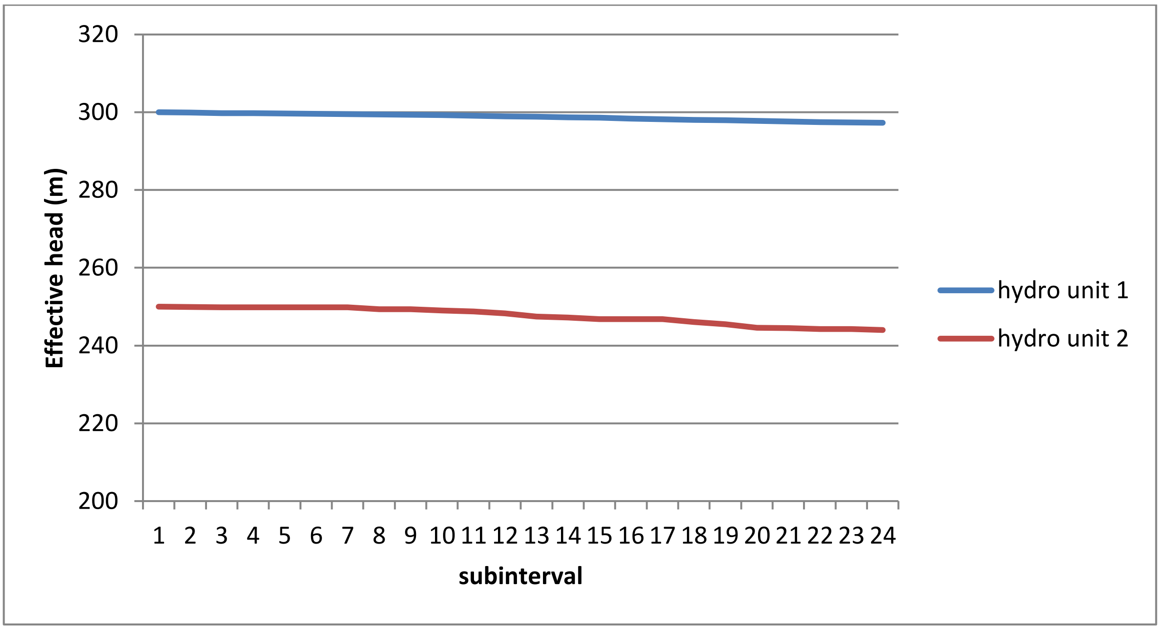


Figure 5.8 Effective head for case II (test system1) using DMSPSO-SQP

5.3.5 RESULTS OBTAINED OF CASE II (TEST SYSTEM2)

This is medium variable head hydrothermal test system. It consists of five thermal units and four hydro units. The cost obtained for this test system using DMSPSO is 4,64,287 $. The thermal power and hydro power for this test system using DMSPSO technique is given in table (5.11) and (5.12), respectively. The water discharge rate and effective head variation for this test system using the DMSPSO technique during the period of 24h. are given in Fig. (5.9) and (5.10), respectively.

Table 5.11 Thermal power generation using DMSPSO

k	Thermal power generation(MW)				
	P_{1k}	P_{2k}	P_{3k}	P_{4k}	P_{5k}
1	923.8156	784.6057	737.8176	774.5580	726.5568
2	784.5080	972.4257	801.5450	831.2109	880.7626
3	758.6437	836.8261	956.7463	825.5034	914.5475
4	853.3079	757.3130	793.1377	678.9836	838.0778
5	952.5236	861.3532	912.7554	966.1500	858.3879
6	774.0831	973.8867	963.1412	949.3078	766.6219
7	914.3632	974.2172	768.1262	838.7032	969.3141
8	915.7121	959.1005	949.2683	852.8315	811.6722
9	766.0674	784.1102	881.7994	783.8780	739.9887
10	710.3624	905.1835	829.5359	769.0604	902.3398
11	893.5404	945.4573	789.5020	918.2769	708.4665
12	736.2924	728.2491	646.4083	927.0951	850.6499
13	630.2257	843.9933	847.3386	691.4503	929.4077
14	826.8661	830.5921	895.3372	972.5317	810.0511
15	409.1240	626.8892	720.2341	488.4560	440.2611
16	582.0173	550.0221	529.7100	543.9357	332.4930
17	451.1458	559.5430	489.9225	672.4333	578.5831
18	546.9828	601.1132	550.6365	465.4247	488.7608
19	514.9875	517.2529	581.5934	514.5630	546.4465
20	461.8542	541.4648	531.6276	599.5637	404.8044
21	560.8157	623.3241	340.0200	752.4385	386.2130
22	472.3954	592.7836	335.9670	462.0875	523.3617
23	561.8918	586.9470	335.2574	523.8203	724.3765
24	509.1605	735.1398	512.5041	640.5989	482.5203

Table 5.12 Hydro power and transmission losses using DMSPSO-SQP

k	Hydro power generation (MW)				P_{Lk}(MW)
	P_{6k}	P_{7k}	P_{8k}	P_{9k}	
1	577.1613	589.3130	475.5711	468.8843	610.2762
2	557.7779	488.7492	649.9763	510.1646	701.1179
3	545.2126	488.4753	545.0686	474.7077	681.7306
4	615.5006	516.1947	586.6600	624.5643	639.7342
5	537.6343	604.6962	472.4745	520.0759	758.0497
6	609.6143	595.0454	559.8093	648.0109	775.5188
7	620.8703	634.3550	648.5635	503.1009	783.6116
8	471.0583	530.6671	561.6401	541.6356	737.5881
9	432.2117	565.0049	574.6910	567.0318	614.7768
10	424.8024	472.2301	522.7214	557.7581	629.9955
11	440.2000	561.4698	542.3832	622.4619	693.7556
12	604.1652	551.8665	507.6465	608.7116	625.0865
13	587.2360	468.2511	552.1705	457.3255	607.3979
14	607.0468	645.4583	509.0800	449.3917	718.3545
15	406.6708	437.5027	277.2051	425.7339	304.0767
16	359.7500	381.6161	414.4024	425.8116	279.7615
17	347.8458	303.8386	389.1634	275.2491	283.7256
18	315.0194	292.5491	276.4286	326.6607	255.5663
19	275.0820	280.3549	308.6266	298.6432	253.5533
20	277.5044	285.0237	359.1994	326.9999	244.0531
21	289.2492	275.0300	275.3008	290.6674	265.0605
22	374.3934	277.3329	342.5865	411.0880	239.9967
23	350.5132	333.5334	276.3705	275.2791	279.9939
24	275.6066	324.6086	299.5648	361.6629	301.3578

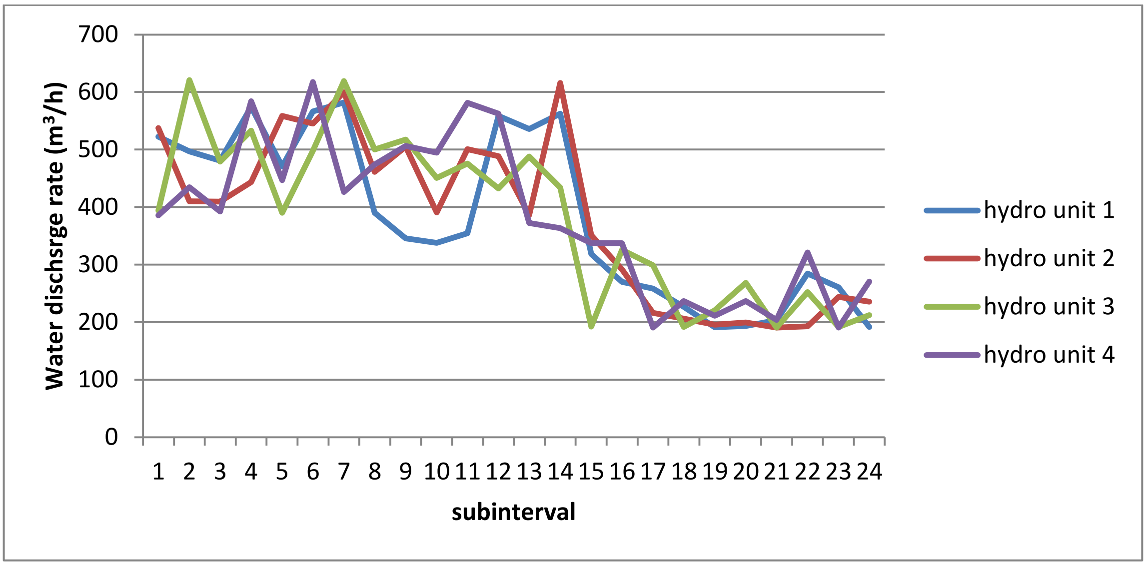


Figure 5.9 Water discharge rate for case II (test system2) using DMSPSO

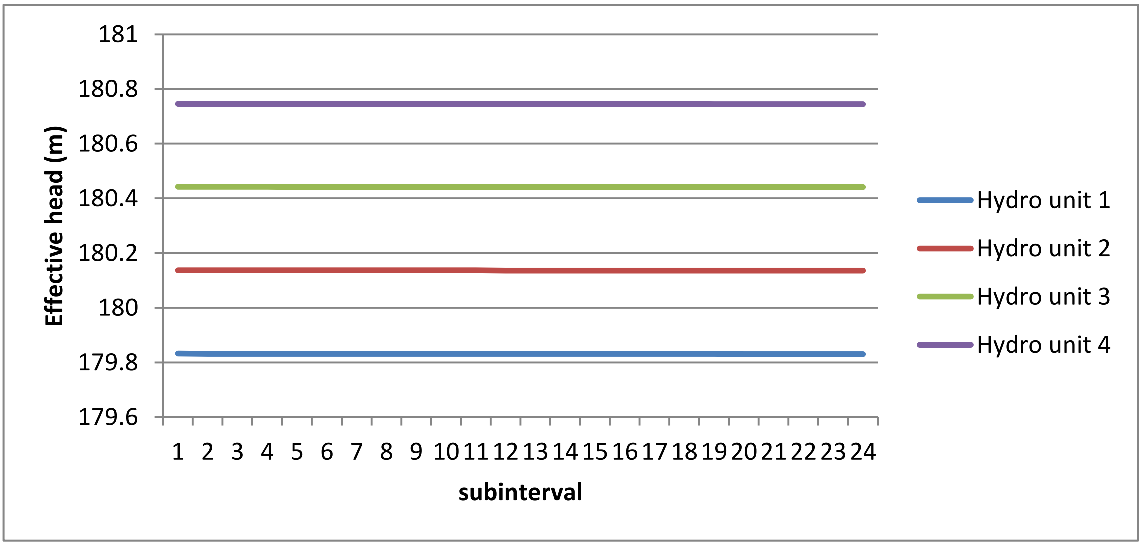


Figure 5.10 Effective head for case II (test system2) using DMSPSO

The hybrid DMSPSO-SQP technique was reduced the cost to 4,64,273 $. The thermal power and hydro power for this test system using DMSPSO technique is given in table (5.13) and (5.14), respectively. The water discharge rate and effective head variation for this test system using the DMSPSO technique during the period of 24h. are given in Fig. (5.11) and (5.12), respectively.

Table 5.13 Thermal power generation for Case II (test system2) using DMSPSO-SQP

k	Thermal power generation (MW)				
	P_{1k}	P_{2k}	P_{3k}	P_{4k}	P_{5k}
1	923.853300	784.558700	737.757100	774.672400	726.373500
2	784.634700	972.516700	801.502100	831.220100	880.918800
3	758.641500	836.674300	956.775900	825.487500	914.663300
4	853.343100	757.177700	793.184900	678.940900	838.091900
5	952.393500	861.345100	912.708900	966.198400	858.356300
6	774.351600	973.808300	963.027600	949.067700	766.587600
7	914.243000	974.226800	768.019000	838.711400	969.466300
8	915.734300	959.077500	949.269500	852.774000	811.582800
9	766.083100	784.072300	881.761000	783.868000	739.846200
10	710.490000	905.131300	829.459700	769.050700	902.314900
11	893.579200	945.475900	789.598300	918.127500	708.332800
12	736.342800	728.460800	646.524000	927.023300	850.679300
13	630.298400	843.944300	847.362700	691.407000	929.434900
14	826.715000	830.537200	895.474700	972.684500	809.788600
15	409.156700	626.978600	720.185100	488.456000	440.300900
16	581.913500	550.224200	529.473000	543.968500	332.571000
17	451.043100	559.543300	489.952300	672.530000	578.419900
18	546.716000	600.905800	550.847500	465.341100	488.887400
19	515.078400	517.196400	581.420000	514.604600	546.475900
20	461.776900	541.357900	531.630900	599.448100	404.752500
21	560.853100	623.234000	339.987500	752.480500	386.252600
22	472.327000	592.717400	335.813400	462.232100	523.325000
23	561.909700	586.789400	335.216600	523.817600	724.273000
24	509.153200	735.023700	512.427500	640.564200	482.530300

Table 5.14 Hydro power generation and transmission losses for case II (test system2)

k	Hydro power generation (MW)				P_{Lk}(MW)
	P_{6k}	P_{7k}	P_{8k}	P_{9k}	
1	577.108400	589.340200	475.555500	468.849200	610.239300
2	557.740800	488.692300	649.910900	510.100200	701.167900
3	545.318100	488.420300	545.077600	474.711700	681.739100
4	615.382800	516.111500	586.747900	624.463400	639.683000
5	537.634100	604.594700	472.474300	520.131700	757.996600
6	609.553200	594.972500	559.861600	648.077600	775.450100
7	620.796300	634.328400	648.508900	503.079900	783.572300
8	471.046800	530.648100	561.721400	541.691600	737.570300
9	432.149500	564.977100	574.697000	567.071400	614.724900
10	424.733300	472.213300	522.857400	557.669600	629.976900
11	440.151900	561.589500	542.480000	622.478800	693.757100
12	604.110900	551.842800	507.533200	608.656400	625.111600
13	587.251800	468.262000	552.091500	457.257700	607.385900
14	607.020000	645.397500	509.084500	449.483000	718.319100
15	406.636700	437.450300	277.194200	425.664600	304.071700
16	359.648300	381.597500	414.275700	425.921700	279.738600
17	347.839900	303.811000	389.140200	275.181500	283.697200
18	314.951400	292.548100	276.496100	326.674800	255.529200
19	275.089900	280.407000	308.573100	298.547000	253.532000
20	277.500900	285.077600	359.182600	327.081400	244.011000
21	289.211900	275.004400	275.325900	290.689100	265.059300
22	374.476100	277.291100	342.527100	411.121400	239.978800
23	350.466400	333.522400	276.364700	275.356300	279.944400
24	275.630800	324.718400	299.531300	361.661000	301.325100

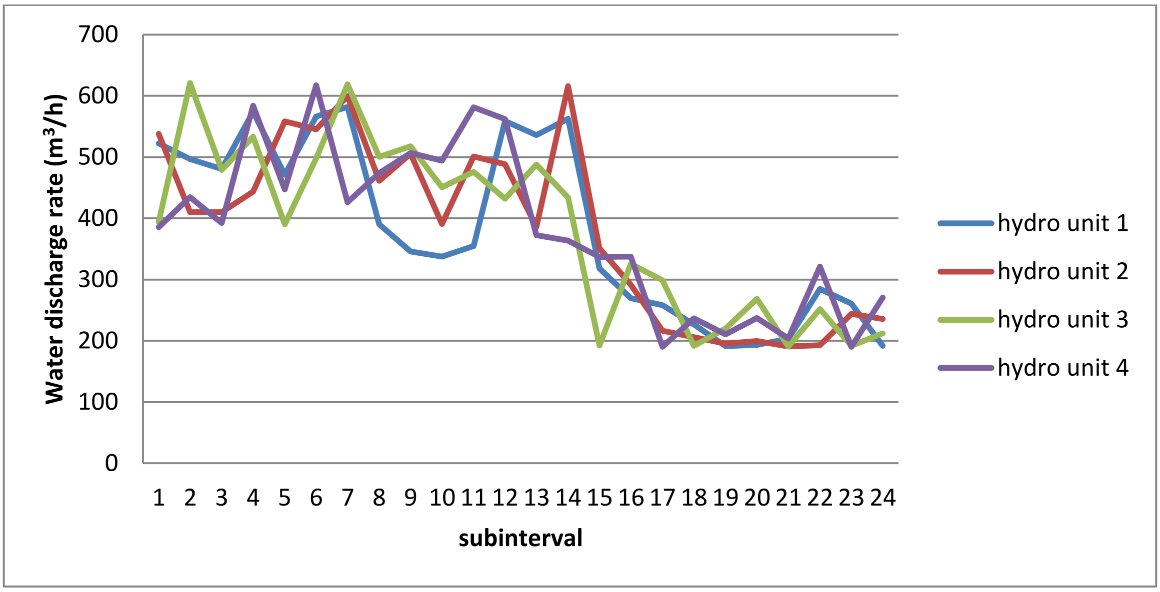


Figure 5.11 Water discharge rate for case II (test system2) using DMSPSO-SQP

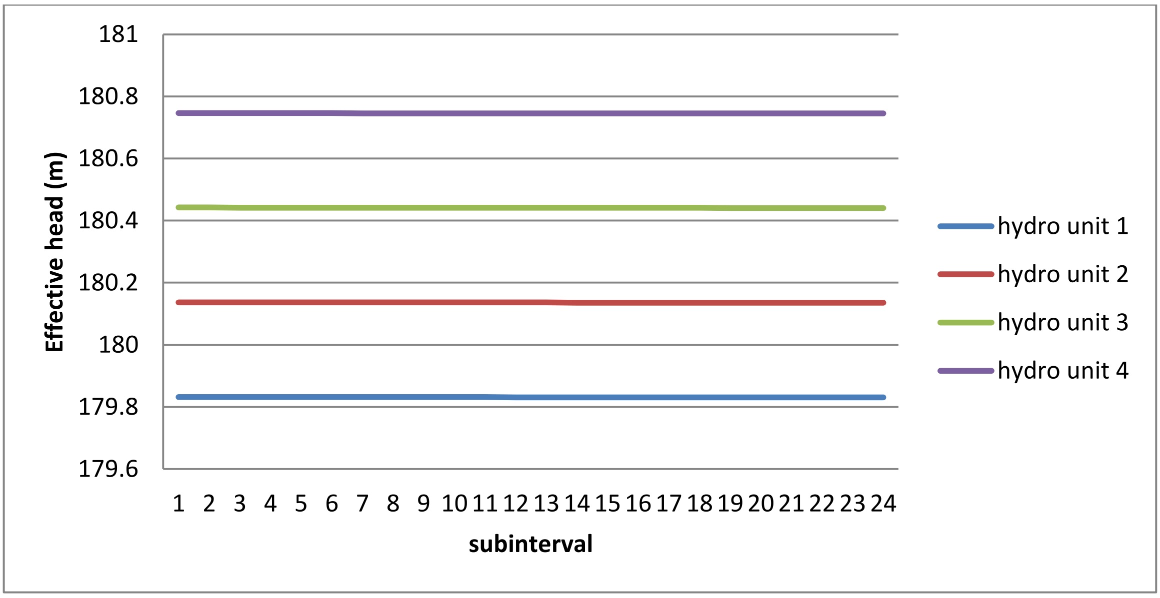


Figure 5.12 Effective head for case II (test system2) using DMSPSO-SQP

CHAPTER-6

CONCLUDING REMARKS AND SCOPE FOR FUTURE WORK

6.1 CONCLUSION

A hybrid optimization technique is applied to fixed and variable head short-term hydrothermal scheduling problem. The hybridization is composed of global search optimization technique DMSPSO and local search optimization technique SQP which helps in avoiding the local minima during the optimization process of STHTS problem. A number of fixed and variable head hydrothermal test systems are used to determine the optimal scheduling of hydrothermal units using the proposed technique. The obtained numerical results are shows the effectiveness of the applied technique for solving the fixed and variable head STHTS problem.

6.2 FUTURE SCOPE

Scope of work after implementing hybrid optimization technique on the fixed and variablr head STHTS problem is summarized as:

1) The problem can be extended for multi-objective problem by considering emission as second objective.
2) The non-conventional power plants like wind power plant can be integrated with the hydro and thermal plants.
3) The proposed technique can be used to solve the mid-term and long-term hydrothermal scheduling problem.

LIST OF PUBLICATIONS

I. International Journal

Published a paper in International Journal of Advanced Research in Computer Engineering and Technology

1. S. Gupta and N. Narang, “Integrated PSO-SQP technique for short-term hydrothermal scheduling”, *International Journal of Advanced Research in Computer Engineering and Technology*, vol.4, no.4, pp.1423-1428, 2015.

I. International Conference

Presented and **published** a paper in International Conference on Advances in Electrical, Power Control, Electronics and Communication Engineering

1. S. Gupta and N. Narang, “Short-term hydrothermal scheduling using dynamic multi-swarm particle swarm optimizer”, *International Conference on Advances in Electrical, Power Control, Electronics and Communication Engineering*, New Delhi, 2015.
2. S. Gupta and N. Narang, “Short-term hydrothermal scheduling using dynamic multi-swarm particle swarm optimizer”, *Advance Research in Electrical and Electronics Engineering*, vol.2, no.10, pp.87-91, June 2015.

REFERENCES

[1] A.J. Wood and B.F. Wollenberg, “Power Generation, Operation and Control”, 2nd ed., *John Wiley and Sons Press*, 2007.

[2] D.P. Kothari, J.S. Dhillon, “Power System Optimization”, 2nd ed., *Prentice Hall of India Pvt. Ltd.*, 2004.

[3] J. Zhu, “Optimization of Power System Operation”, *John Wiley and Sons Press*, 2009.

[4] N. Narang, J.S. Dhillon and D.P. Kothari, “Scheduling short-term hydrothermal generation using predator prey optimization technique”, *Applied Soft Computing*, vol.21, pp.298-308, August 2014.

[5] A.H. Mantawy, S.A. Soliman and M.E. EI-Hawary, “The long-term hydro-scheduling problem-a new algorithm”, *Electric Power Systems Research*, vol.64, no.1, pp.67-72, 2003.

[6] P.H. Chen, “Pumped storage scheduling using evolutionary particle swarm optimization”, *IEEE Transaction on Energy Conversion*, vol.23, no.1, pp.294-301, 2008.

[7] L. Lakshminarasimman and S. Subramanian, “Short-term scheduling of hydrothermal power system with cascaded reservoirs by using modified differential evolution”, *IEEE Proceedings-Generation, Transmission and Dist*ribution, vol.153, no.6, pp.693-700, 2006.

[8] P.K. Roy, “Teaching learning based optimization for short-term hydrothermal scheduling problem considering valve point effect and prohibited discharge constraints”, *Electrical Power and Energy Systems*, vol.53, pp.10-19, December 2013.

[9] A. Halim, A. Rashid and K.M. Nor, “An efficient method for optimal scheduling of fixed head hydro and thermal plants”, *IEEE Transactions on Power Systems*, vol.6, no.2, pp.632–636, 1991.

[10] L. Engles, R.E. Larson, J. Peschon and K.N. Stanton, “Dynamic programming applied to hydro and thermal generation scheduling”, *IEEE tutorial course text*, *76CH1107-2-PWR, IEEE*, NewYork, 1976.

[11] M.S. Salam, K.M. Nor and A.R. Hamdan, “Hydrothermal scheduling based lagrangian relaxation approach to hydrothermal coordination”, *IEEE Transactions on Power Systems,* vol.13, no.1, pp.226–235, 1998.

[12] O. Nilsson and D. Sjelvgren, “Mixed integer programming applied to short-term planning of a hydrothermal system”, *IEEE Transactions on Power Systems,* vol.11, no.1, pp.281–286, 1996.

[13] M.E. EI-Hawary and J.K. Landrigan, “Optimal operation of fixed head hydrothermal electric power system: powell’s method versus newton raphson method”, *IEEE Transaction PAS-101*, no.3, pp.547-554, 1982.

[14] A. Halim, A. Rashid and K.M. Nor, “An algorithm for the optimal scheduling of variable head hydro and thermal plants”, *IEEE Transactions on Power Systems*, vol.8, no.3, pp.1242–1249, 1993.

[15] M.E. EI-Hawary and K.M. Ravindranath, “Optimal operation of variable head hydrothermal system using the Glimn-Kirchmayer model and the newton raphson method”, *Electric Power Systems Research*, vol.14, no.1, pp.11-12, 1988.

[16] L.M. Kimball, K.A. Clements, P.W. Davis and I. Nejdawi, “Multi period hydro thermal economic dispatch by an interior point method”, *Mathematical Problems in Engineering*, vol.8, no.1, pp.33-42, 2002.

[17] J. Ricard, “The determination of optimum operating schedule for interconnected hydro and thermal stations”, *Revue Generale de Electricite, Paris, France*, 1940.

[18] A.F. Glimn and L.K. Kirchmayer, “Economic operation of variable-head hydro-electric plants”, *American Institute of Electrical Engineers Transactions,* vol.77, no.111, pp.1070-1079, 1958.

[19] M. Basu, “Artificial immune system for fixed head hydrothermal power system”, *Energy*, vol.36, no.1, pp.606-612, 2011.

[20] M. Basu, “A simulated annealing based goal-attainment method for economic emission load dispatch of fixed-head hydrothermal power systems”, *Electrical Power and Energy Systems*, vol.27, no.2, pp.147-153, 2005.

[21] M. Basu, “Hopfield neural networks for optimal scheduling of fixed head hydrothermal power systems”, *Electric Power Systems Research*, vol.64, no.1, pp.11-15, 2003.

[22] E. Gil, J. Bustos, and H. Rudnick, “Short-term hydrothermal generation scheduling model using a genetic algorithm”, *IEEE Transactions on Power Systems*, vol.18, no.4, pp.1256-1264 2003.

[23] C. Chao-Lung, “Optimal economic emission dispatch of hydrothermal power systems”, *International Journal of Electrical Power and Energy Systems*, vol.29, no.6, pp.462-469, 2006.

[24] P.K. Hota, R. Chakrabarti and P.K. Chattopadhyay, “Short-term hydrothermal scheduling through evolutionary programming technique”, *Electric Power Systems Research*, vol.52, no.2, pp.189-196, 1999.

[25] T.T. Nguyen, D.N. Vo and A.V. Truong, “Cuckoo search algorithm for short-term hydrothermal scheduling”, *Applied Energy*, vol.132, pp.276-287, November 2014.

[26] V.N. Dieu and W. Ongsakul, “Improved merit order and augmented lagrange hopfield network for short-term hydrothermal scheduling”, *Energy Conversion and Management,* vol.50, no.12, pp.3015-3023, 2009.

[27] M. Omran, A. Engelbrecht and A. Salman, “Bare bones differential evolution”, *European Journal of Operational Research,* vol.196, no.1, pp.128–139, 2009.

[28] J. Sasikala and M. Ramaswamy, “Optimal gamma based fixed head hydrothermal scheduling using genetic algorithm”, *Expert Systems with Applications,* vol.37, no.4, pp.3352-3357, 2010.

[29] M.M. Salama, M.M. Elgazer, S.M. Abdelmaksoud and H.A. Henry, “Variable head hydrothermal generation scheduling using genetic algorithm and constriction factor based particle swarm optimization technique”, *International Organization of Scientific Research Journal of Engineering*, vol.3, no.9, pp.1-16, 2013.

[30] I. A. Farhat and M. E. EI-Hawary, “Scheduling of variable-head hydro-thermal generation using an enhanced bacterial foraging algorithm”, *IEEE Conference on Electrical and Computer Engineering,* pp.436-441, May 2011.

[31] J.S. Dhillon, J.S. Dhillon and D.P. Kothari, “Real-coded genetic algorithm for stochastic hydrothermal generation scheduling”, *Journal of System Science and System Engineering*, vol.20, no.1, pp.87-109, 2011.

[32] A.R. Jordehi and J. Jasni, “Parameter selection in particle swarm optimization: a survey”, *Journal of Experiment and Theoretical Artificial Intelligence*, vol.25, no.4, pp.527-542, 2013.

[33] C. Samudi, G.P. Das, C. Ojha, T.S. Sreeni and S. Cherian, “Hydrothermal scheduling using particle swarm optimization”, *IEEE Transmission and Distribution Conference and Exposition,* pp.1-5, April 2008.

[34] B. Yu, X. Yuan and J. Wang, “Short-term hydrothermal scheduling using particle swarm optimization method”, *Energy Conversion and Management,* vol.48, no.7, pp.1902-1908, 2007.

[35] A.R. Jordehi and J. Jasni, “Particle swarm optimization for discrete optimization problems: a review”, *Artificial Intelligence Review*, vol.43, no.2, pp.243-258, 2015.

[36] A.R. Jordehi, “Enhanced leader PSO (ELPSO): a new PSO variant for solving global optimisation problems”, *Applied Soft Computing*, vol.26, pp.401-417, 2015.

[37] A. Ratnaweera, S. K. Halgamuge and H. C. Watson, “Self-organizing hierarchical particle swarm optimizer with time-varying acceleration coefficients”, *IEEE Transactions on Evolutionary Computation*, vol.8, no.3, pp.240-255, 2004.

[38] K. Tang, Z. Li, L. Luo and B. Liu, “Multi-strategy adaptive particle swarm optimization for numerical optimization”, *Engineering Application of Artificial Intelligence*, vol.37, pp. 9-19, January 2015.

[39] V.H. Hinojosa and C. Leyton, “Short-term hydrothermal generation scheduling solved with a mixed-binary evolutionary particle swarm optimizer”, *Electric Power Systems Research*, vol.92, pp.162-170, November 2012.

[40] S. Lu, C. Sun and Z. Lu, “An improved quantum-behaved particle swarm optimization method for short-term combined economic emission hydrothermal scheduling”, *Energy Conversion and Management*, vol.51, no.3, pp.561-571, 2010.

[41] S. Padmini and C.C. Asir Rajan, “Improved PSO for short-term hydrothermal scheduling”, *International Conference on Sustainable Energy and Intelligent systems,* pp.332-334, July 2011.

[42] A.K. Zadeh, M. Abdel-Akher, M. Wang and T. Senjyu, “Optimized day-ahead hydrothermal wind energy systems scheduling using parallel PSO”, *International Conference on Renewable Energy Research and Application,* pp.1-6, November 2012.

[43] Y. Wang, J. Zhou, C. Zhou, Y. Wang, H. Qin and Y. Lu, “An improved self-adaptive PSO technique for short-term hydrothermal scheduling”, *Expert Systems with Applications*, vol.39, no.3, pp.2288-2295, 2012.

[44] L. Dos, S. Coelho and C.S. Lee, “Solving economic load dispatch problems in power systems using chaotic and gaussian particle swarm optimization approaches”, *International Journal of Electrical Power and Energy Systems*, vol.30, no.5, pp.297-307, 2008.

[45] M. Basu, “Modified particle swarm optimization for non-convex economic dispatch problems”, *Electrical Power and Energy Systems,* vol.69, pp.304-312, July 2015.

[46] K.T. Chaturvedi, M. Pandit, and L. Srivastava, “Particle swarm optimization with time varying acceleration coefficient for non-convex economic power dispatch”, *International Journal of Electrical Power and Energy Systems*, vol.31, no.6, pp.249-257, 2009.

[47] N. Sinha and B. Purkayastha, “PSO embedded evolutionary programming technique for non-convex economic load dispatch”, *IEEE Power System Conference and Exposition*, vol.1, pp.66-71, October 2004.

[48] C. Chuntian, L. Shengli, W. Xinyu and K.W. Chau, “Two stage particle swarm optimisation for long-term operation of a hydro-electric power system”, *The Hong Kong Institution of Engineers Transactions*, vol.16, no.3, pp.8-14, 2009.

[49] J.J. Liang and P.N. suganthan, “Dynamic multi-swarm particle swarm optimizer with local search”, *IEEE congress on Evolutionary Computation*, vol.1, pp.522-528, September 2005.

[50] S.Z. Zhao, J.J. Liang, P.N. Suganthan and M.F. Tasgetiren, “Multi-swarm particle swarm optimizer with local search for large scale global optimization”, *IEEE congress on Evolutionary Computation*, pp.3845-3852, June 2008.

[51] J.J. Liang, B.Y. Qu, B. Niu and P.N. Suganthan, “Dynamic multi-swarm particle swarm optimization for multi-objective optimization problems”, *IEEE congress on Evolutionary Computation*, pp.1-8, June 2012.

[52] Meng-xin, Gao-junru, Li-peng and She-na, “The application of dynamic multi-swarm particle swarm optimization in the optimal dispatch of loads of thermal power unit”, *IEEE workshop on Electronics, Computer and Applications*, pp.573-576, May 2014.

[53] S.S. Rao, “Engineering Optimization”, *John Wiley and Sons Press*, 4th ed., 2009.

[54] S. Sivasubramani and K. Shanti Swarup, “Hybrid DE-SQP algorithm for non-convex short-term hydrothermal scheduling problem”, *Energy Conversion and Management*, vol.52, pp.757-761, 2011.

[55] N. Narang, J.S.Dhillon and D.P.Kothari, “Weight pattern evaluation for multi-objective hydrothermal generation scheduling using hybrid search technique”, *Electrical Power and Energy Systems*, vol.62, pp.665-678, 2014.

[56] M. Basu, “Hybridization of bee colony optimization and sequential quadratic programming for dynamic economic dispatch”, *Electrical Power and Energy Systems*, vol.44, pp.591-596, 2013.

[57] P. Attaviriyanupap, H. Kita and E. Tanaka, “A hybrid EP and SQP for dynamic economic dispatch with non-smooth fuel cost function”, *IEEE Transactions on Power Systems*, vol.17, no.2, pp.411-416, 2002.

[58] C. Nallasivan, D.S. Suman, J. Henry and S. Ravichandran, “A novel approach for short-term hydrothermal scheduling using hybrid technique”, *IEEE Power India Conference*, 2006.

[59] N.C. Nayak and C.C.A. Rajan, “Hydrothermal scheduling by a hybrid evolutionary programming-tabu search method with cooling-banking constraints”, *IEEE International Conference on Computing, Electronics and Electrical Technologies*, pp.98-103, March 2012.

[60] M.E. EI-Hawary and M. Kumar, “Optimal parameter estimation for hydro-plant performance models in economic operation studies”, *IEEE Transactions on Power Systems*, vol. PWRS-1, no.4, 1986.

[61] J. Wang, Q. Dan and Y. Wu, “Long-term optimal generation scheduling for the energy maximization of hydropower systems”, *Automation of Electrical Power Systems*, vol.26, no.24, pp.22-25, 2002.

[62] C. Xue-qing, C. Gang and Z. Hui, “Long, Medium and Short-term energy management systems of large power systems”, *Proceedings of the CSEE*, vol.14, no.6, pp. 41-48, 1994.

[63] J. Kennedy and R.C. Eberhart, “Particle swarm optimization”, *IEEE Conference on Neural Networks*, pp.1942–1948, 1995.

[64] M. Basu, “Economic environmental dispatch of fixed-head hydrothermal power systems using non-dominated sorting genetic algorithm-II”, *Applied Soft Computing*, vol.11, no.3, pp. 3046–3055, 2011.

APPENDIX-A

System data for case I (test system 1)

Hydro unit data						
Hydro unit	y_1 $\mathrm{MCF/(MW)^2h}$	y_2 (MCF/MWh)	y_3 (MCF/h)	R (MCF)	P^{min} (MW)	P^{max} (MW)
1	0.000216	0.306	1.980	2500	0	400
2	0.000360	0.612	0.936	2100	0	300

Thermal unit data							
Thermal unit	a_1 ($\$/(\mathrm{MW})^2\mathrm{h}$)	a_2 ($/MWh)	a_3 ($/h)	a_4 ($/h)	a_5 (1/MW)	P^{min} (MW)	P^{max} (MW)
1	0.0025	3.2	25	0	0	50	300
2	0.0008	3.4	30	0	0	50	700

Load demand		
k	Duration (h)	Power Demand (MW)
1	8	900
2	8	1200
3	8	1100

B-coefficient matrix given as-

$$B = \begin{bmatrix} 0.00014 & 0.00001 & 0.000015 & 0.000015 \\ 0.00001 & 0.00006 & 0.00001 & 0.000013 \\ 0.00001 & 0.00001 & 0.000068 & 0.000065 \\ 0.000015 & 0.000013 & 0.000065 & 0.00007 \end{bmatrix}$$

APPENDIX-B

System data for case I (test system2)

Hydro unit data						
Hydro unit	y_1 MCF/(MW)^{2}h	y_2 (MCF/MWh)	y_3 (MCF/h)	R (MCF)	P^{min} (MW)	P^{max} (MW)
1	0.000216	0.306	1.980	2500	0	400
2	0.000360	0.612	0.936	2100	0	300

Thermal unit data							
Thermal unit	a_1 (\$/(MW)^{2}h)	a_2 (\$/MWh)	a_3 (\$/h)	a_4 (\$/h)	a_5 (1/MW)	P^{min} (MW)	P^{max} (MW)
1	0.0025	3.2	25	12	0.0550	50	300
2	0.0008	3.4	30	14	0.0450	50	700

Load demand		
k	Duration (h)	Demand (MW)
1	8	900
2	8	1200
3	8	1100

B coefficient matrix given as-

$$B = \begin{bmatrix} 0.00014 & 0.00001 & 0.000015 & 0.000015 \\ 0.00001 & 0.00006 & 0.00001 & 0.000013 \\ 0.000015 & 0.00001 & 0.000068 & 0.000065 \\ 0.000015 & 0.000013 & 0.000065 & 0.00007 \end{bmatrix}$$

APPENDIX-C

System data for case II (test system1)

Hydro plant specification			
Hydro unit	Volume, R (ft^3)	Surface area, S (ft^2)	Initial head, h_0 (m)
1	2850	1000	300
2	2450	400	250

Water discharge rate coefficients			
Hydro unit	$y_1(\mathrm{m}^3/\mathrm{MW}^2\mathrm{h})$	$y_2(\mathrm{m}^3/\mathrm{MWh})$	$y_3(\mathrm{m}^3/\mathrm{h})$
1	0.000216	0.306	0.198
2	0.000360	0.612	0.936

Head variation coefficients			
Hydro unit	$z_1(m^{-2})$	$z_2(m^{-1})$	z_3
1	0.00001	-0.003	0.9
2	0.00002	-0.0025	0.95

Load Demand					
k	Demand(MW)	k	Demand(MW)	k	Demand(MW)
1	800	9	1330	17	1450
2	700	10	1350	18	1570
3	600	11	1450	19	1430
4	600	12	1500	20	1350
5	600	13	1300	21	1270
6	650	14	1350	22	1150
7	800	15	1350	23	1000
8	1000	16	1370	24	900

Thermal unit fuel coefficients			
Thermal unit	a_1(\$/(MW)^{2}h)	a_2(\$/MWh)	a_3(\$/h)
1	0.0025	3.20	25
2	0.0008	3.4	30

B coefficient matrix given as-

$$B = \begin{bmatrix} 0.00014 & 0.00001 & 0.000015 & 0.000015 \\ 0.00001 & 0.00006 & 0.00001 & 0.000013 \\ 0.000015 & 0.00001 & 0.000068 & 0.000065 \\ 0.000015 & 0.000013 & 0.000065 & 0.00007 \end{bmatrix}$$

APPENDIX-D

System data for case II (test system2)

Operating characteristics of thermal units					
Thermal unit	a_1(\$/(MW)^{2}h)	a_2(\$/MWh)	a_3(\$/h)	P^{min}(MW)	P^{max}(MW)
1	0.003	2.7	150	325	975
2	0.003	2.8	150	325	975
3	0.003	3.0	150	325	975
4	0.003	3.1	150	325	975
5	0.003	3.2	150	325	975

Head variation coefficients and initial head				
Hydro unit	$z_1(m^{-2})$	$z_2(m^{-1})$	z_3	Initial head(m)
1	1.49567×10^{-4}	-5.93409×10^{-2}	6.8744	179.832
2	1.49567×10^{-4}	-5.93409×10^{-2}	6.8744	180.137
3	1.49567×10^{-4}	-5.93409×10^{-2}	6.8744	180.442
4	1.49567×10^{-4}	-5.93409×10^{-2}	6.8744	180.746

Water discharge rate coefficients and operating limits					
Hydro unit	y_1 (m^3/MW^2h)	y_2 (m^3/MWh)	y_3 (m^3/h)	P^{min} (MW)	P^{max} (MW)
1	7.729×10^{-6}	4.42887×10^{-3}	1.17265×10^{-1}	275	650
2	7.729×10^{-6}	4.42887×10^{-3}	1.17265×10^{-1}	275	650
3	7.729×10^{-6}	4.42887×10^{-3}	1.17265×10^{-1}	275	650
4	7.729×10^{-6}	4.42887×10^{-3}	1.17265×10^{-1}	275	650

Hydro plant’s reservoir details				
Hydro unit	Surface area, S (ft^2)	Proportionality constant, K_j	Water inflow, I (ft^3)	Volume, R (ft^3)
1	6.4747×10^6	95.68744	7.0	9175
2	6.4747×10^6	95.68744	7.1	9175
3	6.4747×10^6	95.68744	7.2	9175
4	6.4747×10^6	95.68744	7.3	9175

Load demand					
k	Demand(MW)	k	Demand(MW)	k	Demand(MW)
1	5448	9	5480	17	3784
2	5776	10	5464	18	3608
3	5664	11	5728	19	3584
4	5624	12	5536	20	3544
5	5928	13	5400	21	3528
6	6064	14	5828	22	3552
7	6088	15	3928	23	3688
8	5856	16	3840	24	3840

B-coefficients are given below:

$B_{ii} = 0.143 \times 10^{-3} \quad , i = 1,2, \dots \dots \dots . .9.$

$B_{ij} = 0 \quad , i = 1,2, \dots \dots \dots . .9; j = 1,2, \dots \dots \dots . .9; i \neq j.$

CURRICULUM VITAE OF AUTHOR

I. Personal background

NAME : Shashank Gupta

FATEHR'S NAME : Mr. Ram kripal Gupta

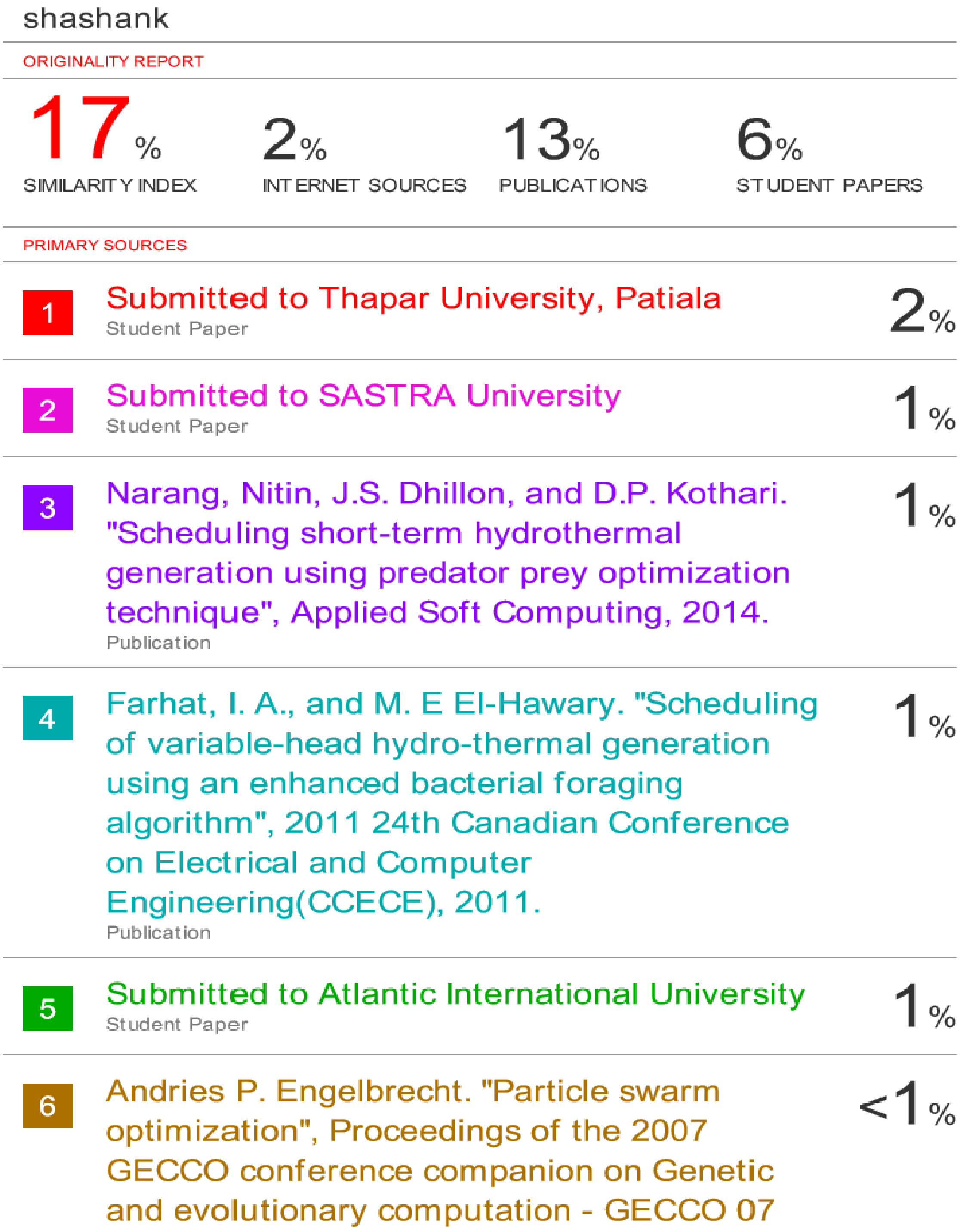
DATE OF BIRTH : 05/12/1989

E-mail : shashank051289@gmail.com

II. Educational Qualification

Degree	Subject	Institute	Board/ University	Marks(%)
S.S.C	Science	JDSVM, Kanpur	CBSE	72.3
H.S.C	PCM	JDSVM, Kanpur	CBSE	60.8
B. Tech	EN	SRMGPC, Lucknow	UPTU	66.0

PLAGIARISM CERTIFICATE



shashank

ORIGINALITY REPORT

17%	2%	13%	6%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Thapar University, Patiala Student Paper	2%
2	Submitted to SASTRA University Student Paper	1%
3	Narang, Nitin, J.S. Dhillon, and D.P. Kothari. "Scheduling short-term hydrothermal generation using predator prey optimization technique", Applied Soft Computing, 2014. Publication	1%
4	Farhat, I. A., and M. E El-Hawary. "Scheduling of variable-head hydro-thermal generation using an enhanced bacterial foraging algorithm", 2011 24th Canadian Conference on Electrical and Computer Engineering(CCECE), 2011. Publication	1%
5	Submitted to Atlantic International University Student Paper	1%
6	Andries P. Engelbrecht. "Particle swarm optimization", Proceedings of the 2007 GECCO conference companion on Genetic and evolutionary computation - GECCO 07	<1%