

Short Range Fixed Head Multi Objective Hydrothermal Scheduling
Using Fuzzy Decision Making Technique

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in

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Certificate

I hereby certify that the work which is being presented in the thesis entitled "**Short Range Fixed Head Multi objective Hydro Thermal Scheduling using fuzzy decision making technique**" in the partial fulfillment of the requirements of the award of degree of master in engineering in power system & electric drives in electrical & instrumentation engineering department of Thapar University 'Patiala' is an authentic record of my own work carried under the supervision of **Mrs. Manbir Kaur**. The matter represented in this thesis has not been submitted for the award of any other degree of this or any other university, except as reported in the text & references

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Abstract

In the multi objective framework, fuzzy decision making methodology is exploited to decide the generation schedule of a short range fixed head hydrothermal problem. The multi objective problem is formulated considering three objectives (i) Fuel cost (ii) SO_2 emission (iii) CO_2 emission which are random variables. The solution set of such formulated problems is non inferior due to contradictions among the objectives taken. The weighting method is used to simulate the trade off relation between the conflicting objectives in the non inferior domain. Once the trade-off has been obtained, fuzzy set theory helps the system operator to choose the weighting pattern and thus the operating point that maximizes the satisfaction of all the objectives.

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List of symbols

- a_i, b_i, c_i Cost coefficients of i^{th} generating unit
- d_i, e_i, f_i CO_2 Emission coefficients of i^{th} thermal unit
- g_i, h_i, j_i SO_2 Emission coefficients of i^{th} thermal unit
- x_j, y_j, z_j Discharge coefficients of j^{th} hydro plant
- R_j Predefined volume of water available for j^{th} hydro plant
- v_j Water conversion factor of j^{th} plant
- P_i Power Generated by i^{th} Thermal unit
- P_j Power Generated by j^{th} Hydro Unit.
- P_d Expected load demand during the interval
- P_l Expected transmission losses
- M Number of hydro units
- N Number of thermal units
- T Total planning period
- w_k Weight for k^{th} objective
- q_j Water discharged for j^{th} hydro unit
- B_{ij} Loss coefficients
- J_i Value of i^{th} objective
- J_i^{\max} Maximum value of i^{th} objective
- J_i^{\min} Minimum value of i^{th} objective
- u_d^k Cardinal priority of k^{th} non inferior solution.

1.1 Introduction

In a large number of real life problems, a decision maker is faced with multiple goals. The levels of attainment of these goals are to be expressed in the form of quantitative performance criteria some of which can be selected as the optimization objectives. The situation is formulated as a multi objective optimization problem in which the goal is to maximize or minimize several objective functions simultaneously. Many approaches and methods have been proposed to solve multi objective problems [1]. These methods are broadly grouped under two major categories; non interactive and interactive methods. In the non interactive method, a global preference function of the objectives is identified and optimized with respect to the constraints. In the interactive method, a local preference function or trade off among objectives is identified by interacting with the decision maker and the solution process gradually proceeds towards a globally satisfactory solution. Qualitatively, a non inferior solution of multi objective problem is one where any improvement of one objective function can be achieved only at the expense of another. The most widely used methods of generating such non inferior solutions are e constraint method, weighting method & the shifted min-max method [2].

The main purpose of the optimal power scheduling problem has mainly confined to minimizing the generation cost of a power system. However, to meet environmental regulations enforced in recent years, emission control has become one of the important operational objectives [3-6]. The pollution of the earth's atmosphere caused by three principal gaseous pollutants, oxides of carbon (CO_2), oxides of sulphur (SO_2) and oxides of nitrogen (NO_2) from thermal generator plants, is of greater concern to power utilities and communities.

The main objective for hydrothermal operation is to minimize the total system operating cost, represented by the fuel cost required for the system's thermal generation subject to the operating constraints of hydro- and thermal plants, over the optimization interval. Each hydro plant is constrained by amount of water available for draw down in the interval. The integrated operation of the hydrothermal system is split into two separate, long-range and short-range problems. The planning period is one year for long-range problem. The short-term hydrothermal scheduling problem is concerned with optimization over a time horizon of an hour, a day or a week. As the scheduling interval of the short-range problem is small, so the water inflows and loads are considered fully known with complete certainty.

The scheduling problem requires an appropriate objective function such as minimum generation cost or transmission losses or minimum pollution level etc. In essence, the hydrothermal scheduling problem can be visualized as a multi objective one [7]. This paper proposes a simple and robust solution methodology for a class of multi objective short-range fixed-head hydrothermal problems which makes use of fuzzy set theory. The expected values of

thermal fuel cost, SO_2 emission and CO_2 emission, over the whole of the planning period are the three conflicting objectives which need to be minimized. Basically, the solution procedure for the multi objective problem is based on the generation of non inferior solutions. The weighting technique [8] is used to generate non inferior solutions, which allows explicit trade-off between objective levels. Exploiting fuzzy set theory [9], a cardinal priority ranking of the non inferior solutions is defined that maximizes the satisfaction of all the objectives and is utilized to find the best compromise solution from the non inferior solution set. The practical viability of the multi objective hydrothermal scheduling problem has been demonstrated using one sample system of one hydro & one thermal plant.

1.2 Multi-objective Optimization

In recent years there has been an increase in research on multi objective optimization methods. Decisions with multi objectives are quite prevalent in government, military, industry, and other organizations. Researches from a wide variety of disciplines such as mathematics, management, science, economics, engineering and others have contributed to the solution methods for multi objective optimization problems. The situation is formulated as a multi objective optimization problem in which the engineer's goal is to maximize or minimize not a single objective function but several objective functions simultaneously [20]. The purpose of multi objective problems in the mathematical programming framework is to optimize the different objective functions subjected to a set of system constraints.

In order to make the problem non trivial, it is assumed that the objectives are in conflict and incommensurable. Owing to the conflicting nature of the objectives, an optimal solution that simultaneously maximizes/minimizes all the criteria is usually not attainable. Instead, there are several solutions, called efficient solutions that have the property, that no improvement in any objective is possible without sacrificing one or more of the other objectives.

The set of all efficient solutions in the continuous case is known as the efficient frontier. An efficient solution is also known as a non dominated solution, non inferior solution or Pareto optimal solution. Many approaches and methods have been proposed in the recent years to solve multi-objective optimization problems. These methods are broadly grouped under two major titles, non interactive and interactive. In the non interactive method, a global preference function of the objectives is identified and optimized with respect to the constraints. On the other hand, in the interactive method the decision maker identifies a local preference function or trade off among objectives and the solution process proceeds gradually towards the globally satisfactory solution. The primary objective of the multi-objective problem solution methods is to find the best compromise solution. The best compromise solution is an efficient solution that maximizes the decision maker preference function.

It may be obvious that tradeoffs among these objectives are difficult because of their different nature. This implies that objectives are 'non – commensurable'. In other words, it is difficult to treat respective objectives under the identical criterion. Principally, methodologies for solving multi objective problem differ in two major ways:

1. The procedure used to generate non inferior solutions
2. The ways and means used to interact with the decision maker and the type of information made available to the decision maker such as tradeoffs.

The weighting & constraint methods identify the non inferior set, within which the best compromise solution lies. In almost all decision making problems, there are several criteria for judging the possible alternatives. The main concern of the decision maker is to fulfill the conflicting goals while satisfying the constraints of the system.

1.3 Literature Review

The performance of each hydro plant is represented by Glimn-Kirchmayer's model [10-11]. In recent years; many approaches have been suggested to solve the hydrothermal scheduling problem. The proposed approaches include, dynamic programming [12], functional analysis technique [13] method of local variations [14], principle of progressive optimality [15], general mathematical programming technique [16]. Generally these methods have slow convergence characteristics.

Another variable technique is the Newton-Raphson method [17-19]. Formulation of the scheduling problem in Newton-Raphson method for solving a set of nonlinear coordination equations leads to a large matrix expression. Problems with Newton's method when applied to fixed head problems include the computation of the inverse of a large matrix, the ill-conditioning of the Jacobian matrix and the divergence caused by starting values.

There are several literature reviews in the area of minimizing pollution level, but still much progress is possible in the area of economic load dispatch. Heslin & Hobbs [1989] have stated a model for evaluating the cost and employment impacts of effluent dispatching & fuel switching as means for reducing emissions from power plants. They have produced trade off curves, which show the costs and coal field job losses associated with reduction in SO_2 emissions. Kermanshahi et al [1990] produced a decision making methodology to determine the optimal generation dispatch and environmental marginal cost for power system operation with multiple conflicting objectives. Palanichamy & Srikrishna [1991] have enumerated an algorithm for successful operation of the system subject to economical and environmental constraints .a price penalty factor has been defined which has blended the emission costs with the normal fuel costs. The familiar quadratic form of objective function has been used and the positive root of such a function gives the optimal dispatch directly.

1.4 Objectives

The topic of the dissertation work is “Short range fixed head multi-objective hydrothermal scheduling using fuzzy decision making technique”. The main objective of this study is to obtain optimal solution of short range fixed head hydrothermal generation schedule by the minimization of the operating cost, CO_2 emission, SO_2 emission. This study is carried out in the following steps:

- (i) To obtain the multi-objective hydrothermal generation scheduling of short range fixed head plants including transmission losses using classical method.
- (ii) To obtain the non inferior solution of the problem using weighting method by using different weight combinations so that the sum of weights equal to unity.
- (iii) To select the weighting pattern comprising the best solution using fuzzy decision making technique

The problem code is developed in MATLAB

1.5 Organization of Thesis

1. An introduction to the optimal operation of hydro thermal systems is presented in Chapter 1 along with the overview and objectives of thesis.
2. Chapter 2 provides a review of the hydro-thermal coordination, performance model of thermal and hydro plants and available literature.
3. Chapter 3 presents overview of the short range fixed head hydrothermal scheduling, problem formulation and the flow chart of the classical method.
4. Chapter 4 presents the fuzzy decision making technique
5. Chapter 5 presents the results and discussions.
6. Chapter 6 presents conclusions and recommendations for future work.

HYDROTHERMAL COORDINATION

2.1 Introduction

In the present set-up of large systems with hydro and thermal power stations, the energy efficient generation scheduling is well considered in power sector in order to reduce the production cost and for the optimum utilization of all energy sources in the most economical manner. The system coordination of the operation of a system of hydro-electric generation plants is usually more complex than the scheduling of an all thermal generation system because the hydro-electric plants may very well coupled both electrically (i.e. they all serve the same load) and hydraulically (i.e. the water outflow from one plant may be a very significant portion of the inflow to one or more other, downstream plants).

The idea of integrated operation of the hydro-electric plants is for optimum utilization of all energy sources in economical manner. The operating cost of the thermal plants is very high, though their capital cost is low. On the other hand, the operating cost of hydro plants is low but their capital cost is high. So, it has become more economical as well as convenient to have both thermal and hydro plants in the same grid. The hydroelectric plants can be started quickly and it has higher reliability and greater speed of response. Hence hydro plants can take up fluctuating loads. In contrast to the hydro plants, the starting of thermal plants is slow and their speed of response is slow as well. Normally the thermal plant is preferred as a base load plant whereas hydro plant is run as peak plant.

In the hydro thermal coordination, it is essential to use the total quantity of water available from the hydro system to the fullest extent. In the hydro system, fixed charges continue regardless of the amount of power generated, as there is no fuel cost associated with hydropower. Therefore minimum overall cost is achieved by maximum exploitation of hydro resources i.e. water available over a time horizon. The hydrothermal coordination problem is the one which deals with how to run all the generation units during the particular period of time to meet the forecasted demand and other operating constraints, especially how the hydro units can be utilized at the maximum level to reduce the total generation fuel cost by minimizing the thermal generator operation. Most of the hydroelectric plants are multipurpose. In such cases, it is necessary to meet certain obligations other than the power generation. These may include a maximum fore way elevation, not to be exceeded because of danger of flooding, and minimum plant discharge and spillage to meet irrigational and navigational commitments. Other distinctions among hydro power systems are the number of hydro stations, their locations and operating characteristics. The problem is different in cases when the hydro plants are located on same stream or on different streams. The operation of downstream plant depends on the immediate upstream plant. But downstream plant influences the immediate upstream plant by its effect on tail water elevation and effective head.

2.1.1 Need of Hydrothermal Scheduling

The operating cost of thermal plant is very high, though their capital cost is low. On the other hand the operating cost of hydroelectric plant is low, though their capital cost is high. So it has become economical as well convenient to have both thermal and hydro plants in the same grid. The hydroelectric plant can be started quickly and it has higher reliability and greater Speed of response. Hence hydroelectric plant can take up fluctuating loads. But the starting of Thermal plants is slow and their speed of response is slow. Normally the thermal plant is preferred as a base load plant whereas the hydroelectric plant is run as a peak load plant.

2.2 Classification of Hydro Plants

Hydro plants are classified on the basis of:

1. Type
2. Quantity of Water
3. Location
4. Availability of head
5. Nature of load

2.2.1 Classification on the Basis of Type:

Hydro power plants on the basis of their type are further classified as:

- Pumped storage plants
- Conventional plants

Pumped Storage Plants

Pumped storage hydro plants are designed to save fuel cost by serving the peak load (a high fuel-cost load) with hydro energy and then pumping the water back up into the reservoir at light load periods (a lower cost load). These plants may involve separate pumps and turbines or more recently, reversible pump turbines. It is associated with upper and lower reservoirs. During light load periods water is pumped from lower to the upper reservoirs using the available energy from other sources as surplus energy. During peak load the water stored in the upper reservoirs is released to generate power to save fuel cost of thermal plants. The pumped storage plant is operated until the added pumping cost exceeds the savings in thermal costs due to the peak sharing operation.

Conventional Plants

These are classified in to two different categories:

- Run-of-river plants
- Storage plants

Run-of-river plants have little storage capacity and use water as it becomes available. The water not utilized is spilled.

Storage plants are associated with reservoirs which have significant storage capacity. During periods of low power requirements, water can be stored and then released when the demand is high.

2.2.2 Classification According to Quantity of Water Available

On the basis of quantity of water available Hydro plants can be classified as:

- Run-off- River Plants without Pondage
- Run-off -River Plants With Pondage
- Reservoir Plants

Run-off- River Plants without Pondage: These plants do not store water; the plant uses water as it comes. The plant can use water as and when available. Since these plants depend for their generating capacity primarily on the rate of flow of water, during rainy season high flow rate may mean some quantity of water to go as waste while during low run-off periods, due to low flow rates the generating capacity will be low.

Run-off -River Plants With Pondage: In these plants pondage permits storage of water during off peak periods and use of this water during peak periods. Depending on the size of pondage provided it may be possible to cope with hour to hour fluctuations. This type of plant can be used on parts of the load curve as required, and is more useful than a plant without storage or pondage. When providing pondage tail race conditions should be such that floods do not raise tail-race water level, thus reducing the head on the plant and impairing its effectiveness. This type of plant is comparatively more reliable and its generating capacity is less dependent on available rate of flow of water.

Reservoir Plants: A reservoir plant is that which has a reservoir of such size as to permit carrying over storage from wet season to the next dry season. Water is stored behind the dam and is available to the plant with control as required. Such a plant has better capacity and can be used efficiently throughout the year. Its firm capacity can be increased and can be used either as a base load plant or as a peak load plant as required. It can also be used on any portion of the load curve as required.

2.2.3 Classification According to Availability of Water Head

On the basis of water head hydro plants are categorized as:

- Low-Head (less than 30 meters) Hydro Electric Plants
- Medium-Head (30 meters - 100 meters) Hydro Electric Plants
- High-Head Hydro Electric Plants

Low head hydro-electric plants are power plants generally utilize heads of only a few meters or less. Power plants of this type may utilize a low dam or weir to channel water, or no dam and simply use the "run of the river". Run of the river generating stations cannot store water, thus their electric output varies with seasonal flows of water in a river. A large volume of water must pass through a low head hydro plant's turbines in order to produce a useful amount of power. Hydro-electric facilities with a capacity of less than about 25 MW are generally referred to as "small hydro", although hydro-electrical technology is basically the same regardless of generating capacity.

Medium-Head (30 meters - 100 meters) Hydro Electric Plants consist of a large dam in a mountainous area which creates a huge reservoir. An open channel brings water from main reservoir to the fore bay from where penstock carries water to turbines.

High-Head Hydro Electric Plants are the most common and generally utilize a dam to store water at an increased elevation. The use of a dam to impound water also provides the capability of storing water during rainy periods and releasing it during dry periods. This results in the consistent and reliable production of electricity, able to meet the load demand. Heads for this type of power plant may be greater than 100 m. Most large hydro-electric facilities are of the high head variety. High head plants with storage are very valuable to electric utilities because they can be quickly adjusted to meet the electrical demand on a distribution system.

2.2.4 Classification According to Nature of Load

- Base Load Plants
- Peak Load Plants

Base load power plant is one that provides a steady flow of power regardless of total power demand by the grid. These plants run at all times through the year except in the case of repairs or scheduled maintenance. Power plants are designated base load based on their low cost generation, efficiency and safety at set outputs. Base load power plants do not change production to match power consumption demands since it is always cheaper to run them rather than running high cost combined cycle plants or combustion turbines. Typically these plants are large enough to provide a majority of the power used by a grid, making them slow to fire up and cool down [21]. Thus, they are more effective when used continuously to cover the power base load required by the grid. Each base load power plant on a grid is allotted a specific amount of the base load power demand to handle. The base load power is determined by the load duration curve of the system. For a typical power system, rule of thumb states that the base load power is usually 35-40% of the maximum load during the year. Load factor of such plants is high. Fluctuations, peaks or spikes in customer power demand are handled by smaller and more responsive types of power plants.

Peak Load Plants are used to cover the peak load due to their operational and economic properties. Gas turbines and storage and pumped storage power plants are used as peak load power plants. The efficiency of such plants is around 60 -70%.

2.2.5 Classification on the Basis of Location

On the basis of their location, hydro plants are classifieds in to three different categories:

- Hydro plants on different streams
- Hydro plants on the same stream
- Multi chain hydro power plants

Hydro Plants on different Streams are those in which all hydro plants on different streams as shown in fig 2.1 . the reservoir inflows include the tributary inflows & some of it may be lost on its way due to irrigation schemes , drainage , etc.

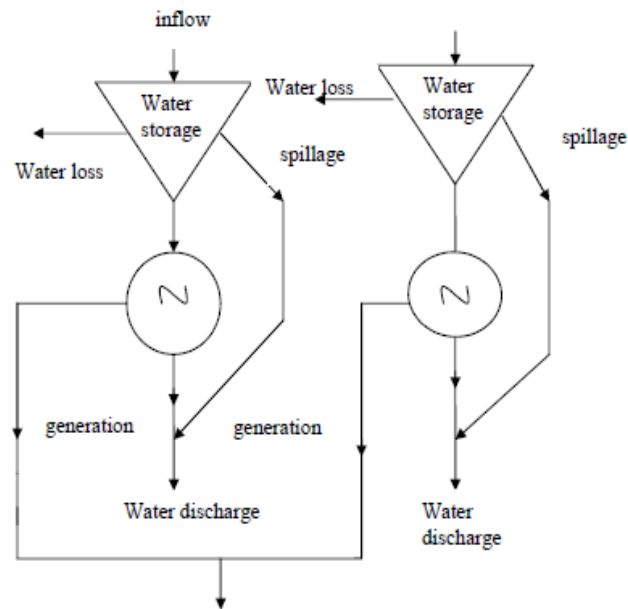


Fig 2.1 Hydro Plants on Different Streams

Hydro Plants on Same streams are those in which all hydro plants are on same stream, i.e. in series as shown in fig 2.2. The reservoir inflows include the tributary inflows, and the water released from the upstream reservoir. Water released from the upstream reservoir after a time delay and some of it may be lost on its way due to irrigation schemes, drainage etc.

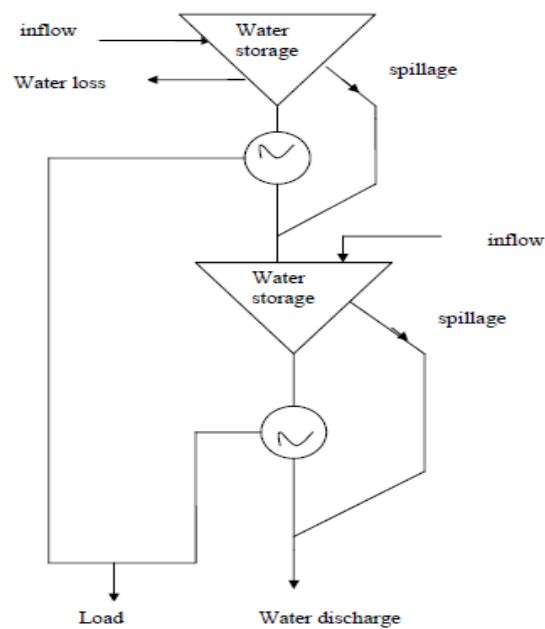


Fig 2.2 Hydro power Plants on Same stream

Multi Chain Hydro Power Plants are those hydro plants are located on different streams as well as on same stream. The arrangement is shown in fig 2.3

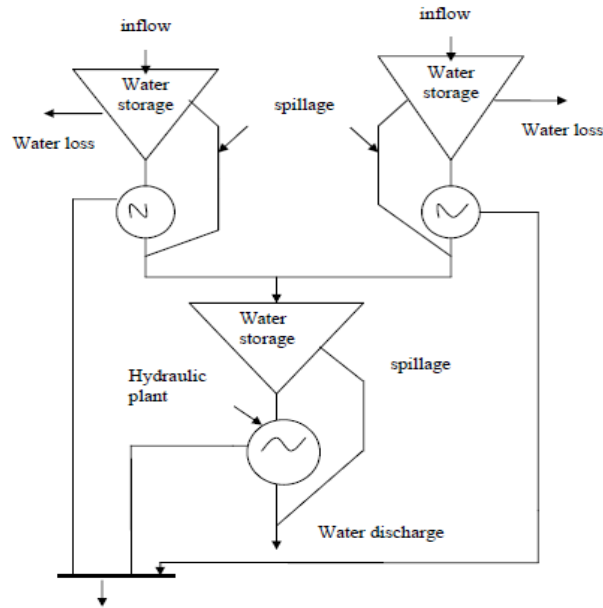


Fig 2.3 Multi Chain Hydro power plants

2.3 Thermal model:

The objective function to be minimized is the total system operating cost represented by the fuel cost of thermal generation over the optimization interval.

$$J_1 = \int_0^T (\sum_{i=1}^N a_i P_i^2 + b_i P_i + c_i) dt \quad (2.3.1)$$

Where a_i, b_i, c_i are the fuel cost coefficients

A stochastic model of function J_1 is formulated by considering errors in coefficients of input output characteristics and load demand during each subinterval as random variables.

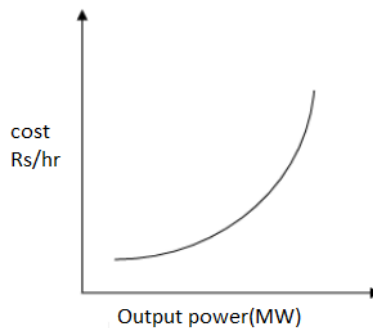


Fig 2.4 Fuel cost for thermal units

2.4 Hydro Plant Performance Models

A basic physically based relationship between the active powers generated (in MW) by a hydro-unit and the rate of water discharge, q (in m^3 / sec), and the effective head, h (in meters), is described with the help of hydro plant performance models which are given below:

2.4.1 Glimn-Kirchmayer Model

This model [1] defines the rate of water discharge, q , as a separable function of P_{ik} and h of the form: $q = k\psi(h)\phi(P_{jk})$

Where h is effective head and is the output power. The parameter k is a constant of proportionality assumed to be unity, and the ψ and ϕ are quadratic functions and given by:

$$\psi(h) = \alpha h^2 + \beta h + \gamma$$

Where α, β, γ are positive Coefficients

$$\phi(P_{jk}) = xP_{jk}^2 + yP_{jk} + z$$

x, y, z are discharge coefficients.

2.4.2 Hildebrand's Model

In this model, the rate of water discharge is given by

$$q = \sum_{i=0}^L \sum_{j=0}^K C_{ij} P^i h^j$$

Where

C_{ij} are coefficients

L is the maximum exponent (usually taken as 2)

K is the maximum exponent (usually taken as 2)

h is the effective head (m)

P is the real power generation

2.4.3 Hamilton –Lamont's Model

The rate of water discharge is defined by

$$q = \psi(h)(\phi(P) / h)$$

Where h is the effective head, P is the real power generation (MW)

The function ψ & ϕ are defined as

$$\psi(h) = \alpha h^2 + \beta h + \gamma$$

Where α, β, γ are positive coefficients

$$\phi(P) = xP^3 + yP + z$$

2.4.4 Arvanitidis – Rosing Model

The real power is defined by

$$P = qh \left[\beta - e^{-\alpha A(h-h_o)} \right]$$

Where

P is the real power generation (MW)

h is the effective head (m)

q is the rate of water discharge (m^3 / s)

A is the area of reservoir (m^2)

h_o is the minimum head (m)

α & β are coefficients

The first three models express water discharge as a function of power output from the i^{th} unit during time interval (k) and head of plant. The main reason for this is to conform with the conventional requirements of economic scheduling methodology treating water discharge as an input and output power (P_{jk}) as an output in much the same manner adopted for the treatment for fuel cost for thermal units. Due to the difficulties in fitting one unit's data to the original form of the Glimn-Kirchmayer's model, a simple extension was devised in the course of this investigation in Hamilton- Lamont's Model where we assume that is a third order polynomial in output power instead of the usual quadratic form. A constant term h_o may be included in Arvantidis- Rosing's model to provide an offset to yield more satisfactory results for some hydro plant types

3.1 Introduction

The short term hydrothermal scheduling problem is concerned with allocating generation among hydro and thermal units over one day or one week, usually discretized in hourly intervals. The problem formulation must take into account many System operating constraints, including hydraulic, thermal and electrical aspects. Each specific formulation will depend on the characteristics of the particular system. The objective is to minimize the total operating cost represented by the fuel cost required for the system’s thermal generation over the optimization interval. Each hydro plant is constrained by the amount of water available for draw down during the interval. A set of starting conditions is given and the optimal hourly schedule that minimizes a desired objective, while meeting hydraulic stream and electric system constraint is sought. The output of each hydro unit varies with the effective head and the rate of water discharge through the turbines. For large capacity reservoir, it is practical to assume that effective head is constant over the optimization interval.

The short range fixed head hydro thermal problem is formulated as: Consider an electric power system network having N thermal generating units and M hydro plants where M+N is the total no. of generating plants. The basic problem is to find the active power generation of each plant in the system as a function of time over a finite time period from 0 to T.

3.2 Problem formulation

3.2.1 Thermal model:

The objective function to be minimized is the total system operating cost represented by the fuel cost of thermal generation over the optimization interval.

$$J_1 = \int_0^T (\sum_{i=1}^N a_i P_i^2 + b_i P_i + c_i) dt \tag{3.2.1}$$

Where a_i, b_i, c_i are the fuel cost coefficients

A stochastic model of function J_1 is formulated by considering errors in coefficients of input output characteristics and load demand during each subinterval as random variables.

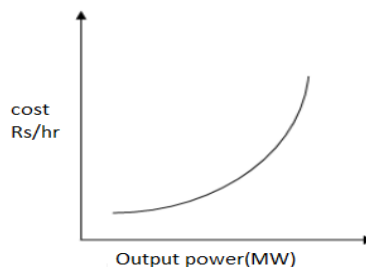


Fig 3.1 Fuel cost for thermal units

3.2.2 Emission models:

Thermal power stations are a major cause of atmospheric pressure because of high concentration of pollutants that they cause. The emission curves for a thermal plant can be directly related to the cost curve through the emission rate per mega joule, which is a constant factor for a given type or grade of fuel, thus yielding quadratic CO_2 and SO_2 emission curves in terms of active power generation. The aim is to optimize the CO_2, SO_2 emissions of thermal plant with full utilization of water available during the optimization period

The CO_2 emission objective can be defined as

$$J_2 = \int_0^T \left(\sum_{i=1}^N (d_i P_i^2 + e_i P_i + f_i) \right) dt \quad (3.2.2)$$

Where d_i, e_i, f_i are the CO_2 emission coefficients

The SO_2 emission objective can be defined as

$$J_3 = \int_0^T \left(\sum_{i=1}^N (g_i P_i^2 + h_i P_i + j_i) \right) dt \quad (3.2.3)$$

Where g_i, h_i, j_i are the SO_2 emission coefficients

Development of stochastic models of functions J_2, J_3 are adopted after much consideration that the thermal generations and load demand during each subinterval are random variables. Any possible deviations of CO_2 and SO_2 emission coefficients and load demand from their expected values is managed through the random power generation P_i . Presuming that random variables are normally distributed and statically independent.

3.2.3 Hydro model:

In a short range hydrothermal scheduling problem, an insignificant fuel cost is incurred in the operation of hydro units. The input output characteristics of a hydro generator are expressed by the water discharge q_j as a function of power output P_j and the net head h . According to Glimn kirachmayer model, the discharge is

$$q_j = k\phi(h)T(P_j), \quad j=1, 2, \dots, M \quad (3.2.4)$$

For a large capacity reservoir, it is practical to assume that the effective head is constant over the optimization interval in the case of constant head, $\phi(h)$ becomes constant, and equation is rewritten as

$$q_j = k^1 T(P_j), \quad j=1, 2, \dots, M \quad (3.2.5)$$

k^1 Becomes new constant and is formed by the multiplication of k and $\phi(h)$. Each hydro plant is constrained by the amount of water available for the optimization interval

$$\int_0^T q_j dt = R_j, \quad j=1, 2, \dots, M \quad (3.2.6)$$

The performance of q_j is represented by

$$q_j = x_j P_j^2 + y_j P_j + z_j, \quad j=1, 2, \dots, M \quad (3.2.7)$$

Since the thermal generations and load demand are random. The hydro generation also becomes random in view of the load demand constraint.

3.2.4 Equality and inequality constraints:

- (i) The expected load demand equality constraint

$$\sum_{i=1}^{M+N} P_i = P_d + P_l \quad (3.2.8)$$

- (ii) The expected limits are imposed as

$$P_i^{\min} \leq P_i \leq P_i^{\max}, \quad i=1, \dots, M+N \quad (3.2.9)$$

3.2.5 Expected transmission loss:

A common approach to model transmission losses in the system is to use Kron approximated loss formula through B coefficients.

$$P_l = \sum_{i=1}^{M+N} \sum_{j=1}^{M+N} P_i B_{ij} P_j \quad (3.2.10)$$

Multi objective formulation:

The multi objective problem is framed considering (i) the Expected operating cost (ii) the expected CO₂ emission (iii) expected SO₂ emission of thermal units. Each hydroplant is constrained by the expected amount of water drawn in the interval. Mathematically multi objective problem is defined as

$$\min [J_1, J_2, J_3]^T$$

Subjected to

$$\sum_{i=1}^{M+N} P_i = P_d + P_l \quad (3.2.11)$$

$$\int_0^T q_j dt = R_j, \quad j=1, 2, \dots, M \quad (3.2.12)$$

$$P_i^{\min} \leq P_i \leq P_i^{\max}, \quad i=1, 2, \dots, M+N \quad (3.2.13)$$

3.3 Algorithm:

To generate the non inferior solution to the multi objective problem, the weighting method is applied. In this method the problem is converted into a scalar optimization as given below

$$\min \sum_{k=1}^n w_k j_k$$

$$\text{and also } \sum_{k=1}^n w_k = 1; w_k \geq 0$$

This approach yields meaningful result to the decision maker when solved many times for different values of w_k , $k=1 \dots n$. Here n is the number of objectives. Weighting factors w_k are determined based on the relative importance of various objectives, which may vary from place to place and utility to utility. The simplest way to arrive at the required equations is to use the calculus of variations. Each constraint is associated with an unknown multiplier function known as the Lagrange multiplier. The augmented objective function is

$$L = \sum_{k=1}^n w_k j_k + \int_0^T \sum_{j=1}^M v_j q_j(t) + \lambda(t) \left(P_d + P_l - \sum_{i=1}^{M+N} P_i \right) dt - \sum_{j=1}^M v_j R_j \quad (3.3.1)$$

The optimally conditions are described by taking the partial derivatives of augmented objective function with respect to the decision variables.

$$\sum_{k=1}^n w_k \left(\frac{\partial J_k}{\partial P_i} \right) + \lambda(t) \left(\frac{\partial P_l}{\partial P_i} - 1 \right) = 0 \quad i=1, 2, 3, \dots, N \quad (3.3.2)$$

$$v_j \left(\frac{\partial q_j}{\partial P_j} \right) + \lambda(t) \left(\frac{\partial P_l}{\partial P_j} - 1 \right) = 0 \quad j=1, 2, 3, \dots, M \quad (3.3.3)$$

$$\int_0^T q_j dt - R_j = 0 \quad j=1, 2, 3, \dots, M \quad (3.3.4)$$

$$P_d + P_l - \sum_{i=1}^{M+N} P_i = 0 \quad i=1, 2, \dots, M+N \quad (3.3.5)$$

These equations are inherently non linear.

Classical method have been applied to solve these equations & to find the solution with a proper initial guess [7]. Once the water constraint & Lagrange multiplier is determined the generation of thermal and hydro-units can be computed.

3.3.1 Initial guess method:

Power demand is equally distributed among hydro & thermal units given as

$$P_{ik} = P_{jk} = \left(\frac{P_{dk}}{M + N} \right) \quad (3.4.1)$$

Further it is assumed that there are no transmission losses

$$\lambda_k^0 = 2 * a_i * P_{ik}^0 + b_i \quad (3.4.2)$$

The water conversion factor can be obtained as

$$v_j^0 (2 * x_j * P_{jk}^0 + y_j) = \lambda_k^0 \quad (3.4.3)$$

$$v_j^0 = (\lambda_k^0 / (2 * x_j * P_{jk}^0 + y_j)) \quad (3.4.4)$$

Using the initial values of $P_{ik}^0, P_{jk}^0, \lambda_k^0, v_j^0$ we can find out power generation by thermal & hydro power plants.

$$P_{ik}^{new} = P_{ik}^0 + \Delta P_{ik}$$

$$\lambda_k^{new} = \lambda_k^0 + \Delta \lambda_k$$

$$v_j^{new} = v_j^0 + \Delta v_j$$

$$\begin{aligned} & \left(t_k \frac{\partial^2 F_i}{\partial P_{ik}^2} + \lambda_k \frac{\partial^2 P_{lk}}{\partial P_{ik}^2} \right) \Delta P_{ik} + \lambda_k \sum_{\substack{j=1 \\ j \neq i}}^{N+M} \frac{\partial^2 P_{lk}}{\partial P_{ik} \partial P_{jk}} \Delta P_{jk} + ((\partial P_{lk} / \partial P_{ik}) - 1) \Delta \lambda_k = \\ & - [t_k (\partial F_i / \partial P_{ik}) + \lambda_k ((\partial P_{lk} / \partial P_{ik}) - 1)] \end{aligned} \quad (i=1,2,\dots,N) \quad (3.4.5)$$

$$\begin{aligned} & \left(v_j t_k \frac{\partial^2 q_{jk}}{\partial P_{mk}^2} + \lambda_k \frac{\partial^2 P_{lk}}{\partial P_{mk}^2} \right) \Delta P_{mk} + \lambda_k \sum_{\substack{l=1 \\ l \neq j}}^{N+M} \frac{\partial^2 P_{lk}}{\partial P_{mk} \partial P_{lk}} \Delta P_{lk} + ((\partial P_{lk} / \partial P_{mk}) - 1) \Delta \lambda_k = \\ & - [v_j t_k (\partial q_{jk} / \partial P_{mk}) + \lambda_k ((\partial P_{lk} / \partial P_{mk}) - 1)] \end{aligned} \quad (j=1,2,\dots,M; m=j+N) \quad (3.4.6)$$

$$\sum_{j=1}^{N+M} ((\partial P_{lk} / \partial P_{jk}) - 1) \Delta P_{jk} = - \left(P_{dk} + P_{lk} - \sum_{i=1}^{N+M} P_{ik} \right) \quad (3.4.7)$$

$$\sum_{k=1}^T ((\partial q_{jk} / \partial P_{mk}) - 1) \Delta P_{mk} = - \left(\sum_{k=1}^T q_{jk}^0 - R_j \right) \quad (3.4.8)$$

Coordination equations

$$\frac{\partial L}{\partial P_{ik}} = 0 = t_k \frac{\partial J_i(P_{ik})}{\partial P_{ik}} + \lambda_k \left[\frac{\partial P_{lk}}{\partial P_{ik}} - 1 \right]$$

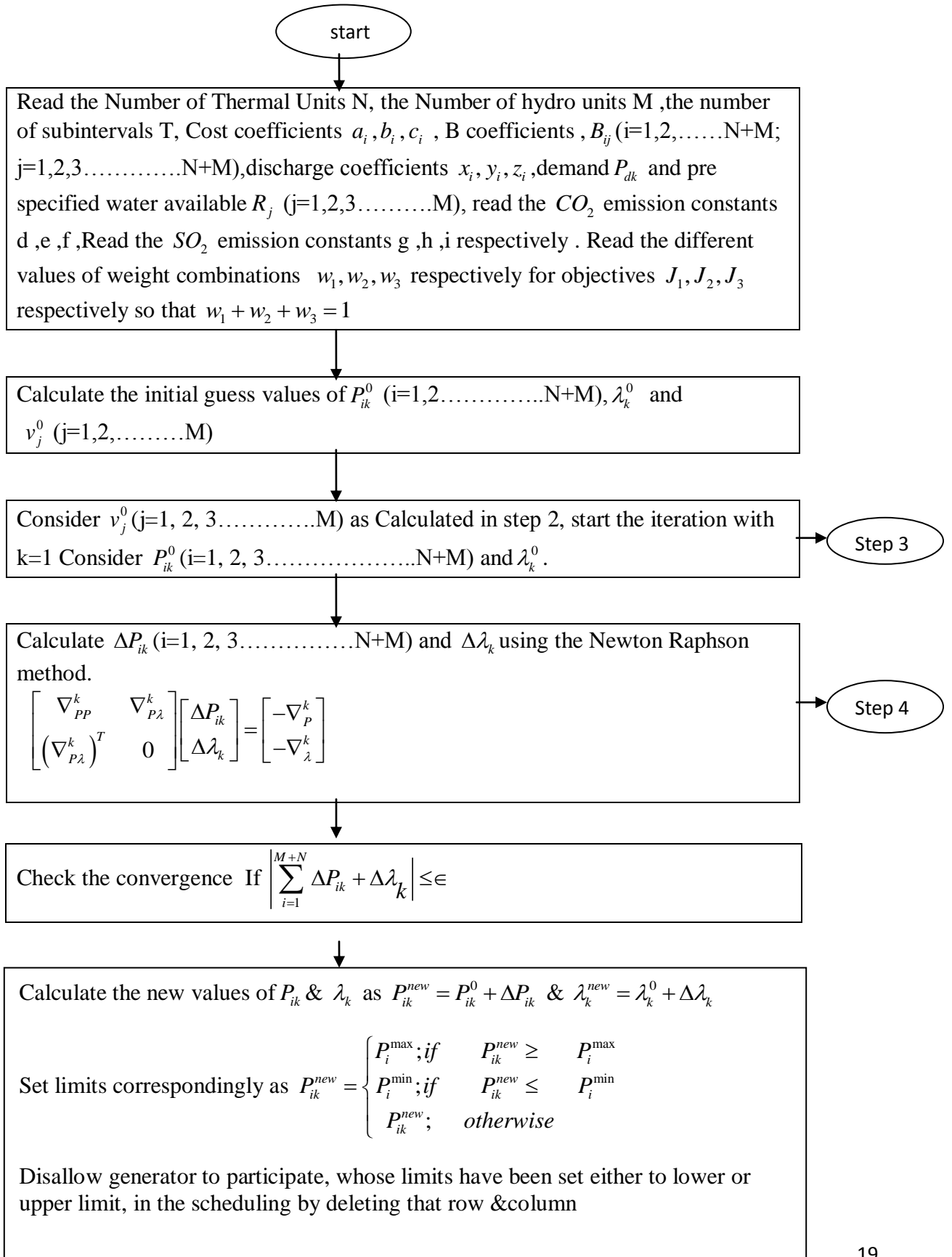
$$\frac{\partial L}{\partial P_{mk}} = 0 = v_j t_k \frac{\partial q_{jk}}{\partial P_{mk}} + \lambda_k \left[\frac{\partial P_{lk}}{\partial P_{mk}} - 1 \right]$$

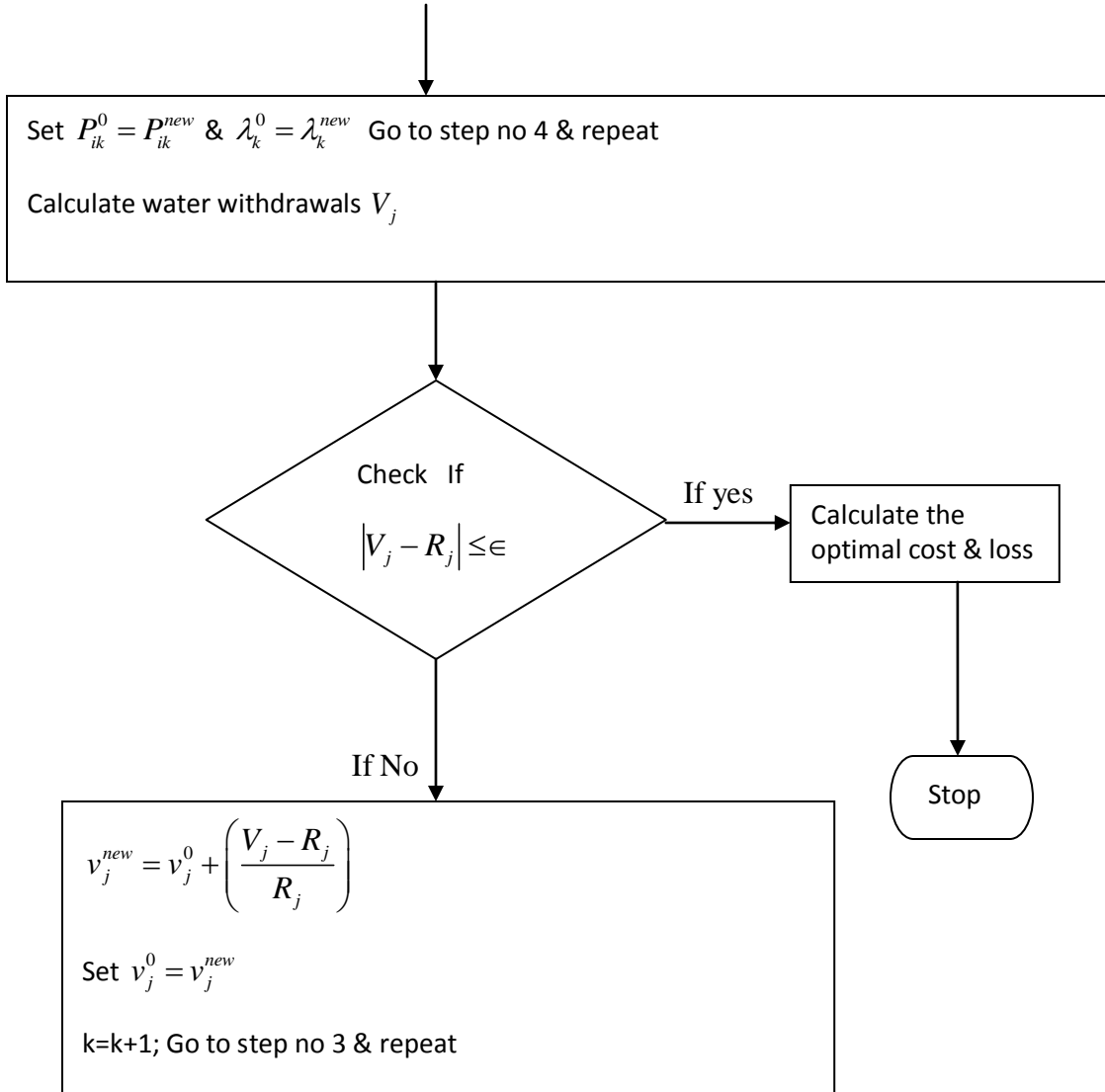
$$\frac{\partial L}{\partial v_j} = 0 = \sum_{k=1}^T t_k q_{jk} = R_j$$

$$\frac{\partial L}{\partial \lambda_k} = 0 = \sum_{i=1}^{N+M} P_{ik} = P_{dk} + P_{lk}$$

These equations are non linear & solved by Classical method.

3.4 Flow chart of multi objective hydrothermal scheduling using Classical Method





4.1 Introduction:

Decision Making is a most important scientific, social, and economic endeavor. To be able to make consistent and correct choices is the essence of any decision process imbued with uncertainty. Most issues in life, as trivial as we might consider them, involve decision processes of one form or another.

It must be kept in mind when dealing with decision making under uncertainty that there is a distinct difference between a good decision and a good outcome. In any decision process we weigh the information about an issue or outcome and choose among two or more alternatives for subsequent action. The information affecting the issue is likely incomplete or uncertain; hence, the outcomes are uncertain, irrespective of the decision made or the alternative chosen. We can make a good decision, and the outcome can be adverse .alternatively, we can make a bad decision, and the outcome can be advantageous. Such are the vagaries of uncertain events. But in the long run, if we consistently make good decisions, advantageous situations will occur more frequently than bad ones.

The problem in making decisions under uncertainty is that the bulk of information we have about the possible outcomes, about the value of new information we have about the possible outcomes, about the value of new information, about the way the conditions change with time, about the utility of each outcome –action pair, and about our preferences for each action is typically vague, ambiguous, and otherwise fuzzy. In some situations the information may be robust enough so that we can characterize it with probability theory.

Acceptance of the fuzzy approach is eased with its natural accommodation within a Classical and historical popular, decision making approach.

4.2 Fuzzy Decision making:

Multi objective problem is solved to obtain the non-inferior solutions. In order to select a suitable compromise solution from all non-inferior, decision making is also necessary. Availability of a number of compromised solutions is useful to decision maker in choosing a particular solution. The presence of multiple solutions will allow the decision maker to compare the solutions and make a more confident decision.[20]

Considering the imprecise nature of the decision maker judgment, it is natural to assume that the decision maker may have fuzzy or imprecise goals for each objective function. The fuzzy sets are defined by equations called membership functions. These functions represent the degree of membership in some fuzzy sets using values from 0 to 1 [9] .The membership 0 indicates the incompatibility with the sets, while 1 means full compatibility. By taking account of the minimum & maximum values of each objective function together with the rate of increase of membership satisfaction. The decision maker must detect membership function $u(J_i)$ in

subjective manner [22]. Here it is assumed that $u(J_i)$ is a strictly monotonic decreasing & continuous function defined as

$$\begin{aligned}
 u(J_i) &= 1 \dots\dots\dots J_i \leq J_i^{\min} \\
 u(J_i) &= \left(\frac{(J_i^{\max} - J_i)}{(J_i^{\max} - J_i^{\min})} \right) \dots\dots\dots J_i^{\min} < J_i < J_i^{\max} \\
 u(J_i) &= 0 \dots\dots\dots J_i \geq J_i^{\max}
 \end{aligned} \tag{4.2.1}$$

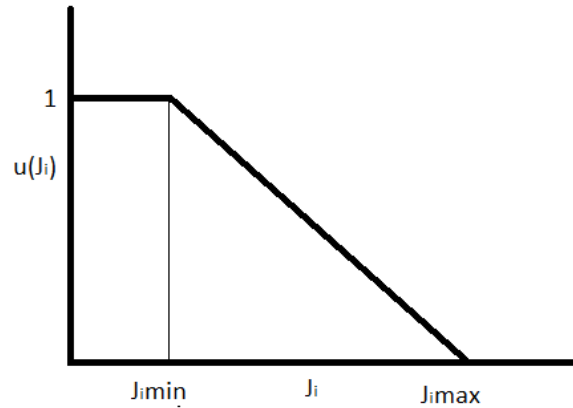


Fig 4.1

Fig 4.1 represents the relationship between objective & membership function of the objective. The value of membership function suggests how far (in the scale from 0 to 1) a non inferior (non dominated) solution has satisfied the J_i objective. The sum of membership function values for all the objectives can be computed to accomplishment of each solution in satisfying the objectives. The accomplishment of each non dominated solution can be rated with respect to all the k non dominated solutions by normalizing its accomplishment over the sum of the accomplishments of k non dominated solutions as follows

$$u_d^k = \left(\frac{\sum_{i=1}^n u(J_i^k)}{\sum_{k=1}^K \sum_{i=1}^n u(J_i^k)} \right) \tag{4.2.2}$$

The function u_d^k in 4.2.2 can be treated as a membership function for non dominated solutions, in a fuzzy set and represented as fuzzy cardinal priority ranking of non dominated solutions. the solution that attains the maximum membership u_d^k in the fuzzy set so obtained can be chosen as best solution or the one having highest cardinal priority ranking.

$$\text{Max}\{u_d^k : k = 1 \dots\dots\dots K\} \tag{4.2.3}$$

4.3 Methods used for fuzzy decision making technique:

Other than the weighting method used for fuzzy decision making technique to generate non inferior solutions some different methods can also be used to generate non inferior solutions such as:

- (1) ϵ Constraint method
- (2) Surrogate worth trade off function
- (3) Utility function

But we have use the weighting method here for fuzzy decision making technique because this method yields meaningful result to the decision maker when solved many times for different values of w_k . Weighting factors w_k are determined based on the relative importance of various objectives, which may vary from place to place and utility to utility. In this method the constraint scalar optimization problem is converted into unconstraint scalar optimization problem. & each constraint equation is associated with an unknown multiplier known as Lagrange multiplier.

4.4 Determination of the optimal or 'best' solution:

The Optimal or best solution is found for three objectives J_1, J_2, J_3 respectively .The weights w_1, w_2, w_3 are varied in the range of 0 to 1. So that the sum of all the weights equal to 1 the non inferior solution that attains the maximum membership u_d^k is distinguished as the 'best' solution among non inferior solutions. The weight combination for maximum u_d^k provides the 'best' or 'preferred' weight combination.

Here the three objectives are fuel cost, CO_2 emission, SO_2 emission respectively

Fuel cost

$$J_1 = a_i P_1^2 + b_i P_1 + c_i \text{ (Rs/hr)} \quad (4.3.1)$$

CO_2 Emission

$$J_2 = d_i P_1^2 + e_i P_1 + f_i \text{ (Kg/hr)} \quad (4.3.2)$$

SO_2 Emission

$$J_3 = g_i P_1^2 + h_i P_1 + j_i \text{ (Kg/hr)} \quad (4.3.3)$$

Here these three objectives have to be minimized using fuzzy decision making technique, the weights are chosen for which the value of non inferior solution u_d^k is maximum.

The values of objectives corresponding to these chosen weights for maximum value of u_d^k are considered as optimized values

5.1 Introduction:

The classical Method is implemented on test system with & without weighting method. Fuzzy decision making technique is implemented on the classical method with weighting method.

Results of the test system are compared between classical method without weights & classical method with weighted fuzzy decision making technique.

Test System

Data for thermal system

Cost coefficients of the i^{th} unit	a_i	b_i	c_i
	0.001991	9.606	373.7

CO_2 emission coefficients	d_i	e_i	f_i
	0.084025	2.9445484	137.7043

SO_2 emission coefficients	g_i	h_i	j_i
	0.00232	3.84632	182.2605

Data for hydro system

Discharge Coefficients	x_j	y_j	z_j
	0.0000219427	0.00025709	1.742333

Fuel cost

$$J_1 = 0.001991 P_1^2 + 9.606 P_1 + 373.7$$

CO_2 Emission

$$J_2 = 0.084025 P_1^2 - 2.9445484 P_1 + 137.7043$$

SO_2 Emission

$$= 0.00232 P_1^2 + 3.84632 P_1 + 182.2605$$

J_3

Water discharged

$$q_j = 0.0000219427 P_j^2 - 0.00025709 P_j + 1.742333$$

Loss Coefficients

$$B_{11}=0.00005, B_{12} = B_{21} =0.00001, B_{22} =0.00015$$

Pre specified volume of water of water available for dispatch $R_j =72.479$ M cubic ft

5.2 Case study 1:

Multi objective hydrothermal scheduling without weighted fuzzy decision making technique using Classical Method

Table 5.1 represents the Load demand, thermal power generated, hydro power generated, Power losses, water discharged per hour, power mismatch during whole of the day

Time Intervals In hrs	Load Demand (MW)	Thermal Power Generated (MW)	Hydro Power Generated (MW)	Losses (MW)	Water Discharged (M cubic ft /hr)	Power mismatch (MW)
1	600	321.5990	298.8947	20.4995	3.6258	2.1621e-008
2	550	293.1824	273.9818	17.1642	3.3190	1.0204e-008
3	455	240.0285	226.6455	11.6739	2.8112	2.1977e-009
4	650	350.3276	323.8051	24.1327	3.9598	4.3400e-008
5	575	307.3526	286.4385	18.7911	3.4690	1.4300e-008
6	615	330.1854	306.3681	21.5535	3.7231	2.6811e-008
7	700	379.3702	348.7117	28.0819	4.3209	8.3319e-008
8	675	364.8093	336.2589	26.0682	4.1369	6.055e-008
9	590	315.8917	293.9123	19.8039	3.5623	1.8683e-008
10	480	253.9109	239.1023	13.0132	2.9353	3.3117e-008
11	475	251.1285	236.6109	12.7394	2.9100	3.0504e-009
12	460	242.7990	229.1368	11.9358	2.8355	2.3849e-009
13	510	270.6689	254.0507	14.7196	3.0932	5.4060e-009
14	525	279.0887	261.5249	15.6136	3.1759	6.8815e-009
15	540	287.5358	268.9991	16.5349	3.2610	8.7200e-009
16	630	338.7990	313.7990	22.6403	3.8229	3.3091e-008
17	620	333.0535	308.8592	21.9127	3.7561	2.8774e-008
18	585	313.0422	291.4210	19.4632	3.5309	1.735e-008
19	400	209.7484	199.2417	8.9901	2.5622	9.3075e-0010
20	720	391.0764	358.6730	29.7494	4.4730	1.067e-007
21	640	344.5570	318.232	23.3803	3.8908	3.7978e-008
22	530	281.9013	264.0163	15.9176	3.2040	7.4522e-009
23	420	220.7180	209.2064	9.9244	2.6489	1.2571e-009
24	410	215.2273	204.2240	9.4514	2.6050	1.0792e-009

Table 5.2 Represents the Fuel Cost, CO_2 & SO_2 emissions over the day

Time Interval in hrs	Load Demand (MW)	Fuel Cost (Rs/hr)	CO_2 emission (Kg/hr)	SO_2 emission (Kg/hr)
1	600	3668.90	7881.10	1659.20
2	550	3361.1	6496.9	1509.4
3	455	2794.1	4271.9	1239.2
4	650	3983.3	9418.5	1814.5
5	575	3514.2	7170.2	1583.6
6	615	3762.5	8326.1	1705.2
7	700	4304.5	11114.0	1975
8	675	4143.0	10246.0	1894.2
9	590	3606.8	7592.2	1628.8
10	480	2941.1	4807.2	1308.5
11	475	2911.6	4697.3	1294.5
12	460	2823.4	4376.2	1252.9
13	510	3119.6	5496.5	1393.3
14	525	3209.7	5860	1436.4
15	540	3300.4	6238	1480.0
16	630	3856.7	8784.9	1751.7
17	620	3793.9	8477.5	1720.6
18	585	3570	7450	1613.7
19	400	2476.1	3216.7	1091.1
20	720	4434.9	1183.7	2041.3
21	640	3919.9	9098.5	1783
22	530	3239.9	5985	1450.9
23	420	2590.9	3581.2	1144.2
24	410	2533.4	3396.2	1117.6

The load curve is shown below in the fig 5.1

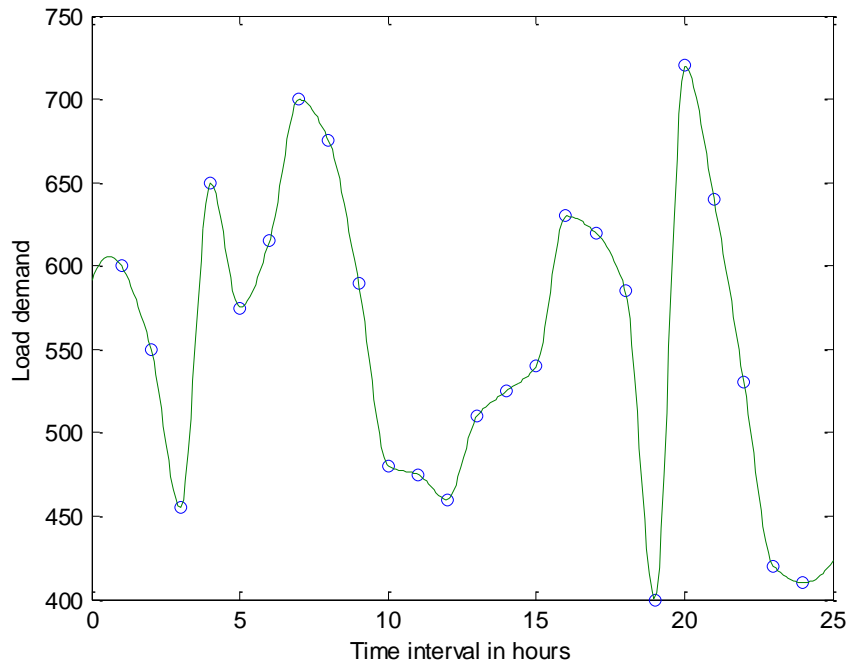


Fig 5.1 Load Curve

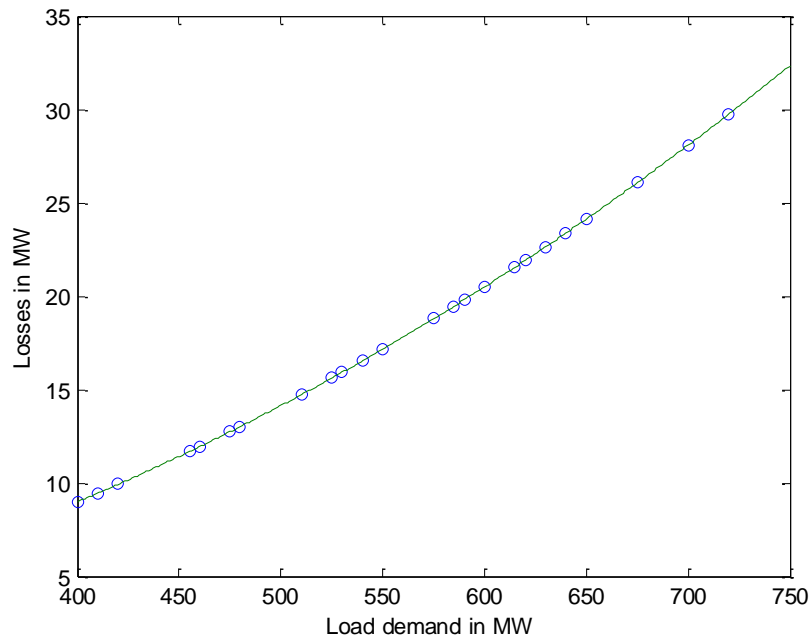


Fig 5.2 Power Losses over the day

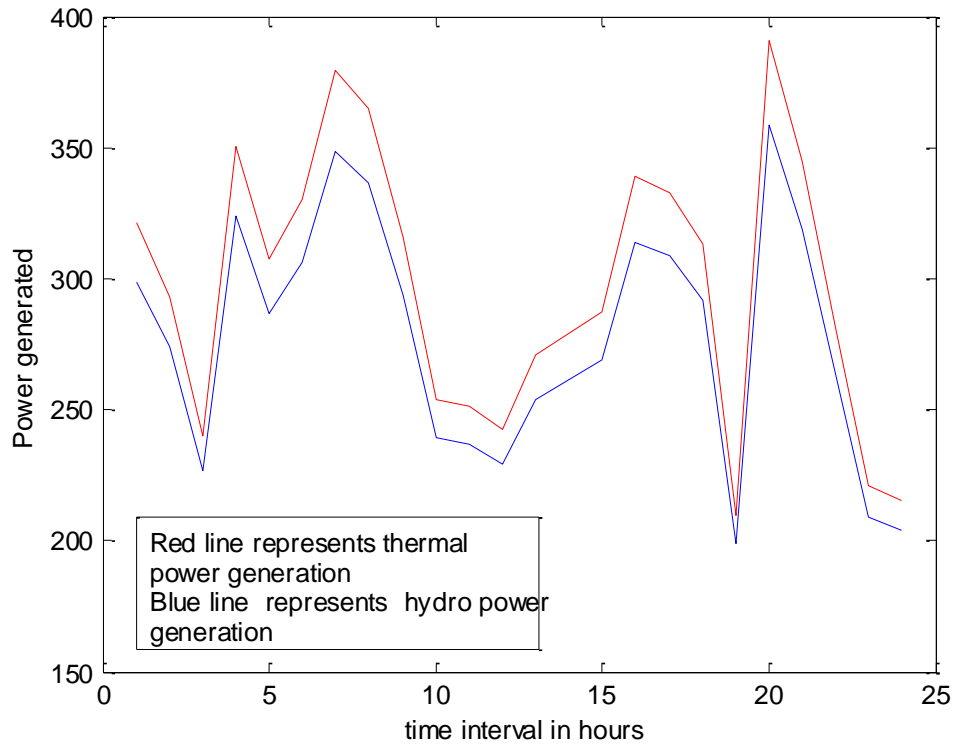


Fig 5.3 Hydro & Thermal power generation throughout the day

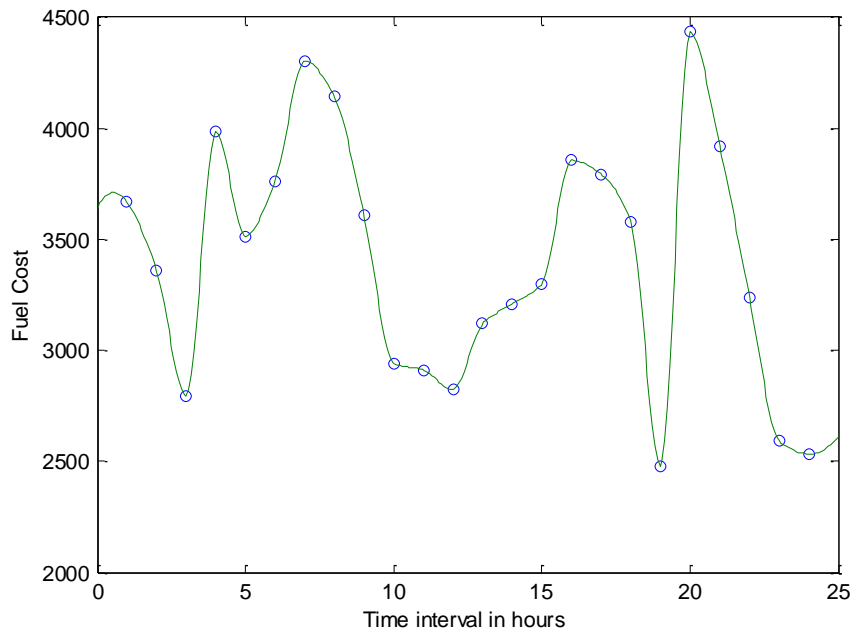


Fig 5.4 Fuel cost over the day

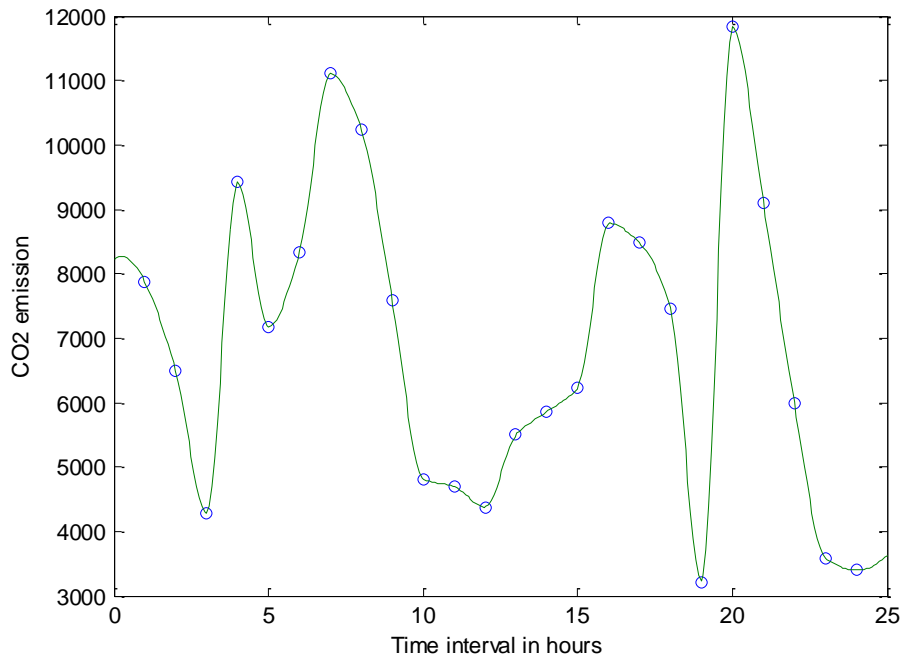


Fig 5.5 CO_2 emissions over the day

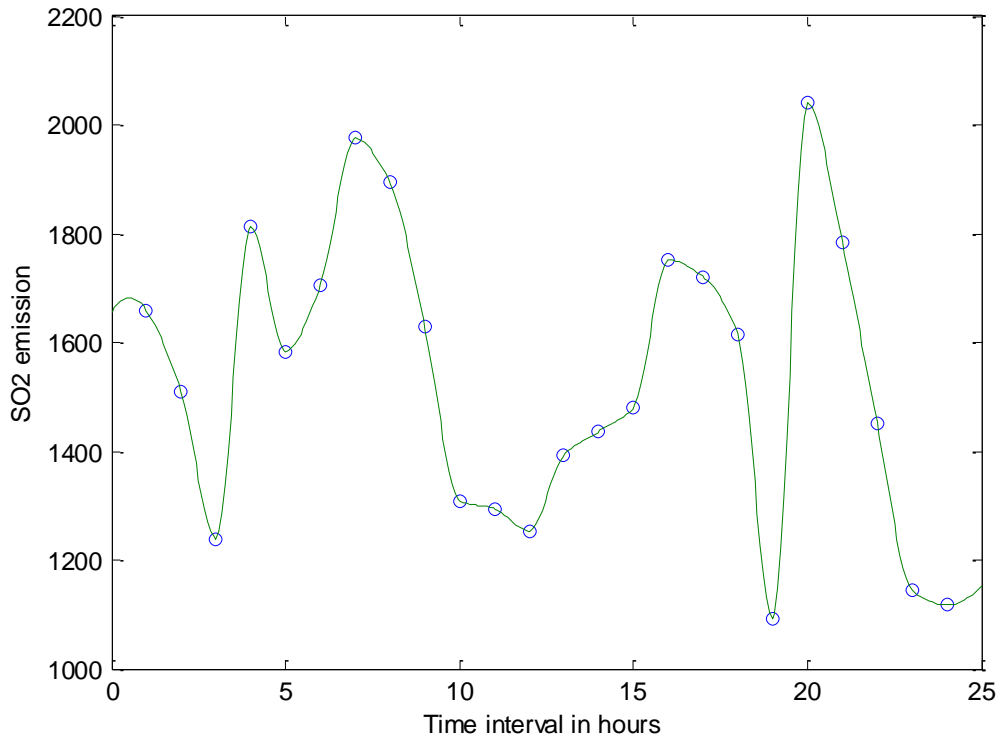


Fig 5.6 SO_2 emissions over the day

5.3 Case study 2. Multi objective hydrothermal scheduling with weighted fuzzy decision making technique using classical method

In the weighting method, weights are varied are in range from 0 to 1. So that

$\sum_{i=1}^n w_i = 1$. n is the number of objectives. Then fuzzy decision making technique is implemented on weighting method

Table 5.3

Thermal, hydro generation, losses, incremental cost, water discharged & power mismatch corresponding to the different combinations of weights for 600MW

S.No	w_1	w_2	w_3	Thermal Power Generation (MW)	Hydro power Generation (MW)	Losses (MW)	Water Discharged M cubic ft/hr	Power mismatch (MW)
1	0.1	0.1	0.8	336.29	283.36	19.60	3.4314	6.244e-008
2	0.2	0.2	0.6	272.6499	351.5185	24.1685	4.3633	1.2544e-004
3	0.3	0.25	0.45	246.9354	379.6030	26.5384	4.8066	2.3687e-006
4	0.4	0.3	0.30	225.5612	403.1854	28.7465	5.2056	8.4892e-007
5	0.5	0.3	0.20	220.2176	409.1154	29.330	5.3098	3.5262e-008
6	0.6	0.3	0.10	214.8845	415.0477	29.9322	5.4156	3.6386e-008
7	0.7	0.3	0	209.3933	421.1705	30.5638	5.5264	6.112e-008
8	0.6	0.25	0.15	229.0329	399.3400	28.3729	5.1389	6.4837e-008
9	0.55	0.2	0.25	249.4294	376.8655	26.2949	4.7619	6.9413e-008
10	0.5	0.25	0.25	234.6225	393.1611	27.7836	5.0331	1.6013e-007
11	0.45	0.3	0.25	222.2491	406.8593	29.1084	5.2700	5.1786e-008
12	0.4	0.25	0.35	240.3704	386.8229	27.1993	4.92	5.0096e-007
13	0.35	0.25	0.4	243.2506	383.6529	26.9034	4.8734	5.0866e-008
14	0.3	0.15	0.55	288.8982	333.9308	22.82	4.1033	4.8854e-005
15	0.2	0.15	0.65	296.1214	326.1507	22.2721	3.9926	1.3824e-008
16	0.15	0.15	0.70	299.7265	322.2766	22.0030	3.9385	4.4623e-008
17	0.15	0.20	0.65	274.9398	349.0326	23.9724	4.3257	2.4267e-006
18	0.25	0.25	0.5	248.9221	377.4221	26.3442	4.7710	2.4545e-006
19	0.35	0.30	0.35	227.3131	401.2442	28.5573	5.1719	8.7905e-007
20	0.4	0.35	0.25	211.4830	418.8387	30.3217	5.4840	1.6619e-007
21	0.5	0.35	0.15	206.5403	424.3575	30.8978	5.5847	3.7402e-008

Table 5.4

Fuel Cost, CO_2 emission, SO_2 emission & their membership functions & non inferior solution u_d^k corresponding to the different combinations of weights for 600MW

S.No	w_1	w_2	w_3	Fuel Cost J_1 (Rs/hr)	CO_2 emission J_2 (Kg/hr)	SO_2 emission J_3 (Kg/hr)	$u(J_1)$	$u(J_2)$	$u(J_3)$	Non inferior solution u_d^k
1	0.1	0.1	0.8	3828.7	8647	1737.8	0	0	0	0
2	0.2	0.2	0.6	3140.8	5581.1	1403.4	0.4732	.5345	.4824	.03292
3	0.3	0.25	0.45	2867.2	4534.2	1273.5	0.6615	.7171	.6698	.04525
4	0.4	0.3	0.30	2641.7	3748.5	1167.9	0.8166	.8541	.8222	.05507
5	0.5	0.3	0.20	2585.7	3564.1	1141.8	0.8552	0.8862	.8598	.05746
6	0.6	0.3	0.10	2592.8	3384.8	1115.9	0.8936	0.9175	.8971	.05983
7	0.7	0.3	0	2472	3205.3	1089.4	0.9331	0.9488	.9354	.06224
8	0.6	0.25	0.15	2678.2	38709.2	1184.9	0.7915	0.8327	.7976	.05350
9	0.55	0.2	0.25	2893.6	4630.9	1286	0.6433	0.7002	.6518	.04408
10	0.5	0.25	0.25	2737.1	4072.2	1212.4	0.7510	0.7976	.7579	.05095
11	0.45	0.3	0.25	2607	3633.7	1151.7	0.8405	0.8741	.8455	.05655
12	0.4	0.25	0.35	2797.7	4284.7	1240.8	0.7093	0.7606	0.7169	.04831
13	0.35	0.25	0.4	2828.2	4393.3	1255.2	.6883	0.7416	0.6963	.04697
14	0.3	0.15	0.55	3315	6299.9	1487.1	0.3534	0.4092	0.3617	0.02483
15	0.2	0.15	0.65	3392.82	6633.7	1524.6	0.2998	0.3510	0.3075	0.02117
16	0.15	0.15	0.70	3431.7	6803.6	1543.5	0.2731	0.3214	0.2803	0.01932
17	0.15	0.20	0.65	3165.2	5679.7	1415.1	.4564	.5173	0.4655	0.03179
18	0.25	0.25	0.5	2888.2	4611.1	1283.4	.6470	.7037	0.6554	0.04432
19	0.35	0.30	0.35	2660.1	3810.0	1176.4	.8039	.8433	0.8098	0.05428
20	0.4	0.35	0.25	2494.2	3273.0	1099.4	.9180	.9370	0.9209	0.01613
21	0.5	0.35	0.15	2442.6	3113.9	1075.6	.9535	.9647	0.9552	0.06348

From the table 5.4 maximum value of non inferior solution u_d^k is coming for the weight combinations $w_1=0.7$, $w_2=0.3$, $w_3=0$ respectively & fuel cost, CO_2 emission, SO_2 emission are minimum corresponding to these combinations of weights. So these combinations of weights are taken as the best combinations of weights for the 600 MW load demand

Table 5.5

Fuel Cost, CO_2 emission, SO_2 emission & their membership functions & non inferior solution u_d^k corresponding to the different combinations of weights for 550 MW

S.No	w_1	w_2	w_3	Fuel Cost J_1 (Rs/hr)	CO_2 emission J_2 (Kg/hr)	SO_2 emission J_3 (Kg/hr)	$u(J_1)$	$u(J_2)$	$u(J_3)$	Non inferior solution u_d^k
1	0.1	0.1	0.8	3580.0	7468.8	1615.6	0	0	0	0
2	0.2	0.2	0.6	2961.6	4884.2	1318.1	0.0465	0.5263	0.4740	0.0326
3	0.3	0.25	0.45	2710.5	3981.0	1200	0.654	0.7102	0.6623	0.0451
4	0.4	0.3	0.30	2502.6	3299.1	1103.3	0.811	0.8491	0.8164	0.0551
5	0.5	0.3	0.20	2447.8	3129.8	1078.04	0.852	0.8836	0.8566	0.0577
6	0.6	0.3	0.10	2393.3	2965.3	1052.94	0.893	0.9171	0.8966	0.0602
7	0.7	0.3	0	2338.6	2804.9	1027.87	0.934	0.9497	0.9366	0.0628
8	0.6	0.25	0.15	2529.5	3384.0	1115.7	0.790	0.8318	0.7965	0.0538
9	0.55	0.2	0.25	2726.4	4035.5	1207.43	0.642	0.6991	0.6505	0.0443
10	0.5	0.25	0.25	2588.3	3573.0	1143.06	0.746	0.7933	0.7530	0.0510
11	0.45	0.3	0.25	2472.9	3206.9	1089.6	0.833	0.8679	0.8382	0.0565
12	0.4	0.25	0.35	2647.5	3767.7	1170.5	0.701	0.7537	0.7092	0.0482
13	0.35	0.25	0.4	2677.1	3867.3	1184.4	0.679	0.7334	0.6872	0.0467
14	0.3	0.15	0.55	3116.2	5483.2	1391.7	0.349	0.4043	0.3568	0.0247
15	0.2	0.15	0.65	3191.3	5785.6	1427.6	0.292	0.3427	0.2996	0.0208
16	0.15	0.15	0.70	3228.9	5939.7	1445.6	0.264	0.3114	0.2709	0.0188
17	0.15	0.20	0.65	2990.2	4992.5	1331.7	0.443	0.5042	0.4524	0.0311
18	0.25	0.25	0.5	2735.8	4067.8	1211.8	0.635	0.6926	0.6435	0.0439
19	0.35	0.30	0.35	2525.1	3370.2	1113.76	0.794	0.8346	0.7977	0.0540
20	0.4	0.35	0.25	2372.6	2904.0	1043.43	0.9089	0.9296	0.9118	0.0612
21	0.5	0.35	0.15	2322.1	2757.3	1020.31	0.9469	0.9594	0.9486	0.0635

Table 5.6

Fuel Cost, CO_2 emission, SO_2 emission & their membership functions & non inferior solution u_d^k corresponding to the different combinations of weights for 455 MW

S.No	w_1	w_2	w_3	Fuel Cost J_1 (Rs/hr)	CO_2 emission J_2 (Kg/hr)	SO_2 emission J_3 (Kg/hr)	$u(J_1)$	$u(J_2)$	$u(J_3)$	Non inferior solution u_d^k
1	0.1	0.1	0.8	3100.7	5421.8	1384.2	0	0	0	0
2	0.2	0.2	0.6	2615.3	3661.1	1155.5	.4474	.5066	0.4548	0.0317
3	0.3	0.25	0.45	2408.7	3011.3	1060.0	.6379	.6936	0.6449	0.0446
4	0.4	0.3	0.30	2235.2	2513.3	980.66	.7978	.8370	0.8027	0.0550
5	0.5	0.3	0.20	2183.7	2373.8	957.24	.8453	.8771	0.8493	0.0580
6	0.6	0.3	0.10	2132.4	2238.8	933.98	.8926	.9159	0.8955	0.0610
7	0.7	0.3	0	2081.1	2107.6	910.78	.9399	.9353	0.9417	0.0639
8	0.6	0.25	0.15	2239.7	2525.6	982.70	.7937	.8334	0.7986	0.0547
9	0.55	0.2	0.25	2397.7	2978.7	1055.0	.6480	.7030	0.6548	0.0452
10	0.5	0.25	0.25	2294.9	2679.7	1007.8	.7428	.7891	0.7486	0.0514
11	0.45	0.3	0.25	2207.8	2438.6	968.1	.8231	.8585	0.8275	0.0566
12	0.4	0.25	0.35	2350.3	2838.9	1033.2	.6917	.7432	0.6981	0.0481
13	0.35	0.25	0.4	2378.1	2920.5	1045.9	.6661	.7198	0.6727	0.0464
14	0.3	0.15	0.55	2724.7	4029.6	1206.6	0.3466	.4005	0.3533	0.0248
15	0.2	0.15	0.65	2793.6	4270.3	1238.9	0.2830	.3313	0.2890	0.2038
16	0.15	0.15	0.70	2828.1	4393.2	1255.1	0.2512	.2959	0.2568	0.0181
17	0.15	0.20	0.65	2642.9	3752.4	1168.4	0.4220	.4803	0.4293	0.0300
18	0.25	0.25	0.5	2433.3	3085.6	1071.3	0.6152	.6722	0.6223	0.0431
19	0.35	0.30	0.35	2257.5	2574.8	990.8	0.7773	.8192	0.7825	0.0536
20	0.4	0.35	0.25	2131.4	2236.2	933.52	0.8935	.9167	0.8964	0.0610
21	0.5	0.35	0.15	2083.7	2114.2	911.95	0.9375	.9518	0.9393	0.0638

Table 5.7

Fuel Cost, CO_2 emission, SO_2 emission & their membership functions & non inferior solution u_d^k corresponding to the different combinations of weights for 650 MW

S.No	w_1	w_2	w_3	Fuel Cost J_1 (Rs/hr)	CO_2 emission J_2 (Kg/hr)	SO_2 emission J_3 (Kg/hr)	$u(J_1)$	$u(J_2)$	$u(J_3)$	Non inferior solution u_d^k
1	0.1	0.1	0.8	4076.3	9896.5	1860.8	0	0	0	0
2	0.2	0.2	0.6	3317.5	6310.7	1488.3	0.478	0.540	0.487	0.0328
3	0.3	0.25	0.45	3020.3	5107.7	1346.0	0.665	0.721	0.674	0.0450
4	0.4	0.3	0.30	2776.4	4209.4	1230.8	0.819	0.856	0.825	0.0546
5	0.5	0.3	0.20	2717.6	4005.2	1203.3	0.856	0.887	0.861	0.0568
6	0.6	0.3	0.10	2659.0	3806.2	1175.9	0.893	0.917	0.897	0.0591
7	0.7	0.3	0	2598.5	3605.9	1147.7	0.931	0.947	0.934	0.0614
8	0.6	0.25	0.15	2819.9	4363.9	1251.3	0.791	0.833	0.798	0.0529
9	0.55	0.2	0.25	3054.5	5240.2	1362.2	0.644	0.701	0.653	0.0436
10	0.5	0.25	0.25	2878.2	4574.7	1278.7	0.755	0.801	0.762	0.0506
11	0.45	0.3	0.25	2732.3	4055.8	1210.1	0.847	0.880	0.852	0.0563
12	0.4	0.25	0.35	2937.0	4791.7	1306.5	0.718	0.769	0.726	0.0483
13	0.35	0.25	0.4	2966.5	4902.6	1320.4	0.699	0.752	0.707	0.0471
14	0.3	0.15	0.55	3497.6	7096.0	1575.5	0.364	0.421	0.373	0.0253
15	0.2	0.15	0.65	3576.3	7451.9	1613.8	0.315	0.368	0.323	0.0219
16	0.15	0.15	0.70	3614.7	7628.7	1632.6	0.290	0.341	0.298	0.0203
17	0.15	0.20	0.65	3319.7	6320.1	1489.3	0.476	0.538	0.486	0.0328
18	0.25	0.25	0.5	3019.6	5105.0	1345.6	0.666	0.721	0.674	0.0450
19	0.35	0.30	0.35	2773.7	4200.0	1229.5	0.821	0.858	0.826	0.0547
20	0.4	0.35	0.25	2594.0	3591.3	1145.6	0.934	0.950	0.936	0.0616
21	0.5	0.35	0.15	2539.6	3415.9	1120.4	0.968	0.976	0.969	0.0636

Table 5.8

Fuel Cost, CO_2 emission, SO_2 emission & their membership functions & non inferior solution u_d^k corresponding to the different combinations of weights for 575 MW

S.No	w_1	w_2	w_3	Fuel Cost J_1 (Rs/hr)	CO_2 emission J_2 (Kg/hr)	SO_2 emission J_3 (Kg/hr)	$u(J_1)$	$u(J_2)$	$u(J_3)$	Non inferior solution u_d^k
1	0.1	0.1	0.8	3704.5	8049.2	1676.6	0	0	0	0
2	0.2	0.2	0.6	3051.3	5227.2	1360.7	0.469	0.5306	0.478	0.0328
3	0.3	0.25	0.45	2788.9	4253.6	1236.7	0.658	0.7138	0.666	0.0452
4	0.4	0.3	0.30	2572.2	3520.5	1135.5	0.813	0.8517	0.819	0.0551
5	0.5	0.3	0.20	2516.7	3343.5	1109.8	0.853	0.8850	0.858	0.0576
6	0.6	0.3	0.10	2461.5	3171.6	1084.3	0.893	0.9173	0.896	0.601
7	0.7	0.3	0	2406.1	3003.8	1058.8	0.933	0.9489	0.935	0.0625
8	0.6	0.25	0.15	2605.3	3628.3	1150.9	0.790	0.8314	0.796	0.0536
9	0.55	0.2	0.25	2812.3	4336.6	1247.7	0.641	0.6982	0.649	0.0441
10	0.5	0.25	0.25	2664.9	3826.1	1178.6	0.747	0.7942	0.754	0.0509
11	0.45	0.3	0.25	2542.0	3423.7	1121.5	0.835	0.8699	0.840	0.0565
12	0.4	0.25	0.35	2724.8	4029.9	1206.6	0.704	0.7559	0.711	0.0482
13	0.35	0.25	0.4	2754.8	4134.0	1220.7	0.682	0.7363	0.690	0.0468
14	0.3	0.15	0.55	3218.0	5895.0	1440.4	0.349	0.4051	0.357	0.0247
15	0.2	0.15	0.65	3294.5	6213.2	1477.2	0.294	0.3452	0.302	0.0209
16	0.15	0.15	0.70	3332.7	6375.3	1495.6	0.267	0.3148	0.274	0.0190
17	0.15	0.20	0.65	3080.0	5340.2	1374.4	0.448	0.5094	0.457	0.0314
18	0.25	0.25	0.5	2814.2	4343.3	1248.5	0.639	0.6969	0.648	0.0440
19	0.35	0.30	0.35	2594.7	3593.7	1146.0	0.797	0.8379	0.803	0.0541
20	0.4	0.35	0.25	2435.4	3091.8	1072.3	0.912	0.9323	0.915	0.0612
21	0.5	0.35	0.15	2384.3	2938.8	1048.8	0.948	0.9611	0.950	0.0635

Table 5.9

Fuel Cost, CO_2 emission, SO_2 emission & their membership functions & non inferior solution u_d^k corresponding to the different combinations of weights for 615 MW

S.No	w_1	w_2	w_3	Fuel Cost J_1 (Rs/hr)	CO_2 emission J_2 (Kg/hr)	SO_2 emission J_3 (Kg/hr)	$u(J_1)$	$u(J_2)$	$u(J_3)$	Non inferior solution u_d^k
1	0.1	0.1	0.8	3903.0	9014.5	1774.6	0	0	0	0
2	0.2	0.2	0.6	3194.1	5797.0	1429.0	0.4741	0.5357	0.4835	0.0328
3	0.3	0.25	0.45	2913.8	4705.7	1295.5	0.6616	0.7175	0.6701	0.0450
4	0.4	0.3	0.30	2683.2	3888.0	1187.2	0.8159	0.8536	0.8216	0.0548
5	0.5	0.3	0.20	2625.4	3694.4	1160.2	0.8546	0.8859	0.8593	0.0572
6	0.6	0.3	0.10	2567.7	3506.2	1133.5	0.8931	0.9172	0.8968	0.0595
7	0.7	0.3	0	2508.4	3317.5	1106.0	0.9328	0.9486	0.9352	0.0619
8	0.6	0.25	0.15	2718.9	4009.5	1203.9	0.7920	0.8334	0.7983	0.0533
9	0.55	0.2	0.25	2939.9	4802.8	1307.9	0.6442	0.7013	0.6528	0.0439
10	0.5	0.25	0.25	2776.6	4210.1	1230.9	0.7534	0.8000	0.7605	0.0509
11	0.45	0.3	0.25	2642.3	3750.6	1168.1	0.8432	0.8765	0.8483	0.0565
12	0.4	0.25	0.35	2836.2	4422.2	1258.9	0.7136	0.7647	0.7213	0.0483
13	0.35	0.25	0.4	2866.9	4533.3	1273.4	0.6930	0.7462	0.7011	0.0470
14	0.3	0.15	0.55	3367.2	6523.1	1512.3	0.3584	0.4148	0.3669	0.0250
15	0.2	0.15	0.65	3445.9	6866.0	1550.4	0.3057	0.3577	0.3163	0.0215
16	0.15	0.15	0.70	3485.2	7040.5	1569.5	0.2794	0.3287	0.2869	0.0196
17	0.15	0.20	0.65	3210.7	5865.0	1436.9	0.4630	0.5244	0.4723	0.0321
18	0.25	0.25	0.5	2921.2	4733.2	1299.0	0.6567	0.7175	0.6652	0.0447
19	0.35	0.30	0.35	2694.2	3925.1	1192.3	0.8085	0.8475	0.8144	0.0543
20	0.4	0.35	0.25	2524.6	3368.5	1113.5	0.9220	0.9402	0.9248	0.0613
21	0.5	0.35	0.15	2472.6	3206.1	1089.5	0.9567	0.9672	0.9584	0.0634

Table 5.10

Fuel Cost, CO_2 emission, SO_2 emission & their membership functions & non inferior solution u_d^k corresponding to the different combinations of weights for 700 MW

S.No	w_1	w_2	w_3	Fuel Cost J_1 (Rs/hr)	CO_2 emission J_2 (Kg/hr)	CO_2 emission J_3 (Kg/hr)	$u(J_1)$	$u(J_2)$	$u(J_3)$	Non inferior solution u_d^k
1	0.1	0.1	0.8	4321.8	11208.9	1984.1	0	0	0	0
2	0.2	0.2	0.6	3494.4	7081.4	1573.9	0.483	0.545	0.493	0.0331
3	0.3	0.25	0.45	3175.2	5720.1	1419.9	0.669	0.725	0.679	0.0451
4	0.4	0.3	0.30	2913.4	4704.2	1295.3	0.822	0.859	0.828	0.0546
5	0.5	0.3	0.20	2853.1	4483.3	1266.9	0.858	0.889	0.863	0.0567
6	0.6	0.3	0.10	2792.9	4267.8	1238.6	0.893	0.917	0.897	0.0589
7	0.7	0.3	0	2730.6	4050	1209.3	0.929	0.946	0.932	0.0610
8	0.6	0.25	0.15	2969.1	4912.5	1321.7	0.790	0.832	0.797	0.0526
9	0.55	0.2	0.25	3223.9	5919.2	1443.2	0.641	0.699	0.650	0.0433
10	0.5	0.25	0.25	3028.3	5138.6	1349.8	0.755	0.802	0.763	0.0504
11	0.45	0.3	0.25	2866.6	4532.2	1273.2	0.850	0.882	0.855	0.0563
12	0.4	0.25	0.35	3087.8	5370.8	1378.1	0.720	0.771	0.729	0.0483
13	0.35	0.25	0.4	3117.7	5489.2	1392.4	0.703	0.756	0.712	0.0472
14	0.3	0.15	0.55	3695.7	8007.4	1672.3	0.365	0.423	0.375	0.0253
15	0.2	0.15	0.65	3776.0	8391.4	1711.8	0.318	0.372	0.327	0.0221
16	0.15	0.15	0.70	3815.2	8581.4	1731.1	0.295	0.347	0.304	0.0206
17	0.15	0.20	0.65	3492.8	7074.4	1573.2	0.484	0.546	0.494	0.0331
18	0.25	0.25	0.5	3170.8	5702.3	1417.8	0.672	0.727	0.681	0.0452
19	0.35	0.30	0.35	2907.1	4681.0	1292.4	0.826	0.862	0.832	0.0458
20	0.4	0.35	0.25	2713.3	3999.6	1201.3	0.939	0.954	0.942	0.0619
21	0.5	0.35	0.15	2657.6	3801.6	1175.2	0.972	0.979	0.973	0.0636

Table 5.11

Fuel Cost, CO_2 emission, SO_2 emission & their membership functions & non inferior solution u_d^k corresponding to the different combinations of weights for 675 MW

S.No	w_1	w_2	w_3	Fuel Cost J_1 (Rs/hr)	CO_2 emission J_2 (Kg/hr)	SO_2 emission J_3 (Kg/hr)	$u(J_1)$	$u(J_2)$	$u(J_3)$	Non inferior solution u_d^k
1	0.1	0.1	0.8	4198.2	10539.4	1921.8	0	0	0	0
2	0.2	0.2	0.6	3405.1	6687.4	1530.6	0.4810	0.5431	0.490	0.3301
3	0.3	0.25	0.45	3096.9	5406.8	1382.5	0.6679	0.7237	0.676	0.0450
4	0.4	0.3	0.30	2844.4	4451.7	1262.8	0.8211	0.8584	0.827	0.0546
5	0.5	0.3	0.20	2784.8	4239.1	1234.8	0.8572	0.8883	0.862	0.0568
6	0.6	0.3	0.10	2725.4	4031.9	1206.9	0.8933	0.9176	0.897	0.0591
7	0.7	0.3	0	2663.9	3822.9	1178.2	0.9305	0.9470	0.933	0.0612
8	0.6	0.25	0.15	2893.9	4632.1	1286.1	0.7911	0.8329	0.797	0.0527
9	0.55	0.2	0.25	3138.3	5571.1	1402.2	0.6429	0.7005	0.652	0.0434
10	0.5	0.25	0.25	2952.6	4850.5	1313.9	0.7554	0.8021	0.762	0.0505
11	0.45	0.3	0.25	2798.9	4289.1	1241.4	0.8487	0.8813	0.853	0.0563
12	0.4	0.25	0.35	3011.7	5074.8	1341.9	0.7196	0.7705	0.727	0.0483
13	0.35	0.25	0.4	3041.4	5189.3	1356.0	0.7016	0.7544	0.710	0.0472
14	0.3	0.15	0.55	3595.8	7541.5	1623.4	0.3653	0.4227	0.374	0.0253
15	0.2	0.15	0.65	3675.3	7911.6	1662.3	0.3171	0.3705	0.325	0.0220
16	0.15	0.15	0.70	3714.2	8095.1	1681.4	0.2935	0.3446	0.301	0.0204
17	0.15	0.20	0.65	3405.5	6689.0	1530.8	0.4808	0.5429	0.490	0.0330
18	0.25	0.25	0.5	3094.4	5396.9	1381.3	0.6694	0.7251	0.678	0.0451
19	0.35	0.30	0.35	2839.9	4435.7	1260.7	0.8238	0.8606	0.829	0.0547
20	0.4	0.35	0.25	2653.2	3786.9	1173.2	0.9371	0.9521	0.939	0.0616
21	0.5	0.35	0.15	2598.1	3604.7	1147.5	0.9705	0.9778	0.971	0.0636

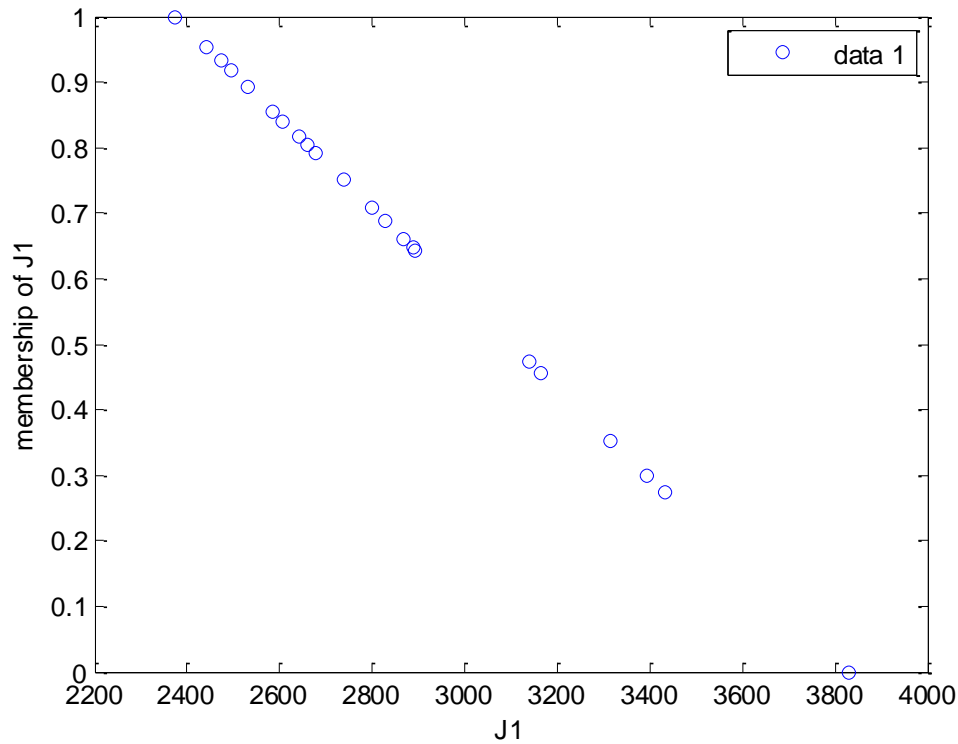


Fig 5.7 Relationship between fuel cost objective & its membership function

5.4 Comparison of results

Table 5.12 shows the Comparison between Fuel Cost, CO_2 emission, SO_2 emission using classical method for hydrothermal scheduling without implementing the fuzzy decision making technique & classical method with implementing the fuzzy decision making technique using weighting pattern method.

Hydrothermal Scheduling Using Classical Method without implementing the fuzzy decision making technique				Hydro Thermal Scheduling by implementing the Fuzzy Decision Making technique using weighting pattern method on classical method		
Load Demand	Fuel Cost (Rs/hr)	CO_2 Emission (kg/hr)	SO_2 Emission (kg/hr)	Fuel Cost (Rs/hr)	CO_2 Emission (Kg/hr)	SO_2 emission (Kg/hr)
600	3668.9	7881.1	1659.2	2472	3205.3	1089.4
550	3361.1	6496.9	1509.4	2338.6	2804.9	1027.87
455	2794.1	4271.9	1239.2	2081.1	2107.6	910.78
650	3983.3	9418.5	1814.5	2598.5	3605.9	1147.7
575	3514.2	7170.2	1583.6	2406.1	3003.8	1058.8
615	3762.5	8326.1	1705.2	2508.4	3317.5	1106.0
700	4304.5	11114.0	1975	2730.6	4050	1209.3
675	4143.0	10246.0	1894.2	2663.9	3822.9	1178.2

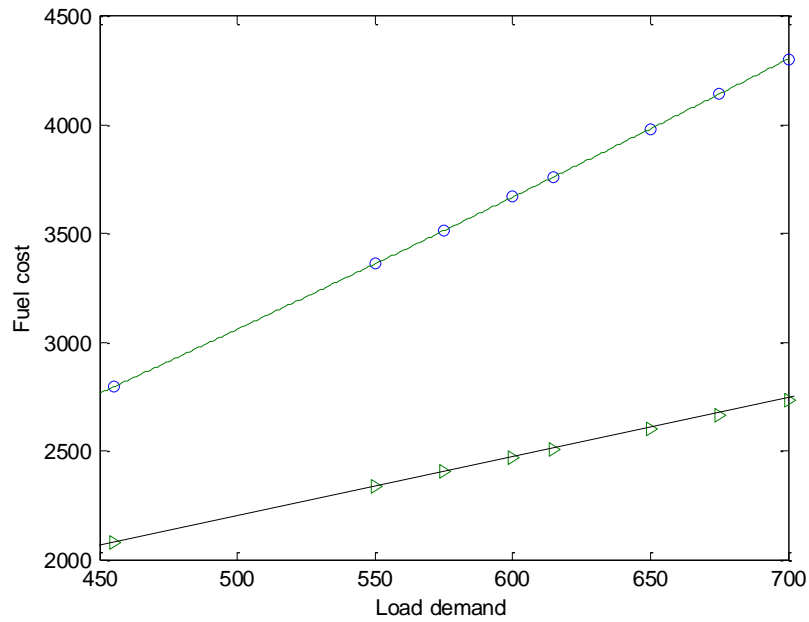


Fig 5.8

Fig 5.8 Represents the comparison between fuel costs for same load demands, without implementing the fuzzy decision making technique on classical method & with implementing the fuzzy decision making technique on classical method using weighting pattern method.

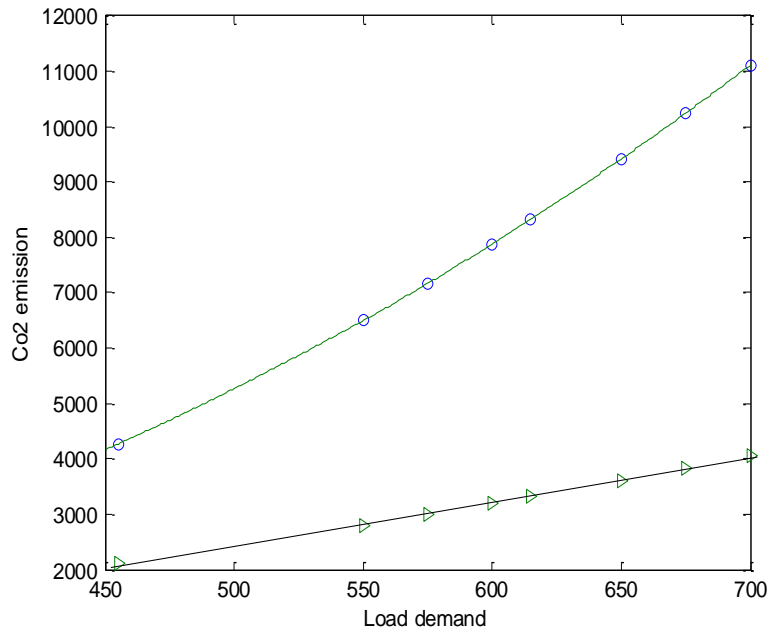


Fig 5.9

Fig 5.9 represents the comparison between CO_2 emissions for same load demands, without implementing the fuzzy decision making technique on classical method & with implementing the fuzzy decision making technique on classical method using weighting pattern method.

o.....represents CO_2 emission without implementing the fuzzy decision making technique on classical method.

- represents CO_2 emission by implementing the fuzzy decision making technique on classical method using weighted method.

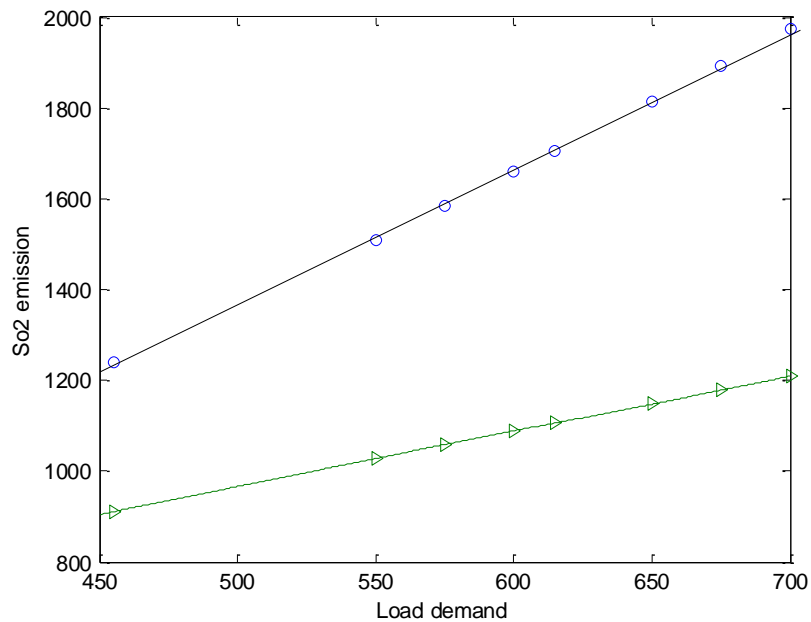


Fig 5.10

Fig 5.10 Represents comparison of SO_2 emissions, without implementing the fuzzy decision making technique on classical method & with implementing the fuzzy decision making technique on classical method using weighting pattern method.

o.....represents SO_2 emission without implementing the fuzzy decision making technique on classical method

- represents SO_2 emission with implementing the weighted pattern fuzzy decision making technique on classical method

Conclusion

The conventional classical method for multi-objective hydrothermal generation scheduling is based upon the deterministic cost function and CO_2 & SO_2 emissions functions, ignoring inaccuracies and uncertainties during estimation. Such generation schedules result in lowest cost or lowest emission but are always associated with large variance. The hydrothermal scheduling program has been developed and tested on a system for different load demands throughout the day. Fuel cost, CO_2 emissions, SO_2 emissions, the water discharge, and transmission losses are calculated from the classical method. Then weighting method is applied to trade-off among conflicting objectives. The decision to obtain best solution among non inferior set of solution, fuzzy decision making technique is applied. The results shows the reduction of the fuel Cost, CO_2 emission & SO_2 emission as compared to those obtained from without implementing the fuzzy decision making on classical method. Therefore it is concluded that fuzzy decision making technique provides the efficient optimal solution.

Major Findings:

Hydrothermal Scheduling without implementing the fuzzy decision making technique on Classical Method				Hydro Thermal Scheduling by implementing Weighted Fuzzy Decision Making technique on classical method		
Load Demand	Fuel Cost (Rs/hr)	CO_2 Emission (kg/hr)	SO_2 Emission (kg/hr)	Fuel Cost (Rs/hr)	CO_2 Emission (Kg/hr)	SO_2 emission (Kg/hr)
600	3668.9	7881.1	1659.2	2472	3205.3	1089.4
550	3361.1	6496.9	1509.4	2338.6	2804.9	1027.87
455	2794.1	4271.9	1239.2	2081.1	2107.6	910.78
650	3983.3	9418.5	1814.5	2598.5	3605.9	1147.7
575	3514.2	7170.2	1583.6	2406.1	3003.8	1058.8
615	3762.5	8326.1	1705.2	2508.4	3317.5	1106.0
700	4304.5	11114.0	1975	2730.6	4050	1209.3
675	4143.0	10246.0	1894.2	2663.9	3822.9	1178.2

The best operating point corresponding to the weight combination when the value of the normalized membership function is maximum among the non-inferior solutions. Fuel cost, CO_2 emissions, SO_2 emissions gets reduced by implementing the weighted fuzzy decision making technique for multi objective hydro thermal scheduling.

Future Scope

Pseudo-weight vector approach

Multi-objective hydrothermal scheduling problem, in which the inaccuracies and uncertainties in input data are incorporated, can also be solved using pseudo-weight vector approach. In this approach, a pseudo-weight vector is calculated for each obtained solution. Weights are assigned to each solution in the Pareto set obtained after optimization, whereas, in classical weighted sum method, weights are assigned before optimization. Further hybrid heuristic techniques can be applied to obtain Pareto optimal solution for multi objective hydrothermal scheduling problem.

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