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Short term hydrothermal scheduling for partial Sudanese national grid using particle swarm optimization

جدولة التوليد المائي الحراري علي المدي القصير لجزء من االشبكة السودانية باستخدام تقنية (PSO)

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By :

Galal Abd Elfatah Mohammed Eltaib

Supervized by :

Dr. Mohammed Osman Hassan

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Galal Abd Alfatah Mohammed

Abstract

Operation of a system having both hydro and thermal plants is more complicated than hydro plants which have negligible operating cost, but are required to operate under constraints of water available for hydro generation in a given period of time. The problem of minimizing the operating cost of a hydrothermal system can be viewed as one of minimizing the fuel cost of thermal plants under the constrains of water availability for hydro generation over a given period of operation.

Earlier, a wide variety of optimization techniques have applied to solve the Hydrothermal scheduling problems such as dynamic programing, gradient search but these methods has drawbacks such as large computation time, algorithm complexity.

The work done in this dissertation presents solution to short-term hydrothermal scheduling problem. The solution approach based on Particle Swarm Optimization (PSO) which applied to a part of Sudanese national grid so that the operation cost minimized by 16.6%.

المستخلص

ان تشغيل انظمة القدرة التي تحتوي علي محطات توليد مائية وحرارية معاً اكثر تعقيداً من تشغيل المحطات المائية والتي ليس لها تكلفة تشغيلية تزكر مع وجود بعض القيود التشغيلية مثل الكمية المتاحة من المياه للتوليد المائي في فترة زمنية محددة. وان مسالة تقليل التكلفة التشغيلية لنظام قدرة يحتوي علي محطات توليد مائي وحراري معاً تتركز في تقليل تكلفة الوقود المستخدم في المحطات الحرارية مع الوضع في الاعتبار القيود التشغيلية.

وفي وقت قريب كانت تستخدم عدة طرق لتقليل التكلفة التشغيلية في انظمة القدرة علي سبيل المثال وليس الحصر البرمجة الدينميكية والبحث التربيعية ولكن هذه الطرق لها عدة مساوي منها انها تستغرق زمن طويل في الحسابات والتعقيد في الخوارزميات مع زيادة حجم النظام.

وان العمل الذي تم في هذه الاطروحة لتقليل التكلفة التشغيلية يصف استخدام خوارزمية سرب الجسيمات في جزء من منشآت التوليد في الشبكة القومية السودانية خلال جدولة يوم واحد للتوليد والذي افضي بتقليل التكلفة التشغيلية بنسبة 16.6%.

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A,B,C	coefficients of thermal machines
B11,B12,B22	transmission line losses coefficient's
C_1, C_2, C_3, C_4, C_5 and C_6	coefficients of hydro units
C_1 ,C_2	pbest and gbest positions coefficient's .
F	cost
F_{Tbest}	best total cost
F_{gbest}	best generation cost
Hr	hour
HFO	heavy fuel oil
ITER	number of iteration
i_{gbest}	best population and it's individual thermal generation
J	interval
LPG	liquid petroleum gas
MW	mega watt
M_{max}	maximum number of population of thermal units
PSO	particle swarm optimization
P_g	output power of gas unit
p_{best}	best particles
P_h	hydro power
P_{hk}^t	hydro power of unit K at period t
P_D^t	demand power at period t
Q	discharge
USD	united states dollar
W	inertia weighting factor

Chapter one

Introduction

1.1 Overview

In present set-up, optimum scheduling of hydrothermal plants is important because of its economical aspect in interconnected power system operation. The hydrothermal scheduling problem is directed to minimize the operating cost of thermal plants as the operating cost of hydro plants is negligible. Thus, the problem of minimizing the operational cost of a hydrothermal system is to minimize the fuel cost of thermal plants subjected to various equality and inequality constraints offered by the operation of hydrothermal plants and power system network. Limited energy storing capacity of water reservoirs and having the stochastic nature of availability of water makes the solution more difficult for hydrothermal systems compared to pure thermal systems [1]. Hydroelectric plants also meet purposes other than power generation including flood control and irrigation purpose [2].

Most of the hydro-systems are having different characteristics mainly due to differences in availability of water, control constraints, non-uniform water flow, number of hydro stations and their locations etc. The problem is different when the plant is located on the same stream or on a different stream. To minimize overall cost of system available hydro resources has to be utilized fully. The hydrothermal problem includes long range problem and short range problem.

The Long-range hydro scheduling problem involves the long range forecasting of water availability and the scheduling of water releases. Typical long-range scheduling goes anywhere from one week to one year or several years. Long range scheduling involves optimizing policy in the context of unknowns such as loads, hydraulic inflows and unit availabilities. These unknowns are treated statistically and long-range scheduling involves optimization of statistical variables. This problem is classified as: multi-storage hydroelectric systems cascaded hydroelectric systems, multi-chain hydroelectric systems.

The Short-range hydro scheduling problem involves one day to one week or hour-by-hour scheduling of all generations on a system to achieve minimum production cost for the given time period. A set of starting conditions is given to get the optimized schedule with the minimum cost which is desired. The amount of water to be utilized for short-range scheduling problem is known from the solution of long-range scheduling problem. This problem is classified as: fixed head hydrothermal scheduling and variable head hydrothermal scheduling. Several methods for solving the problem of short-term hydrothermal scheduling have been proposed. The classical methods of solving the scheduling problem are not suitable when the system size increases. Further the computational requirements also increase with the classical methods. Therefore, various evolutionary techniques such as particle swarm optimization (PSO) [3] [4] [5], constriction factor based particle swarm optimization technique (CFPSO) [6], evolutionary programming (EP) [7], genetic algorithm (GA) [8] [9], differential evolution [10] [11] are used for hydrothermal scheduling.

The short term hydrothermal scheduling of Sudanese generation system based on classical method which may lead sometimes to increase the operational cost.

In this dissertation, particle swarm optimization (PSO), developed by Author is used to solve the problem of short-term hydrothermal scheduling of Sudanese generation system. So that the hydrothermal scheduling problem contain 10 hydro turbine generators installed in Merwee dam and 7 gas turbines at Garri power station.

So that many dissertations was discussed in this field which mentioned below:

Gil et al. [1] proposed genetic algorithms using specialized operators to deal with the short-term generation scheduling problem incorporating three types of scheduling: short-term HCP, UCP, and ELDP for scheduling horizon of a week, and hourly generation schedules are obtained for each hydro and thermal units.

Kothari and Dhillon [2] compiled the problems regarding planning and control of thermal as well as hydrothermal systems. Evolutionary algorithms were used to solve optimization and multi-objective optimization problems.

Mandal and Chakraborty [3] presented self-organizing hierarchical particle swarm optimization technique with time-varying acceleration coefficients algorithm for solving the problem of hydrothermal scheduling. The problem of premature convergence in PSO is avoided.

Sreenivasan et al. [4] presented optimized hourly scheduling of hydrothermal power system using PSO technique and compared the fuel cost and computation time.

Hota et al. [5] used PSO to solve the HTS problem and to find global solution. To show efficiency, the algorithm is applied to problem having prohibited operating zones.

Salama et al. [6] solved the problem of multi-chain hydrothermal scheduling for four hydro units and three thermal units with objective function having valve point loading effect using PSO. Less computational time is expected in this.

Sinha et al. [7] developed fast evolutionary programming algorithms which utilizes evolutionary programming algorithms with Gaussian and Cauchy mutation for the solution of short-term hydro thermal scheduling problems.

Orero and Irving [8] formulated optimal hourly scheduling of hydrothermal power system by genetic algorithm. The system having a non-linear relationship between water discharge rate, net head and power generation was analyzed. The hourly optimal loading of the system generators was offered by a multiple step genetic algorithm search sequence.

Kumar and Naresh [9] solved the scheduling problem of hydrothermal with real coded genetic algorithm which eliminates the need of penalty parameters. The algorithm use binary crossover and polynomial mutation.

Mandal and Chakraborty [10] presented differential evolution based optimization technique for solving optimal generation scheduling of hydrothermal systems and applied to multi-reservoir cascaded hydrothermal system by considering constraints of hydro and thermal units and the effect of valve point loading.

Lakshminarasimman and Subramanian [11] formulated the optimal scheduling problem of short term hydrothermal system with the modified differential evolution algorithm. The algorithm does not require the use of penalty functions to explore the optimum solution.

Hinojosa and Leyton [12] formulated the hydro generation scheduling problem taking into account water discharge as continuous variables and binary thermal states using mixed-binary evolutionary particle swarm optimization. The algorithm works to keep the decision variables in feasible space through the correction operators to improve the quality of the solutions and the convergence of the search process.

Wood and Wollenberg [13] provide the techniques used in modern power systems with the emphasis on the economic aspects of energy management and characteristics of thermal and hydroelectric power generation systems along.

1.2 Objective

The objective of this study is to determine the optimal scheduling of Sudanese hydrothermal system on 500 Kv and 220 Kv grids to meet the load demand over the scheduled horizon of 24 hours with one hour intervals while satisfying the various equality and inequality constraints of hydro and thermal power system network considering transmission line.

1.3 Methodology

Particle swarm optimization (PSO) is used to solve the problem of short-term hydrothermal scheduling of Sudanese generation system. The hydrothermal scheduling problem contain 10 hydro turbine generators installed in Merwee dam and 7 gas turbines at Garri power station.

1.4 Dissertation outlines

Chapter 1 reviews the hydrothermal generation scheduling problem with introduction to the optimization algorithms, the literature review, objective of research and organization of dissertation. Chapter 2 describes the short-term hydrothermal scheduling, need for hydrothermal scheduling, classification of hydro plants and the problem formulation. Chapter 3 explains the particle swarm optimization technique, algorithm and its implementation to the problem of short-term HTS. Chapter 4 details the test system and the results obtained after the implementation of PSO algorithm. Chapter 5 summarizes the conclusions and recommendations.

Chapter two

Short-Term Hydrothermal Scheduling

2.1 Introduction

The basic idea for the scheduling of hydrothermal plant is to meet the given load demand for the specified time horizon. The optimal scheduling of hydrothermal plant involves generation of power from hydro as well as thermal plants so as to minimize the total fuel cost of thermal plant.

Thus the scheduling problem can be solved by minimizing the fuel cost of thermal plant while considering the various hydro plant constraints. The main constraints of problem include: cascaded nature of the hydraulic network, the time coupling effect of the hydro sub problem
where the water inflow of an earlier time interval affects the discharge capability at a later period of time, the varying hourly reservoir inflows, the physical limitations on the reservoir storage and turbine flow rate, the varying system load demand and the loading limits of both thermal and hydro plants [8] [12].

In short-term hydrothermal scheduling, the scheduling period is taken as one day to one week and involves hour-by-hour generation of the scheduling horizon to achieve the minimum production cost for the generation of power. The amount of water utilized for the short-range scheduling problem is known from the solution of long-range scheduling problem. A set of reservoirs conditions for hydro plants is given and the optimal hourly schedule of the desired objective i.e. minimizing the fuel cost, while satisfying the hydro system constraints, is obtained [13].

2.2 Need of hydrothermal scheduling

The idea of hydrothermal coordination is to utilize all energy resources in most economic and efficient manner. The scheduling of hydroelectric plant is more complex than the scheduling of thermal plants. The hydroelectric plants are associated with the water discharge (i.e. water outflow from one plant is the water inflow for one or more downstream plant) from one reservoir to other and plays very significant role for the optimal power generation. It is vital to use the amount of water available by water reservoirs of hydro systems to full extent in hydrothermal integration. In hydro system, there is no fuel cost associated with power generated i.e. the charges are fixed for hydropower regardless of the amount generated.

In hydrothermal systems the optimal cost is achieved by utilizing the available water resources for a given time horizon and run the hydro generation units according to the forecasted load demand so that the fuel cost for thermal generation is minimized.

Thus the hydrothermal scheduling is important as 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 been economical as well as convenient to have both thermal as well as hydro plants in the same grid. The hydroelectric plant can be started quickly and it has higher reliability and greater speed of response. Hence hydro plants can take-up the fluctuating loads. In contrast to hydro plants, starting of thermal plant is slow and their speed of response is slow as well. This is the reason why thermal plants run as base load plants and hydro plants run as peak load plant [2].

2.3 Classification of hydro plants

Classification has been reported based on:

1. type
2. location
3. water head
4. nature of load

2.3.1 Based on type

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

2.3.1.1 Pumped storage plants:

When power from the plant is needed, water stored in an upper reservoir is released into an underground tunnel. The water rushes down the intake tunnel form upper reservoir. The force of the water form reservoir drives huge turbines, which are at the base of a dam. These turbines are connected to large generators, which produce the electricity. The water then flows through a discharge tunnel into a lower reservoir. When demand for electricity is low, the turbines spin backward and pump the water back up into the upper reservoir to make it available to generate electricity when it is needed.

2.3.1.2 Conventional Plants:

These plants utilize the hydraulic energy of the flowing water of the rivers. Dams are constructed to collect the water in the reservoir and are used to run the turbines. Conventional plants are further classified as

- ***Run-of-river plants without poundage*:** These plants do not have storage or poundage to store water. Run-off river plants without poundage use water as it comes. The plant can use water as and when available. Since, generation capacity of these types of plants these plants depend 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 poundage:*** In these plants, poundage allows storage of water during lean periods and use of this water during peak periods. Based on the size of the storage structure 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 poundage. If poundage is provided, 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.
- ***Reservoir plants:*** A reservoir plant is that which has a reservoir of such size as to accede 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. This type of plant has better extent and can be used efficiently throughout the year. Its firm capacity can be expanded and can be utilized 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. Maximum hydro-electric plants are of this type.

2.3.2 Based on location

On the basis of their location, hydro plants are classified into three different categories:

2.3.2.1 Hydro plants on different streams:

These are those hydro plants which are located on different streams and do not depend on each other as shown in Fig. 2.1

2.3.2.2 Hydro plants on same stream:

These plants are in series with each other. The downstream plant depends on the immediate upstream plant and is shown in Fig. 2.2

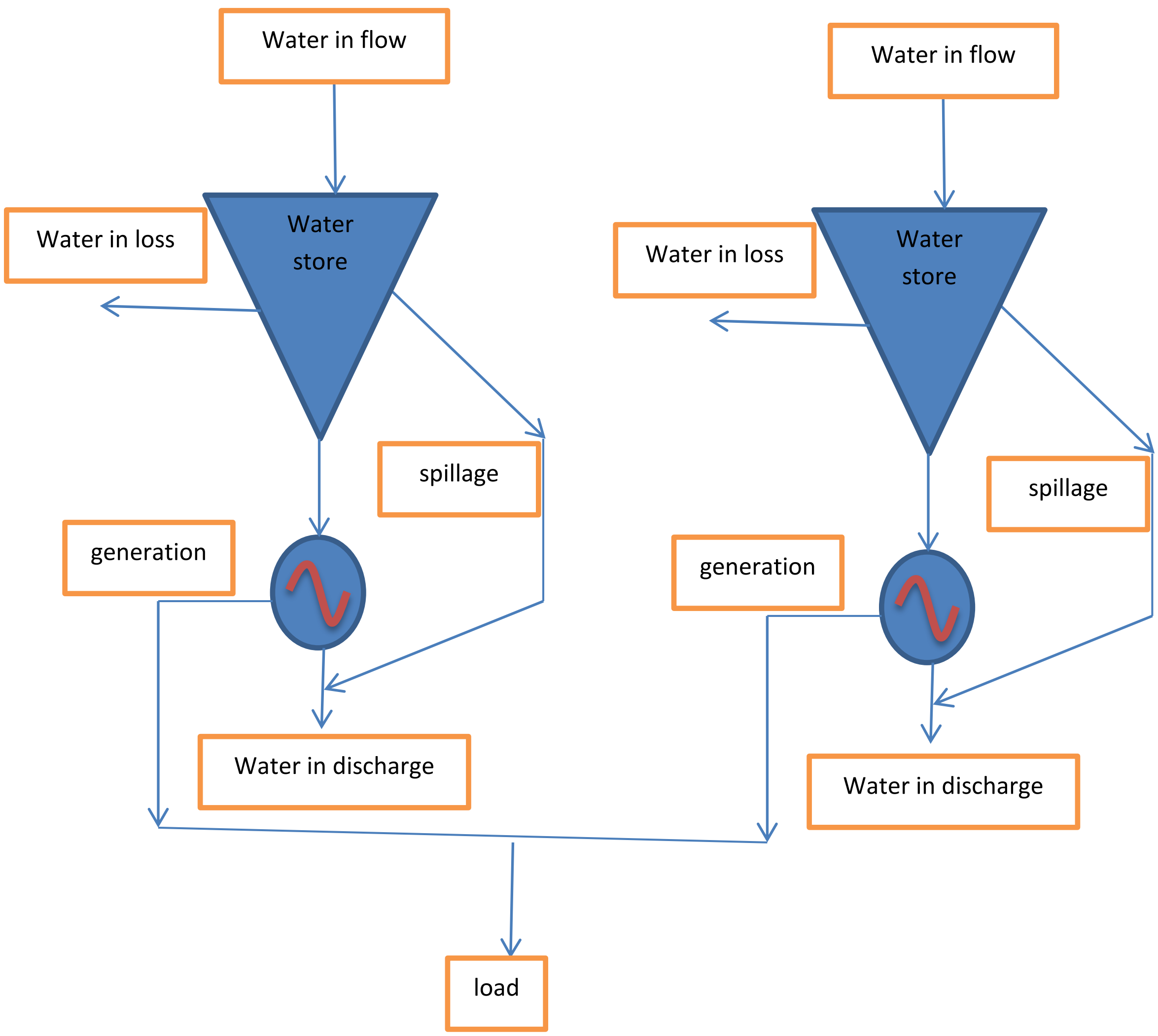

Fig. 2.1 Hydro plants on different streams

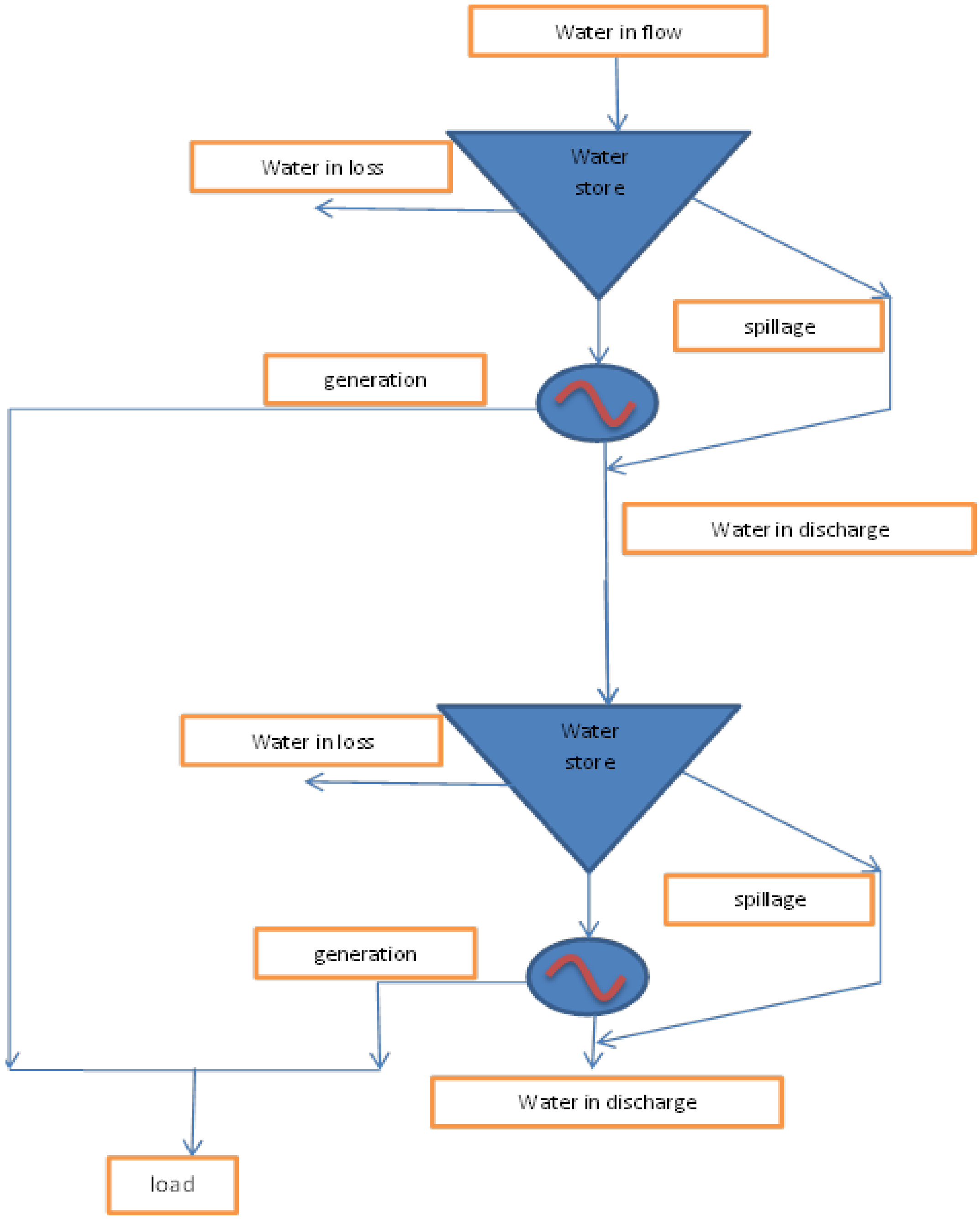

Fig. 2.2 Hydro plants on same stream

2.3.3 Based on availability of water head

There are three types of hydroelectric power plants based on the height of water head available in the reservoir, these are:

- Low-head hydro-electric plants (less than 30 m)
- Medium-head hydro-electric plants (30 - 300 m)
- High-head hydro-electric plants (greater than 1,000 m)

2.3.3.1 Low-head hydro-electric plants:

Low head hydro-electric plants are power plants which generally utilize heads of only a few meters or less. Power plants of this type may utilize a low dam or river 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 vary with seasonal flows of water in a river. A large volume of water must pass through low head hydro plants 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-electric technology is basically the same regardless of generating capacity.

2.3.3.2 Medium-head hydro-electric plants:

These plants consist of a large dam in mountainous area which creates a huge reservoir. Dams are also used for flood control, irrigation, recreation, and often are the main source of potable water for many communities. Hydro-electric development is also possible in areas such where natural elevation changes can be used.

2.3.3.3 High-head hydro-electric plants:

High head power 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 demand.

Heads for this type of power plant may be greater than 1,000 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.

2.3.4 Based on nature of load

Depending on the nature of load on the hydroelectric power plant, two types of hydroelectric power plants are:

2.3.4.1 Peak Load:

The peak load plants are used to supply power at the peak demand phase. The pumped storage plants and Gas Turbine plants are this type of plants. Their efficiency varies between 60 - 70 %.

2.3.4.2 Base Load:

A 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 thecae of repairs or scheduled maintenance.

2.4 Mathematical formulation of short term hydrothermal scheduling (STHTS) problem

In this study, the hydrothermal problem has been formulated for one day ahead taking into account in the optimization problem. The costs of generation of power from hydro units are almost negligible as the power is generated from water. So the main objective of the problem is to minimize the fuel cost for generation of power from thermal plants using hydropower as mochas possible to supply the load demand for the scheduled period, satisfying the various operational constraints.

2.4.1 Objective function

The total fuel cost for the equivalent thermal over the scheduled horizon is given by fuel cost (FC). The objective function with quadratic cost function for thermal units is expressed as

$$F = \min \sum_{t=1}^{J} \sum_{i=1}^{ns} F_i \tag{2.1}$$

$$F_i[P_{si}^t] = a_i + b_i . P_{si} + c_i . {P_{si}}^2 \tag{2.2}$$

Where a_i , b_i and c_i are thermal coefficients

P_{si} is the power output of steam unit i

2.4.2 Constraints

2.4.2.1 Equality constraints:

Various equality constraints for solving the problem of STHTS are discussed as:

i. ***Power balance constraints:*** The total active power generation at each hour must be equal to predicted demand and the transmission loss.

$$\sum_{i=1}^{ns} P_{si}^{t} + \sum_{j=1}^{nh} P_{hj}^{t} + P_{loss}\left[P_{si}^{t}, P_{hj}^{t}\right] = P_{D}^{t} \qquad (2.3)$$

Where P_D^t is load power

P_{hj}^t is the power output of hydro unit j at time t

Q_{hj} is the discharge of hydro unit j

V_{hj} is the volume of hydro unit j

ii. ***Power generation constraints:*** The hydro power generation is a function of water discharge rate of reservoir and storage volume.

$$P_{hj}^{t} = C_1 {V_{hj}^{t}}^{2} + C_2 {Q_{hj}^{t}}^{2} + C_3 Q_{hj}^{t}.V_{hj}^{t} + C_4 V_{hj}^{t} + C_5 Q_{hj}^{t} + C_6 \qquad (2.4)$$

Where $C_1, C_2, C_3, C_4, C_5\ and C_6$ are coefficients of hydro unit

V_{hj}^t Is the discharge of hydro unit j at time t

iii. ***Hydraulic continuity equation constraint:*** Water transportation delay between reservoirs is considered to determine the water storage volume.

$$V_{j+1} = V_j - Q_j - S_j \qquad (2.5)$$

Where V_{j+1} is reservoir volume at period j+1

V_j is reservoir volume at period j

Q_j is discharge at period j

S_j is spillage at period j

iv. ***Reservoir end conditions:*** The desired volume of water to be discharged by each reservoir over the scheduling period,

$$V_{j|j=0} = V^{begin} \qquad (2.6)$$

$$,V_{j|j=j} = V^{end} \qquad (2.7)$$

2.4.2.2 Inequality constraints:

These constraints are the limits pre-specified in the problems and values must satisfy these constraints. The following are the constraints:

i. ***Thermal generation constraints:*** Power generation by equivalent thermal plant must lie within its limits:

$$Ps^{min} \leq Ps \leq Ps^{max} \tag{2.8}$$

Where Ps^{min} is minimum output power of steam unit

Ps^{max} is maximum output power of steam unit

ii. ***Hydro generation constraints:*** Power generated by the hydro plant must lie between its limits:

$$Ph^{min} \leq Ph \leq Ph^{max} \tag{2.9}$$

Where Ph^{min} is minimum output power of hydro unit

Ph^{max} is maximum output power of hydro unit

iii. ***Water discharge constraint:*** Water discharge of hydro plant must lie within its maximum and minimum limits to satisfy the other constraints:

$$Q^{min} \leq Q \leq Q^{max} \tag{2.10}$$

Where Q^{min} is minimum discharge of hydro unit

Q^{max} is maximum discharge of hydro unit

iv. ***Reservoir capacity constraints:*** The operating volume of reservoir storage limit must lie in between the minimum and maximum capacity limits:

$$V^{min} \leq V \leq V^{max} \tag{2.11}$$

Where V^{min} is minimum volume of hydro unit

V^{max} is maximum volume of hydro unit

Chapter three

Particle Swarm Optimization (PSO) Technique, Algorithm and Implementation To The Problem Of Short-Term HTS

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr Ebehart and Dr. Kennedy, inspired by social behavior of bird flocking or fish schooling. PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles. The detailed information will be given in following sections. Compared to GA, the advantages of PSO are that PSO is easy to implement and there are few parameters to adjust. PSO has been successfully applied in many areas: function optimization, artificial neural network training, fuzzy system control, and other areas where GA can be applied.

3.1 Back ground of artificial intelligence:

The term "Artificial Intelligence" (AI) is used to describe research into human-made systems that possess some of the essential properties of life. AI includes two-folded research topic.

- AI studies how computational techniques can help when studying biological phenomena
- AI studies how biological techniques can help out with computational problems

The focus of this dissertation is on the second topic. Actually, there are already lots of computational techniques inspired by biological systems. For example, artificial neural network is a simplified model of human brain; genetic algorithm is inspired by the human evolution. Here we discuss another type of biological system - social system, more specifically, the collective behaviors of simple individuals interacting with their environment and each other. Someone called it as swarm intelligence. All of the simulations utilized local processes, such as those modeled by cellular automata, and might underlie the unpredictable group dynamics of social behavior. Some popular examples are bees and birds. Both of the simulations were created to interpret the movement of organisms in a bird flock or fish school. These simulations are normally used in computer animation or computer aided design. There are two popular swarm inspired methods in computational intelligence areas: Ant colony optimization (ACO) and particle swarm optimization (PSO). ACO was inspired by the behaviors of ants and has many successful applications in discrete optimization problems. The particle swarm concept originated as simulation of simplified social system. The original intent was to graphically simulate the choreography of bird of a bird block or fish school. However, it was found that particle swarm model could be used as an optimizer.

3.2 Particle swarm optimization:

PSO simulates the behaviors of bird flocking. Suppose the following scenario: a group of birds are randomly searching food in an area. There is only one piece of food in the area being searched. All the birds do not know where the food is. But they know how far the food in each iteration. So what's the best strategy to find the food? The effective one is to follow the bird, which is nearest to the food. PSO learned from the scenario and used it to solve the optimization problems. In PSO, each single solution is a "bird" in the search space. We call it "particle". All of particles have fitness values, which are evaluated by the fitness function to be optimized, and have velocities, which direct the flying of the particles. The particles fly through the problem space by following the current optimum particles.

PSO is initialized with a group of random particles (solutions) and then searches for optima by updating generations. In every iteration each particle is updated by following two "best" values. The first one is the best solution (fitness) it has achieved so far. (The fitness value is also stored.)This value is called pbest. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This best value is a global is standing called g-best. When a particle takes part of the population as its topological neighbors, the best value is a local best and is called p-best. After finding the two best values, the particle updates its velocity and positions with following equation (3.1) and (3.2).

$$V_{i(u+1)} = C_1 * W * V_{i(u)} * rand(\quad) * \left(pbest_i - P_{i(u)}\right) + C_2 * rand(\quad) * \left(gbest_i - P_{i(u)}\right) \tag{3.1}$$

$$P_{i(u+1)} = P_{i(u)} + V_{i(u+1)} \tag{3.2}$$

In the above equations,

The term $rand(\quad) * \left(pbest_i - P_{i(u)}\right)$ is called particle memory influence

The term $rand(\quad) * (gbest_i - P_{i(u)})$is called swarm influence.

$V_{i(u)}$Which is the velocity of ith particle at iteration ‘u’ must lie in the range$V_{min} \leq V_{i(u)} \leq V_{max}$

- The parameter V_{max} determines the resolution, or fitness, with which regions are to be searched between the present position and the target position
- If V_{max} is too high, particles may fly past good solutions. If V_{min} is too small, particlesmay not explore sufficiently beyond local solutions.
- In many experiences with PSO, Vmax was often set at 10-20% of the dynamic range on each dimension.
- The constants C_1 and C_2 pull each particle towards pbest and gbest positions.
- Low values allow particles to roam far from the target regions before being tugged back. On the other hand, high values result in abrupt movement towards, or past, target regions.
- The acceleration constants C_1 and C_2 are often set to be 2.0 according to past experiences
- Suitable selection of inertia weight 'ω' provides a balance between global and local explorations, thus requiring less iteration on average to find a sufficiently optimal solution.
- In general, the inertia weight w is set according to the following equation,

$$W = W_{max} - \left[\frac{W_{max} - W_{min}}{ITER_{max}}\right] * ITER \tag{3.3}$$

Where W is the inertia weighting factor

W_{max}Maximum value of weighting factor

W_{min}Minimum value of weighting factor

$ITER_{max}$Maximum number of iterations

$ITER$Current number of iteration

3.3 Particle swarm optimization algorithm:

Figure 3.1 shows Particle swarm optimization algorithm

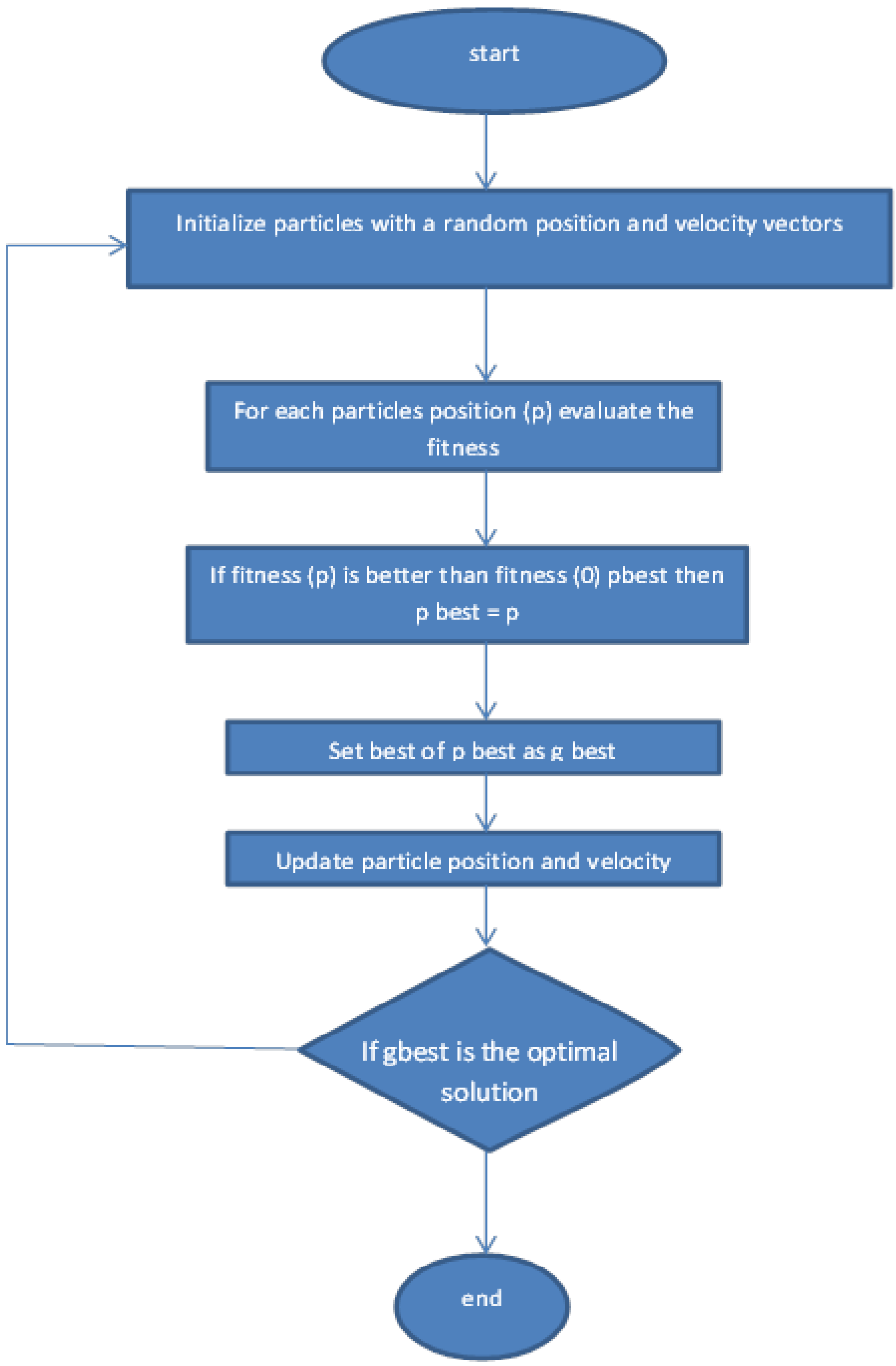

Fig 3.1 PSO algorithm

Chapter four

System evaluation, results and discussion

4.1 System evaluation

The short term hydrothermal scheduling based on 15/1/2015 was evaluated so that the study based on the scheduling of the power generation stations on the voltage level of 500 and 220 Kv namely (Merwee, Garri, Kosti and Rossers power stations) as shown in Fig 4.1 So that the 110 Kv and 33 Kv networks represented in power stations, transmission lines and loads were taken as loads at 220 Kv busbars.

At that period as shown in appendix A , appendix B and fig 4.2 according to load dispatch center (LDC) schedule, KOSTI power station was decommitted for scheduled maintenance and ROSSERS power station was run as base generation with output power of 100 MW (four turbines 25 MW each) and the under scheduling generation were Garri and Merwee power stations and the load at 500 and 220 Kv substations and system shown in appendix C and according to the schedule in appendix A the water volume used over 24 hour period was calculated using equation 4.1 and recorded in table 4.1.

For thermal generation (Garri power station) the heat characteristics showed in appendix D, the heat content and fuel price shown in appendix E. According to equation 4.4 the short term generation cost was calculated as in table 4.2

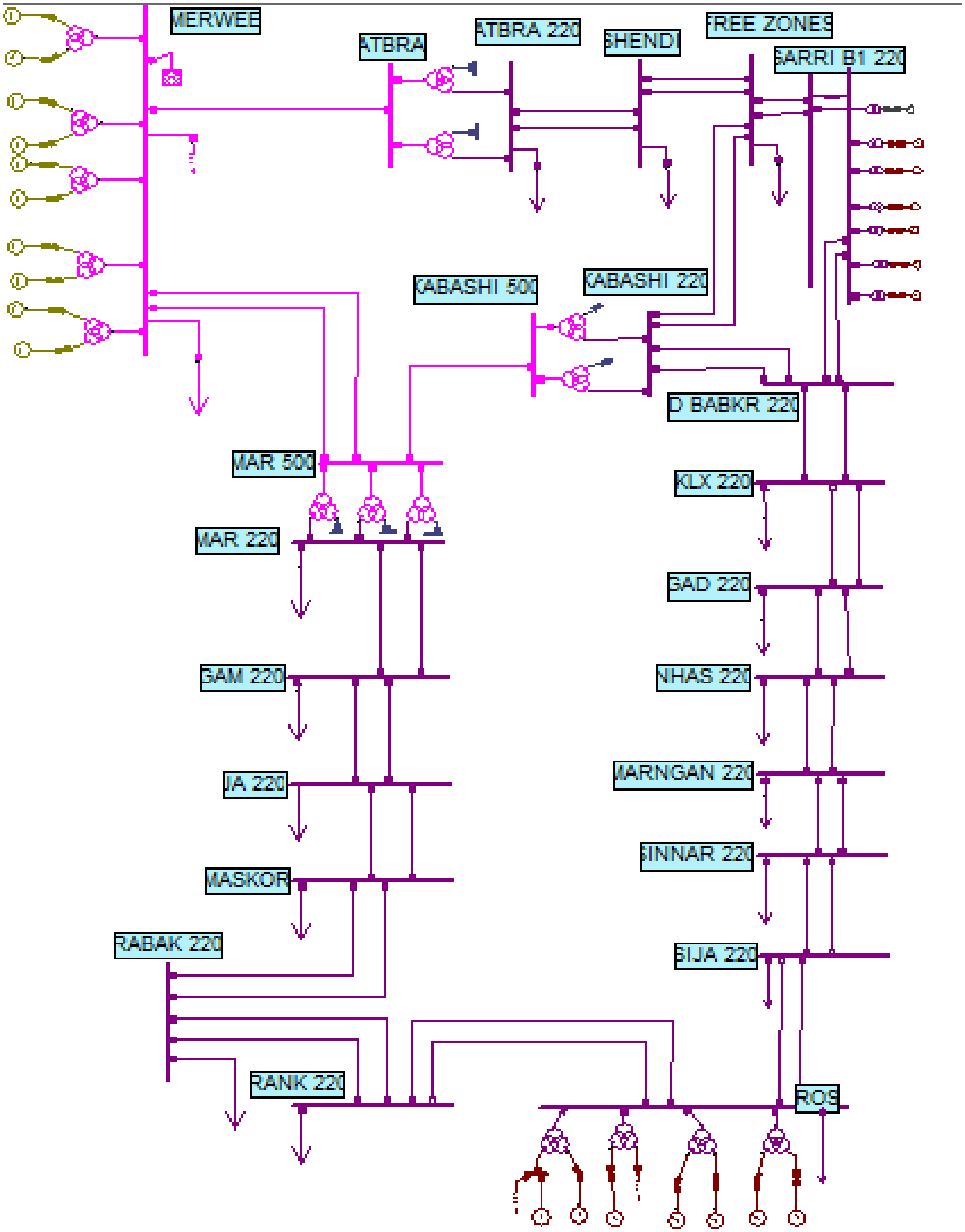

Fig 4.1: Single line diagram of 220 and 500KV network

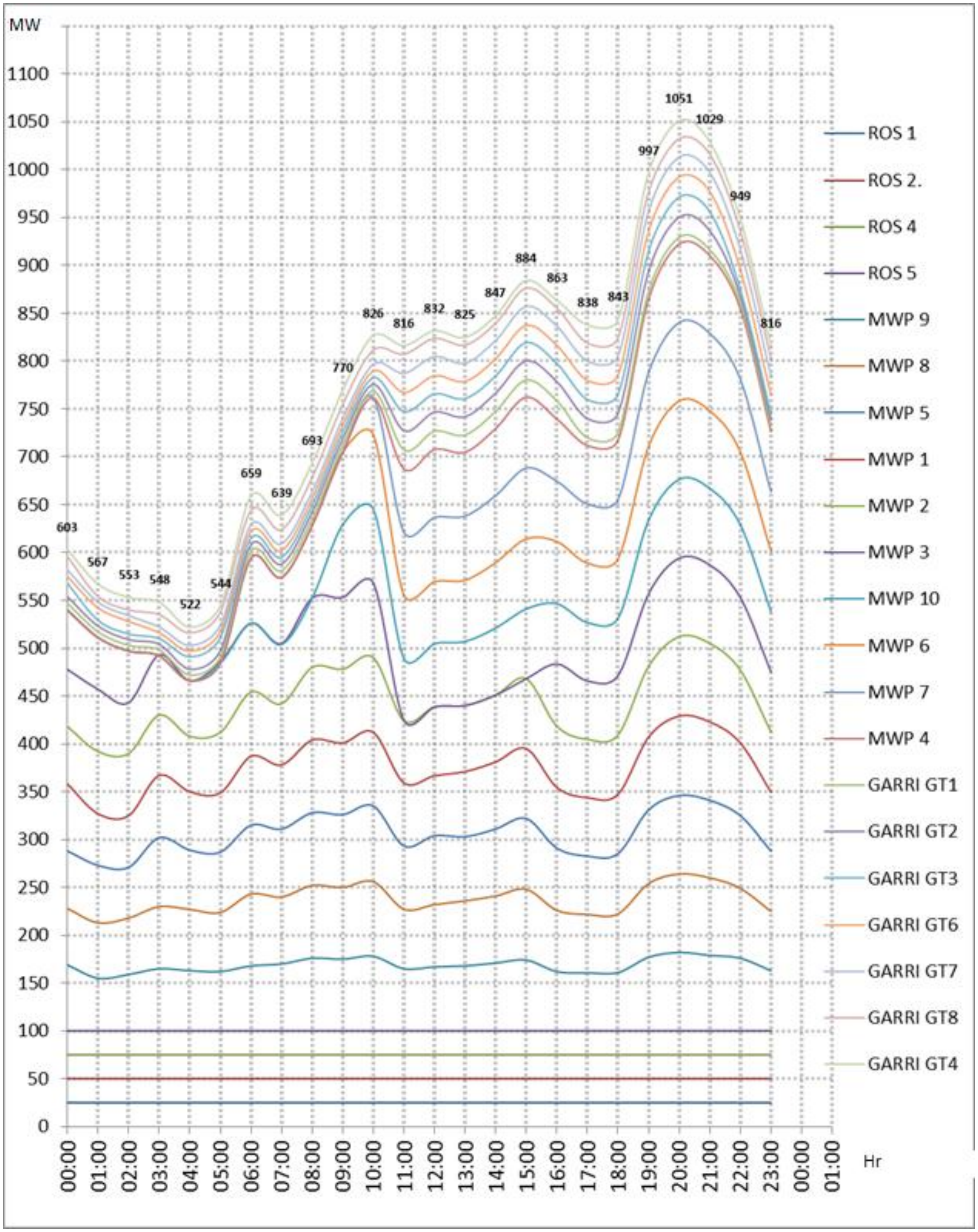

Fig 4.2: Cumulative power delivered form power stations over 24 hours period

$$P = C_1V^2 + C_2Q^2 + C_3Q.V + C_4V + C_5Q + C_6 \quad (4.1)$$

$$C_2Q^2 + [C_3V + C_5]Q + C_1V^2 + C_4V + C_6 - P = 0 \quad (4.2)$$

For Merwee power station where the volume was assumed to be constant which is 11.95 million cubic meter

$C_1 = -52.000286, C_2 = 0.112932, C_3 = 1.041764, C_4 = 0.006016, C_5 = -0.000171, C_6 = -0.009343$

$$0.113Q^2 + 12.45Q - 7425.71 = P \quad (4.3)$$

Table 4.1: Discharge through hydro-turbines over 24 hours period

	00:00	**01:00**	**02:00**	**03:00**	**04:00**	**05:00**	**06:00**	**07:00**	**08:00**	**09:00**	**10:00**	**11:00**
MWP 9	208.27	208.04	208.11	208.21	208.17	208.16	208.26	208.29	208.39	208.37	208.42	208.21
MWP 8	208.11	208.09	208.11	208.21	208.19	208.15	208.37	208.29	208.39	208.37	208.42	208.16
MWP 5	208.12	208.12	208.00	208.32	208.16	208.17	208.32	208.31	208.39	208.39	208.44	208.22
MWP 1	208.29	208.02	208.02	208.21	208.14	208.16	208.32	208.24	208.39	208.37	208.41	208.22
MWP 2	208.12	208.21	208.21	208.17	208.09	208.18	208.24	208.19	208.39	208.41	208.42	208.21
MWP 3	208.12	208.21	208.00	208.17	208.09	208.35	208.32	208.17	208.33	208.37	208.42	207.11
MWP 10	208.16	208.02	208.02	207.09	207.11	207.09	207.11	207.09	207.11	208.39	208.41	208.21
MWP 6	207.11	207.11	207.11	207.11	207.11	207.11	208.26	208.29	208.39	208.39	208.42	208.22
MWP 7	207.11	207.11	207.11	207.11	207.11	207.11	207.11	207.11	207.11	207.11	207.76	208.22
MWP 4	207.11	207.11	207.11	207.11	207.11	207.11	207.11	207.11	207.11	207.11	207.11	208.22
total volume /sec	2078.52	2078.08	2077.89	2077.84	2077.45	2077.80	2079.69	2079.39	2080.35	2081.67	2082.67	2081.47
total volume /Hr	**7482687.9**	**7481096.29**	**7480398.93**	**7480240.68**	**7478814.72**	**7480081.90**	**7486868.03**	**7485808.37**	**7489245.86**	**7494021.63**	**7497613.88**	**7493277.39**

12:00	**13:00**	**14:00**	**15:00**	**16:00**	**17:00**	**18:00**	**19:00**	**20:00**	**21:00**	**22:00**	**23:00**	**volume/turbine**
208.24	208.26	208.31	208.36	208.16	208.13	208.14	208.41	208.49	208.44	208.39	208.17	**4998.40**
208.21	208.26	208.29	208.36	208.19	208.14	208.14	208.41	208.49	208.48	208.34	208.16	**4998.32**
208.32	208.24	208.29	208.36	208.21	208.14	208.17	208.41	208.49	208.48	208.39	208.17	**4998.65**
208.17	208.26	208.29	208.34	208.18	208.14	208.16	208.39	208.51	208.49	208.39	208.15	**4998.26**
208.32	208.27	208.29	208.34	208.19	208.14	208.16	208.36	208.51	208.49	208.39	208.17	**4998.47**
207.11	207.11	207.11	207.11	208.21	208.14	208.16	208.39	208.49	208.49	208.39	208.17	**4992.57**
208.22	208.24	208.29	208.34	208.17	208.14	208.12	208.41	208.50	208.46	208.39	208.17	**4991.27**
208.21	208.19	208.26	208.34	208.21	208.16	208.16	208.41	208.49	208.48	208.39	208.17	**4992.10**
208.24	208.24	208.29	208.36	208.17	208.16	208.16	208.41	208.49	208.48	208.39	208.16	**4986.64**
208.31	208.24	208.29	208.36	208.21	208.14	208.16	208.41	208.49	208.48	208.35	208.17	**4986.05**
2081.85	2081.84	2082.30	2082.89	2082.55	2082.13	2082.26	2084.78	2085.79	2085.63	2084.74	2082.63	**49952.23**
7494660.71	**7494637.97**	**7496278.79**	**7498407.42**	**7497192.18**	**7495666.59**	**7496152.97**	**7505216.44**	**7508852.03**	**7508265.43**	**7505071.18**	**7497462.46**	**179828019.79**

$$F[P] = \frac{H[P]}{\text{Heat content}} * \text{Fuel price} \qquad (4.4)$$

Table 4.2: Cost of thermal generation

Turbine	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	T $ /turbine
GT1	250.20	226.04	226.04	226.04	226.04	237.79	250.20	250.20	250.20	250.20	250.20	613.02	581.90	551.32	551.32	551.32	581.90	274.90	274.90	274.90	250.20	226.04	226.04	226.04	**7826.98**
GT2	250.20	226.04	226.04	226.04	226.04	237.79	250.20	250.20	250.20	250.20	250.20	613.02	613.02	581.90	581.90	613.02	613.02	613.02	613.02	644.68	644.68	613.02	250.20	226.04	**9863.75**
GT3	434.33	226.04	226.04	226.04	406.42	423.85	250.20	250.20	250.20	250.20	250.20	613.02	581.90	581.90	551.32	581.90	581.90	613.02	613.02	644.68	644.68	613.02	250.20	226.04	**10290.36**
GT6	250.20	406.42	406.42	226.04	226.04	237.79	250.20	250.20	250.20	250.20	250.20	613.02	581.90	551.32	551.32	551.32	581.90	613.02	613.02	644.68	644.68	644.68	644.68	613.02	**10852.50**
GT7	250.20	226.04	226.04	226.04	226.04	237.79	250.20	250.20	250.20	250.20	250.20	613.02	613.02	581.90	581.90	613.02	613.02	613.02	613.02	644.68	644.68	613.02	644.68	613.02	**10645.21**
GT8	434.33	226.04	226.04	406.42	406.42	423.85	462.77	462.77	462.77	462.77	462.77	613.02	581.90	581.90	551.32	581.90	581.90	581.90	581.90	613.02	581.90	581.90	581.90	551.32	**12002.75**
ST2	10.64	15.42	15.42	15.42	9.85	10.24	17.03	17.03	17.03	17.03	17.03	12.23	11.44	11.44	11.44	11.44	11.44	20.25	20.25	21.06	20.25	15.42	15.42	15.42	**359.63**
total $/Hr	**1880.11**	**1552.05**	**1552.05**	**1552.05**	**1726.85**	**1809.11**	**1730.81**	**1730.81**	**1730.81**	**1730.81**	**1730.81**	**3690.38**	**3565.10**	**3441.68**	**3380.51**	**3503.92**	**3565.10**	**3329.15**	**3329.15**	**3487.71**	**3431.08**	**3307.12**	**2613.14**	**2470.91**	**61841.21**

4.2 Problem formulation:

4.2.1 Objective function:

The objective of solving STHTS problem is to minimize the cost of the fuel of the thermal generation which is a function of output power of seven gas turbines over 24 hour period as described in equation.

$$F = \min \left[\sum_{t=1}^{24} \sum_{i=1}^{7} F_i\left[P_{gi}^t\right] \right] \qquad (4.5)$$

$$F_i\left[P_{gi}^t\right] = a_1 + b_1 . P_{gi} + c_1 . {P_{gi}}^2 \qquad (4.6)$$

4.2.2Constrains:

The objective function which described in equation 3.8 is subjected to different constrains which are:

i. Equality constrains:

- Real power balance:

$$\sum_{i=1}^{7} P_{gi}^{t} + \sum_{j=1}^{10} P_{hj}^{t} + P_{loss}\left[P_{gi}^{t}, P_{hk}^{t}\right] = P_{D}^{t} \qquad (4.7)$$

$$P_{loss}\left[P_{gi}^{t}, P_{hk}^{t}\right] = B_{11} * \left[P_{gi}^{t}\right]^{2} + 2 * B_{12} * \left[P_{gi}^{t}\right] * P_{hk}^{t} + B_{22} * \left[P_{hk}^{t}\right] \qquad (4.8)$$

Where B_{11}, B_{12}, B_{22} are transmission losses coefficients which are calculated as in appendix I

- Reservoir end volume :

$$Q_{TOT} = \sum_{j=1}^{24} \sum_{k=1}^{10} \left[Q_{jk}\left(p_{Hjk}\right)\right] = 179828019.79 \text{ m}^{3} \qquad (4.9)$$

ii. Inequality constrains:

- Output power of the gas turbines

$$20 \text{ MW} \leq \text{P}_{g} \leq 37 \text{ MW} \qquad (4.10)$$

- Output power of the hydro turbines

$$0 \text{ MW} \leq \text{P}_{h} \leq 125 \text{ MW} \qquad (4.11)$$

4.3 Implementation of PSO for STHTS problem:

To implement PSO for STHTS problem there are various steps which can be summarized below:

4.3.1Handling of constrains:

The STHTS problem is subjected to different constrains which are discharge, water availability, output hydro power limits, thermal output power limits and power balance considering transmission losses constrains so that in the following steps these constrains are handled one by one.

STEP1: Handling discharge constrain:

A random N populations of hydro turbines discharge considering discharge limits for K hydro turbines and load factor during J intervals and as shown below.

$$Q = \begin{bmatrix} Q_{1,1} & \cdots & Q_{1,k*J} \\ \vdots & \ddots & \vdots \\ Q_{N,1} & \cdots & Q_{N,k*J} \end{bmatrix} \tag{4.12}$$

STEP2: Handling water availability constrain:

According to equation 4.12 the total discharge is calculated for each population and readjusted so that it satisfies equation 4.11.

STEP3: Handling hydro output power constrain:

According to the previous step the hydro output power of hydro turbines during J intervals is calculated as shown in equation 4.13 which should satisfy equation 4.12.

$$\text{PH}= \begin{bmatrix} PH_{1,1} & \cdots & PH_{1,k*J} \\ \vdots & \ddots & \vdots \\ PH_{N,1} & \cdots & PH_{N,k*J} \end{bmatrix} \tag{4.13}$$

STEP4: Implementation of the best hydro schedule:

In this step best population of hydro output power is implemented from equation 4.13 which described in equation 4.14

$$\text{PH}_{best} = [PH_{best,1} \quad \dots \dots \quad PH_{best,J*K}] \tag{4.14}$$

STEP5: Implementation of total thermal output power considering power balance constrain:

By rearranging equation 4.7 and 4.8

$$P_{th}^{t} + P_{h}^{t} + B_{11} * [P_{th}^{t}]^2 + 2 * B_{12} * [P_{th}^{t}] * P_{hk}^{t} + B_{22} * [P_{hk}^{t}]^2 = P_{D}^{t} \quad (4.15)$$

This can be arranged as:

$$B_{11} * [P_{th}^{t}]^2 + [1 + 2 * B_{12} * P_{hk}^{t}] * [P_{th}^{t}] + [B_{22} * [P_{hk}^{t}]^2 + P_{h}^{t} - P_{D}^{t}] = \quad (4.16)$$

Using general rule of quadratic equation:

$$P_{th}^{t} = \frac{-[1+2*B_{12}*P_{hk}^{t}] \pm \sqrt{[1+2*B_{12}*P_{hk}^{t}]^2 - 4B_{11}\left[B_{22}*[P_{hk}^{t}]^2 + P_{h}^{t} - P_{D}^{t}\right]}}{2*B_{11}} \quad (4.17).$$

Using equation 4.17 the total thermal output power is calculated during each interval as shown in equation 4.18.

$$P_{th} = [P_{th_{best,1}} \quad \cdots\cdots \quad P_{th_{best,J}}] \quad (4.18)$$

STEP5:Implementation of thermal output power for each thermal unit:

For each J interval form J=1 up to J=24 a random thermal scheduling of M population for output power is formulated as shown in equation 4.19 so that it represent each element in matrix described in equation 4.18 it satisfy equations 4.10 and 4.18.

$$P_{th_{[m,7]}} = \begin{bmatrix} P_{g_{[1,1]}} & \cdots & \cdots & P_{g_{[1,7]}} \\ \vdots & \ddots & \ddots & \vdots \\ \vdots & \ddots & \ddots & \vdots \\ P_{g_{[m,1]}} & \cdots & \cdots & P_{g_{[m,7]}} \end{bmatrix} \quad (4.19)$$

4.3.2: Implementation of PSO for STHTS problem:

According to equation 4.14 the objective function 4.4 evaluated for each M population and the minimum generation cost through M populations is determined which is set to be F_{gbest} or the best generation cost and its position through $M = 1{:}M_{max}$ is set to be i_{gbest} or the best population and it's individual thermal generation is set to be p_{best} or the best particles then by using equations 3.1 and 3.2 a particle swarm optimization initiated for the gas turbine units and the steam turbine unit is float so that it should satisfy equation 4.18 and the inequality constrain 4.9 then the iterations continue until max iteration is reached and the best generation cost during these iteration is determined and its corresponding best generation scheduling.

The above steps are repeated for equation 4.18 so that its result described in equation 4.16 and the total generation cost for each visible unit commitment is calculated using equation 4.19.

$$F = \begin{bmatrix} F_{best(1,1)} & \cdots & F_{best(1,J)} \\ \vdots & \ddots & \vdots \\ F_{best(7,1)} & \cdots & F_{best(7,J)} \end{bmatrix} \tag{4.20}$$

The best generation cost is determined form equation 4.20 using equation 4.19 and handling the startup and shutdown costs the corresponding thermal output power for each gas turbine and also the corresponding hydro output power and the losses during 24 hour period are determined.

$$F_{Tbest} = min \begin{bmatrix} F_{best(1)} \\ \vdots \\ F_{best(J)} \end{bmatrix} \tag{4.21}$$

4.4 Simulation

In this chapter the PSO technique applied to the STHTS problem by using MATLAB code which can be summarized in the following steps:

a. Identifying the parameters
b. Defining the objective function:
c. Calculating load factor:
d. Hydro discharge population implementation considering constrains:
e. Implementation of hydro output power :
f. Calculating total thermal generation with handling transmission line constrain:
g. Calculating losses:
h. Unit commitment implementation:
i. Calculating thermal schedule for all intervals:
j. Evaluate objective for all particles:

k. Particle swarm optimization for thermal scheduling:
l. Calculating the best total cost among all populations considering startup and shutdown costs:
m. Calculating the optimal schedule values:

4.4.1 Program execution:

During program iterations the minimum generation cost is recorded and compared with the previous minimum then if it is less it will be registered as a best cost and the iteration continued until it is reach the max number of iteration. So that the best generation cost at the end of program execution is 51,615 $

4.4.2 Discharge:

The discharge corresponding to the best operating cost is shown in table 5.1 and it is compared with the actual discharge hour by hour and as accumulated value so that during 15 hours there is saving in water consumption from the actual case while this saving is used in the remaining 9 hours.

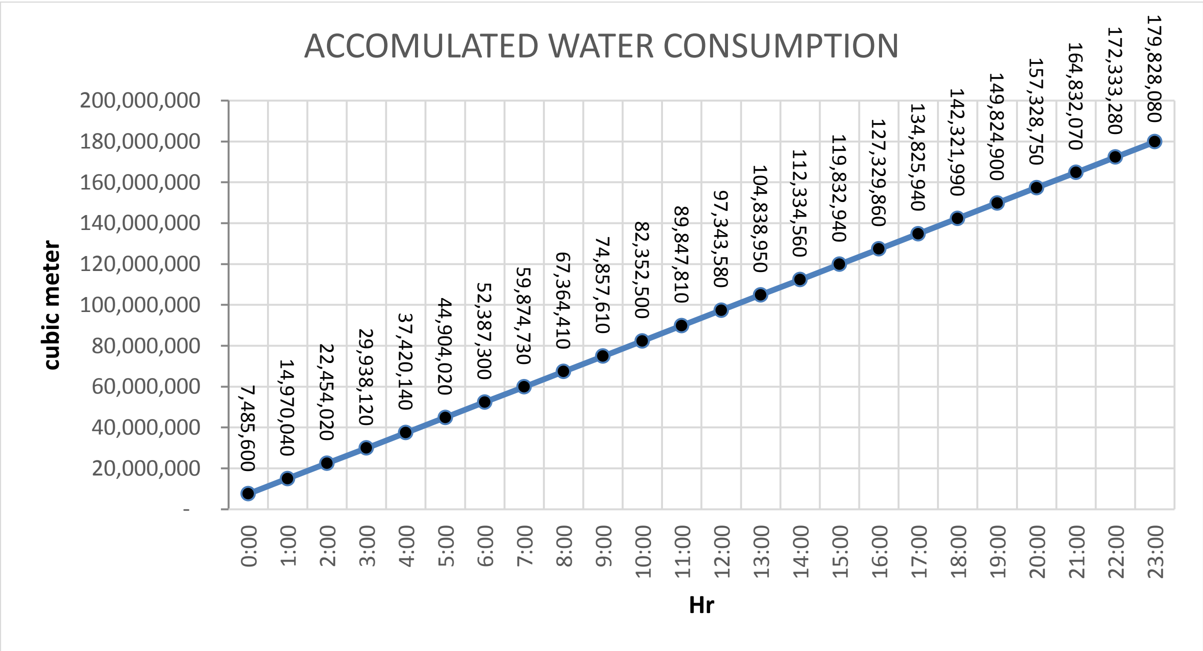

Fig 5.1: Accumulated water discharge

Table 5.1: Discharge through hydro units

HOUR	UNIT 1	UNIT 2	UNIT 3	UNIT 4	UNIT 5	UNIT 6	UNIT 7	UNIT 8	UNIT 9	UNIT 10	PSO		ACTUAL		DEFF
											HOURLY DISCHARGE	ACCOMULATED WATER CONSUMPTION	HOURLY DISCHARGE	ACCOMULATED WATER CONSUMPTION	
00:00	748,430	748,430	748,430	748,430	748,420	748,430	748,420	748,420	748,420	748,430	7,484,260	7,484,260	7,482,688	7,482,688	1,572
01:00	748,240	748,230	748,230	748,230	748,240	748,240	748,230	748,240	748,230	748,240	7,482,350	14,966,610	7,481,096	14,963,784	1,254
02:00	748,150	748,160	748,150	748,150	748,150	748,150	748,150	748,150	748,150	748,150	7,481,510	22,448,120	7,480,399	22,444,183	1,111
03:00	748,140	748,130	748,130	748,130	748,130	748,130	748,130	748,130	748,140	748,130	7,481,320	29,929,440	7,480,241	29,924,424	1,079
04:00	748,000	748,000	748,000	748,000	748,000	748,000	748,000	748,000	748,000	748,000	7,480,000	37,409,440	7,478,815	37,403,239	1,185
05:00	748,110	748,110	748,110	748,110	748,110	748,110	748,110	748,110	748,110	748,110	7,481,100	44,890,540	7,480,082	44,883,320	1,018
06:00	748,190	748,190	748,190	748,190	748,190	748,190	748,190	748,190	748,190	748,190	7,481,900	52,372,440	7,486,868	52,370,188	-4,968
07:00	748,610	748,610	748,610	748,610	748,610	748,610	748,610	748,610	748,610	748,610	7,486,100	59,858,540	7,485,808	59,855,997	292
08:00	748,900	748,900	748,900	748,900	748,900	748,900	748,900	748,900	748,900	748,900	7,489,000	67,347,540	7,489,246	67,345,243	-246
09:00	749,300	749,300	749,300	749,300	749,290	749,300	749,300	749,300	749,300	749,300	7,492,990	74,840,530	7,494,022	74,839,264	-1,032
10:00	749,600	749,600	749,600	749,600	749,600	749,600	749,600	749,600	749,600	749,600	7,496,000	82,336,530	7,497,614	82,336,878	-1,614
11:00	749,550	749,550	749,550	749,540	749,550	749,550	749,540	749,550	749,550	749,550	7,495,480	89,832,010	7,493,277	89,830,156	2,203
12:00	749,620	749,630	749,630	749,630	749,630	749,630	749,630	749,630	749,630	749,630	7,496,290	97,328,300	7,494,661	97,324,816	1,629
13:00	749,590	749,590	749,590	749,590	749,590	749,590	749,590	749,590	749,590	749,590	7,495,900	104,824,200	7,494,638	104,819,454	1,262
14:00	749,700	749,700	749,700	749,700	749,700	749,700	749,700	749,700	749,700	749,730	7,497,030	112,321,230	7,496,279	112,315,733	751
15:00	749,900	749,900	749,900	749,900	749,900	749,900	749,900	749,900	749,900	749,900	7,499,000	119,820,230	7,498,407	119,814,140	593
16:00	749,790	749,790	749,790	749,790	749,790	749,790	749,790	749,790	749,790	749,790	7,497,900	127,318,130	7,497,192	127,311,333	708
17:00	749,660	749,670	749,660	749,670	749,670	749,670	749,670	749,670	749,660	749,660	7,496,660	134,814,790	7,495,667	134,806,999	993
18:00	749,690	749,690	749,690	749,690	749,690	749,690	749,690	749,690	749,690	749,690	7,496,900	142,311,690	7,496,153	142,303,152	747
19:00	750,490	750,490	750,490	750,490	750,480	750,480	750,490	750,480	750,490	750,490	7,504,870	149,816,560	7,505,216	149,808,369	-346
20:00	750,750	750,750	750,750	750,750	750,750	750,750	750,750	750,750	750,750	750,750	7,507,500	157,324,060	7,508,852	157,317,221	-1,352
21:00	750,630	750,640	750,640	750,640	750,640	750,640	750,640	750,640	750,630	750,630	7,506,370	164,830,430	7,508,265	164,825,486	-1,895
22:00	750,220	750,220	750,220	750,220	750,220	750,220	750,220	750,220	750,220	750,220	7,502,200	172,332,630	7,505,071	172,330,557	-2,871
23:00	749,540	749,540	749,540	749,540	749,540	749,540	749,540	749,530	749,540	749,540	7,495,390	179,828,020	7,497,462	179,828,020	-2,072
					TOLAL CONSUMTION							179,828,020		179,828,020	0

4.4.3 Hydro output power:

The hydro output power of the best schedule is shown in table 5.2 and fig 5.2 and compared with the actual schedule so that the PSO schedule has more output power during most of scheduling period while the same hydro resources are used.

Table 5.2: Hydro output power

HOUR	U1	U 2	U 3	U 4	U 5	U 6	U 7	U 8	U 9	U 10	TOTAL PSO	TOTAL ACT	Deff
00:00	46.5	46.5	46.6	46.5	46.5	46.6	46.5	46.5	46.5	46.5	465.4	440	25.4
01:00	43.4	43.4	43.4	43.4	43.4	43.4	43.4	43.4	43.4	43.4	433.9	411	22.9
02:00	42.1	42.0	42.0	42.0	42.0	42.1	42.1	42.1	42.0	42.1	420.5	397	23.5
03:00	41.7	41.7	41.7	41.7	41.7	41.7	41.7	41.7	41.7	41.7	417.0	392	25
04:00	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	39.5	395.0	366	29
05:00	41.4	41.3	41.4	41.4	41.4	41.4	41.3	41.4	41.4	41.3	413.7	385	28.7
06:00	42.7	42.7	42.7	42.7	42.7	42.7	42.7	42.6	42.7	42.6	426.8	494	-67.2
07:00	49.7	49.6	49.6	49.6	49.6	49.6	49.7	49.7	49.6	49.6	496.3	474	22.3
08:00	54.4	54.4	54.4	54.4	54.4	54.4	54.4	54.4	54.4	54.4	544.0	528	16
09:00	61.0	60.9	60.9	60.9	60.9	61.0	60.9	60.9	61.0	60.9	609.4	605	4.4
10:00	65.9	65.9	65.9	66.0	66.0	66.0	66.0	65.9	65.9	66.0	659.4	661	-1.6
11:00	65.1	65.1	65.1	65.0	65.1	65.1	65.1	65.0	65.0	65.0	650.6	587	63.6
12:00	66.4	66.4	66.4	66.4	66.4	66.4	66.4	66.4	66.4	66.4	663.9	608	55.9
13:00	65.8	65.8	65.7	65.8	65.7	65.7	65.8	65.8	65.8	65.8	657.7	605	52.7
14:00	67.6	67.6	67.7	67.6	67.6	67.6	67.6	67.6	67.6	67.6	676.2	629	47.2
15:00	70.9	70.9	70.9	70.9	70.9	70.9	70.9	70.9	70.9	70.9	708.8	662	46.8
16:00	69.2	69.1	69.1	69.1	69.1	69.1	69.1	69.2	69.1	69.1	691.3	639	52.3
17:00	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	67.0	670.0	612	58
18:00	67.4	67.4	67.5	67.4	67.4	67.4	67.4	67.4	67.5	67.5	674.4	617	57.4
19:00	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	80.6	805.9	765	40.9
20:00	84.9	84.9	85.0	84.9	85.0	84.9	85.0	85.0	84.9	84.9	849.5	822	27.5
21:00	83.1	83.1	83.1	83.1	83.1	83.1	83.1	83.1	83.1	83.1	830.9	810	20.9
22:00	76.2	76.2	76.2	76.2	76.2	76.2	76.2	76.2	76.2	76.2	761.9	755	6.9
23:00	64.9	64.9	64.9	64.9	64.9	64.9	64.9	64.9	64.9	64.9	648.9	627	21.9

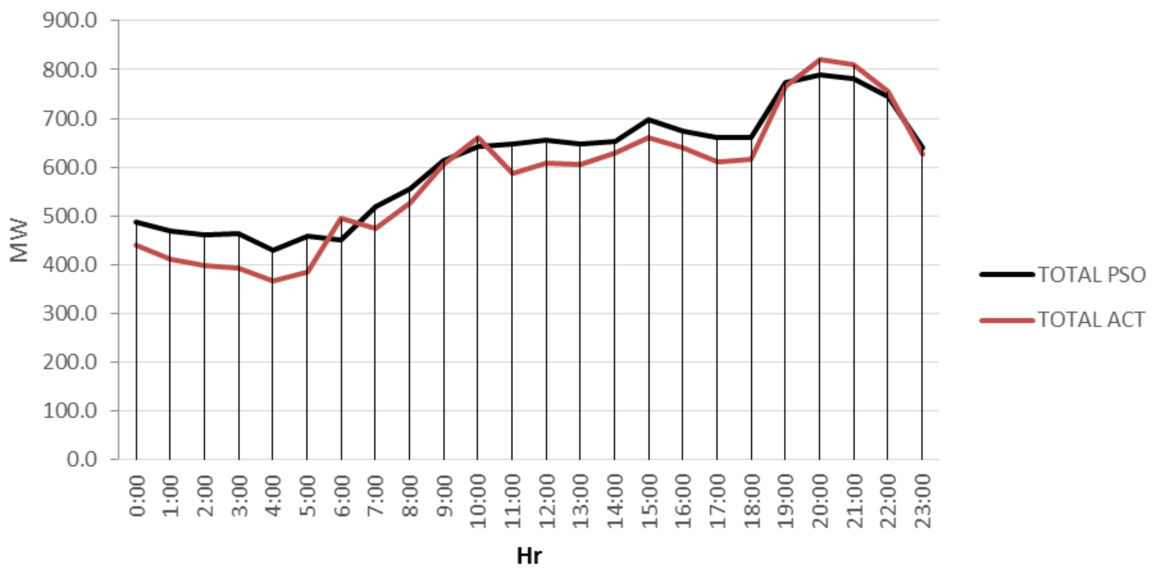

Fig 5.2: Hydro output power (MW)

From table 5.2 and figure 5.2 the PSO algorithm has more output power in most of operation period from hour 00:00 to 5:00, from hour 7:00 to 9:00 and form hour 11:00 to 23:00 while in hour 10:00 the output power approximately equal in PSO and actual case so that during 92% form the operation period the PSO algorithm give schedule has more output power form the actual case.

4.4.4 Total thermal output power:

Figure 5.3 and 5.2 illustrates that the best use of water resources the hydro power maximized while the thermal power minimizes which reflect directly on the operation cost.

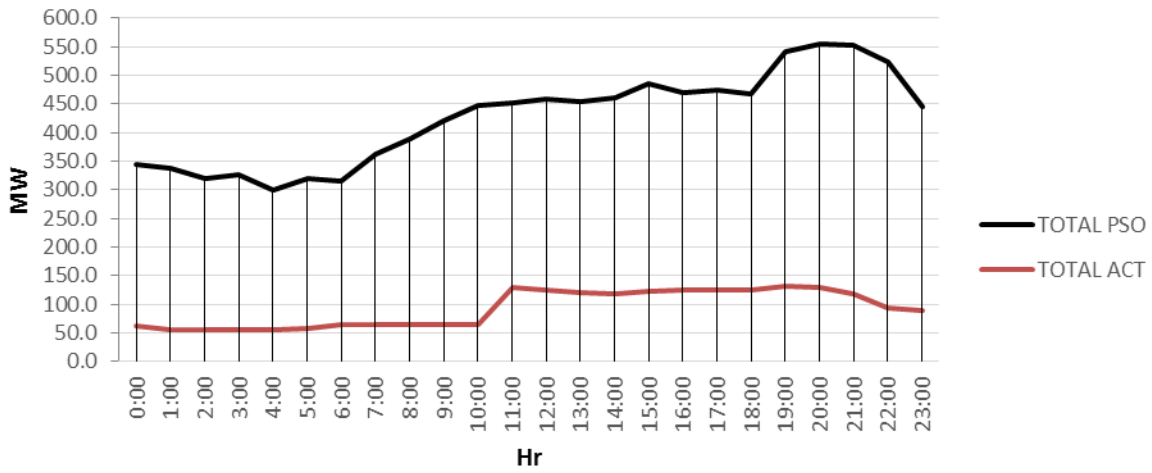

Fig 5.3: Thermal output power (MW)

During 92% form the operation period the thermal power plan has less output power than the actual case which reflected on minimization of the operational cost.

4.4.5 Unit commitment:

As shown in figure 5.4 the units committed and decommitted according to the required power form thermal plan so that as discussed before it was minimized then less number of thermal units are committed while in actual case all thermal units are on line during all scheduling period.

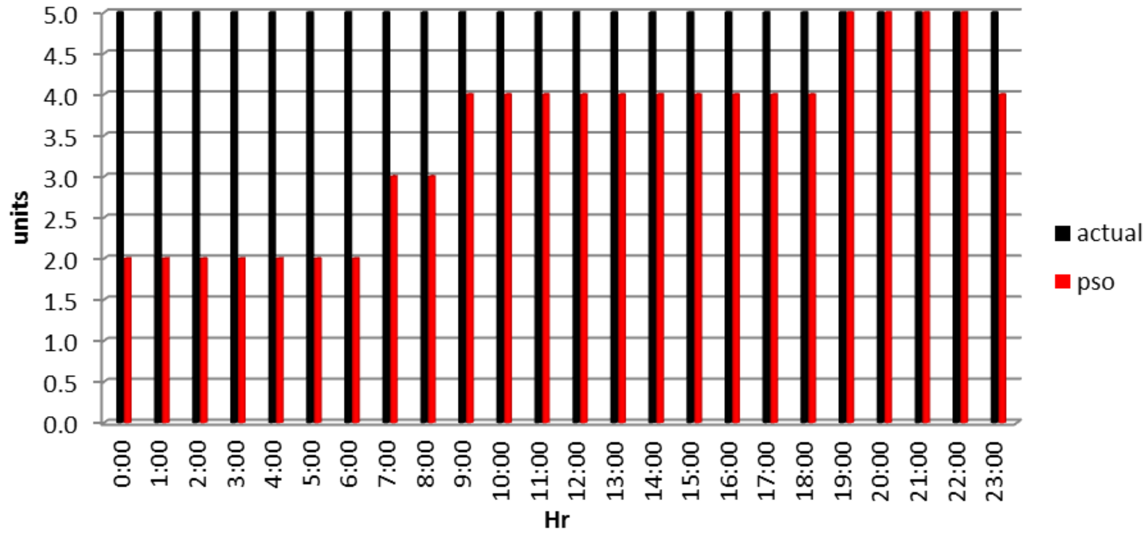

Fig 5.4: Unit commitment

Also fewer units committed mean that the life time of the plan includes boilers, turbines and generators can be extended and less maintenance required which lead to decreasing number of spare parts required which related to the global sanction for Sudan also saving foreign currency for supplying this spare parts which can be used in construction of new power plants to cover the load growth in the national grid.

4.4.6 Thermal scheduling :

According to the total thermal output power and the unit commitment discussed before the thermal schedule corresponding to the best operational cost is shown in table 5.3. So that during each hour the thermal machines have an equal incremental rate.

Table 5.3: Thermal output power

HOUR	UNIT 1	UNIT 2	UNIT 3	UNIT 4	UNIT 5	UNIT 6	UNIT 7	TOTAL PSO	TOTAL ACT
00:00	17.7	17.7	0.0	0.0	0.0	0.0	0.0	17.7	63
01:00	15.0	15.0	0.0	0.0	0.0	0.0	0.0	15.0	56
02:00	13.9	13.9	0.0	0.0	0.0	0.0	0.0	13.9	56
03:00	13.6	13.6	0.0	0.0	0.0	0.0	0.0	13.6	56
04:00	11.8	11.8	0.0	0.0	0.0	0.0	0.0	11.8	56
05:00	13.3	13.3	0.0	0.0	0.0	0.0	0.0	13.3	58
06:00	14.4	14.4	0.0	0.0	0.0	0.0	0.0	14.4	65
07:00	13.5	13.5	13.5	0.0	0.0	0.0	0.0	13.5	65
08:00	16.2	16.2	16.2	0.0	0.0	0.0	0.0	16.2	65
09:00	15.0	15.0	15.0	15.0	0.0	0.0	0.0	15.0	65
10:00	17.3	17.2	17.2	17.3	0.0	0.0	0.0	17.3	65
11:00	16.9	16.8	16.8	16.9	0.0	0.0	0.0	16.9	129
12:00	17.4	17.4	17.5	17.4	0.0	0.0	0.0	17.4	124
13:00	17.1	17.2	17.2	17.2	0.0	0.0	0.0	17.1	120
14:00	18.0	18.0	18.0	17.9	0.0	0.0	0.0	18.0	118
15:00	19.5	19.5	19.5	19.5	0.0	0.0	0.0	19.5	122
16:00	18.8	18.7	18.7	18.7	0.0	0.0	0.0	18.8	124
17:00	17.7	17.7	17.7	17.7	0.0	0.0	0.0	17.7	126
18:00	17.9	17.9	17.9	17.9	0.0	0.0	0.0	17.9	126
19:00	19.1	19.3	19.2	19.1	19.3	0.0	0.0	19.1	132
20:00	20.8	20.8	20.9	20.8	20.9	0.0	0.0	20.8	129
21:00	20.2	20.1	20.2	20.2	20.2	0.0	0.0	20.2	119
22:00	17.6	17.5	17.5	17.6	17.6	0.0	0.0	17.6	94
23:00	16.8	16.7	16.7	16.7	0.0	0.0	0.0	16.8	89

4.4.7 Total output power of the best schedule:

The total generation during scheduling period is shown in figure 5.5 so that the thermal output power varies from 3.7% from the total generation at hour 00:00 to 2.26% in hour 22:00.

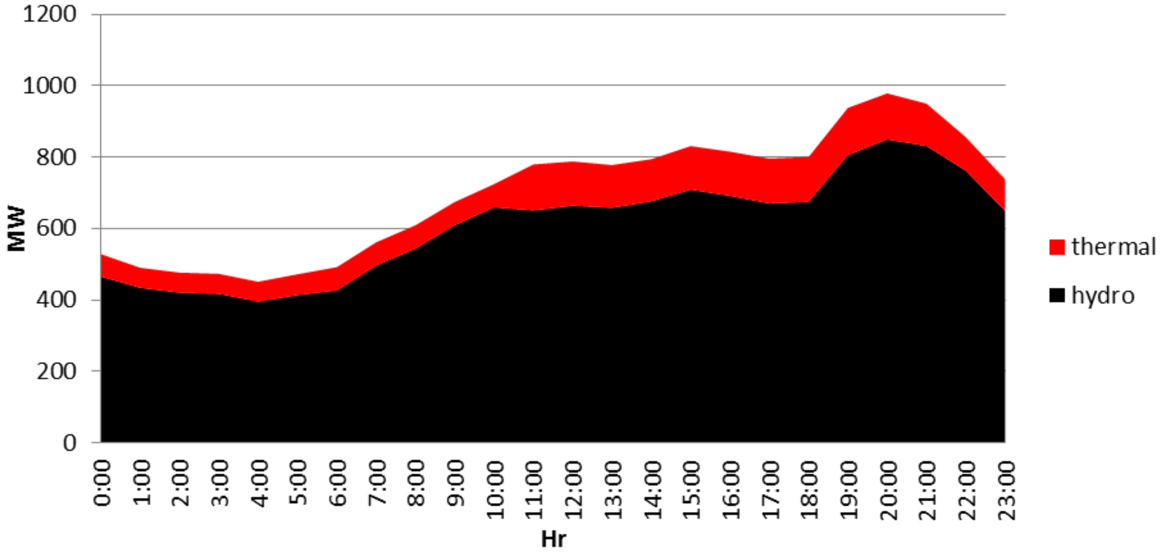

Fig 5.5: Total output power

4.4.8 Cost comparison:

As shown in figure 5.6 the operational cost of the best schedule is 51,615$ which represent 83.4 % from the actual cost in other words the best cost obtained is an actual operation cost up to hour 19:00 and the operation cost from 19:00 up to 23:00 is saving

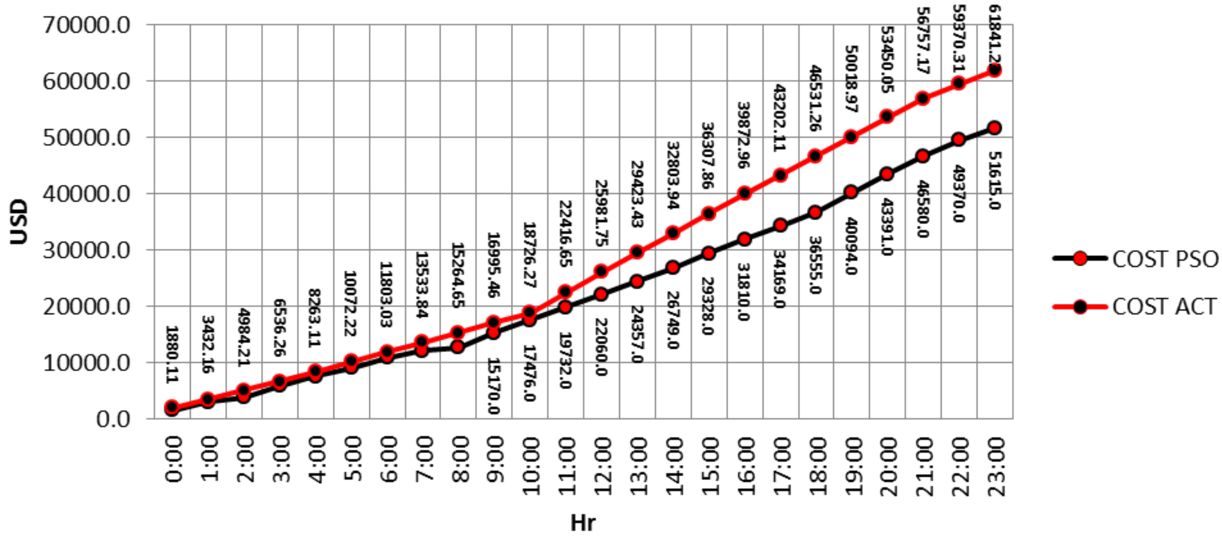

Fig 5.6: Cost comparison

4.4.9 Losses comparison:

Table 5.4 and fig 5.7 indicate that the system loss slightly increase because the most of loads near the thermal plan (KHARTUOM load) as a result of that more power as discussed before will flow from the hydro plan which lead to increase the transmission line losses but as a final result the total operational cost of the system is minimized.

Table 5.4: Losses

HOUR	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00
losses pso	7.8	6.8	6.4	6.3	5.6	6.2	6.6	8.8	10.6	13.2	15.5	15.1
losses act	9.8	9.7	10.5	10.0	9.0	9.3	10.1	11.0	11.0	13.7	13.5	13.3

12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
15.7	15.4	16.3	17.9	17.0	16.0	16.2	23.1	25.6	24.5	20.6	15.0
13.6	13.8	14.4	15.2	14.4	12.7	13.3	19.6	23.4	22.1	19.8	14.5

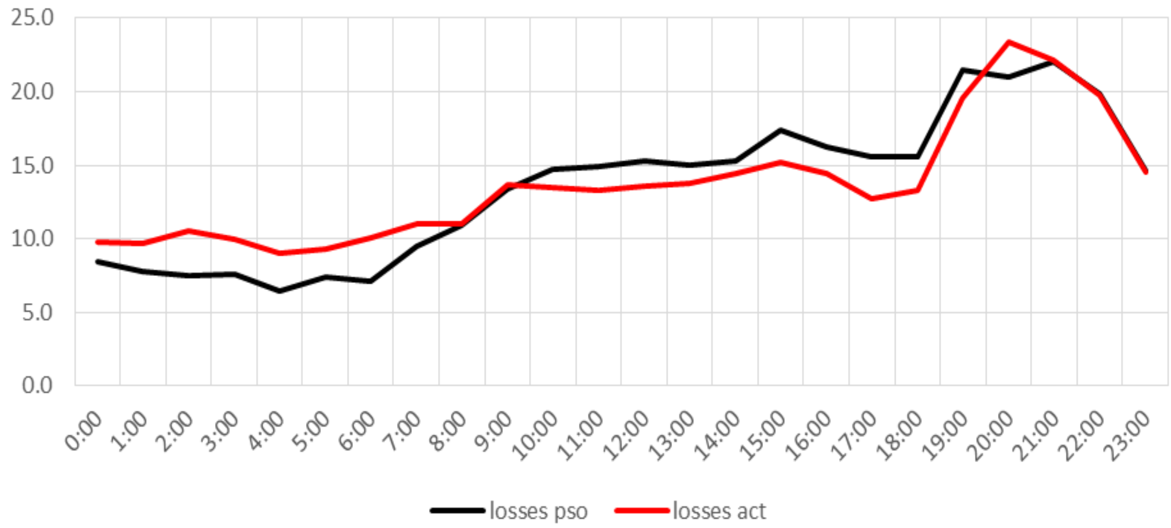

Fig 5.7: Losses comparison

Chapter fife

Conclusions and recommendations

5.1 Conclusions:

The particle swarm optimization algorithm has been applied to the short-term hydrothermal scheduling problem over the time horizon of 24 hours with one hour time interval. The presented algorithm determines the fuel cost of thermal generation for each time interval and give the optimum solution. So that the PSO algorithm has been applied to the Garri and Merwee power stations which containing 7 gas units and 10 hydro units respectively and the following conclusions are drawn:

- With the same water volume used in short-term hydrothermal scheduling period on day (15/1/2015) and with handling the constrains the PSO algorithm give the best schedule which lead to minimize the operation cost by 14.5 %.
- The losses of system slightly increase because most load located near the thermal plant as a result of that the hydro plant participation increase.

5.2 Recommendations:

1. The PSO algorithm used for partial system can be extended for the whole system and more saving in operation and maintenance cost can be achieved.
2. PSO algorithm gives more optimal results when using unit commitment than economic dispatch.

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Appendices

Appendix: A: Power delivered form power stations over 24 hours period

TIME	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
GARRI GT1	7	6	6	6	6	6	7	7	7	7	7	20	19	18	18	18	19	8	8	8	7	6	6	6
GARRI GT2	7	6	6	6	6	6	7	7	7	7	7	20	20	19	19	20	20	20	20	21	21	20	7	6
GARRI GT3	14	6	6	6	13	14	7	7	7	7	7	20	19	19	18	19	19	20	20	21	21	20	7	6
GARRI GT6	7	13	13	6	6	6	7	7	7	7	7	20	19	18	18	18	19	20	20	21	21	21	21	20
GARRI GT7	7	6	6	6	6	6	7	7	7	7	7	20	20	19	19	20	20	20	20	21	21	20	21	20
GARRI GT8	14	6	6	13	13	14	15	15	15	15	15	20	19	19	18	19	19	19	19	20	19	19	19	18
GARRI GT4	7	13	13	13	6	6	15	15	15	15	15	9	8	8	8	8	8	19	19	20	19	13	13	13
MWP 1	70	54	54	65	61	62	72	67	76	75	77	66	63	68	70	73	63	61	62	76	83	82	76	62
MWP 10	62	54	54	-1	0	-1	0	-1	0	76	77	65	66	67	70	73	63	61	60	77	82	80	76	63
MWP 2	60	65	65	63	58	63	67	64	76	77	78	65	72	69	70	73	64	61	62	74	83	82	76	63
MWP 3	60	65	53	63	58	74	72	63	72	75	78	0	0	0	0	0	65	61	62	76	82	82	76	63
MWP 4	0	0	0	0	0	0	0	0	0	0	0	66	71	67	70	74	65	61	62	77	82	81	74	63
MWP 5	60	60	53	72	62	63	72	71	76	76	79	66	72	67	70	74	65	61	63	77	82	81	76	63
MWP 6	0	0	0	0	0	0	68	70	76	76	78	66	65	64	68	73	65	62	62	77	82	81	76	63
MWP 7	0	0	0	0	0	0	0	0	0	0	38	66	67	67	70	74	63	62	62	77	82	81	76	62
MWP 8	59	58	59	65	64	62	75	70	76	75	78	62	65	68	70	74	64	61	61	77	82	81	73	62
MWP 9	69	55	59	65	63	62	68	70	76	75	78	65	67	68	71	74	62	61	61	77	82	79	76	63
ROS 1	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
ROS 2.	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
ROS 4	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
ROS 5	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
	603	567	553	548	522	544	659	639	693	770	826	816	832	825	847	884	863	838	843	997	1051	1029	949	816

Appendix: B: Cumulative power delivered form power stations over 24 hours period

TIME	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
ROS 1	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
ROS 2.	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50	50
ROS 4	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75
ROS 5	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
MWP 9	169	155	159	165	163	162	168	170	176	175	178	165	167	168	171	174	162	161	161	177	182	179	176	163
MWP 8	228	213	218	230	227	224	243	240	252	250	256	227	232	236	241	248	226	222	222	254	264	260	249	225
MWP 5	288	273	271	302	289	287	315	311	328	326	335	293	304	303	311	322	291	283	285	331	346	341	325	288
MWP 1	358	327	325	367	350	349	387	378	404	401	412	359	367	371	381	395	354	344	347	407	429	423	401	350
MWP 2	418	392	390	430	408	412	454	442	480	478	490	424	439	440	451	468	418	405	409	481	512	505	477	413
MWP 3	478	457	443	493	466	486	526	505	552	553	568	424	439	440	451	468	483	466	471	557	594	587	553	476
MWP 10	540	511	497	492	466	484	526	504	552	629	645	489	505	507	521	541	546	527	531	634	676	667	629	539
MWP 6	540	511	497	492	466	484	594	574	628	705	723	555	570	571	589	614	611	589	593	711	758	748	705	602
MWP 7	540	511	497	492	466	484	594	574	628	705	761	621	637	638	659	688	674	651	655	788	840	829	781	664
MWP 4	540	511	497	492	466	484	594	574	628	705	761	687	708	705	729	762	739	712	717	865	922	910	855	727
GARRI GT1	547	517	503	498	472	491	601	581	635	712	768	707	727	723	747	780	758	720	725	873	929	916	861	733
GARRI GT2	554	523	509	504	478	497	608	588	642	719	775	727	747	742	766	800	778	740	745	894	950	936	868	739
GARRI GT3	568	529	515	510	491	511	615	595	649	726	782	747	766	761	784	819	797	760	765	915	971	956	875	745
GARRI GT6	575	542	528	516	497	518	622	602	656	733	789	767	785	779	802	837	816	780	785	936	992	977	896	765
GARRI GT7	582	548	534	522	503	524	629	609	663	740	796	787	805	798	821	857	836	800	805	957	1013	997	917	785
GARRI GT8	596	554	540	535	516	538	644	624	678	755	811	807	824	817	839	876	855	819	824	977	1032	1016	936	803
GARRI GT4	603	567	553	548	522	544	659	639	693	770	826	816	832	825	847	884	863	838	843	997	1051	1029	949	816

Appendix: C: Load at each substation over 24 hours period

Time	0:00	1:00	2:00	3:00	4:00	5:00	6:00	7:00	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00
MWP	27	26	26	27	28	29	33	39	45	53	60	55	56	57	57	57	53	49	45	47	48	44	39	30
ATBRA	123	123	122	121	118	119	124	127	122	119	131	126	129	121	129	143	144	140	140	152	153	156	139	132
SHENDI	9	9	7	9	9	9	11	13	16	17	18	18	17	16	15	15	15	14	15	20	21	20	17	13
FRE ZO	5	5	5	5	5	5	6	6	7	8	10	10	10	9	9	9	9	9	9	9	10	10	9	7
MRK	84	77	71	67	69	70	71	80	88	98	106	108	109	110	113	114	116	113	111	127	127	125	116	101
GAM	83	68	66	64	61	62	65	81	93	100	111	112	114	111	114	119	110	109	111	133	134	133	122	104
JA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MASH	3	3	3	3	3	3	3	3	4	4	4	4	4	4	5	5	4	4	4	6	8	7	7	5
RANK	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47
RBK	32	30	29	31	35	36	36	39	48	45	47	49	51	46	45	45	44	46	44	55	63	62	55	42
SNG	18	26	24	19	7	21	9	24	20	44	52	53	53	53	56	60	59	57	56	71	76	72	67	58
SNJ	22	19	18	16	17	18	18	22	25	25	26	25	25	24	24	24	25	25	26	35	38	36	34	26
NHAS	34	32	31	30	29	31	31	34	39	44	45	41	40	44	45	47	47	43	45	61	69	64	60	44
MAR	36	33	33	33	32	32	33	35	39	46	45	44	45	46	47	48	49	48	49	66	73	70	64	51
GAD	18	16	20	26	18	18	20	27	30	34	26	24	25	25	27	35	27	23	34	33	36	42	39	36
KLX	90	79	76	75	69	65	70	78	83	93	104	103	109	109	110	110	106	102	98	113	118	111	105	98
ROS	6	6	6	5	5	5	6	6	6	7	8	8	7	7	8	8	8	8	8	11	12	12	11	8
load	593	557	542	538	513	534	549	628	682	756	813	803	818	811	832	869	849	825	830	979	1028	1007	929	801
loss	9.8	9.7	10.5	10.0	9.0	9.3	10.1	11.0	11.0	13.7	13.5	13.3	13.6	13.8	14.4	15.2	14.4	12.7	13.3	19.6	23.4	22.1	19.8	14.5
load and losses	603	567	552	548	522	543	559	639	693	770	827	816	832	825	847	884	863	837	844	999	1051	1029	949	815

Appendix: D: Heat characteristics of thermal generation

thermal machines H(P)=a+b*P+c*P^2 GJ/Hr																			
No.	**plant name**	**unit type**	**p(min)**	**p(max)**	**ramp up(mw)**	**ramp do (mw)**	**min up time(min)**	**min do time (min)**	**aux%**	**cold start $**	**cold start T**	**warm start$**	**warm start T**	**hot start $**	**hot start T**	**A**	**B**	**C**
1	GAR	GAS	20	37	5	5	1440	720	3	500	20	0	0	0	0	34.19	7.66	0.09914
2	GAR	STEAM	20	37	2	2	1440	720	3	0	0	0	0	0	0	1.9	0.29	0.00025

Appendix: E: Heat content and fuel price

No.	fuel name	fuel price Euro/Ton	heat content GJ/Ton
1	HFO	108	40
2	LPG	171	45.8
3	GASOIL	350	42.5
4	DIESEL	275	42.1
5	SPONJCOKE	42.9	47
6	LFO	108	40
7	HC	108	40
8	CRUDEOIL	108	40

Appendix: F: PSO matlab code

```
>> %IDENTIFYING PARAMETER

%the main objective from this program is to minimize the thermal generation cost

TU=7; % NO.OF THERMAL UNITS

SU=1; % NO.OF STEAM UNITS

GU=6; % NO.OF GAS UNITS

HU=10; % NO. OF HYDRO UNITS

c1=2.5; % PSO CONSTANT

c2=4-c1; % PSO CONSTANT

N=30; % NO. OF PSO GENERATIONS FOR HYDRO MACHINES

M=30; %NO. OF POPULATION OF THERMAL MACHINES

J=24; %24 HOUR PERIOD

BF=.999; % BAISING FACTOR

QT=179828019.79; %TOTAL WATER VOLUME AVIALABLE FOR STHTS

ITMAX=30; % NO. OF PSO ITERATIONS

ITER=500;

A1=0.267678;B1=20.682;C1=92.313; %COFF. OF THERMAL UNITS

A3=0.113;B3=12.45;C3=-7425.71; % COFF. OF HYDRO UNITS

A2=0.000675;B2=0.783;C2=5.13; % COFF.OF STEAM UNIT

WMAX=1;WMIN=0.4; % ITERATION WEIGHT FOR PSO

PLOAD=[493 457 442 438 413 434 449 528 582 656 713 703 718 711 732 769 749 725 730 879 928
907 829 701];

B11=0.00005713375;B12=-0.000010680625;B22=0.00003725; % LOSSES COFF.

OBJF=inline('0.267678*(PG1^2+ PG2^2+ PG3^2+ PG4^2+ PG5^2+ PG6^2)+ 20.682*(PG1+ PG2+
PG3+ PG4+ PG5+ PG6)+
92.313*6+0.000675*PS^2+0.783*PS+5.13','PG1','PG2','PS','PG3','PG4','PG5','PG6');

OBJF=vectorize(OBJF);

MINHYDRO=745793.352;MAXHYDRO=752563.26; % FORMULATION OF HYDROTURBINE
LIMITS MATRICIES

MIN(1:M,1:GU)=5; MINI =5;MAXI=32;MAX(1:M,1:GU)=32; %GAS TURBINE LIMITS

MIN(1:M,GU+1:GU+SU)=5;MAX(1:M,GU+1:GU+SU)=32; %STEAM TURBINE LIMITS

%CALCULATING LOAD FACTOR

for e=1:J
```

```
LF(e)=PLOAD(e)/max(PLOAD);
end
%HYDRO DISCHARGE POPULATION  IMPLEMENTATION CONSIDERING CONSTRAINS
D=MAXHYDRO-MINHYDRO; %HYDRO MACHINES OPERATION RANGE
Q=D/4; %QUARTER RANGE
D=D*ones(N,HU*J);
for N=1:N
for J=1:J
for H=1:HU
DISBAIS(N,HU*(J-1)+H)=D(N,HU*(J-1)+H)*LF(J)*BF;
end
end
end
for N=1:N
for Z=1:HU*J
DISCHARGE(N,Z)=D(N,Z)*rand(1,1)*(1-BF)+DISBAIS(N,Z);
end
end
C=ones(HU*J,1);
TOTDISCHARGE=DISCHARGE*C;
QTA=QT*(HU*J)/240-MINHYDRO*HU*J;
QTN=ones(N,1)*QTA;
DEV=QTN-TOTDISCHARGE;
for m=1:N
DEVON(m)=DEV(m)/ TOTDISCHARGE (m);
DEVONE=DEVON';
end
for N=1:N
for A=1:HU*J
DISCHARGE(N,A)=MINHYDRO+DISCHARGE(N,A)+DISCHARGE(N,A)*DEVONE(N);
end
```

```
end
for N=1:N
COUNT(N)=sum(DISCHARGE(N,:)<=MAXHYDRO);
for A=1:HU*J
if DISCHARGE(N,A)>MAXHYDRO
DEV(N,A)=DISCHARGE(N,A)-MAXHYDRO;
DISCHARGE(N,A)=MAXHYDRO;
else
DEV(N,A)=0;
end
end
end
DEVTOT=DEV*ones(HU*J,1);
for N=1:N
SUBDEV(N)=DEVTOT(N)/COUNT(N);
end
for N=1:N
for A=1:HU*J
if DISCHARGE(N,A)<MAXHYDRO
DISCHARGE(N,A)=DISCHARGE(N,A)+SUBDEV(N);
end
end
end
TOTDISCHARGE=DISCHARGE*ones(HU*J,1);
DISCHARGESEC=DISCHARGE/3600;
for N=1:N
for B=1:HU*J
PH(N,B)=0.113*DISCHARGESEC(N,B)^2+12.45*DISCHARGESEC(N,B)-7425.71;
end
end
for N=1:N
```

```
for B=1:HU*J
if PH(N,B)<0
PH(N,:)=0;
elseif PH(N,B)>125
PH(N,:)=0;
end
end
end
%CALCULATING TOTAL  HYDRO GENERATION IN EACH PERIOD  FOR ALL POPULATION
for L=1:N
for K=1:J
PHA(L,K)=(PH(L,HU*(K-1)+1:HU*K)*ones(HU,1));
end
end
for N=1:N
for J=1:J
PHALL(N,J)=PHA(N,J);
end
end
PHALL*ones(J,1);
[Y,d]=max(PHALL*ones(J,1));
PHALL=PHALL(d,:)
PHACTUAL=[440 411 397 392 366 385 494 474 528 605 661 587 608 605 629 662 639 612 617 765 822 810 755 627];
TIME=[1:24];
plot(TIME, PHALL, 'blue', TIME, PHACTUAL, 'red')
title('PSO AND ACTUAL HYDRO POWER') % title
ylabel('MW') % label for y axis
xlabel('Time (Hr)') % label for x axis
grid
legend('pso', 'actual')
```

```
BESTHYDROSCHEDULING=PH(d,:);

for J=1:24

for A=1:HU

X(J,A)= BESTHYDROSCHEDULING ((J-1)*(HU)+A);

end

end

BESTHYDROSCHEDULING=X

for A=1:N

for Q=1:J

PLA(A,Q)=PLOAD(Q);

end

end

for N=1

for J=1:24

PTA1(N,J)=(-(2*B12*PHALL(N,J)-1)+sqrt ((2*B12*PHALL(N,J)-1)^2-4*B11*(PLA(N,J)-
PHALL(N,J)+B22*PHALL(N,J)^2)))/(2*B11);

PTA2(N,J)=(-(2*B12*PHALL(N,J)-1)-sqrt ((2*B12*PHALL(N,J)-1)^2-4*B11*(PLA(N,J)-
PHALL(N,J)+B22*PHALL(N,J)^2)))/(2*B11);

if PTA1(N,J)>0&&PTA1(N,J)<280

PTA(N,J)=PTA1(N,J);

else if PTA2(N,J)>0&&PTA2(N,J)<280

PTA(N,J)=PTA2(N,J);

end

end

end

end

for N=1

for j=1:J

if PTA(N,j)>280

PTA(N,:)=0;

end

end
```

```
end

pt=PTA

ptactual=[63 56 56 56 56 58 65 65 65 65 65 129 124 120 118 122 124 126 126 132 129 119 94 89];

plot(TIME, pt, 'blue', TIME, ptactual, 'red')

title('PSO AND ACTUAL THERMAL POWER') % title

ylabel('MW') % label for y axis

xlabel('Time (Hr)') % label for x axis

grid

legend('pso', 'actual')

PLOSSES=PTA+PHALL-PLOAD

PLOSSESACT=[9.8 9.7 10.5 10.0     9.0 9.3 10.1 11.0 11.0 13.7 13.5 13.3 13.6 13.8 14.4 15.214.4
    12.7 13.3 19.6 23.4 22.119.8 14.5];

plot(TIME, PLOSSES, 'blue', TIME, PLOSSESACT, 'red')

title('PSO AND ACTUAL LOSSES') % title

ylabel('MW') % label for y axis

xlabel('Time (Hr)') % label for x axis

grid

legend('pso', 'actual')

actualcost=616000000;

startupcost=500;

for j=1:24

u=7;

mini=20;

maxi=37;

n=100;

itmax=10;

c1=2;

c2=4-c1;

wmax=.5;

wmin=0.2;

w=linspace(wmax,wmin,itmax); %linear variation of w
```

```
objf=inline('0.267678*(PG1^2+ PG2^2+ PG3^2+ PG4^2+ PG5^2+ PG6^2)+20.682*(PG1+ PG2+
PG3+ PG4+ PG5+
PG6)+92.313*6+0.000675*PS^2+0.783*PS+5.13','PG1','PG2','PG3','PG4','PG5','PG6','PS');

objf=vectorize(objf);

if ceil(pt(j)/mini)<u

h=ceil(pt(j)/mini);

else

h=u;

end

for d=ceil(pt(j)/maxi):h;

aaa=d;

q=(maxi-mini)/100;

for n=1:n

for d=1:d

r(n,d)=mini+rand(1,1)*q*4;

v(n,d)=q*rand(1,1);

end

for x=d+1:u;

r(n,x)=0;

v(n,x)=0;

end

end

r;

tot=r*ones(u,1);

dev=ones(n,1)*pt(j)-r*ones(u,1);

for n=1:n

for c=1:d

x(n,c)=r(n,c)*dev(n)/tot(n);

end

end

for u=d+1:u

x(:,u)=0;
```

```
end
r1=r+x;
for n=1:n
for d=1:d-1
if r1(n,d)>maxi
r1(n,d+1)=r1(n,d+1)+r1(n,d)-maxi;
r1(n,1:d)=maxi;
elseif r1(n,d)<0
r1(n,1:d)=maxi;
end
end
for n=1:n
for d=1:d
if r1(n,d)>maxi
r1(n,1:d)=maxi;
end
end
end
end
r=r1;
f=objf(r(:,1),r(:,2),r (:,3), r (:,4),r (:,5), r (:,6),r(:,7));
 [fgbest,igbest]=min(f);
gbest=r(igbest,:);
pbest=r; fpbest=f;
for it =1:itmax
v(1:n,1:d)=w(it)*v(1:n,1:d)+c1*rand*(pbest(1:n,1:d)-r(1:n,1:d))+c2*rand*(repmat(gbest(1:d),n,1)-
r(1:n,1:d));
r(1:n,1:d)=r(1:n,1:d)+v(1:n,1:d);
tot=r*ones(7,1);
dev=ones(n,1)*pt(j)-r*ones(7,1);
for n=1:n
for c=1:d
```

```
x(n,c)=r(n,c)*dev(n)/tot(n);
end
end
for e=d+1:7
x(:,e)=0;
end
r1=r+x;
for n=1:n
for d=1:d-1
if r1(n,d)>maxi
r1(n,d+1)=r1(n,d+1)+r1(n,d)-maxi;
r1(n,1:d)=maxi;
elseif r1(n,d)<0
r1(n,1:d)=maxi;
end
end
r(1:n,d+1:u)=0;
f=objf(r(:,1),r(:,2),r (:,3), r (:,4),r (:,5), r (:,6),r(:,7));
%Find gbest and pbest
[minf,iminf]=min(f);
if minf<= fgbest
fgbest=minf;
gbest=r(iminf,:);
end
end
end
[gbest,fgbest];
aaa;
TG(aaa,(j-1)*(u)+1:(u)*j)=gbest;
TC(aaa,j)=fgbest;
end
```

```
end

for s=1:6

for j=1:24

uniton(s,j)=TC(s,j)/TC(s,j)*s;

end

end

for j=1:24

aaa(j)= ceil(pt(j)/maxi);

if ceil(pt(j)/mini)<u

h(j)=ceil(pt(j)/mini);

else

h(j)=u;

end

end

for h1=aaa(1):h(1)  for h2=aaa(2):h(2)  for h3=aaa(3):h(3)  for h4=aaa(4):h(4)

for h5=aaa(5):h(5) for h6=aaa(6):h(6) for h7=aaa(7):h(7) for h8=aaa(8):h(8)

for h9=aaa(9):h(9) for h10=aaa(10):h(10) for h11=aaa(11):h(11) for h12=aaa(12):h(12)

for h13=aaa(13)+1:h(13) for h14=aaa(14)+1:h(14) for h15=aaa(15)+1:h(15)  for h16=aaa(16)+1:h(16)

for h17=aaa(17)+1:h(17)  for h18=aaa(18)+1:h(18)  for h19=aaa(19)+1:h(19) for
h20=aaa(20)+1:h(20)

for h21=aaa(21)+1:h(21) for h22=aaa(22)+1:h(22) for h23=aaa(23)+1:h(23) for h24=aaa(24)+1:h(24)

cost=TC(h1,1)+TC(h2,2)+TC(h3,3)+TC(h4,4)+TC(h5,5)+TC(h6,6)+TC(h7,7)+TC(h8,8)+TC(h9,9)+
TC(h10,10)+TC(h11,11)+TC(h12,12)+TC(h13,13)+TC(h14,14)+TC(h15,15)+TC(h16,16)+TC(h17,1
7)+TC(h18,18)+TC(h19,19)+TC(h20,20)+TC(h21,21)+TC(h22,22)+TC(h23,23)+TC(h24,24);

uc1=1;

if uniton(h2,2)-uniton(h1,1)>0

uc2=(uniton(h2,2)-uniton(h1,1))*startupcost;

else

uc2=0;

end

if uniton(h3,3)-uniton(h2,2)>0

uc3=(uniton(h3,3)-uniton(h2,2))*startupcost;

else
```

```
uc3=0;
end
if uniton(h4,4)-uniton(h3,3)>0
uc4=(uniton(h4,4)-uniton(h3,3))*startupcost;
else
uc4=0;
end
if uniton(h5,5)-uniton(h4,4)>0
uc5=(uniton(h5,5)-uniton(h4,4))*startupcost;
else
uc5=0;
end
if uniton(h6,6)-uniton(h5,5)>0
uc6=(uniton(h6,6)-uniton(h5,5))*startupcost;
else
uc6=0;
end
if uniton(h7,7)-uniton(h6,6)>0
uc7=(uniton(h7,7)-uniton(h6,6))*startupcost;
else
uc7=0;
end
if uniton(h8,8)-uniton(h7,7)>0
uc8=(uniton(h8,8)-uniton(h7,7))*startupcost;
else
uc8=0;
end
if uniton(h9,9)-uniton(h8,8)>0
uc9=(uniton(h9,9)-uniton(h8,8))*startupcost;
else
uc9=0;
```

```
end
if uniton(h10,10)-uniton(h9,9)>0
uc10=(uniton(h10,10)-uniton(h9,9))*startupcost;
else
uc10=0;
end
if uniton(h11,11)-uniton(h10,10)>0
uc11=(uniton(h11,11)-uniton(h10,10))*startupcost;
else
uc11=0;
end
if uniton(h12,12)-uniton(h11,11)>0
uc12=(uniton(h12,12)-uniton(h11,11))*startupcost;
else
uc12=0;
end
if uniton(h13,13)-uniton(h12,12)>0
uc13=(uniton(h13,13)-uniton(h12,12))*startupcost;
else
uc13=0;
end
if uniton(h14,14)-uniton(h13,13)>0
uc14=(uniton(h14,14)-uniton(h13,13))*startupcost;
else
uc14=0;
end
if uniton(h15,15)-uniton(h14,14)>0
uc15=(uniton(h15,15)-uniton(h14,14))*startupcost;
else
uc15=0;
end
```

```
if uniton(h16,16)-uniton(h15,15)>0
uc16=(uniton(h16,16)-uniton(h15,15))*startupcost;
else
uc16=0;
end
if uniton(h17,17)-uniton(h16,16)>0
uc17=(uniton(h17,17)-uniton(h16,16))*startupcost;
else
uc17=0;
end
if uniton(h18,18)-uniton(h17,17)>0
uc18=(uniton(h18,18)-uniton(h17,17))*startupcost;
else
uc18=0;
end
if uniton(h19,19)-uniton(h18,18)>0
uc19=(uniton(h19,19)-uniton(h18,18))*startupcost;
else
uc19=0;
end
if uniton(h20,20)-uniton(h19,19)>0
uc20=(uniton(h20,20)-uniton(h19,19))*startupcost;
else
uc20=0;
end
 if uniton(h21,21)-uniton(h20,20)>0
uc21=(uniton(h21,21)-uniton(h20,20))*startupcost;
else
uc21=0;
end
if uniton(h22,22)-uniton(h21,21)>0
```

```
uc22=(uniton(h22,22)-uniton(h21,21))*startupcost;
else
uc22=0;
end
 if uniton(h23,23)-uniton(h22,22)>0
uc23=(uniton(h23,23)-uniton(h22,22))*startupcost;
else
uc23=0;
end
if uniton(h24,24)-uniton(h23,23)>0
uc24=(uniton(h24,24)-uniton(h23,23))*startupcost;
else
uc24=0;
end
uc=uc1+uc2+uc3+uc4+uc5+uc6+uc7+uc8+uc9+uc10+uc11+uc12+uc13+uc14+uc15+uc16+uc17+uc18+uc19+uc20+uc21+uc22+uc23+uc24;
costwithuc=cost+uc;
if costwithuc<actualcost
actualcost=costwithuc
bestcommetment=[h1,h2,h3,h4,h5,h6,h7,h8,h9,h10,h11,h12,h13,h14,h15,h16,h17,h18,h19,h20,h21,h22,h23,h24]
end
end
end
end
end
end
end
end
end
end
end
```

```
end
end
end
end
end
end
end
end
end
end
end
end
end
end
>> for j=1:24
for a=1:6
thermalpower(j,a)=TG(bestcommetment(j),(j-1)*7+a);
end
end
thermalpower
```

Appendix: G: line parameters

NO.	LINE	L	R	X	TO R	TO X	TO R P.U	TO X P.U	Z LINE P.U	Z EQU. P.U
1	ATBBTA SHENDI L2	140	0.067	0.302	9.38	42.28	0.0194	0.0874	0.0194+0.0874i	0.0097+0.0437i
2	ATBRA SHENDI L1	140	0.067	0.302	9.38	42.28	0.0194	0.0874	0.0194+0.0874i	
3	FRZ GARRI L1	5	0.067	0.302	0.335	1.51	0.0007	0.0032	0.0007+0.0032i	0.00035+0.0016i
4	FRZ GARRI L2	5	0.067	0.302	0.335	1.51	0.0007	0.0032	0.0007+0.0032i	
5	FRZ KAB L1	38	0.067	0.302	2.546	11.476	0.0053	0.0238	0.0053+0.0238i	0.00265+0.0119i
6	FRZ KAB L2	38	0.067	0.302	2.546	11.476	0.0053	0.0238	0.0053+0.0238i	
7	GAM JA L1	39.88	0.067	0.302	2.67196	12.04376	0.0056	0.0249	0.0056+0.0249i	0.0028+0.01245i
8	GAM JA L2	39.88	0.067	0.302	2.67196	12.04376	0.0056	0.0249	0.0056+0.0249i	
9	GARRI ID BABIKR 1	60	0.067	0.302	4.02	18.12	0.0084	0.0375	0.0084+0.0375i	0.0042+0.01875i
10	GARRI ID BABIKR L2	60	0.067	0.302	4.02	18.12	0.0084	0.0375	0.0084+0.0375i	
11	GIAD KLX L1	43	0.076	0.403	3.268	17.329	0.0068	0.0359	0.0068+0.0359i	0.0034+0.01795i
12	GIAD KLX L2	43	0.076	0.403	3.268	17.329	0.0068	0.0359	0.0068+0.0359i	
13	JA GAD L1	36	0.067	0.302	2.412	10.872	0.005	0.0225	0.005+0.0225i	0.0025+0.01125i
14	JA GAD L2	36	0.067	0.302	2.412	10.872	0.005	0.0225	0.005+0.0225i	
15	JA MASHKOOR L1	147.7	0.067	0.302	9.8959	44.6054	0.0205	0.0922	0.0205+0.0922i	0.01025+0.0461i
16	JA MASHKOR L2	147.7	0.067	0.302	9.8959	44.6054	0.0205	0.0922	0.0205+0.0922i	
17	KAB KLX L1	30	0.067	0.302	2.01	9.06	0.0042	0.0188	0.0042+0.0188i	0.0021+0.0094i
18	KAB KLX L2	30	0.067	0.302	2.01	9.06	0.0042	0.0188	0.0042+0.0188i	
19	KLX ID BABIKR L1	14	0.067	0.302	0.938	4.228	0.002	0.0088	0.002+0.0088i	0.001+0.0044i
20	KLX ID BABKR L2	14	0.067	0.302	0.938	4.228	0.002	0.0088	0.002+0.0088i	
21	MAR GAM L1	39.88	0.067	0.302	2.67196	12.04376	0.0056	0.0249	0.0056+0.0249i	0.0028+0.01245i
22	MAR GAM L2	39.88	0.067	0.302	2.67196	12.04376	0.0056	0.0249	0.0056+0.0249i	
23	MARINGAN NHAS L2	55	0.076	0.403	4.18	22.165	0.0087	0.0458	0.0087+0.0458i	0.00435+0.0229i
24	MARINJAN NHAS L1	55	0.076	0.403	4.18	22.165	0.0087	0.0458	0.0087+0.0458i	
25	MASHKOR RABAK L1	107.2	0.067	0.302	7.1824	32.3744	0.0149	0.0669	0.0149+0.0669i	0.00745+0.03345i
26	MASHKOR RABAK L2	107.2	0.067	0.302	7.1824	32.3744	0.0149	0.0669	0.0149+0.0669i	
27	MRK KAB L1	36.8	0.028	0.276	1.0304	10.1568	0.0022	0.021	0.0022+0.021i	0.0011+0.0105i
29	MWP - ATBRA L1	236.7	0.028	0.276	6.6276	65.3292	0.0137	0.135	0.0137+0.135i	0.00685+0.0675i
30	MWP - MRK L1	345	0.028	0.276	9.66	95.22	0.02	0.1968	0.02+0.1968i	0.01+0.0984i
28	MWP -MRK L2	345	0.028	0.276	9.66	95.22	0.02	0.1968	0.02+0.1968i	
31	NHAS GIAD L1	86	0.076	0.403	6.536	34.658	0.0136	0.0717	0.0136+0.0717i	0.0068+0.03585i
32	NHAS GIAD L2	86	0.076	0.403	6.536	34.658	0.0136	0.0717	0.0136+0.0717i	
33	RABAK RANK L1	163.3	0.067	0.302	10.9411	49.3166	0.0227	0.1019	0.0227+0.1019i	0.01135+0.05095i
34	RABAK RANK L2	163.3	0.067	0.302	10.9411	49.3166	0.0227	0.1019	0.0227+0.1019i	
35	RANK ROSERS L1	163.3	0.067	0.302	10.9411	49.3166	0.0227	0.1019	0.0227+0.1019i	0.01135+0.05095i
36	RANK ROSERS L2	163.3	0.067	0.302	10.9411	49.3166	0.0227	0.1019	0.0227+0.1019i	
37	ROSERS SINJA L2	178	0.076	0.403	13.528	71.734	0.028	0.1483	0.028+0.1483i	0.014+0.07415i
38	ROSSERS SINJA L1	178	0.076	0.403	13.528	71.734	0.028	0.1483	0.028+0.1483i	
39	SHENDI FRZ L1	115	0.067	0.302	7.705	34.73	0.016	0.0718	0.016+0.0718i	0.008+0.0359i
40	SHENDI FRZ L2	115	0.067	0.302	7.705	34.73	0.016	0.0718	0.016+0.0718i	
41	SINJA SINNAR L2	50	0.076	0.403	3.8	20.15	0.0079	0.0417	0.0079+0.0417i	0.00395+0.02085i
42	SINJA SINNER L1	50	0.076	0.403	3.8	20.15	0.0079	0.0417	0.0079+0.0417i	
43	SINNAR MARINGAN L1	84	0.076	0.403	6.384	33.852	0.0132	0.07	0.0132+0.07i	0.0066+0.035i
44	SINNAR MARINGAN L2	84	0.076	0.403	6.384	33.852	0.0132	0.07	0.0132+0.07i	

Appendix: H: Implementation of current distribution factor sign (neplan):

No.	Transmission line	Current flow polarity with respect to transmission line nomination when both power stations are on	Current flow polarity with respect to transmission line nomination when network feed from GARRI	Current distribution factor sign when network feed from GARRI	Current flow polarity with respect to transmission line nomination when network feed from MERWEE	Current distributio n factor sign when network feed from MERWEE
1	TL ATBRA SHENDI	P	N	-	P	+
2	TL FRZ GARRI	P	N	-	N	-
3	TL FRZ KAB	N	P	-	N	+
4	TL GAM JA	P	N	-	P	+
5	TL GARRI ID BABIKR	P	P	+	P	+
6	TL GIAD KLX	N	N	+	N	+
7	TL JA GAD	P	N	-	P	+
8	TL JA MASHKOOR	P	P	+	P	+
9	TL KAB ID BABIKR	P	P	+	P	+
10	TL KLX ID BABIKR	N	N	+	N	+
11	TL MAR GAM	P	P	+	P	+
12	TL MARINGAN NHAS	N	N	+	N	+
13	TL MASHKOR RABAK	P	P	+	P	+
14	TL MRK KAB	P	N	-	P	+
15	TL MWP ATBRA	p	P	+	P	+
16	TL MWP MRK	p	N	-	P	+
17	TL NHAS GIAD	N	N	+	N	+
18	TL RABAK RANK	P	P	+	P	+
19	TL RANK ROSERS	P	P	+	P	+
20	TL ROSERS SINJA	P	P	+	P	+
21	TL SHENDI FRZ	P	N	-	P	+
22	TL SINJA SINNAR	N	N	+	N	+
23	TL SINNAR MARINGAN	N	N	+	N	+

Appendix: I: Transmission lines loss coefficients calculation code

```
>> IL1=282*exp(j*174.34*pi/180);
IL2=912*exp(j*179.67*pi/180);
IL3=593*exp(j*-0.33*pi/180);
IL4=97*exp(j*173.86*pi/180);
IL5=550*exp(j*0*pi/180);
IL6=538*exp(j*174.72*pi/180);
IL7=227*exp(j*174.13*pi/180);
IL8=130*exp(j*-5.87*pi/180);
IL9=196*exp(j*-1.94*pi/180);
IL10=746*exp(j*176.9*pi/180);
IL11=86*exp(j*-5.9*pi/180);
IL12=183*exp(j*171.6*pi/180);
IL13=122*exp(j*-7.24*pi/180);
IL14=175*exp(j*175.28*pi/180);
IL15=18*exp(j*-5.18*pi/180);
IL16=48*exp(j*174.82*pi/180);
IL17=269*exp(j*172.54*pi/180);
IL18=43*exp(j*-8.17*pi/180);
IL19=35*exp(j*-8.67*pi/180);
IL20=20*exp(j*-9.09*pi/180);
IL21=306*exp(j*177.16*pi/180);
IL22=49*exp(j*170.59*pi/180);
IL23=99*exp(j*170.82*pi/180);
IT1=1462*exp(j*180*pi/180);
>> IL12=102*exp(j*-5.06*pi/180);
IL22=114*exp(j*-6.73*pi/180);
IL32=49*exp(j*173.27 *pi/180);
IL42=223*exp(j*-7.71*pi/180);
IL52=114*exp(j*-6.77*pi/180);
IL62=218*exp(j*171.44*pi/180);
IL72=84*exp(j*-8.9*pi/180);
IL82=139*exp(j*-8.35*pi/180);
IL92=310*exp(j*-6.59*pi/180);
IL102=425*exp(j*172.32*pi/180);
IL112=407*exp(j*-6.55*pi/180);
IL122=173*exp(j*168.44*pi/180);
IL132=131*exp(j*-9.82*pi/180);
IL142=158*exp(j*-4.07*pi/180);
IL152=187*exp(j*0*pi/180);
IL162=426*exp(j*0*pi/180);
IL172=260*exp(j*169.34*pi/180);
IL182=53*exp(j*-10.82*pi/180);
IL192=45*exp(j*-11.44*pi/180);
IL202=29*exp(j*-11.96*pi/180);
IL212=78*exp(j*-6.08*pi/180);
IL222=39*exp(j*167.55*pi/180);
IL232=89*exp(j*167.74*pi/180);
```

```
IT2=643*exp(j*-180*pi/180);
>> KVBASE=220000;
>> MVABASE=100000000;
>> IBASE=MVABASE/KVBASE;
>> IBASE=MVABASE/KVBASE;
>> IL1PU=IL1/IBASE;
>> IL2PU=IL2/IBASE;
>> IL3PU=IL3/IBASE;
>> IL4PU=IL4/IBASE;
>> IL5PU=IL5/IBASE;
>> IL6PU=IL6/IBASE;
>> IL7PU=IL7/IBASE;
>> IL8PU=IL8/IBASE;
>> IL9PU=IL9/IBASE;
>> IL10PU=IL10/IBASE;
>> IL11PU=IL11/IBASE;
>> IL12PU=IL12/IBASE;
>> IL13PU=IL13/IBASE;
>> IL17PU=IL17/IBASE;
>> IL18PU=IL18/IBASE;
>> IL19PU=IL19/IBASE;
>> IL20PU=IL20/IBASE;
>> IL21PU=IL21/IBASE;
>> IL22PU=IL22/IBASE;
>> IL23PU=IL23/IBASE;
>> IL16PU=IL16/MVABASE*500000;
>> IL15PU=IL15/MVABASE*500000;
>> IL14PU=IL14/MVABASE*500000;
>> IL12PU=IL12/IBASE;
>> IL22PU=IL22/IBASE;
>> IL32PU=IL32/IBASE;
>> IL42PU=IL42/IBASE;
>> IL52PU=IL52/IBASE;
>> IL62PU=IL62/IBASE;
>> IL72PU=IL72/IBASE;
>> IL82PU=IL82/IBASE;
>> IL92PU=IL92/IBASE;
>> IL102PU=IL102/IBASE;
>> IL112PU=IL112/IBASE;
>> IL122PU=IL122/IBASE;
>> IL132PU=IL132/IBASE;
>> IL172PU=IL172/IBASE;
>> IL182PU=IL182/IBASE;
>> IL192PU=IL192/IBASE;
>> IL202PU=IL202/IBASE;
>> IL212PU=IL212/IBASE;
>> IL222PU=IL222/IBASE;
>> IL232PU=IL232/IBASE;
>> IL162PU=IL162/MVABASE*500000;
>> IL152PU=IL152/MVABASE*500000;
>> IL142PU=IL142/MVABASE*500000;
```

```
>> IL142PU=IL142/MVABASE*500000;
>> IT1PU=IT1/MVABASE*500000;
>> IT2PU=IT2/IBASE;
>> RL1=0.0097;
RL2=0.00035;
RL3=0.00265;
RL4=0.0028;
RL5=0.0042;
RL6=0.0034;
RL7=0.0025;
RL8=0.01025;
RL9=0.0021;
RL10=0.001;
RL11=0.0028;
RL12=0.00435;
RL13=0.00745;
RL14=0.0011*220000^2/500000^2;
RL15=0.00685*220000^2/500000^2;
RL16=0.01*220000^2/500000^2;
RL17=0.0068;
RL18=0.01135;
RL19=0.01135;
RL20=0.014;
RL21=0.008;
RL22=0.00935;
RL23=0.0066;
>> N1= -abs(IL1PU/IT1PU);
>> N2=- abs(IL2PU/IT1PU);
>> N3= -abs(IL3PU/IT1PU);
>> N4= -abs(IL4PU/IT1PU);
>> N5= abs(IL5PU/IT1PU);
>> N6= abs(IL6PU/IT1PU);
>> N7= -abs(IL7PU/IT1PU);
>> N8= abs(IL8PU/IT1PU);
>> N9= abs(IL9PU/IT1PU);
>> N10= abs(IL10PU/IT1PU);
>> N11= abs(IL11PU/IT1PU);
>> N12= abs(IL12PU/IT1PU);
>> N13= abs(IL13PU/IT1PU);
>> N14= -abs(IL14PU/IT1PU);
>> N15= abs(IL15PU/IT1PU);
>> N16= -abs(IL16PU/IT1PU);
>> N17= abs(IL17PU/IT1PU);
>> N18= abs(IL18PU/IT1PU);
>> N19= abs(IL19PU/IT1PU);
>> N20= abs(IL20PU/IT1PU);
>> N21= -abs(IL21PU/IT1PU);
>> N22= abs(IL22PU/IT1PU);
>> N23= abs(IL23PU/IT1PU);
N12= abs(IL12PU/IT1PU);
N22= -abs(IL22PU/IT1PU);
```

```
N32= abs(IL32PU/IT1PU);
N42= abs(IL42PU/IT1PU);
N52= abs(IL52PU/IT1PU);
N62= abs(IL62PU/IT1PU);
N72= abs(IL72PU/IT1PU);
N82= abs(IL82PU/IT1PU);
N92= abs(IL92PU/IT1PU);
N102= abs(IL102PU/IT1PU);
N112= abs(IL112PU/IT1PU);
N122= abs(IL122PU/IT1PU);
N132= abs(IL132PU/IT1PU);
N142= abs(IL142PU/IT1PU);
N152= abs(IL152PU/IT1PU);
N162= abs(IL162PU/IT1PU);
N172= abs(IL172PU/IT1PU);
N182= abs(IL182PU/IT1PU);
N192= abs(IL192PU/IT1PU);
N202= abs(IL202PU/IT1PU);
N212= abs(IL212PU/IT1PU);
N222= abs(IL222PU/IT1PU);
N232= abs(IL232PU/IT1PU);
PF1=0.939;
PF2=0.73;
V1PU=1;
V2PU=1;
SIGMA2=3.14;
SIGMA1=-5.57/180*3.14;
b11=(RL1*N1^2+RL2*N2^2+RL3*N3^2+RL4*N4^2+RL5*N5^2+RL6*N6^2+RL7*N7^2+RL8*N8^2+
RL9*N9^2+RL10*N10^2+RL11*N11^2+RL12*N12^2+RL13*N13^2+RL14*N14^2+RL15*N15^2+RL
16*N16^2+RL17*N17^2+RL18*N18^2+RL19*N19^2+RL20*N20^2+RL21*N21^2+RL22*N22^2+RL2
3*N23^2)/(PF1*PF2);
b22=(RL1*N12^2+RL2*N22^2+RL3*N32^2+RL4*N42^2+RL5*N52^2+RL6*N62^2+RL7*N72^2+RL8
*N82^2+RL9*N92^2+RL10*N102^2+RL11*N112^2+RL12*N122^2+RL13*N132^2+RL14*N142^2+R
L15*N152^2+RL16*N162^2+RL17*N172^2+RL18*N182^2+RL19*N192^2+RL20*N202^2+RL21*N2
12^2+RL22*N222^2+RL23*N232^2)/(PF1*PF2);
b12=(RL1*N12*N1+RL2*N22*N2+RL3*N32*N3+RL4*N42*N4+RL5*N52*N5+RL6*N62*N6+RL7*
N72*N7+RL8*N82*N8+RL9*N92*N9+RL10*N102*N10+RL11*N112*N11+RL12*N122*N12+RL13*
N132*N13+RL14*N142*N14+RL15*N152*N15+RL16*N162*N16+RL17*N172*N17+RL18*N182*N1
8+RL19*N192*N19+RL20*N202*N20+RL21*N212*N21+RL22*N222*N22+RL23*N232*N23)*cos(SI
GMA2-SIGMA1)/(PF1*PF2);
b11=0.00091414
b12=-0.00017089
b22=0.000596
```