Optimal Generation Scheduling of Hydro System Using Differential Evolution Algorithm

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***Abstract*- Hydro generation scheduling is a nonlinear programming problem. This paper describes the hydro generation scheduling problem constraints. The optimal hydro scheduling problem is formulated as a large scale linear programming algorithm and is solved using a commercially available linear programming package. The selected objective function requires minimization of demand and generation of a hydro system. This paper also proposes Differential Evolution (DE) algorithm to solve the nonlinear optimization problem for hydro generation scheduling. The feasibility of the proposed method is demonstrated for the daily generation scheduling of a hydro system.**

Keywords- Genetic Algorithm , Daily optimal scheduling

I. INTRODUCTION

The efficient utilization of hydro resources plays an important role in the economic operation of a power system where the hydroelectric plants constitute a significant portion of installed capacity. Determination of daily optimal hydroelectric generation scheduling is a crucial task in water resource management.

Optimal hydropower scheduling is a nonlinear programming problem. Non-linearity is due to the generating characteristic of hydro plant, whose outputs are generally a non linear function of water discharge and net hydraulic head[1].Linear programming , nonlinear programming, dynamic programming and heuristic algorithm et al. are used to solve the hydro scheduling problem[2].The daily hydro scheduling process commences with the application of the mid-term operating policy to determine the amount of water to be released from storages to meet the daily forecasted energy requirement. This allocation of energy is performed using a set of rules to transfer mid-term planning into short-term scheduling constraints taking into account inflows and load forecast. The result of this daily energy allocation process is a set of daily water releases for each unit. Many methods have been developed to solve optimal scheduling problem in the past decades. The major method includes the variation calculus [3] ,function analysis [4] , dynamic programming[5], nonlinear programming [6], Evolutionary algorithm[7]. But these methods have drawbacks, such as dimensionality difficulty, larger memory requirement, or inability to handle nonlinear characteristics, premature phenomena and trap into local optimum, taking much computational time.

The field of optimization has been the focus of much attention in recent years. Optimization techniques and concepts are not limited to any particular discipline and are playing an increasingly important role in the solution and modeling of engineering, economic, design and scientific systems. Optimization is viewed as a decision problem that involves finding the best values of the decision variables over all possibilities. The best values would give the smallest objective function value for a minimization problem or the largest objective function value for a maximization problem. In terms of real world applications, the objective function is often a representation of some physically significant measure such as profit, loss, utility, risk or error. Hence optimizing the system or design to make it as effective or functional as possible is an important part of the overall application.[8].

In recent years, a new optimization method known as Differential Evolution (DE) algorithm has gradually become more popular and has been used in many practical cases , mainly because it has demonstrated good robust , convergence properties and is principally easy to understand.

II. HYDRO SYSTEM MODEL

Hydro plants are multipurpose. In such cases , it is necessary to meet certain obligations other then power generation. These may include a maximum fore-bay elevation, not to exceed because of danger of flooding, ana a 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 the same stream or on different streams.

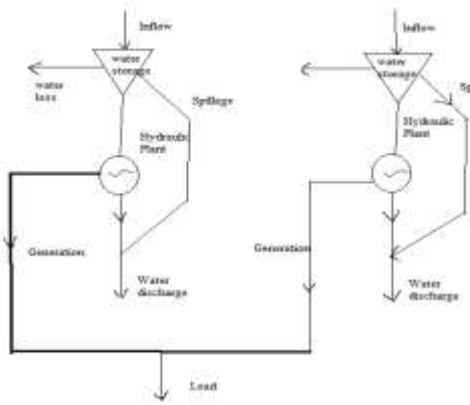

Fig. 1 Hydro plants on different streams

The hydro plants are located on the different streams and are independent of each other as shown in Fig. 1. The cyclic nature of water flows and load demand, as well as the validity of model assumptions, suggest splitting the problem of optimal generation scheduling into long and short periods.

A number of proposed models can be found in the literature. Hawary and Christensen, due to diversity of the plant types and their characteristics.

III. OPTIMIZATION OF HYDRO GENERATION SCHEDULING PROBLEM STATEMENT

The Hydro generation scheduling problem is non-linear programming problem.

A. Notation

Let us define some notations:

$P_i(t)$	Power generation of i^{th} plant at time interval t
$P_D(t)$	Load demand during sub-interval
$P_L(t)$	Transmission loss during sub-interval
P_i^{min}	Lower limit of i^{th} generator output
P_i^{max}	Upper limit of i^{th} generator output
$Q_j(t)$	Rate of water discharge (m^3/sec)
V	Reservoir volume
H	Net water head
x_j,y_j and z_j	Discharge coefficients
t	Time index
N	Number of hydro plants
η	Function of Q and H

B. Objective Function

In a large interconnected power system various sources of electric energy e.g., thermal, hydro, nuclear etc. are interconnected and attempt is made to optimize the operation of the system in terms of cost of generation to meet a certain load. The efficient scheduling of available energy resources for satisfying load demand has became an important task in modern power systems. The generation scheduling problem consists of determining the optimal operation strategy for the next scheduling period, subject to a variety of constraints. The objective function is to minimize the deviation between hourly load demand and hydro system total power generation throughout the whole day dispatching time horizon, while satisfying all kinds of physical and operational constraints. The equality and inequality constraints is shown in equation number

$$\sum_{i=1}^{N} P_i(t) = P_D(t) + P_L(t) \quad (1)$$

Subjected to following constraints

- Hydro power plant limits

$P^{min}_i \leq P_i(t) \leq P_i^{max}$ (2)

- Hydro discharge limits

$Q_i^{min} \leq Q_i(t) \leq Q^{max}_i$ (3)

- Reservoir storage volume limits

$V_i^{min} \leq V_i(t) \leq V_i^{max}$ (4)

- Active power generated

$P = 0.0085QH\,\eta(q,h)$ (5)

- Water dynamic balance equation

$Q_j(t)=x_jP^2_{j+N(t)}+y_jP_{j+N(t)}+Z_j$ m^3/h (6)

- Initial and terminal reservoir storage volumes

$V_i^0 = V_i^{begin}$, $V^T_i = V_i^{end}$ i= 1,2,3… N. (7)

IV. DIFFERENTIAL EVOLUTION ALGORITHM

A global optimization technique known as genetic algorithm has emerged as a candidate due to its flexibility and efficiency for many optimization applications. It is a stochastic searching algorithm. Problems which involve global optimization over continuous spaces are ubiquitous throughout the scientific community. In general, the task is to optimize certain properties of a system by pertinently choosing the system parameters. For convenience, a system's parameters are usually represented as a vector. The standard approach to an optimization problem begins by designing an objective function that can model the problem's objectives while incorporating any constraints. Especially in the circuit design community, methods are in use which do not need an objective function but operate with so-called regions of acceptability: Brayton *et al*. (1981), Lueder (1990), Storn (1995). Although these methods can make formulating a problem simpler, they are usually inferior to techniques which make use of an objective function. Consequently, we will only concern ourselves with optimization methods that use an objective function. In most cases, the objective function defines the optimization problem as a minimization task. To this end, the following investigation is further restricted to minimization problems.

Differential evolution (DE), invented by Price and stron in 1995, is simple yet powerful heuristic method for solving nonlinear, non-differentiable and multi-modal optimization problems. The DE algorithm has gradually become more popular and has been use in many practical cases, mainly because it has demonstrated good convergence properties and is principally easy to understand.[10]

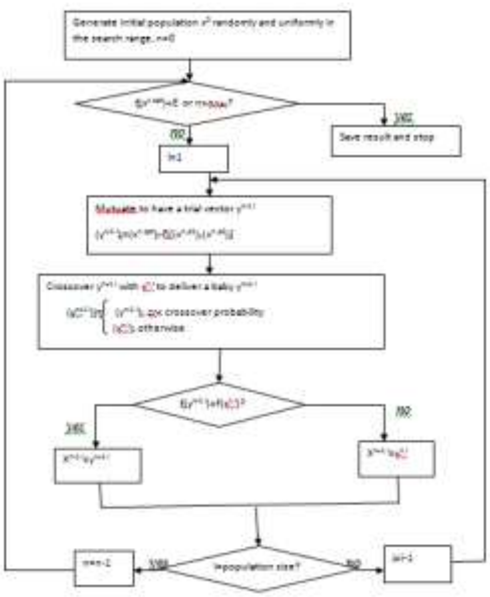

Fig 2 Flow chart of Differential Evolution Algorithm

1. *Mutation*

For target vector $X_{i,j}$(i= 1,2,…,NP), a mutant vector $V_{i,G+1}$ is generated according to

$V_{i,G+1}=X_{r1.G}+F.(X_{r2,G}-X_{r3.G})$, r1 ≠ r2 ≠ r3 ≠ i (8)

With randomly chosen integer indexes r1 , r2, r3 ϵ {1,2,…,NP}. F is called mutation factor is between [0,1] which controls the amplification of the differential variation ($X_{r2,G}-X_{r3,G}$).

2. *Crossover*

In order to increase the diversity of the perturbed parameter vectors, crossover is introduced. The target vector is mixed with the mutated vector, using the following scheme, to yield the trial vector $U_{i,G+1}=(u_{1i,G+1},...u_{Di,G+1})$, that is

$$U_{ji.G+1} = \begin{Bmatrix} V_{ji.G+1} & \text{if rand } \le CR \text{ or } j=rnb(i) \\ X_{j,i.G} & \text{otherwise} \end{Bmatrix} \quad (9)$$

j= 1,2,…,D

where rand(j) is the j^{th} evolution of a uniform random number generator between [0,1]. CR is the crossover rate constant.

3. *Selection*

To decide whether or not it should become a member of the next generation G+1, the trial vector $U_{i,G+1}$ is compared to target vector $X_{i,G}$ using greedy criterion. Assume that the objective function is to be minimized according to the following rule:

$$X_{i.G+1} = \begin{Bmatrix} U_{i.G+1} & \text{if } f(U_{i.G+1}) \le f(X_{i.G}) \\ X_{i.G} & \text{otherwise} \end{Bmatrix} \quad (10)$$

That is if vector $U_{i,G+1}$ yields a better evaluation function value than $X_{i,G}$, then $X_{i,G+1}$ is a set to $U_{i,G+1}$; otherwise the old value $X_{i,G}$ retained.

Fig 2 shows the flow chart of differential evolution algorithm. The steps of mutation, crossover & selection are follows in a sequence. For initially generation output of generator are selected randomly in the permissible limit as mention in equation number (2).

For random number generation initially

$$P_i^j = P_i^{\min} + rand()(P_i^{\max} - P_i^{\min}) \quad (11)$$

Using mutation operator shown in equation (7) mutation for each population are defined.

Crossover between the target vector and trial vector [11] as shown in equation (8) are completed. The CR operator is selected randomly between [0,1]. CR operator is used to compare the trial and target vector [12].

In this case the each trial vector $U_{i,G+1}$ is compared with that of its parent target vector $P_{i,j}$. If the water discharge Q of the target vector $P_{i,j}$, is lower then the trial, vector the target vector is allowed to advance to the next generation. Otherwise, a trial vector replaces the target vector in the next generation as shown in equation number (10).

The flow chart of each steps of differential evolution algorithm is shown in Fig 2.

V. OPTIMAL SCHEDULING OF HYDRO

Hourly water discharge of a plant discharge for each plant shown in Fig 3. Optimal scheduling of 4 plants of Fig 4 & Fig 5 are using DE operator of equation from (8) to (11). The daily load curve schedule of the plants are illustrated into DE to form optimal scheduling so that the water discharge will in comfortable rage to maintain minimum difference between demand and generation. The input output characteristics of hydro plant Shown in Fig 5. The Hourly Discharge of Hydro Plant as shown in Fig 3 .Using Differential evolution Algorithm the optimal scheduling of Fig 3 has been done.

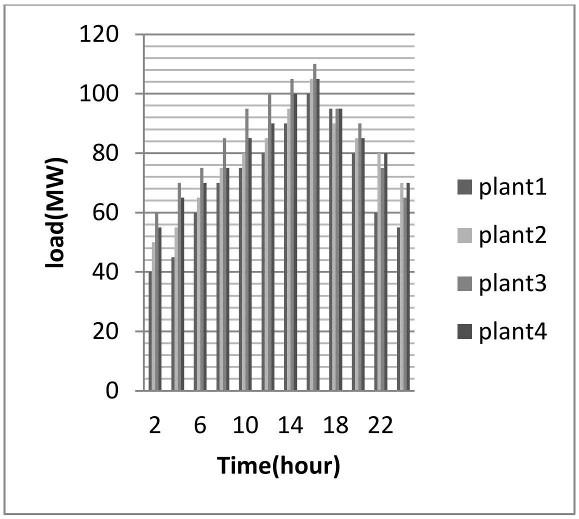

Fig 3. Hourly discharge of Hydro Plant

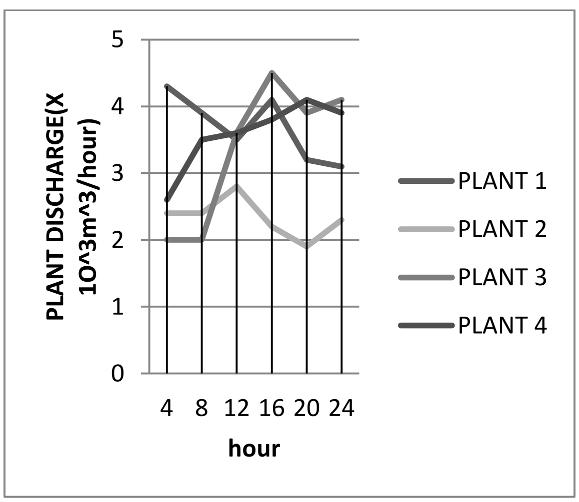

Fig 4. Hourly hydro plant Discharge

When the demand is high, the water discharge is also high i.e power generation is directly proportional to the power demand. Scheduling of the hydro power generation is to maintain the equality between the power generation and the power demand.

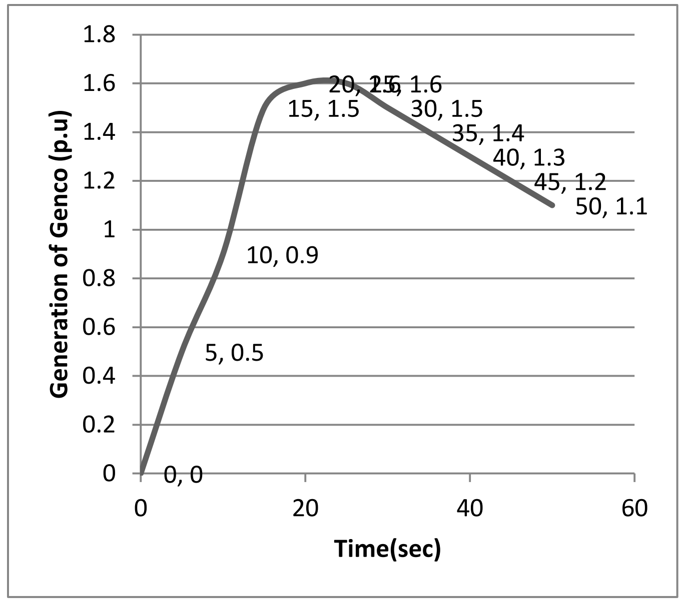

Fig 5 Characteristics of GENCOs of a hydro plant

VI. Results After DE Operation

The result of optimal scheduling of hydro plant using DE population size of 50. Mutation factor F=0.48, cross over rate, CR=0.5. 50 iteration is taking for randomly generation of values of F and CR. Each plants maximum and minimum limits are shown below

40 MW $\leq$ Plant1 $\leq$ 100 MW

50 MW $\leq$ Plant2 $\leq$ 105 MW

60 MW $\leq$ Plant3 $\leq$ 110 MW

55 MW $\leq$ Plant4 $\leq$ 105 MW.

The peak demand for each plants are shown below

$P_{D,PLANT1} = 100$ MW

$P_{D,PLANT2} = 105$ MW

$P_{D,PLANT3} = 110$ MW

$P_{D,PLANT4} = 105$ MW

Above formulation is done considering no loss i.e $P_L = 0$.

Time duration (hour)	Plant1 (MW)	Plant2 (MW)	Plant3 (MW)	Plant4 (MW)
0-1	40.10	48.87	61.76	52.45
1-2	42.58	53.46	63..98	57.11
2-3	43.1	59.98	68.36	61.99
3-4	45.6	61.10	69.07	65.93
4-5	47.2	71.10	73.26	69.22
5-6	53.3	76.9	79.96	79.54
6-7	67.0	78.3	80.07	85.12
7-8	69.1	83.6	87.78	85.33
8-9	73.8	88.23	87.98	86.80
9-10	75.6	91.23	88.22	92.45
10-11	81.1	95.97	90.98	94.35
11-12	83.3	95.98	91.76	96.76
12-13	91.7	97.87	92.98	99.89
13-14	93.9	98.44	95.99	101.11
14-15	97.10	99.87	106.98	103.99
15-16	99.06	104.34	109.88	104.16
16-17	95.90	98.88	96.11	98.12
17-18	92.10	96.27	93.87	96.99
18-19	87.45	90.12	91.99	87.12
19-20	80.98	87.78	82.99	86.11
20-21	76.45	86.23	75.11	76.29
21-22	71.87	82.12	71.11	73.44
22-23	64.6	75.00	68.11	71.33
23-24	53.2	71.87	65.13	69.22

Table 1. Result After DE

The optimal scheduling considering the water discharge and reservoir volume shown in Table 1. The limit is best suitable and economical operation.

VII. CONCLUSION

In the daily optimal generation scheduling of hydro systems, the complexity introduced by the cascade nature of the hydraulic network, the scheduling time linkage, nonlinear non- convex relationship among the hydro power generation, turbine discharge, the net hydraulic head of the corresponding reservoir and the water transport delay time, has made this problem difficult to solve using optimization methods. In this paper by using randomly selection the values of parameters F and CR in DE are devised to effectively handling constraints.

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