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Solution of Short Term Hydro-Thermal Generation Scheduling Problem using Crow Search Algorithm

Parminder Singh[1], Mrs. Shivani Mehta[2]

[1]M.Tech Scholar, Dept. of Electrical Engg., DAVIET Jalandhar, Punjab
[2]Asst. Professor, Dept. of Electrical Engg., DAVIET Jalandhar, Punjab

INTRODUCTION

Short-term hydro-thermal generation scheduling is one of the troublesome power system advancement issues, which has complex and non-direct attributes with different sorts of requirements. The principle target of here and now aqueous era planning is to plan the power era of the hydro and warm units in the framework to meet the heap requests for 1 day or a couple of days while fulfilling different imperatives on the water driven and control framework organize. Short-term hydro-thermal generation scheduling to limit the target work that is the aggregate fuel cost of warm units, subject to different equity and disparity requirements. The equity limitations incorporate era request adjust, dynamic adjust of repository stockpiling for fell hydro plants, limit conditions for supply stockpiling and so on. The disparity requirements are as far as possible on the hydro and warm generators, limits on the repository stockpiling levels and the turbine release rates and so forth. Likewise, the valve point loading effect (VPLE) of warm units adds to the many-sided quality of the issue. Hydro warm planning is required with a specific end goal to locate the ideal distribution of hydro vitality so the yearly working expense of a blended hydro-thermal system is limited.

HYDRO-THERMAL SCHEDULING PROBLEM FORMULATION

The aggregate fuel cost for running the thermal system to meet the load demand in scheduling is given by F. The target work is communicated numerically, as

Minimize $$F = \sum_{i=1}^{m} f_i(P_{Ti}) \qquad (1)$$

Where fi is the cost work comparing to the proportionate thermal unit's power generation PTi at ith interval. M is the aggregate number of intervals considered for short term scheduling. The minimization issue is liable to the accompanying different system constraints:

(a) Demand requirements: This limitation depends on the guideline of vitality protection. The aggregate power created by thermal unit and hydro units set up together ought to be satisfying both the power request and the power loss occurring.

$$P_{T(i)} + \sum_{K=1}^{N} P_{H(k,i)} = P_{D(i)} + P_{Loss(i)} \qquad (2)$$

where PHki is the power created by the kth hydro unit at the ith interval PDi and PLossi is represent the power demad and power loss at the ith interval respectively. N is the aggregate number of hydro units.

b) Thermal generator constraints: The power generations by the thermal generator has a lower and upper bound with the goal that it lies in the middle of these limits at any ith interval.

$$P_T^{\min} \le P_{T(i)} \le P_T^{\max} \qquad (3)$$

c) Hydro generator constraint: Each of the hydro plant's power generation must lie in between its upper and lower bounds of operation

$$P_{H(k)}^{\min} \le P_{H(k,i)} \le P_{H(k)}^{\max} \qquad (4)$$

d) Reservoir capacity constraint: The operating volume of each reservoir's storages at any i^{th} interval must lie in between the minimum and maximum capacity limits of the reservoir.

$$V_{(k)}^{\min} \leq V_{(k,i)} \leq V_{k}^{\max} \qquad (5)$$

Also, the reservoirs have restrictions on the initial and final storage volume they can possess.

$$V_{(k,0)} = V_{k}^{initial} \quad \text{and} \quad V_{(k,M)} = V_{k}^{final} \qquad (6)$$

e) Water discharge constraint: The variable net head operation when considered, the physical limitation of water discharge rate of turbines must be in between its maximum and minimum operating limits.

$$Q_{(k)}^{\min} \leq Q_{(k,i)} \leq Q_{k}^{\max} \qquad (7)$$

f) Hydraulic continuity constraint: The storage volume of the k^{th} reservoir for the $(i+1)^{th}$ interval is found from the following continuity equation.

$$V_{(k,i+1)} = V_{(k,i)} + \sum_{j=\Omega_{(k)}} [Q_{(j,i-\tau)} + S_{(j,i-\tau)}] - Q_{(k,i)} - S_{(k,i)} + R_{(k,i)} \qquad (8)$$

where $\Omega(k)$ is the index set of the upstream reservoirs contributing to the k^{th} reservoir, τ is the time delay occurring for the water in j^{th} upstream reservoir to reach the k^{th} reservoir. S and R represents the spillage and inflow rate respectively.

g) Hydro power generation equation: The hydro power generated by the k^{th} unit at i^{th} interval is taken as a function of discharge rate and storage volume of that unit in that interval.

$$P_{H(k,i)} = C_{(1,k)} V_{(k,i)}^{2} + C_{(2,k)} Q_{(k,i)}^{2} + C_{(3,k)} (V_{(k,i)} Q_{(k,i)}) + C_{(4,k)} V_{(k,i)} + C_{(5,k)} Q_{(k,i)} + C_{(6,k)} \qquad (9)$$

Where, c(1,k) , c(2,k) , c(3,k) , c(4,k) , c(5,k) and c(6,k) are the constant coefficients of the system for the kth reservoir.

MATHEMATICAL FORMULATION OF CROW SEARCH ALGORITHM

Pseudo code of CSA is shown in Fig. 3.2. The step-wise procedure for the implementation of CSA is given in this section.

Step 1: *Initialize problem and adjustable parameters*

The optimization problem, decision variables and constraints are defined. Then, the adjustable parameters of CSA (flock size (N), maximum number of iterations ($iter_{max}$), flight length (fl) and awareness probability (AP)) are valued.

Step 2: *Initialize position and memory of crows*

N crows are randomly positioned in a d-dimensional search space as the members of the flock. Each crow denotes a feasible solution of the problem and d is the number of decision variables.

$$\text{Crows} = \begin{bmatrix} x_1^1 & x_2^1 & \dots & x_d^1 \\ x_1^2 & x_2^2 & \dots & x_d^2 \\ \vdots & \vdots & \vdots & \vdots \\ x_1^N & x_2^N & \dots & x_d^N \end{bmatrix} \qquad (10)$$

The memory of each crow is initialized. Since at the initial iter-ation, the crows have no experiences, it is assumed that they have hidden their foods at their initial positions.

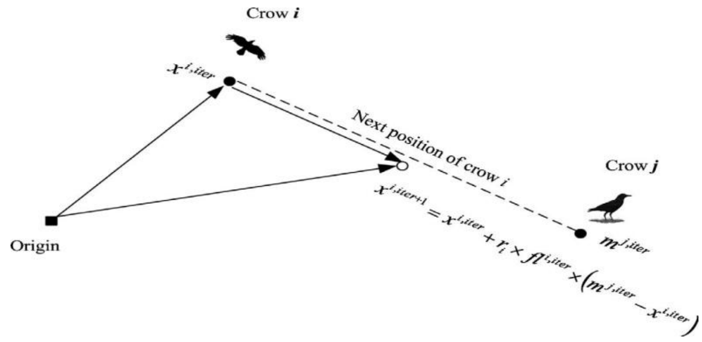

Fig. 1: Flow chart of state 1 in CSA (a) fl < 1 and (b) fl > 1. Crow i can go to every position on the dash line.

$$\text{Memory} = \begin{bmatrix} m_1^1 & m_2^1 & \dots & m_d^1 \\ m_1^2 & m_2^2 & \dots & m_d^2 \\ \vdots & \vdots & \vdots & \vdots \\ m_1^N & m_2^N & \dots & m_d^N \end{bmatrix} \quad (11)$$

Step 3: *Evaluate fitness (objective) function*

For each crow, the quality of its position is computed by inserting the decision variable values into the objective function.

Step 4: *Generate new position*

Crows generate new position in the search space as follows: sup-pose crow i wants to generate a new position. For this aim, this crow randomly selects one of the flock crows (for example crow j) and follows it to discover the position of the foods hidden by this crow (m^j). The new position of crow i is obtained by Eq. (3.11). This process is repeated for all the crows.

Step 5: *Check the feasibility of new positions*

The feasibility of the new position of each crow is checked. If the new position of a crow is feasible, the crow updates its position. Otherwise, the crow stays in the current position and does not move to the generated new position.

Step 6: *Evaluate fitness function of new positions*

The fitness function value for the new position of each crow is computed.

Step 7: *Update memory*

The crows update their memory as follows:

$$m^{i,iter+1} = \begin{cases} x^{i,iter+1} & f(x^{i,iter+1}) \text{ is better than } f(m^{i,iter}) \\ m^{i,iter} & \text{o.w.} \end{cases} \quad (12)$$

Where, f(.) denotes the objective function value.

It is seen that if the fitness function value of the new position of a crow is better than the fitness function value of the memorized position, the crow updates its memory by the new position.

Step 8: *Check termination criterion*

Steps 4–7 are repeated until $iter_{max}$ is reached. When the termi-nation criterion is met, the best position of the memory in terms of the objective function value is reported as the solution of the optimization problem

Steps of Crow Search Algorithm

Crow search algorithm

Randomly initialize the position of a flock of N crows in the search space
Evaluate the position of the crows
Initialize the memory of each crow
while $iter < iter_{max}$
  for $i = 1 : N$ (*all N crows of the flock*)
    Randomly choose one of the crows to follow (for example j)
    Define an awareness probability
      if $r_j \geq AP^{j,iter}$
        $x^{i,iter+1} = x^{i,iter} + r_i \times fl^{i,iter} \times \left(m^{j,iter} - x^{i,iter}\right)$
      else
        $x^{i,iter+1} = a\ random\ position\ of\ search\ space$
      end if
  end for
Check the feasibility of new positions
Evaluate the new position of the crows
Update the memory of crows
end while

FLOW CHART OF CROW SEARCH ALGORITHM

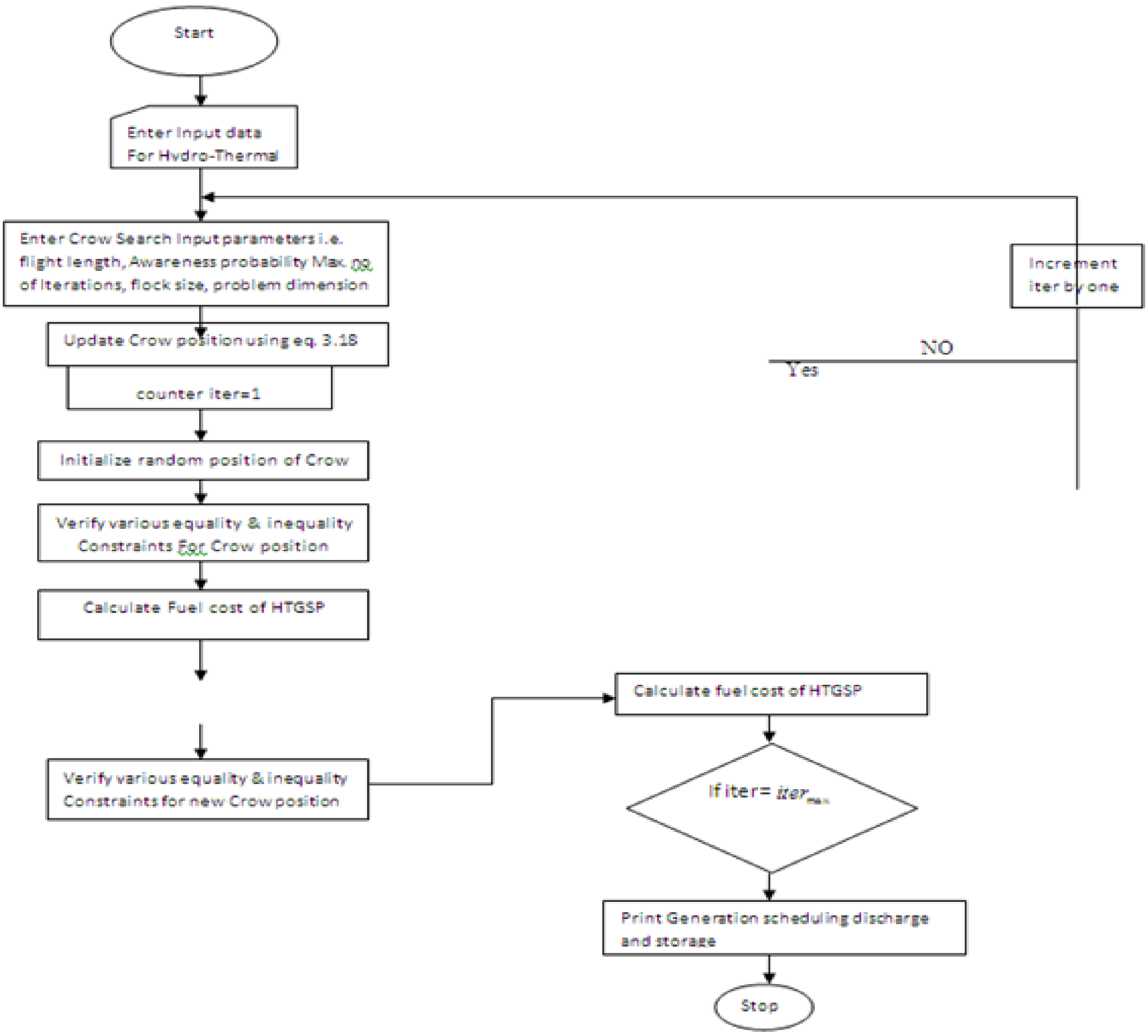

Fig.2: Flow Chart of Crow Search Algorithm for the Hydro-Thermal Scheduling Problem

TEST SYSTEMS FOR HYDRO-THERMAL SCHEDULING PROBLEM

The four different types of hydro-thermal systems are taken into consideration while performing analysis for hydro-thermal scheduling problem of electric power system. MIWOA algorithm was implemented on a test system given in [11]. It consists of an equivalent thermal power plant and a multi-chain cascade of four hydro plants. The schedule horizon is one day with 24 intervals of one hour each. System specifications of hydro plants are given in the appendix. The thermal plant's range of production was from 500 MW to 2500 MW.

The fuel cost function of the equivalent thermal unit with valve point loading is

$$f(P_{T(i)}) = 5000 + 19.2P_{T(i)} + 0.002P_{T(i)}^2 + |700\sin(0.085(P_{T(i)}^{\min} - P_{T(i)}))| \quad (13)$$

- Test System-I: For the sake of comparison with the reported results, the test system-I is considered without valve point loading effect and no prohibited discharge zones.
- Test System-II: The test system-II consists of the Nigerian 330 kV, 24-bus system. The unit characteristics of these test systems along with load demand are depicted in following sub-sections.

TEST SYSTEM-I: QUADRATIC COST CURVE WITHOUT PROHIBITED DISCHARGE ZONES

This case does not consider the prohibited discharge zones and the valve point loading effect. The unit data for Test System-I is depicted in Tables-5.1 through Table-5.5. The table-5.1 shows hydro power generation coefficient of 4-unit test system, Table-5.2 shows the upstream of reservoirs, Table-5.3 shows hourly load demand for 24-hours; Table-5.4 shows reservoir inflow and Table-5.5 shows Reservoir storage capacity limits, plant discharge limit and hydro generation limits.

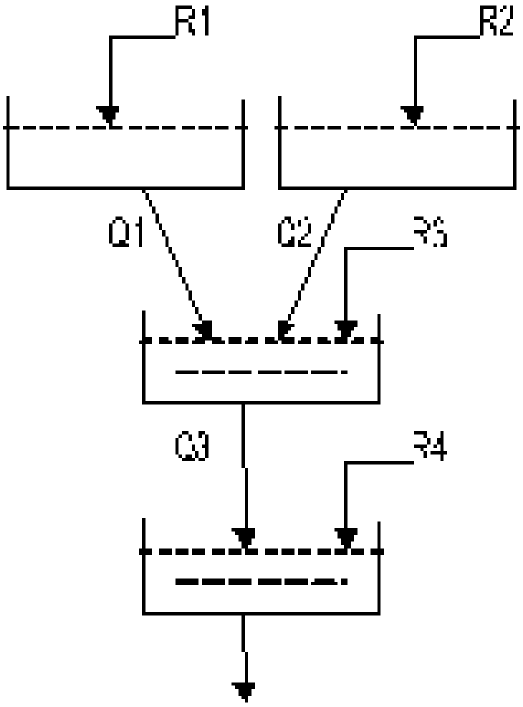

Fig.-3: Hydraulic system test network for Test System-I

Table -1: Hydro power generation coefficients for test system-I

Plant	c_1	c_2	c_3	c_4	c_5	c_6
1	-0.0042	-0.42	0.030	0.9	10	-50
2	-0.0040	-0.30	0.015	1.14	9.5	-70
3	-0.0016	-0.30	0.014	0.55	5.5	-40
4	-0.0030	-0.31	0.027	1.44	14	-90

Table-2: Upstream of Reservoirs

Plant	1	2	3	4
Time Delay (τ)	2	3	4	0

Table-3: Hourly load demand for test system-I

Load Demand (in MW)					
Hour	Load	**Hour**	Load	**Hour**	Load
1	1370	**9**	2240	**17**	2130
2	1390	**10**	2320	**18**	2140
3	1360	**11**	2230	**19**	2240
4	1290	**12**	2310	**20**	2280
5	1290	**13**	2230	**21**	2240
6	1410	**14**	2200	**22**	2120
7	1650	**15**	2130	**23**	1850
8	2000	**16**	2070	**24**	1590

Table-4: reservoir inflows for test system-I

Hour	Reservoir				**Hour**	Reservoir			
	1	2	3	4		1	2	3	4
1	10	8	8.1	2.8	**13**	11	8	4	0
2	9	8	8.2	2.4	**14**	12	9	3	0
3	8	9	4	1.6	**15**	11	9	3	0
4	7	9	2	0	**16**	10	8	2	0
5	6	8	3	0	**17**	9	7	2	0
6	7	7	4	0	**18**	8	6	2	0
7	8	6	3	0	**19**	7	7	1	0
8	9	7	2	0	**20**	6	8	1	0
9	10	8	1	0	**21**	7	9	2	0
10	11	9	1	0	**22**	8	9	2	0
11	12	9	1	0	**23**	9	8	1	0
12	10	8	2	0	**24**	10	8	0	0

Table-5: reservoir inflows for test system-I

Hour	Reservoir				**Hour**	Reservoir			
	1	2	3	4		1	2	3	4
1	10	8	8.1	2.8	**13**	11	8	4	0
2	9	8	8.2	2.4	**14**	12	9	3	0
3	8	9	4	1.6	**15**	11	9	3	0
4	7	9	2	0	**16**	10	8	2	0
5	6	8	3	0	**17**	9	7	2	0
6	7	7	4	0	**18**	8	6	2	0
7	8	6	3	0	**19**	7	7	1	0
8	9	7	2	0	**20**	6	8	1	0
9	10	8	1	0	**21**	7	9	2	0
10	11	9	1	0	**22**	8	9	2	0
11	12	9	1	0	**23**	9	8	1	0
12	10	8	2	0	**24**	10	8	0	0

Table-6: Reservoir storage capacity limits, plant discharge limits, plant generation limits, reservoir end conditions, prohibited discharge zones and hydro generation limits

Plant	V_{min}	V_{max}	$V_{initial}$	V_{final}	Q_{min}	Q_{max}	$Q_{prohibited}$	Ph_{min}	Ph_{max}
1	80	150	100	120	5	15	8-9	0	500
2	60	120	80	70	6	15	7-8	0	500
3	100	240	170	170	10	30	22-27	0	500
4	70	160	120	140	13	25	16-18	0	500

TEST-II: NIGERIAN 330 KV, 24-BUS SYSTEM

In order to verify the effect of combined hydro-thermal system, the Nigerian 330 kV, 24-bus [415-416] system was taken into consideration, which consists of 7 units comprising 3 hydro and 4 thermal units. The quadratic cost function model was taken into consideration for thermal generating units, while hydro units are used at the peak load demand period. The test data for combined hydro-thermal system with different fuel cost characteristics, the minimum up and down time along with start-up cost, cold start hours and initial status of each generating unit is mentioned in Table-5.7. The load demand profile for 24-hours is mentioned in Table-5.8.

Table-7: Generator data for combined hydro-thermal unit system

Unit No.	Fuel Cost Coefficients			P_{max} (MW)	P_{min} (MW)	Minimum Up-Down Time (h)		Start-up Costs ($)		CSH (h)	IS
	a ($/MW^{2}h)	b ($/MWh)	c ($/h)			MUT	MDT	HSC	CSC		
U1 (Hydro)	0	0	0	150	10	15	3	0	0	0	0
U2 (Hydro)	0	0	0	260	35	15	3	0	0	0	0
U3 (Hydro)	0	0	0	450	125	15	3	0	0	0	0
U4(Thermal)	0.00048	16.19	1000	445	150	8	8	4500	9000	5	8
U5(Thermal)	0.00031	17.26	970	445	150	8	8	5000	10000	5	8
U6(Thermal)	0.002	16.6	700	130	20	5	5	550	1100	4	-5
U7(Thermal)	0.00398	19.7	450	162	25	6	6	900	1800	4	-6

Table-8: Load Demand for combined hydro-thermal system for 24-hours

h	1	2	3	4	5	6	7	8	9	10	11	12
Demand (MW)	850	750	730	700	850	950	1150	1300	1400	1500	1550	1600
h	**13**	**14**	**15**	**16**	**17**	**16**	**19**	**20**	**21**	**22**	**23**	**24**
Demand (MW)	1700	1850	1900	1950	2000	2010	1950	1800	1600	1450	1150	910

RESULTS AND DISCUSSION FOR TEST SYSTEM-I USING CROW SEARCH ALGORITHM

Table 9: Time Interval, Net Hydro-Thermal Generation and Load Demand for Test System-I

Time Interval, Net Hydro-Thermal Generation and Load Demand for Test System-I		
INTVL	NET HYDRO GENERATION	LOAD DEMAND
1	366.13	1370
2	364.75	1390
3	363.55	1360
4	329.94	1290
5	350.88	1290
6	383.74	1410
7	332.99	1650
8	358.25	2000
9	357.60	2240
10	360.46	2320
11	375.95	2230
12	373.30	2310
13	341.07	2230
14	425.88	2200
15	379.34	2130
16	386.58	2070
17	409.95	2130
18	396.29	2140
19	411.98	2240
20	406.84	2280
21	490.88	2240
22	426.19	2120
23	432.27	1850
24	451.78	1590

Table-10: Generation Scheduling of Hydro-Thermal Generating Units using Crow Search Algorithm

Generation Scheduling of Hydro-Thermal Generating Units				
Hydro Generation				Thermal Generation
P_{H1}	P_{H2}	P_{H3}	P_{H4}	P_{T1}
72.88	53.15	47.86	207.49	988.62
54.14	63.91	24.82	199.69	1047.43
86.27	65.92	45.55	181.49	980.77
81.02	56.16	51.33	152.20	949.29
76.15	64.35	23.58	179.33	946.59
57.56	81.51	7.51	173.64	1089.78
86.60	67.42	52.32	176.63	1267.02
67.31	62.04	52.15	179.54	1638.96
71.45	63.30	39.99	175.85	1889.42
78.77	50.05	55.05	194.88	1941.25
98.01	55.86	43.16	198.43	1834.54
62.89	60.46	56.09	196.87	1933.69
78.62	66.05	56.45	216.40	1812.48
78.64	48.17	25.50	202.22	1845.47
81.63	61.19	26.14	198.64	1762.40
77.35	61.79	39.03	216.64	1675.19
92.52	61.10	47.32	207.26	1721.80
71.97	49.10	41.88	204.39	1772.66
96.08	48.37	33.57	208.26	1853.71
64.02	67.74	43.29	222.58	1882.38
90.05	80.35	48.79	170.87	1849.93
67.88	59.18	46.47	241.29	1705.17
75.32	65.78	57.26	257.11	1394.54
88.73	53.53	58.78	239.70	1149.27

Table-11: Water Discharge and Storage of Hydro-Units Using Crow Search Algorithm

Water Discharge and Storage of Hydro-Units							
Water Discharge				Storage			
Q_1	Q_2	Q_3	Q_4	V_1	V_2	V_3	V_4
7.55	6.47	18.38	14.00	102.45	81.53	159.72	108.80
5.05	8.18	22.34	14.95	106.40	81.35	145.57	96.25
9.73	8.48	17.08	14.82	104.67	81.87	140.04	83.03
8.85	6.68	13.85	13.29	102.83	84.19	139.71	69.74
8.13	7.97	22.07	17.27	100.69	84.22	138.56	70.85
5.54	12.47	24.34	14.55	102.16	78.75	135.55	78.65
10.13	9.59	12.10	14.47	100.03	75.15	141.26	81.26
6.77	8.78	13.95	15.14	102.26	73.38	142.81	79.97
7.25	9.17	19.40	13.08	105.01	72.20	147.01	88.96
8.25	6.64	11.95	13.81	107.77	74.56	152.42	99.48
12.58	7.38	18.90	14.67	107.18	76.18	150.54	96.92
5.98	8.17	13.41	14.56	111.20	76.00	156.56	96.30
8.01	9.39	15.23	16.95	114.19	74.62	164.55	98.75
7.92	6.09	23.02	15.49	118.27	77.52	157.91	95.21
8.31	8.02	22.69	14.22	120.97	78.50	154.40	99.90
7.65	8.14	20.16	17.70	123.31	78.36	153.55	95.60
10.11	8.15	17.82	16.40	122.20	77.21	152.12	94.42
6.94	6.28	19.23	14.47	123.26	76.93	150.56	102.97
10.99	6.09	20.96	13.65	119.27	77.84	148.85	112.01
6.01	9.49	18.49	14.61	119.26	76.35	146.45	117.56
9.86	14.14	7.78	8.57	116.40	71.20	157.94	126.82
6.49	8.46	18.26	15.11	117.91	71.75	153.79	130.95
7.43	10.07	12.51	16.53	119.48	69.68	161.64	135.38
9.48	7.68	12.27	13.86	120.00	70.00	170.00	140.00

Table 12: Water Discharge and Storage of Hydro-Units

Overall Results for Test System-I using Crow Search Algorithm										
INTVL	Q1	Q2	Q3	Q4	S1	S2	S3	S4	HG	TG
1	5.28	8.50	20.29	13.76	104.72	79.50	157.81	109.04	366.13	1003.87
2	8.82	9.16	21.59	13.06	104.90	78.35	144.42	98.37	364.75	1025.25
3	6.52	8.82	17.82	15.80	106.38	78.53	135.88	84.17	363.55	996.45
4	7.04	9.66	19.40	13.37	106.34	77.86	135.80	70.80	329.94	960.06
5	6.08	8.88	12.61	14.51	106.27	76.98	141.86	76.58	350.88	939.12
6	9.43	10.23	16.68	14.76	103.84	73.76	145.04	83.41	383.74	1026.26
7	7.69	6.24	21.64	14.58	104.15	73.52	142.14	86.65	332.99	1317.01
8	7.67	10.52	21.03	13.73	105.48	70.00	141.41	92.32	358.25	1641.75
9	5.57	10.39	16.92	13.98	109.91	67.61	143.40	90.95	357.60	1882.40
10	6.59	10.17	20.80	15.52	114.32	66.44	137.51	92.11	360.46	1959.54
11	6.61	9.90	15.80	14.01	119.71	65.54	138.80	99.75	375.95	1854.05
12	6.23	7.08	11.97	14.17	123.49	66.46	145.81	106.61	373.30	1936.70
13	5.58	7.39	22.47	13.85	128.91	67.07	144.11	109.68	341.07	1888.93
14	8.09	8.13	17.13	18.55	132.81	67.94	146.12	111.93	425.88	1774.12
15	9.40	7.44	23.91	15.96	134.41	69.50	137.87	111.78	379.34	1750.66
16	13.11	6.82	23.88	16.21	131.30	70.68	131.48	107.54	386.58	1683.42
17	10.09	7.83	11.91	13.29	130.20	69.85	139.09	116.72	409.95	1720.05
18	7.36	6.92	13.80	13.85	130.84	68.93	147.85	119.99	396.29	1743.71
19	9.06	8.16	19.90	14.21	128.78	67.77	145.87	129.69	411.98	1828.02
20	7.17	6.75	17.88	14.08	127.61	69.02	144.17	139.49	406.84	1873.16
21	14.13	13.51	10.41	16.74	120.48	64.52	151.75	134.66	490.88	1749.12
22	8.69	6.50	15.08	15.16	119.79	67.02	154.00	133.30	426.19	1693.81
23	7.06	6.88	13.23	15.95	121.73	68.13	162.64	137.24	432.27	1417.73
24	11.73	6.13	14.84	15.12	120.00	70.00	170.00	140.00	451.78	1138.22

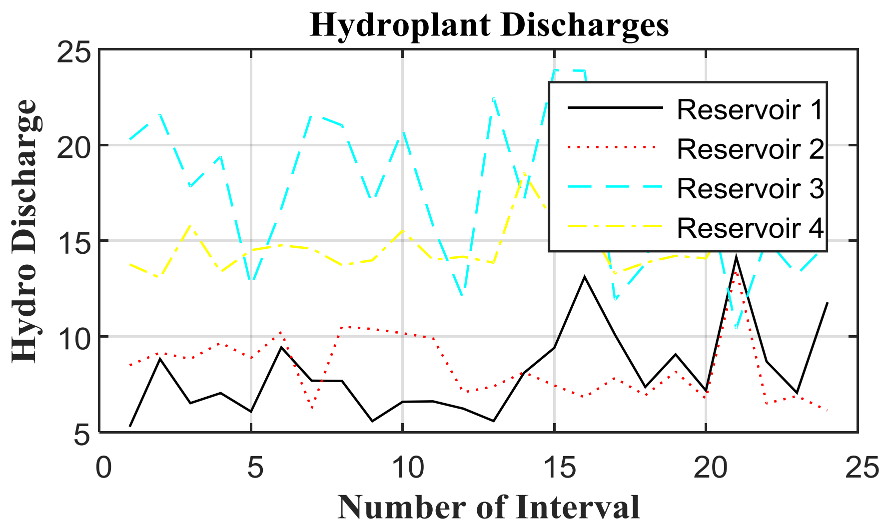

Fig.4: Discharges of Hydro Plants using Crow Search Algorithm

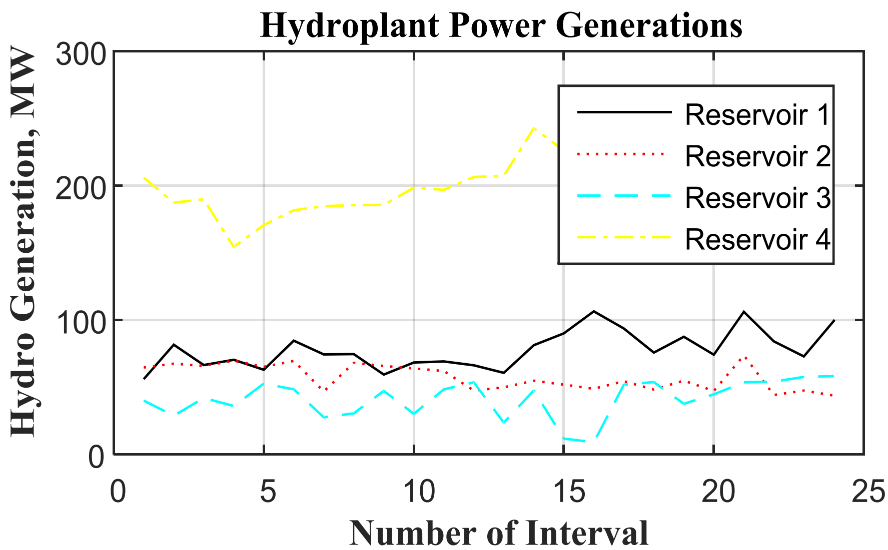

Fig.5: Power Generation of Hydro Plants using Crow Search Algorithm

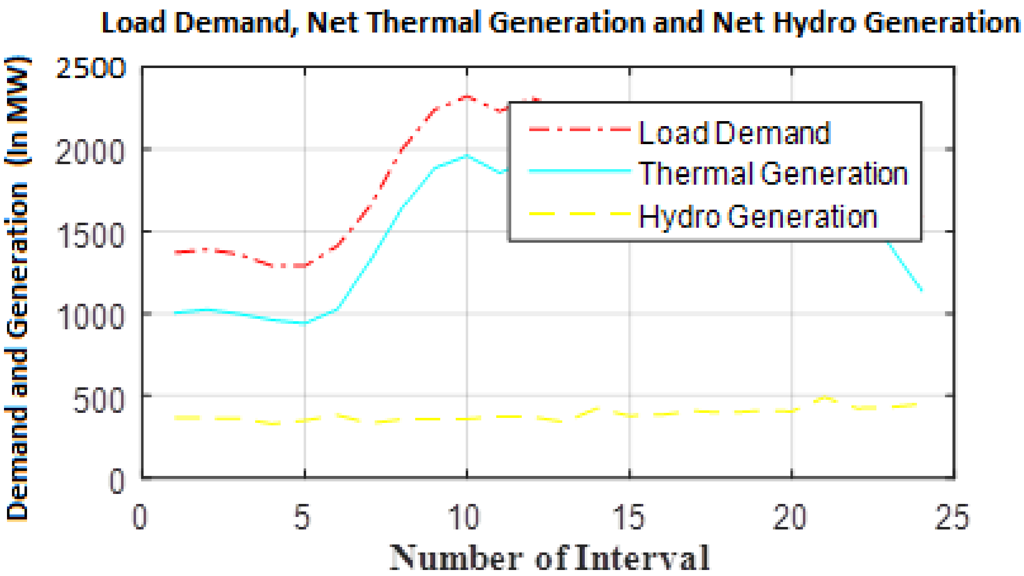

Fig. 6: Load Demand, Net Thermal and Hydro Generation using Crow Search Algorithm

RESULTS AND DISCUSSION FOR TEST SYSTEM-II USING CROW SEARCH ALGORITHM

Table-13: Optimal commitment and generation schedule of 7-unit hydro-thermal test system using Crow Search algorithm

Time (h)	Hydro Units Contribution			Thermal Units Contribution				Generated Power (MW)	Hourly Fuel Cost ($)
	U_{h1}	U_{h2}	U_{h3}	U_{h4}	U_{h5}	U_{h6}	U_{h7}		
1	0	0	437.56	161.72	250.72	0	0	850	8947.645
2	0	0	445.76	304.24	0	0	0	750	5970.116
3	0	0	439.12	290.88	0	0	0	730	5749.964
4	0	0	446.695	253.31	0	0	0	700	5131.814
5	0	0	442.05	335.12	0	0	72.827	850	8385.293
6	0	0	449.94	445	0	0	55.061	950	9846.375
7	0	229.21	450	445	0	0	25.786	1150	9260.224
8	0	226.79	450	445	0	78.049748	100.163	1300	12770.549
9	126.83	254.66	450	356.07	0	50.432149	162	1400	12113.785
10	134.62	260	450	200.80	226.57	66.006611	162	1500	14717.164
11	131.23	260	450	388.23	150	101.11008	69.42	1550	15159.504
12	97.78	260	450	444.44	236.75	22.77567	88.26	1600	16662.796
13	140.51	215.83	411.26	383.41	431.36	78.1963	39.44	1700	18994.398
14	83.77	254.99	399.83	445	445	117.89182	103.52	1850	22228.524
15	144.00	217.51	418.02	445	445	106.66904	123.81	1900	22455.204
16	123.17	259.67	450	445	445	120.56737	106.60	1950	22337.344
17	136.15	231.85	450	445	445	130	162	2000	23649.341
18	128.99	260	450	445	445	126.62021	154.39	2010	23432.036
19	147.98	260	450	445	445	40.023954	162	1950	22125.142
20	35.66	260	438.80	335.78	445	122.75506	162	1800	21716.273
21	94.35	260	450	284.27	445	0	66.37	1600	16128.335
22	110.41	239.24	411.12	405.03	284.20	0	0	1450	13536.629
23	109.01	249.65	434.14	0	357.20	0	0	1150	7174.815
24	112.70	0	450	0	347.30	0	0	910	7001.706
Fuel Cost ($)=345494.978335048					**Overall Generation Cost($)**=406608.502178106				

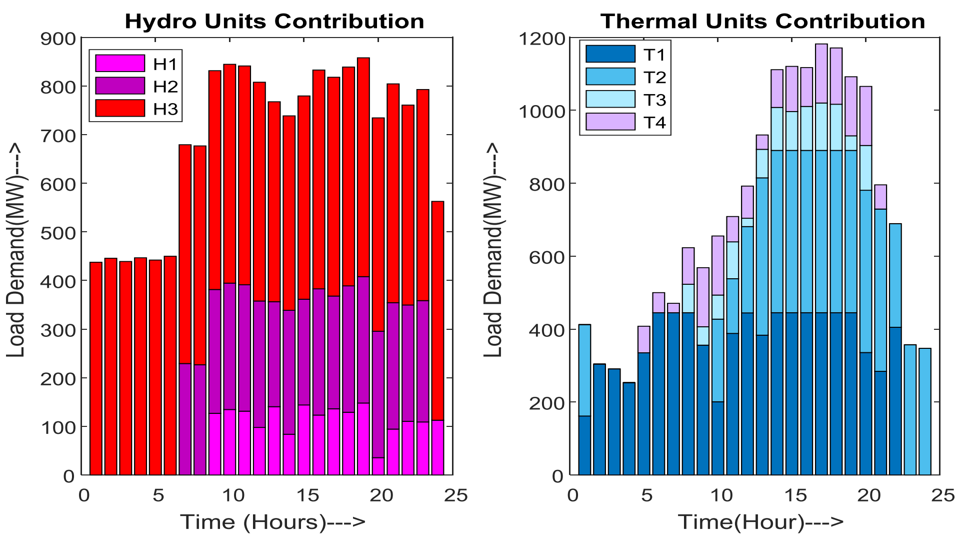

Fig. 7: Contribution of Hydro and Thermal Units for Nigerian 330 KV, 7-unit test system using Crow Search algorithm

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