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Economic Emission Dispatch of Thermal Units with Wind Power and Pumped Hydro Power Plant

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Abstract: In the recent years the power industry has faced many economic and environmental issues. This will effectively deal with issues including global warming, environmental pollution, and energy shortage. Economic load dispatch is the short term determination of the optimal output of a number of electricity generation to meet the system load at the lowest possible cost subject to the emission, transmission and operation constraints. Renewable Energy Sources (RESs) can be a preferable solution to the raised energy crises as well as environmental concerns. Wind power is the use of air flow through wind turbines to mechanically power generators for electricity. The rotor extract the kinetic energy of the wind, changing it into mechanical torque in the shaft and in the generation system converts this .torque into electricity. A combined economic load dispatch integrated with a renewable energy source can be optimized by using PSO optimization algorithm. The effects of wind power with the pumped storage plant on overall emission are also investigated here. A pumped storage hydroelectric power plant converts the gravitational potential energy of water flowing from a higher elevation through a penstock to a lower elevation where a water turbine is used to drive an electric generator. Day-ahead operational planning and an online adjustment procedure to be done for continuous operation of the system with the available data. The proposed technique will reduce the production cost and emission of the generated power. The IEEE 39 bus system has been taken for the simulation work of the proposed method with wind farms and pumped hydro plants.

Keywords: Renewable Energy Sources, Economic load dispatch, Combined Economic Emission Dispatch (CEED), PSO.

1. INTRODUCTION

Electrical power systems are designed and operated to meet the continuous variation of power demand. Economic dispatch have been used to plan over a given time horizon the most economical schedule of committing and dispatching generating units to meet forecasted demand levels and spinning reserve requirements while all generating unit constraints are satisfied.

A large interconnection of the electric networks, the energy crisis in the world and continuous rise in prices, it is very essential to reduce the running costs of electric energy. A saving in the operation of the power system brings about a significant reduction in the operating cost as well as in the quantity of fuel consumed. The main aim of modern electric power utilities is to provide high-quality reliable power supply to the consumers at the lowest possible cost while operating to meet the limits and constraints imposed on the generating units and environmental considerations. These constraints formulates the economic load dispatch (ELD)problem for finding the optimal combination of the output power of all the online generating units that minimizes the total fuel cost, while satisfying an equality constraint and a set of inequality constraints.

Combined Economic Emission Dispatch (CEED) is an optimization problem that allocates power to each committed generating unit so as to minimize the total operational cost and emission, subject to constraints like power balance, power limits of generators, ramp rate limits. The formulation takes into account ramping

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and reserve costs, carbon-di-oxide emissions from expected dispatches, and the transitions over time. Significant research has been conducted throughout the world for development of sustainable, renewable and efficient energy systems in order to meet the requirements of increased population and to reduce the extensive use of fossil fuels. Increasing energy prices, environmental concerns and rapid depletion of the known fuel reserves have significantly increased the scope of renewable energy resources.

It is important to realize that the objectives of operations planning are (a) economic operation (to minimize total cost); (b) secure and reliable operation (to observe operating constraints of all equipment and to supply all loads without interruptions). Specific implementations and procedures are driven by system structure and available technology. The recent advances in computer technology and analytical tools for power system operation analysis have greatly affected operations planning procedures. For example, in the past, the economic objective was accomplished in the planning stage. The operations planner would compute the economic dispatch for projected electric loads and provide a list of generation operating schedules versus electric load. Then, the power system operator will use this list in order to operate the system. However, in actual operation, the system loading conditions and available units may be quite different from those assumed at the planning stage. The introduction of energy management systems provided the ability to optimize system economic operation in real time. Economic scheduling functions have been integrated in the real time control of power systems. Security functions have been also integrated in the control scheme. The integration of these functions has followed an evolutionary process.

2. COMBINED ECONOMIC AND EMISSION DISPATCH

Economic load dispatch is one of the main functions in electrical power system operation, management and planning. Security, reliability, economy and stability are characterized and included to form the dispatching objective or constraints in various forms. Typically, the main objective of economic load dispatch is to minimize the total production cost of the generating system while the required equality and inequality constraints must be satisfied. Nowadays, energy sources to produce mechanical power applied to the rotor shaft of generating units are of fossil fuels.

This can cause a vast amount of carbon dioxide, sulfur dioxide and nitrogen oxides emissions in which atmospheric pollution is created. Emission control over environmental pollution caused by fossil-fired generating units and the enforcement of environmental regulations has received careful attention. Generation allocation of thermal power plants have emphasized the essence of pollution control in electrical power systems. However, taking only the operation of minimum environmental impact is impractical due to causing the higher production cost of the system.

Economic Dispatch (ED) optimization is the most important issue which is to be taken into consideration in power systems. The problem of ED in power systems is to plan the power output for each devoted generator unit in such a way that the operating cost is minimized and simultaneously, matching load demand, power operating limits and maintaining stability. The total generator operating cost includes fuel, labour, supplies and maintenance costs. For simplicity we consider fuel cost as the only variable cost since generally the costs of labour, supplies and maintenance are fixed percentages of the fuel cost. Hence only thermal plants are considered in this research. Over the recent years there has been much research in the area of the combined economic and emission dispatch problem. Gopal Krishnan et al, 2011 outlines a summary of techniques that have been applied so far to the combined economic and emission dispatch problem.

In the solution of the CEED problem, the point at issue is to minimize both fuel cost and emission, simultaneously, while satisfying equality and inequality constraints. Cost and emission functions, which are independent of each other, make the CEED problem bi-objective. Bi-objective problem solving can be done by two objective functions turned into a single objective function. This operation is enhanced using a price penalty factor and the CEED problem is converted into a single-objective function. These objectives and constraints, and the formulation of the CEED problem.

During the minimization process, some equality and inequality constraints must be satisfied. In this process, an equality constraint is called a power balance. According to this constraint, the total power generated must supply the total power demand and total power losses in the network. Besides, an inequality constraint is called a generation capacity constraint. According to this constraint, the power output of each generator is restricted by min and max power limits. These two constraints are expressed as follows,

(i) Power balance constraint

$$\sum_{i=1}^{NG} P_{Gi} - P_{ld} - P_{loss} = 0 \tag{1}$$

Where P_{Loss} is called network losses, which can be assessed by B matrix and formulated as follows:

$$P_{loss} = \sum_{i=1}^{N} \sum_{j=1}^{N} P_{Gi} B_{ij} B_{Gj} \tag{2}$$

(ii) Generation capacity constraint

$$P_{Gi^{min}} < P_{Gi} < P_{Gi^{max}} \tag{3}$$

3. PROBLEM FORMULATION

In this paper, the objective function is set to be the minimization of the generation cost and emission, as given in equation. For a specified power plant, both cost and emission can be expressed as a quadratic function, as described in equations as physical and operating constraints.

Objective function

$$\begin{aligned} \text{Min} & \left[\sum_{t=1}^{NT} \sum_{i=1}^{NG} (p^b F_{c,i}(P_{i,t}) + SU_{i,t} + SD_{i,t}) + \sum_{t=1}^{NT} \sum_{h=1}^{NH} p^b C_{h,t} \right] \\ & + \left[\sum_{t=1}^{NT} \sum_{i=1}^{NG} F_{c,i}^{r}(\Delta_{i,t}^{max}) + \sum_{t=1}^{NG} \sum_{h=1}^{NH} C_{h,t}^{r} \right] \\ & + \left[\sum_{N=1}^{NS} p^s \left(\sum_{t=1}^{NT} \sum_{h=1}^{NH} F_{c,i}(P_{i,t}^{s}) + \sum_{t=1}^{NT} \sum_{h=1}^{NH} C_{h,t}^{s} \right) \right] \end{aligned} \tag{4}$$

Where,

$F_{c,t}(P_{i,t})$ = production cost function of a thermal unit,

$SU_{i,t}$ = startup cost of a unit,

$SD_{i,t}$ = shutdown cost of a unit,

$C_{h,t}$ = operation cost of a pumped storage unit,

$F_{c,i}^{r}$ = availability cost function of a unit,

$\Delta_{i,t}^{max}$ = maximum permissible real power adjustment,

$C_{h,t}^{r}$ = cost of corrective action by a pumped storage unit,

$F_{c,i}(P_{i,t}^{s})$ = production cost function of a wind unit,

$C_{h,t}^{s}$ = operation cost of a wind unit.

Equality Constraints

$$\sum_{i=1}^{NG} p_{i,t} + \sum_{h=1}^{NH} p_{h,t} + \sum_{w=1}^{NW} p_{w,t} = p_{D,t} + p_{loss,t} \tag{5}$$

Thermal Power Plant

Total cost function

$$TC = \sum_{i=1}^{N} a_i + b_i(t) + c_i P_i^2(t) \tag{6}$$

Total emission function

$$TE = \sum_{i=1}^{N} (A \times (\gamma_i P_i^2 + \beta_i P_i(t) + \alpha_i) + \xi_i \times \exp(P_i(t) \times \lambda_i)) \tag{7}$$

Demand

$$D(t) = \sum_{i=1}^{N} P_i(t) + P_{loss}(t) \tag{8}$$

OF = Objective function

TC = Total cost,

TE = Total Emission,

D (t) = Demand of Network,

$P_i(t)$ = Generating power,

$P_{loss}(t)$ = Active power loss,

ω_c = Cost coefficient,

ω_e = Emission coefficient,

a_i, b_i, c_i = Positive fuel cost coefficient,

$\alpha_i, \beta_i, \gamma_i, \xi_i, \lambda_i$ = Greenhouse gases emission coefficient.

4. WIND POWER PLANT

Underestimation and overestimation of the available wind energy, which may happen as a result of WF's imperfect modelling, can impose additional costs on a private owner who participates in the electricity market. For this reason, it is necessary to model WF in a more detailed and accurate manner. In this study, a new WF cost function has been proposed in the ED formulation, which is composed of three sub-objective terms.

$$C = \sum_{i=1}^{N_{wf}} C_{w,i}(w_i) + \sum_{i=1}^{N_{wf}} C_{p,w,i}(W_{i,av} - w_i) + \sum_{i=1}^{N_{wf}} C_{r,w,i}(w_i - W_{i,av}) \tag{9}$$

Where,

w_i = scheduled wind power for wind farm,

$W_{i,av}$ = available wind power for wind farm,

$C_{w,i}(W_i)$ = cost function for wind farm,

$C_{p,w,i}(W_{i,av} - w_i)$ = penalty cost because of under estimation of wind power for wind farm,

$C_{p,w,i}(w_i - W_{i,av})$ = reserve cost because of over estimation of wind power for wind farm.

$$C_w = d_i P_w \tag{10}$$

Pumped Storage Hydro Power Plant

Power Balance Constraint

$$\sum_{i=1}^{N} P_{Gi,\,hr} = P_{d,\,hr} + \lambda_{hr} P_{gp,\,hr} - p_{wind} - p_{thermal} \tag{11}$$

where, $P_{d,\,hr}$ = Total power demand

λ_{hr} = Parameter to indicate operating mode of pumped storage unit,

$P_{gp,\,hr}$ = Power term related to pumped storage unit,

p_{wind} = Power generated by wind turbine,

$p_{thermal}$ = Power generated by thermal source

Inequality Constraint

$$p_{Gi,\,hr}^{max} \le p_{Gi,\,hr} \le p_{Gi,\,hr}^{min} \tag{12}$$

5. SOLUTION METHODOLOGY

The PSO has been used to solve the unit commitment, we focus on applying PSO methods to solve OPF problem. They are, conventional particle swarm optimization passive congregation - based PSO

Step 1: Specify the maximum and minimum limits of generation power of each generating unit, maximum number of iterations to be performed and fuel cost co-efficient of each unit.

Step 2: Initialize randomly the individuals of the population of all units other than the reference unit according to the limit of each unit. Many such population can be generated randomly for better sharing nature.

Step 3: To each individual population of the population array, employ B-coefficient loss formula to calculate the transmission losses P (L).

Step 4: The individuals of the reference unit is obtained from the equality constraint

$$P1 = (PD + PL) - (P2 + P3)$$

Step 5: Calculate the evaluation value of each population Pgusing the evaluation equations. Calculate the price penalty factor.

Step 6: Compute the new evaluation function.

Step 7: Compare each population's evaluation value with its p_{best}. The best evaluation value among the p_{best} is denoted as g_{best}.

Step 8: Modify the member velocity v of each individual Pg.

Step 9: Modify the velocity V of each particle

Step 10: Modify the member position of each individual Pg. If Pg violates the constraints then it must be set to the near margin of that particular unit.

Step 11: If the evaluation value of each population is better than the previous p_{best} the current value is set to be p_{best}. If the best p_{best} is better than the g_{best} the value is set to be g_{best}.

Step 12: If the number of iterations reaches the maximum then go to step 13, otherwise go to step 3.

Step 13: The individual that generates the latest g_{best} is the optimal generation power of each unit.

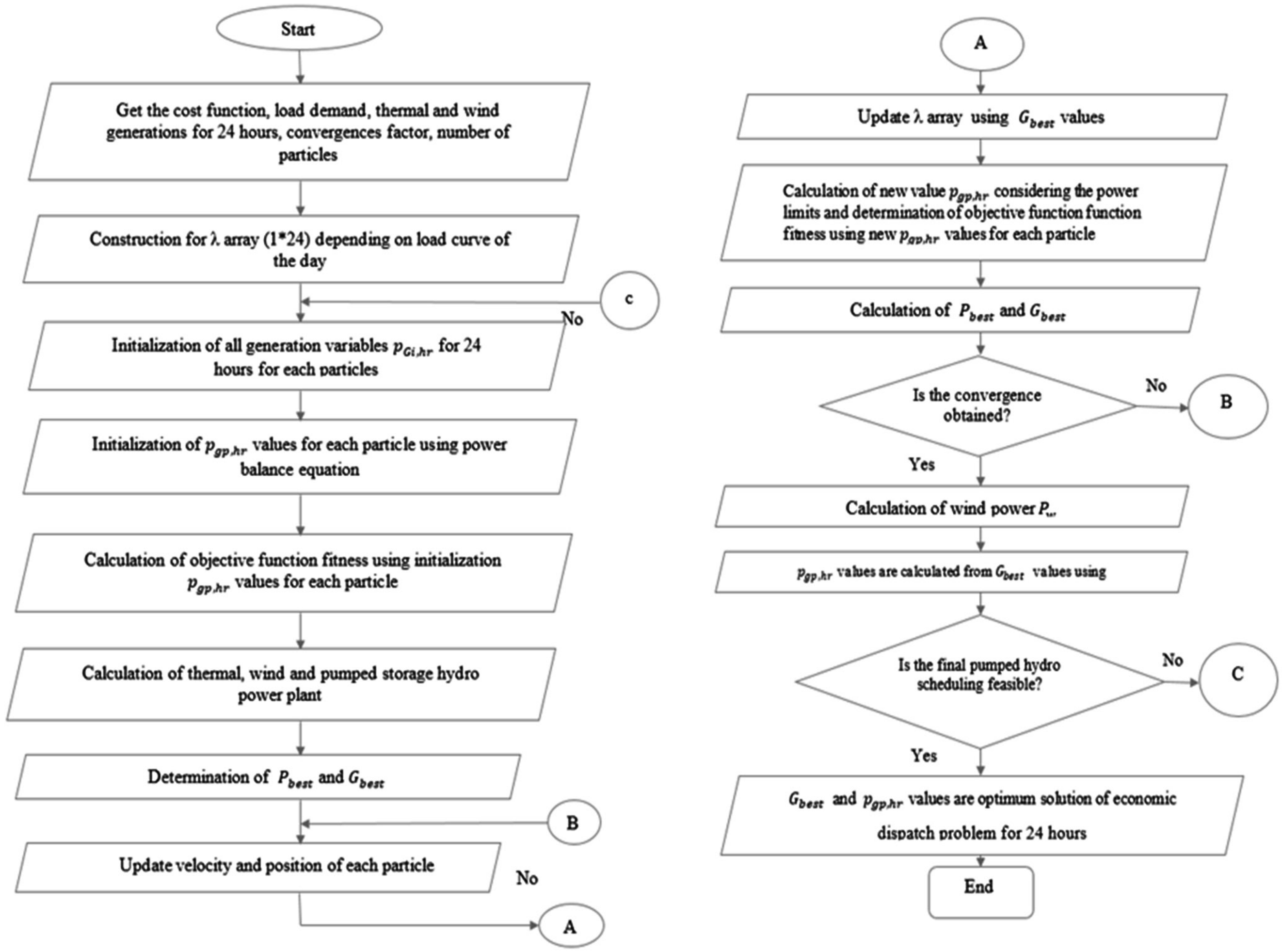

Figure 1: Flow chart for CEED using PSO

6. RESULTS AND DISCUSSION

In this paper, PS and wind unit generation is coordinated and optimized with a stochastic SCUC model through several coordination strategies. The evaluation of the proposed method is based on the total operation cost, wind energy curtailment, and the corrective action cost. The proposed scenarios would include generator and transmission line outages, as well as the hourly wind speed and load forecast errors. The operating strategies are investigated in details. It is shown that the system-level coordination of wind-PS units may lead to the least total operation cost, wind energy curtailment, and cost of corrective actions in scenarios. It is also shown that a smaller wind energy curtailment may not lead to a lower total operation cost. The wind-PS energy coordination will lead to more wind energy curtailments as the coordination imposes additional binding operation constraints among scenarios.

7. CONCLUSION

It is recognized that the optimal combined economic emission dispatch (CEED) of thermal systems results in reduction of cost as well as emission. CEED is the problem of determining the schedule of generating units subject to device and operating constraints. In Economic dispatch of wind energy using with PSO fuel cost is less and emission is more. The formulation of combined economic emission dispatch (CEED) has been discussed and the solution is obtained by particle swarm optimization method (PSO). The effectiveness of these algorithms has been tested on systems comprising ten units wind, thermal and pumped storage hydro compared for total fuel cost and emission cost.

Table 1
Output for thermal units

Hours	*Power generation of units (MW)*										*Generation cost ($)*	*Emission cost(ton)*	*Startup cost($)*	*Total cost($)*	*Max capacity (MW)*	*Total demand (MW)*	*Loss (MW)*	*Reserve (MW)*
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*								
1	455	266	0	0	0	0	0	0	0	0	16248.97	8351.96	0	16248.97	910	700	21.4	210
2	455	315	0	0	0	0	0	0	0	0	17103.44	9120.93	0	17103.44	910	750	20.9	160
3	455	283	130	0	0	0	0	0	0	0	18737.23	8932.9	550	19287.23	1040	850	18.3	290
4	455	388	130	0	0	0	0	0	0	0	20571.08	10874.62	0	20571.08	1040	950	23.8	90
5	455	306	130	130	0	0	0	0	0	0	21318.88	9630.36	560	21878.88	1170	1000	21.9	170
6	455	383	130	130	25	0	0	0	0	0	23159.28	11023.5	900	24059.28	1332	1100	23.9	232
7	455	435	130	130	25	0	0	0	0	0	24069.89	12223.38	0	24069.89	1332	1150	25.7	182
8	455	455	130	130	30	0	25	0	0	0	24520.35	12720.43	260	24780.35	1417	1200	25.2	217
9	455	455	130	130	121	20	25	0	0	0	26815.76	12783.62	170	26985.76	1497	1300	26.7	197
10	455	455	130	130	162	58	25	10	0	0	28536.64	12980.48	30	28566.64	1552	1400	25.7	152
11	455	455	130	130	162	80	25	28	10	0	29047.98	13004.03	30	29077.98	1607	1450	25.8	157
12	455	455	130	130	162	80	25	55	17	17	29047.98	13004.03	30	29077.98	1662	1500	26.2	162
13	455	455	130	130	162	0	25	55	13	0	27221.61	13088.93	0	27221.61	1527	1400	25.4	127
14	455	332	130	130	126	0	0	10	10	10	26471.14	12869.54	30	26501.14	1497	1300	26.7	197
15	455	281	130	130	58	0	0	0	0	0	25081.76	12698.43	0	25081.76	1332	1200	28.4	132
16	455	384	130	130	25	0	0	0	0	0	22267.93	10010.69	0	22267.93	1332	1050	22.8	282
17	455	455	130	130	25	0	0	0	0	0	21377.92	9159.87	0	21377.92	1332	1000	21.7	332
18	455	455	130	130	25	0	0	0	0	0	23177.04	11045.31	0	23177.04	1332	1100	24.9	232
19	455	455	130	130	30	0	25	0	0	0	24520.34	12720.44	260	24780.34	1417	1200	25.3	217
20	455	455	130	130	162	58	25	10	0	0	28536.65	12983.48	200	28736.65	1552	1400	25.7	152
21	455	455	130	130	111	20	25	0	0	0	26609.53	12741.94	0	26609.53	1497	1300	26.7	197
22	455	455	130	0	67	20	0	0	0	0	23530.93	12309.13	0	23530.93	1282	1100	27.7	182
23	455	423	0	0	25	20	0	0	0	0	19935.48	11207.05	0	19935.48	1152	900	23.7	252
24	455	367	0	0	0	0	0	0	0	0	18012.03	10099.78	0	18012.03	910	800	22.4	110

Table 2
Output for wind-thermal units

Hours	*Power generation of units(MW)*										*Generation cost ($)*	*Emission cost (ton)*	*Startup cost($)*	*Wind (MW)*	*Wind Cost ($)*	*Wind Speed (m/s)*	*Total cost($)*	*Max capacity (MW)*	*Total demand (MW)*	*Loss (MW)*	*Reserve (MW)*
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*											
1	455	266	0	0	0	0	0	0	0	0	16248.97	8351.96	0	11.3	169.6	7.784	16418.57	910	700	21.4	210
2	455	315	0	0	0	0	0	0	0	0	17103.44	9120.93	0	26.9	403.5	11.679	17506.94	910	750	20.9	160
3	455	283	130	0	0	0	0	0	0	0	18737.23	8932.9	550	21.9	328.5	9.73	19615.73	1040	850	18.3	290
4	455	388	130	0	0	0	0	0	0	0	20571.08	10874.62	0	41.3	619.5	16.541	21190.58	1040	950	23.8	90
5	455	306	130	130	0	0	0	0	0	0	21318.88	9630.36	560	41.3	619.5	17.514	22498.38	1170	1000	21.9	170
6	455	383	130	130	25	0	0	0	0	0	23159.28	11023.5	900	41.3	619.5	17.514	24678.78	1332	1100	23.9	232
7	455	435	130	130	25	0	0	0	0	0	24069.89	12223.38	0	41.3	619.5	16.541	24689.39	1332	1150	25.7	182
8	455	455	130	130	30	0	25	0	0	0	24520.35	12720.43	260	26.9	403.5	11.676	25183.85	1417	1200	25.2	217
9	455	455	130	130	121	20	25	0	0	0	26815.76	12783.62	170	37.5	562.5	13.622	27548.26	1497	1300	26.7	197
10	455	455	130	130	162	58	25	10	0	0	28536.64	12980.48	30	41.3	619.5	17.514	29186.14	1552	1400	25.7	152
11	455	455	130	130	162	80	25	28	10	0	29047.98	13004.03	30	39.4	591	14.595	29668.98	1607	1450	25.8	157
12	455	455	130	130	162	80	25	55	17	17	29047.98	13004.03	30	41.3	619.5	21.406	29697.48	1662	1500	26.2	162
13	455	455	130	130	162	0	25	55	13	0	27221.61	13088.93	0	41.3	619.5	16.541	27841.11	1527	1400	25.4	127
14	455	332	130	130	126	0	0	10	10	10	26471.14	12869.54	30	21.9	328.5	9.73	26829.64	1497	1300	26.7	197
15	455	281	130	130	58	0	0	0	0	0	25081.76	12698.43	0	4.4	66	6.84	25147.76	1332	1200	28.4	132
16	455	384	130	130	25	0	0	0	0	0	22267.93	10010.69	0	25.5	382.5	10.703	22650.43	1332	1050	22.8	282
17	455	455	130	130	25	0	0	0	0	0	21377.92	9159.87	0	13.1	196.5	8.757	21574.42	1332	1000	21.7	332
18	455	455	130	130	25	0	0	0	0	0	23177.04	11045.31	0	13.1	196.5	8.757	23373.54	1332	1100	24.9	232
19	455	455	130	130	30	0	25	0	0	0	24520.34	12720.44	260	21.9	328.5	10.703	25108.84	1417	1200	25.3	217
20	455	455	130	130	162	58	25	10	0	0	28536.65	12983.48	200	32.9	493.5	12.649	29230.15	1552	1400	25.7	152
21	455	455	130	130	111	20	25	0	0	0	26609.53	12741.94	0	26.9	403.5	11.676	27013.03	1497	1300	26.7	197
22	455	455	130	0	67	20	0	0	0	0	23530.93	12309.13	0	25.5	382.5	10.703	23913.43	1282	1100	27.7	182
23	455	423	0	0	25	20	0	0	0	0	19935.48	11207.05	0	32.5	487.5	12.649	20422.98	1152	900	23.7	252
24	455	367	0	0	0	0	0	0	0	0	18012.03	10099.78	0	32.5	487.5	12.649	18499.53	910	800	22.4	110

Table 3
Output for wind, thermal and pumped hydro storage units

Hours	*Power generation of units(MW)*										*Generation cost ($)*	*Emission cost(ton)*	*Start-up cost($)*	*Wind (MW)*	*Wind Cost ($)*	*Wind Speed (m/s)*	*Strategy*	P_{PH}	*Total cost($)*	*Max capacity (MW)*	*Total demand (MW)*	*Loss (MW)*	*Reserve (MW)*
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*													
1	455	334	0	0	0	0	0	0	0	0	17430.7	9453.88	0	11.3	169.6	7.784	P	–114	17486.3	910	800	21.4	110
2	455	368	0	0	0	0	0	0	0	0	18031.83	10122.98	0	26.9	403.5	11.679	P	–114	18435.3	910	850	20.9	60
3	455	343	130	0	0	0	0	0	0	0	19786.37	9960.21	550	21.9	328.5	9.73	P	–114	20550.9	1040	950	18.3	90
4	455	324	130	0	0	0	0	0	0	0	19448.05	9604.55	0	41.3	619.5	16.541	S	0	20067.6	1040	950	23.8	90
5	455	244	130	130	0	0	0	0	0	0	20233.68	8714.68	560	41.3	619.5	17.514	S	0	21413.2	1170	1000	21.9	170
6	455	319	130	130	25	0	0	0	0	0	22036.44	9733.93	900	41.3	619.5	17.514	S	0	23555.9	1332	1100	23.9	232
7	455	369	130	130	25	0	0	0	0	0	22909.85	10723.92	0	41.3	619.5	16.541	S	0	23529.4	1332	1150	25.7	182
8	455	408	130	130	25	0	25	0	0	0	23598.96	11582.07	260	26.9	403.5	11.676	S	0	24262.5	1417	1200	25.2	217
9	455	378	130	130	25	20	25	0	0	0	23511.27	10844.15	170	37.5	562.5	13.622	G	104	24647.8	1497	1200	26.7	197
10	455	455	130	130	34	20	25	10	0	0	25043.19	12651.86	30	41.3	619.5	17.514	G	104	25796.7	1552	1300	25.7	252
11	455	455	130	130	76	20	25	10	10	0	25886.38	12649.73	30	39.4	591	14.595	G	104	26611.4	1607	1350	25.8	257
12	455	455	130	130	114	20	25	10	10	10	26666.18	12752.72	30	41.3	619.5	21.406	G	104	27419.7	1662	1400	26.2	262
13	455	455	130	130	44	0	25	10	10	0	24795.25	12702.89	0	41.3	619.5	16.541	G	104	25519.8	1527	1300	25.4	227
14	455	408	130	130	25	0	0	10	10	10	23599.2	11582.38	30	21.9	328.5	9.73	G	104	24061.7	1497	1200	26.7	297
15	455	455	130	130	26	0	0	0	0	0	24433.18	12728.75	0	4.4	66	6.84	S	0	2449.18	1332	1200	28.4	132
16	455	284	130	130	25	0	0	0	0	0	21438.78	9212.92	0	25.5	382.5	10.703	S	0	21821.3	1332	1050	22.8	282
17	455	247	130	130	25	0	0	0	0	0	20783.15	8681.1	0	13.1	196.5	8.757	S	0	20979.7	1332	1000	21.7	332
18	455	347	130	130	25	0	0	0	0	0	22527.5	10289.07	0	13.1	196.5	8.757	S	0	22724	1332	1100	24.9	232
19	455	413	130	130	25	0	25	0	0	0	23686.86	11698.38	260	21.9	328.5	10.703	S	0	24275.4	1417	1200	25.3	217
20	455	455	130	130	42	20	25	10	0	0	25210.74	12641.78	200	32.9	493.5	12.649	G	104	26008.2	1552	1300	25.7	252
21	455	388	130	130	25	20	25	0	0	0	23696.99	1071.75	0	26.9	403.5	11.676	G	104	24204.5	1497	1200	26.7	297
22	455	444	130	0	25	20	0	0	0	0	22503.88	12067.22	0	25.5	382.5	10.703	S	0	22886.4	1282	1100	27.7	182
23	455	455	0	0	37	20	0	0	0	0	20745.69	11984.4	0	32.5	487.5	12.649	P	–114	21119.2	1152	1000	23.7	252
24	455	412	0	0	0	0	0	0	0	0	18808.18	11094.92	0	32.5	487.5	12.649	P	–114	19151.7	910	900	22.4	10

Table 4
Thermal Units Data

	Unit 1	*Unit 2*	*Unit 3*	*Unit 4*	*Unit 5*	*Unit 6*	*Unit 7*	*Unit 8*	*Unit 9*	*Unit 10*
P_i(max)	455	455	130	130	162	80	85	55	55	55
P_i(min)	150	150	20	20	25	20	25	10	10	10
A_i	1000	970	700	680	450	370	480	660	665	670
B_i	16.19	17.26	16.6	16.5	19.7	22.26	27.74	25.92	27.27	27.79
C_i	0.00048	0.00031	0.002	0.00211	0.00398	0.00712	0.00079	0.00413	0.00222	0.00173
MU_i	8	8	5	5	6	3	3	1	1	1
MD_i	8	8	5	5	6	3	3	1	1	1
$Hcost_i$	4500	5000	550	560	900	170	260	30	30	30
$Ccost_i$	9000	10000	1100	1120	1800	340	520	60	60	60
$Chour_i$	5	5	4	4	4	2	2	0	0	0
I. state	8	8	-5	-5	-6	-3	-3	-1	-1	-1
α_i(ton/h)	10.3391	10.3391	30.0391	30.0391	32.0001	32.0001	33.0006	33.0006	35.0006	36.0001
β_i(ton/MW)	–0.24444	–0.24444	–0.407	–0.407	–0.38132	–0.38132	–0.39023	–0.39023	–0.39524	–0.39864
γ_i(ton/MW^{2}h)	0.00312	0.00312	0.00509	0.00509	0.00344	0.00344	0.00465	0.00465	0.00465	0.0047

Table 5
Wind Power to Speed

Wind Speed (m/s)	3	4	5	5.5	6	7	8	9	10	11	12	13	13.5	14	15	16-25
Output Power (W)	20	50	75	100	125	200	450	600	900	1050	1250	1400	1500	1550	1600	1650

Table 6
Pumped Storage Hydro Plant

Water levels	
Max. water level in the upper reservoir	1160 m
Min. water level in the upper reservoir	1135 m
Max. water level in the lower reservoir	734 m
Min. water level in the lower reservoir	726 m
Turbines	
Turbine type	f 10 dia 2600
Normal rpm	500
Max. operating rpm	867
Max. single turbine operation gradient	428 m
Max. double turbine operation gradient	423 m
Min. double turbine operation gradient	391 m
Max. turbine flow rate	30 m^3/s
Max. output at turbine coupling	115 mw
Mean. output at turbine coupling	104 m
Max. operating pressure in the spiral casing	6178 mpa

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