ADJUSTING THE ENERGY VALUE OF WATER CONSUMPTION FOR PQ_POWER OPTIMIZATION IN HYDRO-THERMAL POWER SYSTEM

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ABSTRACT The characteristics of water consumption (W) and the characteristics of incremental consumption (w) of water are used to calculate the optimal condition of the operating mode of the hydroelectric generators. The general characteristics of the hydro-turbine are built respect to some unchanged levels of efficiency of turbine pressure and can be gotten by experiments in laboratory or on the hydroelectric plants. A method called using the characteristics of the changing of water head level is often applied to build the characteristics of water consumption. The characteristics of incremental consumption of water for a hydro power unit can be received, then the energy value of water consumption of the problem of pq-power optimization in hydro-thermal power system can be found. The quantity of energy value of water consumption for the hydropower production is a factor at the t-th interval of period (T) of time of calculation, is a measure of the efficiency of water consumption corresponding to the level of water head (H) in the hydro plants.

This paper presents a new algorithm of pq-power optimization in hydrothermal power system, the energy values of water consumption of the hydro-generators are adjusted to minimize the fuel cost of thermal generators and the cost of transmission MW losses. Some numerical results are compared and shown in this article.

1. INTRODUCTION

The characteristics of water consumption and the characteristics of incremental consumption of water are used to calculate the optimal condition of the operating mode of the hydroelectric generator, also using the water head and water tail basing on general characteristics (function of water head (H) depending on active power) of hydro-turbine. The general characteristics are built respect to some unchanged levels of efficiency of turbine pressure and can be gotten by experiments in laboratory or on the hydro plants. For each level of water head, following on the general characteristics of the turbine to determine the function of electric power losses depending on the turbine power

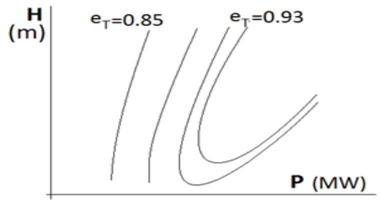

Fig.1 General Characteristics of hydro-turbine

This method is called using the characteristics of the changing of water head level is often applied to build the characteristics of water consumption.

$$0.0098W(H-\Delta H)e_T = (P_T - \Delta P_T); \qquad (1)$$

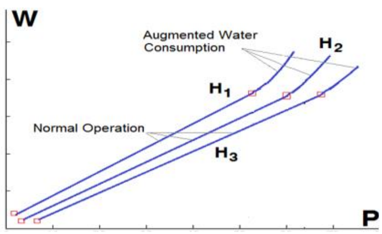

Fig.2 Characteristic of Water Consumption

The characteristics of incremental consumption of water (w) can be directly built basing on the operating function of e_{Tg}, which depends on P_g, where e_{Tg}=$e_T e_g$; and P_g=P_T e_g. Hence

$$\mathrm{w} = \frac{1+\dfrac{P_g}{e_{T-g}}\dfrac{\partial e_{T-g}}{\partial P_g}}{0.0098H}; \qquad (2)$$

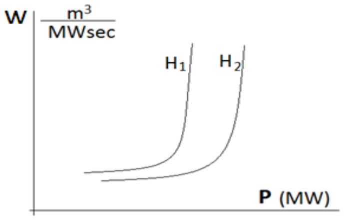

Fig.3 Characteristic of Incremental Consumption of water

The characteristics of water consumption (W) and the characteristics of incremental consumption (w) of water are used to optimize the pq_power outputs in hydro-thermal multi-machine power system.

2. PROBLEM OF PQ POWER OPTIMIZATION IN HYDRO-THERMAL POWER SYSTEM

The problem of pq-power optimization is expressed for a short term forecasting in a period of T, the target function is

$$C_{Thermal} = \int_o^T \sum_{i=1}^{N} C_{i\,Thermal}\, dt \to \min; \qquad (3)$$

Subject to the constraint of active power balancing in t-th time interval

$$g_t(P_{g\,i\,t}) = P_{Dt} + \Delta P_t - \sum_{i=1}^{n} P_{ther\,i\,t} - \sum_{j=1}^{m} P_{hyd\,j\,t} = 0; \qquad (4)$$

and subject to the constraint of the water balancing relating to a water amount that must be known by forecasting in a cycle controlling the water discharge

$$\mathrm{W}_j = \int_o^T \mathrm{W}_{jt} dt - \mathrm{W}_{j\,o} T \simeq 0; \quad j = 1, 2 \ldots m; \qquad (5)$$

Let's choose the time period of T=24h for a daily dispatching in short time with reliable hydrological forecasting, hence, the problem (3)-(4)-(5) may be transformed into a problem of static optimization for every one hour (Δt=1h) as follows

$$L_t = \sum_{i=1}^{n} C_{i\,Thermal\ t} + \sum_{j=1}^{m} V_{W\,j\,t} \mathrm{W}_{jt} + \lambda_t g_t(P_{g\,i\,t}) \to \min; \qquad (6)$$

The problem of optimization of reactive power generation is to minimize the transmission active power losses, taking into account the steady-state stability margin of every generator in electric power system. The target function is

$$\Delta P(Q_g) = \sum_{m=1}^{N_g} \sum_{n=1}^{N_g} Q_{gm} B_{mn} Q_{gn} \to \min; \qquad (7)$$

The problems of (6) and (7) can be solved by algorithm describing in (Luu H.V. Quang, 2015) using the gradient search method.

The quantity of $V_{W\,j\,t}$ is a factor at t-th interval of the period (T) of calculation characterizing the energy value of water consumption for hydropower production, is a measure of the efficiency of water consumption corresponding to a level of water head (H_j) in the hydro plants, the unit of V_W is \$/m^3.

3. EXAMPLES AND TYPICAL RESULTS

3.1 First Example

Let's survey the optimum condition of operation of a 75-bus power system consisting of 3 thermal plants with 11 generators-units and 2 hydro plants with 7 generators-units. Basic power is 100 MVA. The datum of the test system is given in (Luu H.V. Quang, 2015), assuming the initial conditions of optimization calculation are similar, the results of pq-power optimization using the gradient search method are shown below.

The energy values of water consumption are adjusting for the hydro-generators in the process of optimization are shown in the figure 4. The processes of optimization of such as the fuel cost of thermal plants, the hydro cost, the cost of transmission MW losses, and the total cost are shown in the figures 5, 6, 7, 8 and 9 as follows

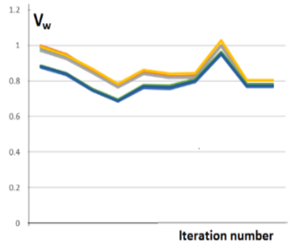

Fig.4 Adjusting energy values of water consumption

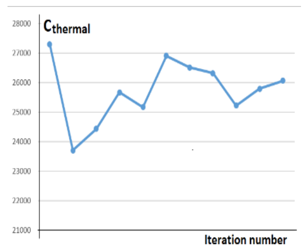

Fig.5 Optimizing the fuel-costs of thermal plants

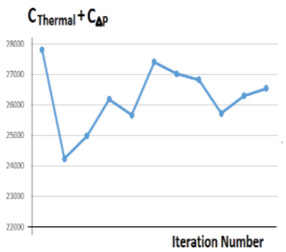

Fig.6 Optimizing the fuel cost of thermal plants and cost of MW losses

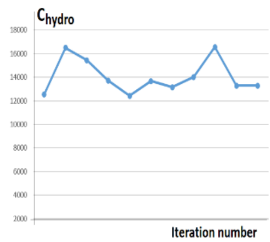

Fig.7 Optimizing the cost of water consumption

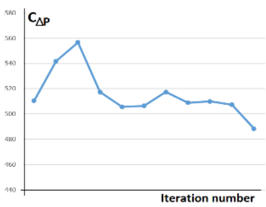

Fig.8 Optimizing the transmission MW losses

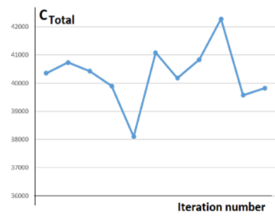

Fig.9 Optimizing the total cost

Let's compare the optimum pq_powers of two cases: the first case concerning to adjusting the energy values of water consumption and the second case is concerned with holding the energy values of water consumption equal to zero, as shown in the table 1, the bus numbers, counting from 1 to 7, are denoted for hydro-generator and the rest of bus numbers are denoted for thermal generators, as following

Table 1. Comparison of optimum pq_powers

Gen	Case of adjusting $V_{W\,i}$		Case of $V_{W\,i} \equiv 0$	
Bus	P(MW)	Q(MVAR)	P(MW)	Q(MVAR)
1	47.646	2.949	42.6576	3.0234
2	48.199	2.966	42.6377	3.0171
3	47.668	2.939	42.6182	3.0108
4	47.645	2.933	42.5991	3.0044
5	47.000	4.324	47.0000	4.4711
6	47.000	4.315	47.0000	4.4622
7	47.000	4.307	47.0000	4.4535
8	33.095	3.577	38.3904	3.6657
9	48.711	4.054	40.2780	3.7146
10	27.847	3.486	41.3711	3.7443
11	36.625	3.657	42.2282	3.7685
12	42.334	7.166	46.9609	7.6043
13	43.051	7.293	46.3337	7.6644
14	47.406	6.087	47.9190	6.1385
15	43.752	4.025	43.8007	4.0387
16	34.466	3.766	43.9749	4.0345
17	40.287	3.899	43.9859	4.0250
75	33.954	8.040	17.1187	8.8859
	MW Losses : 16.277		MW Losses : 16.468	

The optimum costs in case of adjusting energy values of water consumption are shown in the table 2.

Table 2. Optimal Costs

Economic Fuel-Cost	26056.29 $/h
Economic MW-Loss Cost	488.32 $/h
Rating of Energy-Losses	30.00 $/MWh
Economic Objective	26544.61 $/h
Economic Hydro-Cost	13275.39 $/h
Total Economic-Cost	39819.90 $/h

3.2 Second Example

Let's investigate another level of total MW load demand of 524.058 MW with some suitable levels of compensating reactive power, the load bus-data in this case is given in table 3 as follow

Table 3. Load Bus-Data

Load Bus	P (MW)	Q (MVAR)		Load Bus	P (MW)	Q (MVAR)
18	0.058	0.4		46	0.15	1
19	0.058	0.4		47	0.2	1.6
20	0.084	0.56		48	0.2	1.6
21	0.058	0.4		49	0.2	1.6
22	61.25	21.3		50	0.2	1.6
23	20.65	7.784		51	0.14	0.96
24	24.5	8.629		52	54.95	20.6
25	24.5	8.641		53	0	-11.855
26	25.9	7.578		54	0	4.456
27	20.3	7.176		55	0	-30.000
28	18.9	6.419		56	0	6.525
29	21.7	7.182		57	0	2.595
30	23.1	8.072		58	0.14	0.96
31	41.3	11.46		59	0.058	0.4
32	13.3	6.527		60	0.058	0.4
33	14.7	6.64		61	0.058	0.4
34	12.6	4.717		62	0.07	0.48
35	14	5.85		63	0.058	0.4
36	14.7	6.629		64	0.058	0.4
37	18.9	6.295		65	0.058	0.4
38	20.3	7.544		66	0.058	0.4
39	16.8	7.652		67	0.084	0.56
40	29.4	8.1		68	0.042	0.272
41	14.7	6.524		69	0.042	0.272
42	14.7	4.766		70	0.042	0.272
43	0.15	1		71	0.042	0.272
44	0.2	1.6		72	0.042	0.272
45	0.2	1.6		73	0.042	0.272
46	0.15	1		74	0.058	0.4

Hence, the optimum power outputs and the relating costs in cases pertaining to adjusting the energy values of water consumption are shown in the table 4 and the table 5

Table 4. Optimum pq_powers

Gen Bus	P (MW)	Q (MVAR)		Gen Bus	P (MW)	Q (MVAR)
1	40.522	-7.675		10	34.545	-6.509
2	41.099	-7.652		11	35.346	-6.496
3	40.315	-7.688		12	42.514	-4.980
4	40.209	-7.695		13	15.210	-3.113
5	20.716	-10.348		14	16.989	-5.493
6	22.019	-10.521		15	15.280	-5.388
7	24.830	-10.883		16	41.170	-7.666
8	31.464	-6.452		17	14.243	-5.238
9	33.941	-6.514		75	20.876	-10.799

Table 5. Optimum Costs

Economic Fuel-Cost	19249.85 $/h
Economic MW-Loss Cost	216.93 $/h
Rating of Energy-Losses	30.00 $/MWh
Economic Objective	19466.78 $/h
Economic Hydro-Cost	9538.17 $/h
Total Economic-Cost	29004.95 $/h

In this case, the process of adjusting energy values for the hydro-generators is shown in figure 10. The processes of optimization of such as the fuel cost of thermal plants, the cost of transmission MW losses, the cost of hydro plants and the total cost are shown in the figures 11, 12, 13 and 14 following

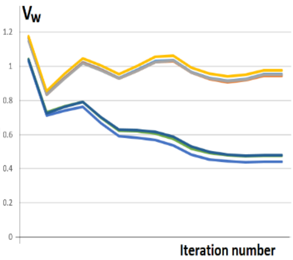

Fig.10 Adjusting energy values of water consumption

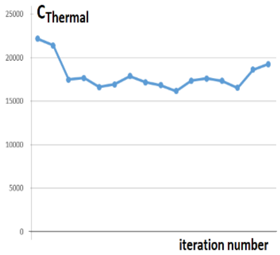

Fig.11 Optimizing the fuel-costs of thermal plants

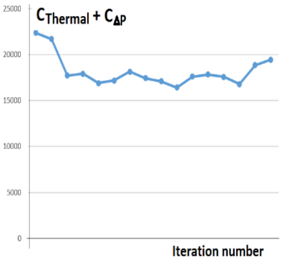

Fig.12 Optimizing the fuel cost of thermal plants and the cost of MW losses

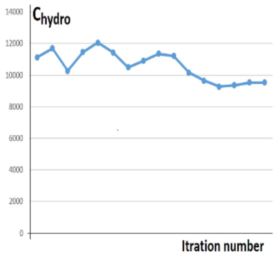

Fig.13 Optimizing the costs of water consumption of hydro-plants

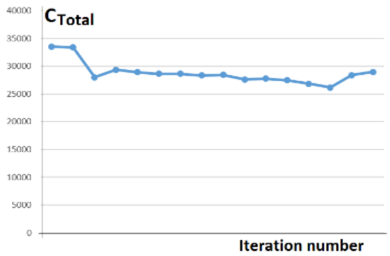

Fig.14 Optimizing the total costs

4. CONCLUSION

The problem of dynamic optimization can be transformed into successive sub-problems of static optimization for pq-power optimization in framework of short term hydrological forecasting, hence, a new algorithm relating to adjusting the energy values of water consumption is created for solving the problem of optimum dispatching of pq-power for the daily load forecasting in multi-machine hydro-thermal power system.

The test results show that the new proposed algorithm is reliable, the gradient search technique has a good convergence by choosing the suitable gradient steps.

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NOMENCLATURE

W : water consumption
w : incremental consumption of water
H : water head
ΔH : water head deviation
P_T : turbine power
ΔP_T : turbine power loss
P_g : generator power
e_T : efficiency of turbine
e_g : efficiency of generator
$e_{T\text{-}g}$: efficiency of turbine-generator unit
$C_{Thermal}$: fuel-cost of thermal generation
C_{hydro} : water consumption cost
$C_{\Delta P}$: transmission MW loss cost
P_{ther} : MW-output of thermal generator
P_{hyd} : MW-output of hydro generator
P_D : total power demand
ΔP : transmission MW losses
T : time period
W_o : water amount depending on forecasting
V_W : energy value of water consumption
λ : lagrange multiplier
Q_g : MVAR-output of generator
B_{mn} : mn-th element of B-coefficient matrix