PQ_POWER OPTIMIZATION IN HYDRO-THERMAL POWER SYSTEM USING NEWTON ITERATION TECHNIQUE

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ABSTRACT A new algorithm of optimal coordination of power of the generator units in hydro-thermal power system is proposed for daily dispatching in multi-machine power system, a problem of dynamic optimization is solved by transforming into a series of the successive sub-problems of static optimization. Using the adjustable energy values of water consumption, the hydro-thermal power outputs are controlled under condition of the technical thermal-power and the seasonal hydro-power limits satisfying to the specific constraints to minimize the thermal fuel cost and the transmission active power losses. The fuel cost characteristics of the thermal generator are simulated in form of superposition of some high order polynomial and sinusoidal functions considering the turbine back-pressure effect of thermal generator units. The water consumption characteristic of the hydro unit is approximately simulated in a form considering the water limit constraints of hydro power generation under condition of dry or rain seasons. A new loss factor formula expressing the network transmission power losses is proposed to build the new algorithm using the newton iteration technique for optimum solution of active and reactive powers of the generators in hydro-thermal multi-machine power system. Some typical numerical examples are presented in this article.

INTRODUCTION

The main objective of an economic power dispatch strategy of the hydro-thermal power system is to determine the optimal operating state of a multi-machine power system by optimizing a particular objective while satisfying certain specified physical and operating constraints. The initial statement of this problem is expressed for a period of T, the target is written as follows

$$C_{Ther} = \int_o^T \left(\sum_{i=1}^{N_g} C_{Ther\,i} \right) dt \;\rightarrow \min; \qquad (1)$$

The problem (1) is the economic power dispatch strategy, belonging to the problems of dynamic optimization, considering the conditions of the period of T, depending on the seasonal hydrological forecast.

The fuel cost characteristics of the thermal unit rating upper 25 MW may be fit for n^{th} order polynomial superposing some sinusoidal function to simulate the turbine back-pressure effect of generator on the thermal electrical stations, approximately

$$C_{Ther\,i} = \sum_{m=o}^{3} a_{i\,(3-m)} P_{gi\,t}^{(3-m)} + b_i \sin(c_i (P_{gi\,t} - d_i)); \qquad (2)$$

The target (1) should subject to the active power balancing in t^{th} interval of time

$$g_t(P_{g\,t}) = P_{Dt} + \Delta P_t - \sum_{i=1}^{n} P_{gt\,i\,t} - \sum_{j=1}^{m} P_{gh\,j\,t} = 0; \qquad (3)$$

and to the water balancing relating to the water amounts that must be known by forecasting in a seasonal period controlling the water discharge

$$\mathrm{W}_j = \int_o^T \mathrm{W}_{j\,t} dt - \mathrm{W}_{j\,o} T \simeq 0; \quad j = 1, 2...m; \qquad (4)$$

The characteristics of water consumption of the hydro units can be built in the laboratory or on the hydro plants by using the general characteristic curves and by applying the method called using the characteristics of the changing of water head level, may be taken in the form of some curve (Luu H.V.Quang, 2016), simulating as follows:

$$\mathrm{W}_{jt}(P_{gh}, H_{\mathrm{W}}) = a_{h\,j} P_{gh\,j}^2 + b_{h\,j} P_{gh\,j} + \mathrm{c}_{h\,j}; \qquad (5)$$

MATHEMATICAL MODELING

Let's suppose the weather and hydrological forecasts in short time are reliable, the water inflow and water storage amounts into the reservoir and the average water availability per hour in the reservoir of hydro plant can be known with a certain water head in daily time. Let’s choose the period of T=24h for a daily dispatching and take the active power outputs of thermal and of hydro units to be the control variables, hence, the problem described by (1), (2), (3), (4) and (5) may be transformed into a problem of static optimization for every one hour (Δt=1h), the target will be written as

$$L_t = \sum_{i=1}^{n} C_{Ther\,i\,t} + \sum_{j=1}^{m} V_{W\,jt} W_{jt} + \lambda_t g_t(P_{gt}) \to \min; \tag{6}$$

Considering the reliable short-term forecast, the constraints for the controlled variables can be simplified under condition of solving the static optimization of active power for every one hour (Δt=1h) as follows

$$(P^{-}_{gt\,i} \le P_{gt\,i} \le P^{+}_{gt\,i}); \tag{7}$$

$$(P^{-}_{gh\,i} \le P_{gh\,i} \le P^{+}_{gh\,i}); \tag{8}$$

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

$$\Delta P(Q_{g\,i}) + \lambda_q h(Q_{g\,i}) \to \min; \tag{9}$$

Where $h(Q_{g\,i})$ is the constraint demonstrating the reactive power balancing in the t-th interval of time

$$h(Q_{g\,i}) = Q_D + \Delta Q_L - Q_C - \sum_{i=1}^{N_g} Q_{g\,i} = 0; \tag{10}$$

Using the MW-loss factor B_{mn} finding under condition of the tth solution of the load power flow problem to write the target function

$$\sum_{m=1}^{N_g} \sum_{n=1}^{N_g} Q_{gm\,t} B_{mn\,t} Q_{gn\,t} + \lambda_{q\,t} h(Q_{gi\,t}) \to \min; \tag{11}$$

herein

$$B_{mn} = \frac{\cos(\alpha_m - \alpha_n)}{V_m V_n \cos\varphi_m \cos\varphi_n} \sum_{r=1}^{N_b} \frac{\left|\sum_{h=1}^{N} c_{rh} J_h - c_{rm} J_\Sigma\right| \times \left|\sum_{h=1}^{N} c_{rh} J_h - c_{rn} J_\Sigma\right|}{\left|J_\Sigma\right|^2};$$

The controlled variables in (11) should be satisfying

$$Q^{-}_{gi\,t}(S_{i\,t}) \le Q_{gi\,t} \le Q^{+}_{gi\,t}(S_{i\,t}); \tag{12}$$

$$V^{-}_{i\,t} \le V(Q_g)_{i\,t} \le V^{+}_{i\,t}; \tag{13}$$

The problems of (6)-(7)-(8) and (11)-(12)-(13) can be written in the general form as follows

$$\begin{cases} F(X_t) \to \min; \\ X_i^{-} \le X_{it}^{(s)} \le X_i^{+}; \\ y_i^{-} \le y(X)_{it}^{(s)} \le y_i^{+}; \end{cases} \tag{14}$$

Solving by the newton iteration technique, the controlled variables (X_i) are alternatively the active or reactive power outputs of the generators.

The controlled variables can be adjusted step-by-step in the process of newton iteration, the sth iteration step is as follows

$$X^{(s+1)} = X^{(s)} - H_F^{(s)}(\nabla F^{(s)} + \nabla f^{(s)}); \tag{15}$$

where H_F and $(\nabla F^{(s)}+\nabla f^{(s)})$ are the inverse hessian matrix and the vector gradient, relating to the target functions.

The penalty vector ($f^{(s)}$) is introducing for each violated inequality constraint with respect to the controlled variables, the ith element of which is

$$f_i^{(s)} = \mu((X_i^{(s)} - X_i^{+})^2 + (X_i^{(s)} - X_i^{-})^2); \tag{16}$$

The iteration process will be converging on condition of $(\nabla F^{(s)}+\nabla f^{(s)}) \to 0$.

NUMERICAL EXAMPLE

Let’s survey the optimum 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 is given in the table 1, table 2, table 3 and table 4, as follows

Table 1. Linedata

Bus (i)	Bus (j)	R (pu)	X (pu)	B/2 (pu)
1	48	0.0083	0.2066	0
2	48	0.0083	0.2066	0
3	48	0.0083	0.2066	0
4	48	0.0083	0.2066	0
5	50	0.0083	0.2066	0
6	50	0.0083	0.2066	0
7	44	0.0021	0.2066	0
8	44	0.0083	0.2066	0
9	44	0.0083	0.2066	0
10	44	0.0083	0.2066	0
11	45	0.0083	0.2066	0
12	45	0.0083	0.2066	0
13	45	0.0083	0.2066	0
14	45	0.0083	0.2066	0
15	47	0.0055	0.1504	0
16	47	0.0055	0.1504	0
17	47	0.0055	0.1504	0
18	19	0.0353	0.0856	0.021199
18	39	0.0102	0.2087	0
18	74	0.0563	0.0886	0.020231
19	20	0.0219	0.0531	0.013165
19	40	0.0102	0.2087	0
19	48	0.0009	0.0393	0
19	53	0.0007	0.0702	0
20	21	0.0456	0.0717	0.016359
20	41	0.0058	0.1299	0
21	42	0.0102	0.2087	0
21	60	0.0547	0.1328	0.032865
22	58	0.0026	0.0646	0
23	59	0.0102	0.2087	0
24	60	0.0102	0.2087	0
25	61	0.0102	0.2087	0
26	62	0.0075	0.1624	0
27	63	0.0102	0.2087	0
28	64	0.0102	0.2087	0
29	65	0.0102	0.2087	0
30	66	0.0102	0.2087	0
31	67	0.0058	0.1299	0
32	68	0.0177	0.3236	0
33	69	0.0177	0.3236	0
34	70	0.0177	0.3236	0
35	71	0.0177	0.3236	0
36	72	0.0177	0.3236	0
37	73	0.0177	0.3236	0

38	74	0.0102	0.2087	0
43	44	0.0015	0.0628	0
43	54	0.0013	0.1033	0
43	62	0.0288	0.0823	0.021006
43	63	0.0706	0.1713	0.010600
43	68	0.0728	0.0703	0.015052
44	45	0.0090	0.0471	0.266829
44	46	0.0071	0.0313	0.172652
45	47	0.0108	0.0566	0.320553
45	58	0.0009	0.0393	0
46	71	0.0015	0.0628	0
47	48	0.0144	0.0633	0.349357
47	67	0.0009	0.0393	0
49	50	0.0090	0.0471	0.266829
49	60	0.0009	0.0393	0
50	51	0.0015	0.0628	0
50	75	0.0083	0.2066	0
51	52	0.0026	0.0646	0
55	58	0.0007	0.0702	0
56	67	0.0007	0.0702	0
57	71	0.0013	0.1033	0
58	59	0.0552	0.0868	0.019796
58	60	0.0340	0.0970	0.024732
58	61	0.0242	0.0690	0.017618
60	61	0.0476	0.1359	0.008664
62	63	0.0797	0.1254	0.007163
64	65	0.0354	0.0859	0.021248
65	67	0.0258	0.0736	0.018779
66	67	0.0441	0.1070	0.026475
67	73	0.1397	0.2198	0.012536
69	70	0.0405	0.0512	0.011374
70	71	0.0422	0.0663	0.015149
71	72	0.0502	0.0789	0.018005
72	73	0.0695	0.1093	0.006244

The total daily load contains different load levels, let's investigate one level of the daily load, showing in the table 3 as follow

Table 2. Load bus-data

Bus (i)	Load		Bus (i)	Load	
	MW	MVAR		MW	MVAR
18	0.058	0.4	44	0.2	1.6
19	0.058	0.4	45	0.2	1.6
20	0.084	0.56	46	0.15	1
21	0.058	0.4	47	0.2	1.6
22	48.125	17.545	48	0.2	1.6
23	16.225	6.655	49	0.2	1.6
24	19.25	7.865	50	0.2	1.6
25	19.25	8.47	51	0.14	0.96
26	20.35	9.075	52	43.175	13.915
27	15.95	7.26	58	0.14	0.96
28	14.85	6.05	59	0.058	0.4
29	17.05	7.865	60	0.058	0.4
30	18.15	7.865	61	0.058	0.4
31	32.45	10.285	62	0.07	0.48
32	10.45	4.235	63	0.058	0.4
33	11.55	5.445	64	0.058	0.4
34	9.9	3.63	65	0.058	0.4
35	11	4.84	66	0.058	0.4
36	11.55	3.63	67	0.084	0.56
37	14.85	5.445	68	0.042	0.272
38	15.95	7.865	69	0.042	0.272
39	13.2	3.025	70	0.042	0.272
40	23.1	9.68	71	0.042	0.272
41	11.55	4.235	72	0.042	0.272
42	11.55	4.235	73	0.042	0.272
43	0.15	1	74	0.058	0.4

The limits of active power outputs of the thermal units are determined under technical conditions. The limits of active power outputs of the hydro units are determined not only under technical conditions, but also under seasonal conditions relating to the solution of static optimization for daily dispatching applying to every one hour. Let's the power limits are given in table 3 as follows

Table 3. Limits of Power Generation

Bus (i)	Unit Type	P_{min} (MW)	P_{max} (MW)	$S_{nominal}$ (MVA)
1	Thermal	13	67	75
2	Thermal	13	67	75
3	Thermal	13	67	75
4	Thermal	13	67	75
5	Thermal	13	55	63
6	Thermal	13	55	63
7	Thermal	13	55	63
8	Thermal	13	55	63
9	Thermal	13	52	60
10	Thermal	13	52	60
11	Hydro	12	51	62
12	Hydro	12	51	62
13	Hydro	12	51	62
14	Hydro	12	51	62
15	Hydro	12	47	72
16	Hydro	12	47	72
17	Hydro	12	47	72
75	Thermal	13	55	63

The fuel cost characteristics of the thermal units and the characteristics of water consumption of the hydro units are given in forms (2), (5), containing the suitable coefficients as shown in table 4 as follow

Table 4. Characteristic Coefficients

Bus	a_3	a_2	a_1	a_o	b	c	d
1	0.000162	0.3039	40.5	323	270	0.126	14
2	0.000168	0.3017	39.19	304	267	0.126	14
3	0.000167	0.3021	39.2	305	267	0.126	14
4	0.000167	0.3019	39.18	304	267	0.126	14
5	0.000199	0.3037	41.51	321	270	0.126	14
6	0.0002	0.304	41.49	322	270	0.126	14
7	0.0002	0.3038	41.49	323	270	0.126	14
8	0.000198	0.304	41.48	322	270	0.126	14
9	0.000145	0.3007	38.17	301	270	0.126	14
10	0.000147	0.3009	38.2	302	270	0.126	14
11	-	0.015	42.349	252.65	-	-	-
12	-	0.016	41.292	253.95	-	-	-
13	-	0.015	43.146	251.25	-	-	-
14	-	0.014	42.451	253.32	-	-	-
15	-	0.023	47.945	283.83	-	-	-
16	-	0.021	48.121	282.97	-	-	-
17	-	0.022	47.915	285.18	-	-	-
75	0.000148	0.3028	41.6	320	270	0.126	14

The 75^{th} bus is pilot-slack, the voltage of which is maintained of 1.05p.u. Typical results of pq-optimization are shown in the table 5, table 6, fig.1 and fig.2, as follows

Table 5. Optimum Costs

Category	Quantity
Economic Fuel-Cost \$/h	12382.85
Rating of Energy-Losses \$/MWh	30.00
Economic MW-Loss Cost \$/h	134.47
Economic Objective \$/h	12517.32
Economic Hydro-Cost \$/h	4793.94
Total Economic \$/h	17311.26

Table 6. Optimum hydro-thermal generation

Bus (i)	Generation MW	MVAR	Bus (i)	Generation MW	MVAR
1	13.254	-8.227	10	13.000	-4.775
2	13.254	-8.227	11	51.000	-11.778
3	13.254	-8.227	12	12.000	-10.879
4	13.254	-8.227	13	51.000	-11.778
5	15.392	-3.839	14	12.000	-10.879
6	15.392	-3.839	15	47.000	-10.385
7	31.423	-10.317	16	12.000	-15.121
8	13.000	-4.775	17	47.000	-10.385
9	13.000	-4.775	75	30.641	-13.054

The process of pq-optimization is implemented with adjusting the energy values of water consumption

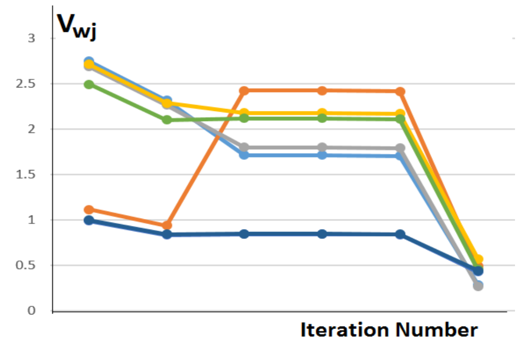

Fig.1 Adjusting the energy values of water consumption

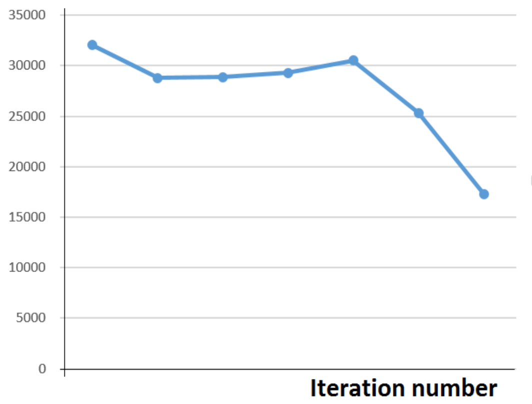

Fig.1 Optimizing the total cost

CONCLUSION

The new algorithm of pq_optimization of the hydro thermal power generation has the advatages, basing on the transformation of problem of dynamic optimization into successive sub-problems of static optimization, allowing to use the newton iteration technique for the calculation controlling the power outputs of the thermal units in conjunction with the power outputs of the hydro units, satisfying to the specific technical and the seasonal constraints to minimize the thermal fuel cost and the active power losses in a hydro-thermal multi-machine power system.

The application of the specific type of fuel cost function for the problem of optimizing the active and reactive power generation is verified by new algorithm, allowing to simulate the back-pressure effect of thermal turbine regulation.

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NOMENCLATURE

C_{Ther} : fuel-cost
P_{gt} : active power output of thermal generator
P_{gh} : active power output of hydro generator
P_D : total active power demand
ΔP : transmission MW-losses
W_j : water consumption
$V_{W\,j\,t}$: energy value of water consumption
Q_D : total reactive power demand
ΔQ_L : transmission MVAR-losses
Q_C : sum of line MVAR-charging
Q_g : reactive power output of generator
V_m : voltage modul of mth generator
α_m : argument
$\cos\varphi_m$: power factor of mth generator
J_h : current at the hth bus
J_Σ : Sum of all of bus current
N : number of bus (h=1..N)
N_g : number of generator bus
N_b : number of branch (r=1..N_b)
$c_{r\,n}$: current distribution factor taken from the matrix equation of the first Kirchhoff's rule