Considering the turbine back-pressure effect of thermal units to optimize the PQ_power generation in power system

- **Luu Huu Vinh Quang**

University of Technology, VNU-HCM

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ABSTRACT:

A new algorithm of PQ_power optimization is mentioned and some typical numerical examples are presented in this article. The fuel cost characteristics being obtained in form of superposition of some high order polynomial and sinusoidal functions can approximately simulate the turbine back-pressure effect of the generator units at the electrical thermal stations and solve the problem of economic active power dispatch.

A new loss factor formula expressing the network transmission power losses is a second order polynomial function of generator powers containing a square matrix. This loss factor formula is proposed for optimum solution of generator reactive powers in multi-machine power system.

Keywords: *Steady-State Optimization; Turbine Back-Pressure Effect; Power System Operation.*

INTRODUCTION

Optimal pq_power generation (OPQG) containing economic p_power generation (EPG) and optimum q_power generation (OQG) is important problem to be solved in the operation and planning of a power system. The objective of the OPQG problem is to determine the optimal combination of pq_power output of all generator unit so as to meet the required load demand at minimum operating cost while satisfying system technical constraints.

The main objective of an economic power dispatch strategy is to determine the optimal operating state of a power system by optimizing a particular objective while satisfying certain specified physical and operating constraints. In its most general formulation, the economic power dispatch is a nonlinear, nonconvex, large-scale, static optimization problem.

In reality, the turbine fuel cost characteristics can be obtained in form of some convex fracture, this is notably arised from the back-pressure turbine characteristic, in addition, the turbine regulation method also raises some effect to the appearance of turbine fuel cost characteristics, and it may be briefly called the turbine back-pressure effect, practically showing as follows [1],[2]

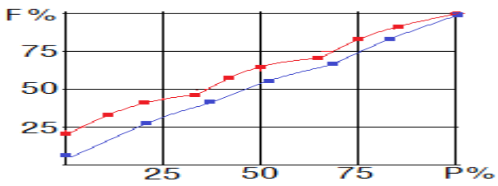

Fig.1 Fuel cost function F(P) in p.u.

In most cases, the fuel cost characteristics of the units rating under 25MW may be determined experimentally and fit for the 2nd order polynomial function. The fuel cost characteristics of unit rating upper 25MW 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

$$C(P_g) = \sum_{m=0}^{n} a_{n-m} P_g^{n-m} + b\sin(c(P_g - d)); \qquad (1)$$

Some typical unit fuel cost characteristics are approximately rated for simulation of turbine back-pressure effect as follows

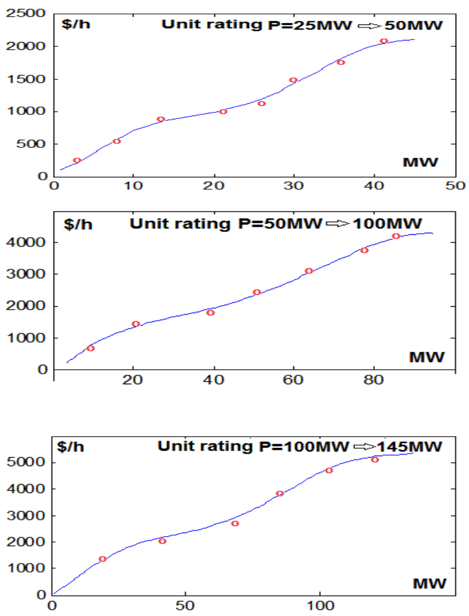

Fig.2 Typical Unit rating fuel cost functions.

This paper is organized as follows 2.Statement of EPG Problem. 3.Statement of OQG problem. 4.Statement of SVC q_power optimization. 5.Numerical examples; 6.Conclusion; 7.References.

STATEMENT OF EPG PROBLEM

Using the fuel costs (1) to solve the economic p_power dispatch (EPD) problem minimizing the total fuel cost in the whole of electrical power system which consists of many stations. The target function is

$$F = C(P_{gi}) + \lambda G(P_{gi}, V) \rightarrow \min; \qquad (2)$$

subject to

$$(P^{-}_{gi} \le P_{gi} \le P^{+}_{gi}); \qquad (3)$$
$$i = (1 \ldots N_g)$$

where

$$C(P_{gi}) = \sum_{i=1}^{N_g} \left(b_i \sin(c_i (P_{gi} - d_i)) + \sum_{k=0}^{n} a_{i,n-k} P_{ngi}^{n-k} \right); \qquad (4)$$

$$G(P_{gi}, V) = \Delta P_P(P_{gi}, V) + P_D - \sum_{i=1}^{N_g} P_{gi}; \qquad (5)$$

N_g is number of generator unit; (i,m,r=1..N_g); P_D is total MW_power load demand;

$\Delta P_P(P_{g\,i}, V)$ is total transmission MW loss which is taken form in

$$\Delta P_P(P_{m\,gi}, V) = \sum_{m=1}^{N_g} \sum_{r=1}^{N_g} P_{m\,gi} B_{mr} P_{r\,gi}; \qquad (6)$$

MW-loss factors B_{mr} can be found on condition of the t-th solution of LPF problem [1].

$$B_{mr} = \frac{\cos(\alpha_m - \alpha_r)}{V_m V_r \cos\varphi_m \cos\varphi_r} \times \sum_{j=1}^{N_b} \frac{\left|\sum_{h=1}^{N} C_{jh} J_h - C_{jm} J_\Sigma\right| \times \left|\sum_{h=1}^{N} C_{jh} J_h - C_{jr} J_\Sigma\right|}{\left|J_\Sigma\right|^2}; \qquad (7)$$

where V_m is m-th bus voltage modul; α_m is argument of current output from the m-th generator; $\cos\varphi_m$ is power factor of m-th generator; J_h is h-th bus current; J_Σ is sum of all of bus currents; C_{jm} is current distribution factor;

N is number of bus (h=1..N); N_b is number of branch (j=1..N_b).

The solution of the problem (2), (3) is iterative calculation of hessian matrix [1], [3], as follows

$$P_g^{(t+1)} = P_g^{(t)} - H_F^{(t)}(\nabla F^{(t)} + \nabla f^{(t)}); \qquad (8)$$

where t is iteration number; P_g is variable vector of p_power; H_F is inversive hessian matrix of target function; $(\nabla F^{(t)}+\nabla f^{(t)})$ is vector gradient of target function; $f^{(t)}$ is penalty vector, the i^{th} element of which is

$$f_i^{(t)} = \mu((P_{gi}^{(t)} - P_{gi}^{+})^2 + (P_{gi}^{(t)} - P_{gi}^{-})^2); \qquad (9)$$

The iteration process of generator p_power optimization will be converged on condition of $(\nabla F^{(t)}+\nabla f^{(t)})\to 0$.

STATEMENT OF OQG PROBLEM

The OQG problem 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

$$F_q = \sum_{i=1}^{N_g}\sum_{j=1}^{N_g} Q_{gi} B_{ij}^{*} Q_{gj} \to min \qquad (10)$$

subject to

$$Q_{gi}^{-}(S_i) \le Q_{gi} \le Q_{gi}^{+}(S_i); \qquad (11)$$

$$V_i^{-} \le V(Q_g)_i \le V_i^{+}; \qquad (12)$$

$$Q_D + \Delta Q_L - Q_C - \sum_{i=1}^{N_g} Q_{gi} = 0; \qquad (13)$$

Q_{gi} is MVAR output from i^{th} generator; i,j=1..N_g ;

S_i is MVA output from i^{th} generator;

Q_D is total MVAR load in power system;

ΔQ_L is total transmission MVAR loss in the inductive elements of network; Q_C is total capacitive reactive power charging of transmission lines.

The solution of the problem (10),(11), (12),(13) is iterative calculation of gradient [1], as follows

$$Q_{gi}^{(t+1)} = Q_{gi}^{(t)} - \gamma \nabla F_q^{(t)}; \qquad (14)$$

γ is gradient step value;

The t^{th} iterative gradient of target function [1] may be determined as follows:

$$\nabla F_q^{(t)} = 2\sum_{j=1}^{N_g} B_{ij}^{*} Q_{gi}^{(t)} + 2\mu_q Q_{gi}^{(t)} - \frac{1}{N_g}\sum_{i=1}^{N_g}\left(2\sum_{j=1}^{N_g} B_{ij}^{*} Q_{gi}^{(t)} + 2\mu_q Q_{gi}^{(t)}\right); \qquad (15)$$

μ_q is penalty factor;

The iteration process of generator q_power optimization will be converged on condition of $(\nabla F^{(t)}_q \to 10^{-6})$.

STATEMENT OF REACTIVE POWER OPTIMIZATION FOR VAR SUPPORTING DEVICES

Let's refer to [4],[5]. In this case, the operation conditions requiring a specific steady state at each time interval of load changing in 24 hours, and the test algorithm can reach a purpose which is to solve optimization commitment of device supporting MVAR power, such as TSC, TCR, SVC or synchronous condensers... This proposed mathematical model can be applied to schedule the operation charts of VAR optimization in a power system with multiple voltages level. Here, the problem of optimizing the voltage and q_power in a power system is solved separately for p_power, i.e. the number of bus of p_power generation in the target network may be generally different from the number of bus of q_power supporting device, and assuming that the bus p_power does not change, it may have been optimized before. The target of VAR optimization problem is established to minimize the total cost value [4] consisting of following cost components:

- electrical energy and power losses in the power transmission network;

- installation and operation for var supporting devices;

- depreciation and operation of transfo-LTC;

- q_power generation of power plant;

- optimization of voltage level of power system;

A general form of the objective function of the total cost calculation is written as

$$\mathbf{c(x_j)=c_{qb}(q_{bj})+c_{dp}(x_j)+c_{mba}(q_{kr})+c_{qg}(x_j)+c_{du}(x_j);} \quad (16)$$

where j=1,2,…number of independent bus in power system; $q_{b\ j}$ is the controlled MVAR capacity at the bus (j) to meet objective; $c_{qb}(q_{bj})$ is the cost of installation and operation for VAR supporting devices; $c_{dp}(x_j)$ is the cost of electrical energy and power losses in the power transmission network; $c_{mba}(q_{kr})$ is the cost of depreciation and operation of transfo-LTC; $c_{qg}(x_j)$ is the cost of VAR generation of power plant; $c_{du}(x_j)$ is the costs optimizing the average voltage level in the power system; x_j is the controlled variables corresponding to bus (j) to meet objective. The controlled variable (x) is a collective set of the numeric value of voltage module of the power plant busbars and of the transformer station busbar with LTC; or a set of numeric value of VAR capacity of compensation devices located at the bus (i) in power system; or a set of numeric value simulating the transfo LTC at the bus (i) in a power system.

The problem of VAR and voltage optimization is written as follows:

Determine the condition $w(x,y)\rightarrow 0$, such that $c(x)\rightarrow min$ and satisfy the constraints :

$(v^-_j \le v_j(q_{c\ j},a_j)\le v^+_j)$; j=1,2 ,.., total bus number;

$(q_{c\ j}\ge 0)$;

$(k^-_{min\ m} \le k_m(v_r,a_r) \le k^+_{max\ m})$; m=1,2,…., total transformer number;

$(q^-_{g\ i} \le q_{g\ i}(v_i,a_i)\le q^+_{g\ i})$; i=1,2 ,.., total PV bus number;

where: q_{bj} is the VAR capacity to be supported at the bus (j); (q_b, a_i) is the voltage at the j^{th} bus; $q_{gi}(v_i, a_i)$ is the generated VAR capacity of the i^{th} power plant; a_i is the i_th element of the eigen-image vector A simulating a certain steady state structure of power system; k_m is the numeric value corresponds to one simulated ratio of the LTC of m_th transformer; w(x,y) is the vector balance indicating a certain technical condition of steady state of power system; x is the vector controlled to meet objectives (the v_g, q_b and the k_{mba}); y is the non-controlled vector.

In reality, we can apply some specific factors or choose some parameters depending on concrete conditions of q_power optimization to take account of total cost function $c(x_j)$ or of just one component function.

In this article the component function $c_{dp}(x_j)$ is used to make the target function of q_power optimization problem. The statement of q_power optimization of VAR supporting device is to determine $c_{dp}(q_{bj})\rightarrow min$. Then, this pq_power optimization problem may be solved with multi-target function by applying the method of optimum co-ordination, i.e. the main function (2) must be satisfied (10) under condition of $c_{dp}(q_{bj})\rightarrow min$.

NUMERICAL EXAMPLE

Let's survey the optimum condition operartion of a 68-bus power system consisting of 4 thermal stations with 15 generation units and of 5 SVC stations. Basic power is 100MVA. The linedata is given in p.u. in table 1 as follows:

Table 1. Linedata

Bus (i)	Bus (j)	R (pu)	X (pu)	B/2 (pu)
49	50	0.055207202	0.086838638	0.019818687
49	51	0.033958779	0.096990529	0.024738886
49	52	0.024158946	0.069000979	0.01759974
49	22	0.002620277	0.064573756	0
49	45	0.000870248	0.039256198	0
50	23	0.010239233	0.20865162	0
51	52	0.047584215	0.135906483	0.008666262
51	24	0.010239233	0.20865162	0
52	25	0.010239233	0.20865162	0
53	54	0.079699126	0.125363417	0.007152746
53	26	0.007538333	0.162367539	0
53	43	0.028823037	0.082322209	0.020997517
54	27	0.010239233	0.20865162	0
54	43	0.070558795	0.171287676	0.010596018
55	56	0.035405171	0.085949163	0.021267541
55	28	0.010239233	0.20865162	0
56	58	0.025783517	0.073640957	0.018783217
56	29	0.010239233	0.20865162	0
57	58	0.044083527	0.107016632	0.02648056
57	30	0.010239233	0.20865162	0
58	16	0.139724411	0.2197807	0.012539811
58	31	0.005804919	0.129894031	0
58	47	0.000870248	0.039256198	0
59	32	0.01765663	0.323615302	0
59	43	0.072803366	0.070299545	0.015033814
60	61	0.040505438	0.051240957	0.011359432
60	33	0.01765663	0.323615302	0
61	62	0.042158227	0.066313143	0.015134293
61	34	0.01765663	0.323615302	0
62	15	0.050188366	0.078944217	0.018016997
62	35	0.01765663	0.323615302	0
62	46	0.001539669	0.062809917	0
15	16	0.069460698	0.109258798	0.006233872

15	36	0.01765663	0.323615302	0
16	37	0.01765663	0.323615302	0
17	18	0.056311347	0.088575411	0.020215083
17	38	0.010239233	0.20865162	0
18	19	0.035279399	0.085643839	0.021191988
18	39	0.010239233	0.20865162	0
19	20	0.021884545	0.053126659	0.013145827
19	40	0.010239233	0.20865162	0
19	48	0.000870248	0.039256198	0
20	21	0.045571037	0.071681349	0.016359442
20	41	0.005804919	0.129894031	0
21	42	0.010239233	0.20865162	0
43	44	0.001539669	0.062809917	0
44	45	0.008976942	0.04710124	0.2668292
44	46	0.007107025	0.031283058	0.17265248
45	47	0.01078438	0.056584711	0.3205532
47	48	0.014380847	0.06330031	0.349357008
44	1	0.002066116	0.20661157	0
44	2	0.008264463	0.20661157	0
44	3	0.008264463	0.20661157	0
44	4	0.008264463	0.20661157	0
45	5	0.008264463	0.20661157	0
45	6	0.008264463	0.20661157	0
45	7	0.008264463	0.20661157	0
45	8	0.008264463	0.20661157	0
47	9	0.005454545	0.150413223	0
47	10	0.005454545	0.150413223	0
47	11	0.005454545	0.150413223	0
48	12	0.008264463	0.20661157	0
48	13	0.008264463	0.20661157	0
48	14	0.008264463	0.20661157	0
48	68	0.008264463	0.20661157	0
19	63	0.00072562	0.070247934	0
43	64	0.001283471	0.103305785	0
49	65	0.00072562	0.070247934	0

58	66	0.00072562	0.070247934	0
62	67	0.001283471	0.103305785	0

Let's investigate the case of loud load. The busdata of initial operation condition of power system is given in tables 2a, 2b and 2c as follows:

Table 2a. SVC-data

Bus (i)	Max-MVAR of TCR	Max-MVAR of TSC
63	-20	20
64	-30	20
65	-40	30
66	-50	40
67	-30	20

Table 2b. Loud Load-data

Bus (i)	Load MW	Load MVAR	Fixed Capacitor MVAR
49	0.14	0.96	0
50	0.06	0.4	0
51	0.06	0.4	0
52	0.06	0.4	0
53	0.07	0.48	0
54	0.06	0.4	0
55	0.06	0.4	0
56	0.06	0.4	0
57	0.06	0.4	0
58	0.08	0.56	0
59	0.04	0.272	0
60	0.04	0.272	0
61	0.04	0.272	0
62	0.04	0.272	0

15	0.04	0.272	0
16	0.04	0.272	0
17	0.06	0.4	0
18	0.06	0.4	0
19	0.06	0.4	0
20	0.08	0.56	0
21	0.06	0.4	0
22	77.5	58	20
23	27.5	18.12	7
24	35	29.47	12
25	31	24.63	10
26	35	27.54	11
27	25	19.68	8
28	23	18.17	7
29	27	18.26	7
30	31	20.96	8
31	50	33.8	15
32	15	11.61	3
33	17	11.2	4
34	17	14.31	6
35	17	13.5	5
36	17	16.47	7
37	25	20.85	9
38	27	26.92	12
39	21	20.36	8
40	39	30	15
41	18	17.32	7
42	17	13.38	6
43	0.15	1	0
44	0.2	1.6	0
45	0.2	1.6	0
46	0.15	1	0

47	0.2	1.6	0
48	0.2	1.6	0

Table 2c. Generator-data

Bus (i)	Initial Generator MW	Initial Bus Voltage (p.u.)
1	40	1.08
2	40	1.08
3	40	1.08
4	40	1.08
5	40	1.08
6	40	1.08
7	40	1.08
8	40	1.08
9	40	1.08
10	40	1.08
11	40	1.08
12	40	1.08
13	40	1.08
14	40	1.08
68	Pilot-Slack	1.08

The fuel cost characteristics of thermal unit are given in form of a third order polynomial adding a sinusoidal function of p_power generation:

$$C(P_g) = a_3P_g^3 + a_2P_g^2 + a_1P_g + a_o + b\sin(c(P_g - d));$$

and the specific data of which is given in table 3 with suitable coefficients as follows:

Table 3. Characteristic coefficients

Bus	a_3	a_2	a_1	a_o	b	c	d
1	0.0002	0.304	40.41	324	270	0.126	14
2	0.00021	0.3039	40.45	325	270	0.126	14
3	0.00019	0.3038	40.46	323	270	0.126	14
4	0.0002	0.3039	40.45	324	270	0.126	14
5	0.00019	0.3037	40.44	323	270	0.126	14
6	0.00021	0.304	40.45	324	270	0.126	14
7	0.0002	0.3038	40.5	325	270	0.126	14
8	0.00019	0.3039	40.5	323	270	0.126	14
9	0.00017	0.3017	39.19	303	267	0.126	14
10	0.00017	0.3021	39.2	301	267	0.126	14
11	0.00017	0.3019	39.18	302	267	0.126	14
12	0.00019	0.303	40.51	321	270	0.126	14
13	0.0002	0.304	40.49	322	270	0.126	14
14	0.0002	0.303	40.49	323	270	0.126	14
68	0.00019	0.304	40.5	322	270	0.126	14

Generation limit data is given in table 4 as follows:

Table 4. Generation limit data

Bus (i)	P_{min} (MW)	P_{max} (MW)	$S_{nominal}$ (MVA)
1	1	60	62
2	1	60	62
3	1	60	62
4	1	60	62
5	1	60	62
6	1	60	62
7	1	60	62
8	1	60	62
9	1	72	75
10	1	72	75
11	1	72	75
12	1	60	62
13	1	60	62
14	1	60	62
68	1	60	62

The pilot-slack bus is 68th and voltage of which is 1.08p.u.

Typical results are shown in table 5 by comparing the initial powers with the optimum power as follows

Table 5. Comparison of generation

Bus (i)	Bus Code	Initial Generation		Optimum Generation	
		MW	MVAR	MW	MVAR
1	Generator	40	8.7020	40.48866	0.41239
2	Generator	40	7.4868	40.31214	0.40703
3	Generator	40	7.4868	40.37952	0.40702
4	Generator	40	7.4868	40.34666	0.40701
5	Generator	40	8.66521	40.3981	0.40728
6	Generator	40	8.66521	40.30547	0.4073
7	Generator	40	8.66521	40.31607	0.40733
8	Generator	40	8.66521	40.34492	0.40732
9	Generator	40	8.45011	41.1155	0.40823
10	Generator	40	8.45011	41.09443	0.40826
11	Generator	40	8.45011	41.11474	0.40821
12	Generator	40	7.40968	40.1322	0.39782
13	Generator	40	7.40968	40.04765	0.39783
14	Generator	40	7.40968	40.11039	0.39784
68	Generator	47.38853	7.69065	40.08194	-0.47976
63	SVC	0	0	0	19.96
64	SVC	0	0	0	6.87161
65	SVC	0	0	0	26.46949
66	SVC	0	0	0	33.18359
67	SVC	0	0	0	8.9178
Initial Fuel Cost 36140.93$/h					
Optimum Fuel Cost 36047.61$/h					
Saving Fuel Cost 93.32$/h					

The bus voltages are compered in table 6 as follows

Table 6. Voltage comparison

Bus (i)	Initial Voltage (p.u.)	Optimum Voltage (p.u.)
1	1.08	1.0755
2	1.08	1.0778
3	1.08	1.0778
4	1.08	1.0778
5	1.08	1.0786
6	1.08	1.0786
7	1.08	1.0786
8	1.08	1.0786
9	1.08	1.0872
10	1.08	1.0872
11	1.08	1.0872
12	1.08	1.0817
13	1.08	1.0817
14	1.08	1.0817
15	1.0065	1.032
16	0.9966	1.0248
17	0.9698	0.9957
18	1.0000	1.025
19	1.0405	1.064
20	1.0249	1.0489
21	1.0123	1.0367
22	0.9995	1.0259
23	0.9735	1.0009
24	0.9567	0.9848
25	0.9697	0.9973
26	0.9837	1.0012
27	0.981	0.9985
28	0.967	1.0014
29	0.9843	1.0179
30	0.9804	1.0141
31	1.0121	1.0443
32	0.9937	1.0108
33	0.965	0.9899
34	0.9725	0.9971
35	0.9971	1.0209
36	0.9704	0.9969
37	0.948	0.9779
38	0.9316	0.9587

39	0.9703	0.996
40	1.0023	1.0268
41	1.0103	1.0347
42	0.9945	1.0193
43	1.0419	1.0581
44	1.0653	1.0767
45	1.0631	1.0775
46	1.0533	1.0687
47	1.0676	1.0861
48	1.0655	1.0806
49	1.0272	1.0529
50	1.0019	1.0284
51	1.0013	1.028
52	1.0066	1.033
53	1.0153	1.0321
54	1.0098	1.0267
55	0.9947	1.0281
56	1.0125	1.0451
57	1.0133	1.0457
58	1.041	1.0722
59	1.0255	1.042
60	0.9939	1.0179
61	1.0047	1.0285
62	1.0291	1.052
63	1.0405	1.077
64	1.0419	1.0647
65	1.0272	1.0703
66	1.041	1.0936
67	1.0291	1.0607
68	1.08	1.08

Let's investigate the case of slight load.

In this case, the SVC-data is also refered to the table 2a. The busdata of initial operation condition of power system is given in table 7a and 7b as follows:

Table 7a. Slight Load-data

Bus (i)	Load MW	Load MVAR	Fixed Capacitor MVAR
15	0.042	0.272	0
16	0.042	0.272	0
17	0.058	0.4	0
18	0.058	0.4	0
19	0.058	0.4	0
20	0.084	0.56	0
21	0.058	0.4	0
22	31	34.88	20
23	12.65	7.98	7
24	19.6	21.7	12
25	22.01	16.74	10
26	14	15.75	11
27	10	11.25	8
28	9.2	10.35	7
29	12.42	7.83	7
30	14.26	8.99	8
31	23	16.5	15
32	6	6.75	3
33	7.82	4.93	4
34	9.52	10.54	6
35	12.07	9.18	5
36	6.8	7.65	7
37	6.8	7.65	9
38	11.5	12.25	12
39	15.12	16.74	8
40	14.91	15.34	15
41	15.6	17.55	7
42	7.2	8.1	6
43	0.15	1	0
44	0.2	1.6	0
45	0.2	1.6	0
46	0.15	1	0

47	0.2	1.6	0
48	0.2	1.6	0
49	0.14	0.96	0
50	0.058	0.4	0
51	0.07	0.48	0
52	0.058	0.4	0
53	0.07	0.48	0
54	0.058	0.4	0
55	0.058	0.4	0
56	0.058	0.4	0
57	0.07	0.48	0
58	0.118	0.82	0
59	0.042	0.272	0
60	0.042	0.272	0
61	0.042	0.272	0
62	0.042	0.272	0

Table 7b. Generator-data

Bus (i)	Initial Generator MW	Initial Bus Voltage (p.u.)
1	19	1.05
2	19	1.05
3	19	1.05
4	19	1.05
5	19	1.05
6	19	1.05
7	19	1.05
8	19	1.05
9	19	1.05
10	19	1.05
11	19	1.05
12	19	1.05
13	19	1.05
14	19	1.05
68	Pilot-Slack	1.05

The pilot-slack bus is 68^{th} and voltage of which is 1.05p.u.

Let's compare the initial powers with the optimum power in case of slight load refering to the table 8 as follows

Table 8. Comparison of generation

Bus (i)	Bus Code	Initial Generation		Optimum Generation	
		MW	MVAR	MW	MVAR
1	Generator	19	-13.01599	18.8412	-1.38059
2	Generator	19	-13.57139	18.9548	-1.28669
3	Generator	19	-13.57139	18.9466	-1.28665
4	Generator	19	-13.57139	18.9490	-1.28686
5	Generator	19	-12.09338	18.9257	-3.91745
6	Generator	19	-12.09338	18.9488	-3.9178
7	Generator	19	-12.09338	18.9657	-3.91777
8	Generator	19	-12.09338	18.9620	-3.91775
9	Generator	19	-18.95797	19.3596	-5.60036
10	Generator	19	-18.95797	19.3227	-5.60023
11	Generator	19	-18.95797	19.3657	-5.60036
12	Generator	19	-9.67552	19.1943	-5.80648
13	Generator	19	-9.67552	19.2092	-5.80652
14	Generator	19	-9.67552	19.1898	-5.80646
68	Generator	20.50082	-9.67984	19.32799	-11.02943
63	SVC	0	0	0	-2.71557
64	SVC	0	0	0	-25.9234
65	SVC	0	0	0	-32.3743
66	SVC	0	0	0	-39.7525
67	SVC	0	0	0	-25.2343
Initial Fuel Cost 20406.75$/h					
Optimum Fuel Cost 20403.71$/h					
Saving Fuel Cost 3.04$/h					

The comparison of bus voltages in case slight load is refering to the table 9 as follows

Table 9. Voltage comparison

Bus (i)	Initial Voltage (p.u.)	Optimum Voltage (p.u.)
1	1.05	1.0666
2	1.05	1.0679
3	1.05	1.0679
4	1.05	1.0679
5	1.05	1.0613
6	1.05	1.0613
7	1.05	1.0613
8	1.05	1.0613
9	1.05	1.0672
10	1.05	1.0672
11	1.05	1.0672
12	1.05	1.0604
13	1.05	1.0604
14	1.05	1.0604
15	1.0753	1.0488
16	1.0756	1.0517
17	1.0457	1.0474
18	1.0508	1.0526
19	1.0633	1.065
20	1.0539	1.0556
21	1.0502	1.0519
22	1.0535	1.0356
23	1.0538	1.0359
24	1.0294	1.0110
25	1.0372	1.0189
26	1.0589	1.0358
27	1.0582	1.0351
28	1.0626	1.0438
29	1.0715	1.0529
30	1.0704	1.0518
31	1.0754	1.0571
32	1.0554	1.0323
33	1.0612	1.0323
34	1.0528	1.0236
35	1.0617	1.0329
36	1.072	1.0454
37	1.0783	1.0545
38	1.0438	1.0455
39	1.0312	1.0330
40	1.0608	1.0625
41	1.0397	1.0414
42	1.0452	1.0469
43	1.0738	1.0512
44	1.0759	1.0696
45	1.073	1.0681
46	1.0784	1.0647
47	1.0765	1.0744
48	1.0682	1.0709
49	1.0635	1.0459
50	1.0573	1.0394
51	1.0517	1.0337
52	1.0538	1.0359
53	1.0674	1.0445
54	1.0658	1.0428
55	1.0702	1.0516
56	1.0745	1.056
57	1.074	1.0555
58	1.0788	1.0605
59	1.0681	1.0453
60	1.0656	1.0368
61	1.0687	1.0400
62	1.077	1.0487
63	1.0633	1.0632
64	1.0738	1.0251
65	1.0635	1.0236
66	1.0788	1.0335
67	1.077	1.0232
68	1.05	1.05

The comparison of voltage levels may be graphically shown as refering to the figures 3 and 4.

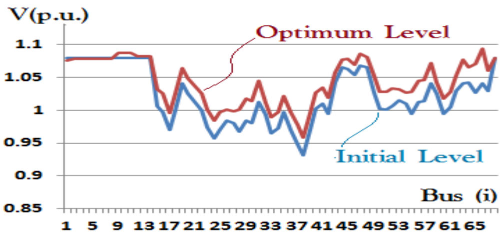

Fig.3 Voltage levels in case of loud load

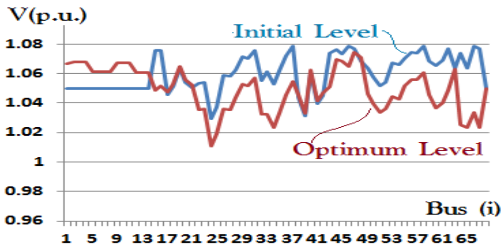

Fig.4 Voltage levels in case of slight load

CONCLUSION

The new algorithm of optimal pq_power flow problem is proved with good convergence.

The application of the speccific type fuel cost functions for the optimal pq_power generation problem allows to simulate the back-pressure effect of turbine regulation.

The process of calculation obtains a good results of voltage optimum levels according to the solution of optimal pq_power flow problem.

Xét hiệu ứng áp suất ngược của tuabin các máy phát nhiệt điện nhằm tối ưu hóa công suất tác dụng và công suất phản kháng trong hệ thống điện

- **Lưu Hữu Vinh Quang**

Trường Đại học Bách khoa, VNU-HCM

TÓM TẮT:

Đề xuất một giải thuật lập trình mới nhằm giải bài toán phân bố công suất và tối ưu hóa công suất P(MW) và công suất Q(MVAR) với các số liệu ví dụ kết quả tiêu biểu.

Đặc tính chi phí nhiên liệu của các máy phát nhiệt điện mà nhận được ở dạng hàm số đa thức bậc cao xếp chồng lên hàm số dạng sin có thể xét đến hiệu ứng áp suất ngược của turbin và giải quyết vấn đề tối ưu *hóa công suất tác dụng của nhà máy nhiệt điện trong hệ thống điện.*

Một công thức mới biểu thị tổng tổn hao công suất truyền tải là một hàm số bậc hai mà bao gồm một ma trận hệ số dạng vuông. Công thức tính toán hệ số tổn hao này được đề xuất để giải quyết bài toán tối ưu hoá công suất phản kháng phát ra của các máy phát trong hệ thống điện có nhiều máy phát.

***Từ khóa**: Tối ưu hóa trạng thái xác lập; Hiệu ứng áp suất ngược của tuabin; Vận hành hệ thống.*

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