Research Paper

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Optimal Power Flow Using Newton's Method

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ABSTRACT

The main objective of this paper is to use of Newton's method for optimization techniques. Power flow is an electrical engineering known problem, which determines the power system operation point in the steady state. Power flow studies are used to ensure that electrical power transfer from the generator to consumer, through gird system, is stable, reliable and economic.OPF determines voltage, current and injected power throughout an electrical power system. In this paper, use of IEEE 30 bus systems for OPF usingNewton'smethod.

I: INTRODUCTION

Optimal Power Flow (OPF) problem can find objective function, constrains and applications. Mathematical programming approaches, such as Nonlinear Programming (NLP), linear programming (LP), Quadratic Programming (QP), Gradient method, Newton's method and Interior point method. The OPF is a power flow problem in which certain controllable variables are adjusted to minimize an objective function such as the cost of active power generation or the losses, while satisfying physical and operating limits on various controls, dependent variables and function of variables. The Newton's method is used to solve non-linear equations.

II: OPTIMAL POWER FLOW PROBLEM

The general definition of the optimization problems is given as,

Minimize :f (x,v)

Subject to : g (v,x)=0

h (v,x)≥ 0

Where,

f=function for minimization or maximization

g=equality constrains

h=inequality constrains

v,x represents set of controllable and dependable variables.

Optimization variables of given function are discrete or continuous. Continuous variables are dependent variables like voltage magnitude, voltage angle and reactive power generation units. Transformer taps, reactor bank and load shedding are control variables. The above definition of optimization is used for objective function to be minimize or maximize constrains under the suitable variables and suitable sets of equality and inequality constrains.OPF have different application like, voltage stability, economic load dispatch, and flexible AC Transmission Systems and base case development.

III. NEWTON'S METHOD

For minimization operating cost of thermal stations,

Minimize Operating cost:

$$F_1=\sum_{i=1}^{NG}(a_iP^2_{gi} + b_iP_{gi} + c_i) \text{ Rs/h}$$

subject to,

(a) Active power balance in the network

$Pi(V,\delta) - Pgi + Pdi = 0 (i=1,2,3.......,NB)$

(b) Reactive power balance in the network

$Qi(V,\delta) - Qgi + Qdi = 0$ (i= NV+1, NV+2,.....,NB)

(C) Security related constrains called soft constrains.

- Limits on real power generations

$P^{min}_{Gi} \le P_{Gi} \le P^{max}_{Gi}$ (i=1,2,…….NG)

- Limits on voltage magnitudes

$V^{min}i \le Vi \le V^{max}i$

- Limits on voltage angles

$\delta min\, i \le \delta i \le \delta maxi$

(d) Functional constrain which is a function of control variables

$Q^{min}_{Gi} \le Q_{Gi}\ Q^{max}_{Gi}$ (i=1,2,…….NG)

Real power flow equations are

$Pi(V,\delta) = Vi \sum Vj\,(Gij \cos(\delta i - \delta j) + Bij\sin(\delta i - \delta j))$

Reactive power flow equations are

$Qi(V,\delta) = Vi \sum Vj(Gij \sin(\delta i - \delta j) - Bij\cos(\delta i - \delta j))$

NG is the number of generator buses.

NB is the number of buses.

NV is the number of voltage controlled buses.

Pi is the active power injection into bus i.

Qi is the reactive power injection into bus i.

Pdi is the active load on bus i.

Qdi is the reactive load on bus j.

Pgi is the active generation on bus i.

Qgi is the reactive generation on bus i.

Vi is the magnitude of voltage at bus i.

δi is the voltage phase angle at bus i.

Yij =Gij +j Bij

Steps for Optimal Power Flow Based on Newton Method :

1. Read data ai, bi and ci (i= 1,2,……..,NG) load on each bus, line data for the power system network.
2. Obtain Ybus using the Y-bus algorithm.
3. Calculate the initial values of Pgi(i= 1,2,……..,NG) and λ by assuming that $P^L=0$. Initialize all λpi = λ (i= 1,2,…….,NB), λqi =0 (i=NV +1, NV+2, …..,NB),
4. Vi = 1 p.u. (i=2,3, ……,NB) and δi =0 (i= 2,3, …….,NB).
5. Calculate the Jacobian and Hessian matrix elements.

$$[H]\begin{pmatrix}\Delta Pg\\ \Delta\delta\\ \Delta\lambda p\\ \Delta V\\ \Delta\lambda q\end{pmatrix} = \begin{pmatrix}\partial L/\partial Pg\\ \partial L/\partial\delta\\ \partial L/\partial\lambda p\\ \partial L/\partial V\\ \partial L/\partial\lambda q\end{pmatrix}$$

The Gauss elimination method is used to find ΔPg, Δδ, Δλp, ΔV and Δλq.

6. Check convergence

$$\left[\sum_{i=1}^{NG}(\Delta Pgi)^2 + \sum_{i=1}^{NG}(\Delta\delta)^2 + \sum_{i=1}^{NG}(\Delta\lambda pi)^2 + \sum_{i=NV+1}^{NG}(\Delta Vi)^2 + \sum_{i=NV+1}^{NG}(\Delta\lambda q)^2\right]^{1/2} \le \varepsilon$$

And optimality conditions. If condition is not satisfied then GOTO step 6 else GOTO step 9.

7. Modify the variables,
Pgi = Pgi +ΔPgi (i=1,2,…….,NG)

δ = δi +Δδi (i=1,2,…….,NB)

λpi = λpi +Δλpi (i=1,2,…….,NB)

Vi = Vi + ΔVi (i= NV+1, NV+2, ……..,NB)

λqi = λqi + Δλqi (i= NV+1, NV+2, ………, NB)

8. Check the limits, if any limit of a variable is violated, then impose or remove power flow equation or a penalty for inequality. Add or remove derivatives for penalty or equation change and GOTO step 4 to update the solution.
9. Calculate the total cost.
10. Stop.

IV:TEST CASE AND SIMULATION RESULTS
IEEE 30 bus system is used to optimal power flow problem using Newton's method. The data and the results are as follows.

stopping criteria details
Active inequalities (to within ptions.TolCon = 5e-006):

lower	upper	ineqlin	ineqnonlin
1	1	10	
	59	76	

Converged in 0.44 seconds
Objective Function Value = 576.89 $/hr

System Summary			
How many?	How much?	P (MW)	Q (MVAr)
Buses 30	Total Gen Capacity	335.0	-95.0 to 405.9
Generators 6	On-line Capacity	335.0	-95.0 to 405.9
Committed Gens 6	Generation (actual)	192.1	105.1
Loads 20	Load	189.2	107.2
Fixed 20	Fixed	189.2	107.2
Dispatchable 0	Dispatchable	-0.0 of -0.0	-0.0
Shunts 2	Shunt (inj)	-0.0	0.2
Branches 41	Losses (I^2 * Z)	2.86	13.33
Transformers 0	Branch Charging (inj)	-	15.2
Inter-ties 7	Total Inter-tie Flow	51.0	58.1
Area 3			
Minimum		Maximum	
Voltage Magnitude	0.961 p.u. @ bus 8	1.069 p.u. @ bus 27	
Voltage Angle	-5.69 deg @ bus 19	0.00 deg @ bus 1	
P Losses (I^2*R)	-	0.30 MW @ line 2-6	
Q Losses (I^2*X)	-	2.39 MVAr @ line 28-27	
Lambda P	3.66 $/MWh @ bus 1	5.38 $/MWh @ bus 8	
Lambda Q	-0.06 $/MWh @ bus 29	1.40 $/MWh @ bus 8	

Bus Datat								
Bus	Voltage		Generation		Load		Lambda($/MVA-hr)	
No.	Mag (pu)	Ang. (deg)	P (MW)	Q (MVAr)	P (MW)	Q MVAr	P (MW)	Q (MVAr)
1	0.982	0.000	41.54	-5.44	-	-	3.662	-0.000
2	0.979	-0.763	55.40	1.68	21.70	12.70	3.689	-0.000
3	0.977	-2.390	-	-	2.40	1.20	3.754	-0.016
4	0.976	-2.839	-	-	7.60	1.60	3.771	-0.021
5	0.971	-2.486	-	-	-	-	3.744	-0.001
6	0.972	-3.229	-	-	-	-	3.779	-0.020
7	0.962	-3.491	-	-	22.80	10.90	3.801	0.003
8	0.961	-3.682	-	-	30.00	30.00	5.383	1.404
9	0.990	-4.137	-	-	-	-	3.823	0.020
10	1.000	-4.600	-	-	5.80	2.00	3.846	0.039
11	0.990	-4.137	-	-	-	-	3.823	0.020
12	1.017	-4.498	-	-	11.20	7.50	3.810	0.000
13	1.064	-3.298	16.20	35.92	-	-	3.810	0.000
14	1.007	-5.040	-	-	6.20	1.60	3.868	0.018
15	1.009	-4.814	-	-	8.20	2.50	3.856	0.018
16	1.003	-4.839	-	-	3.50	1.80	3.849	0.031
17	0.995	-4.887	-	-	9.00	5.80	3.862	0.047
18	0.993	-5.485	-	-	3.20	0.90	3.911	0.047
19	0.987	-5.688	-	-	9.50	3.40	3.926	0.058
20	0.990	-5.472	-	-	2.20	0.70	3.910	0.055
21	1.009	-4.621	-	-	17.50	11.20	3.854	0.017
22	1.016	-4.503	-	-	22.74	34.20	3.843	0.000
23	1.026	-3.756	16.27	6.96	3.20	1.60	3.813	0.000
24	1.017	-3.885	-	-	8.70	6.70	3.884	0.028
25	1.044	-2.073	-	-	-	-	3.932	0.022
26	1.027	-2.476	-	-	3.50	2.30	3.999	0.067
27	1.069	-0.715	39.91	31.76	-	-	3.916	-0.000
28	0.982	-3.215	-	-	-	-	4.106	0.250
29	1.050	-1.850	-	-	2.40	0.90	3.966	-0.059
30	1.039	-2.643	-	-	10.60	1.90	4.051	-0.012
Total:			192.06	105.08	189.20	107.20		

Branch Data

Branch number	From Bus	To Bus	From Bus Injection		To Bus Injection		Loss (I^2 * Z)	
			P (MW)	Q (MVAr)	P (MW)	Q (MVAr)	P (MW)	Q (MVAr)
1	1	2	21.04	-2.34	-20.95	-0.27	0.092	0.28
2	1	3	20.50	-3.10	-20.28	2.02	0.220	0.84
3	2	4	18.63	-5.85	-18.40	4.60	0.232	0.66
4	3	4	17.88	-3.22	-17.84	3.36	0.035	0.14
5	2	5	14.36	-0.69	-14.25	-0.78	0.108	0.43
6	2	6	21.66	-4.21	-21.36	3.21	0.301	0.90
7	4	6	17.58	5.68	-17.55	-5.54	0.036	0.14
8	5	7	14.25	0.96	-14.15	-1.64	0.109	0.26
9	6	7	8.70	8.46	-8.65	-9.26	0.049	0.13
10	6	8	23.82	21.37	-23.71	-20.93	0.108	0.43
11	6	9	7.27	-8.27	-7.27	8.54	0.000	0.27
12	6	10	4.15	-4.73	-4.15	4.96	0.000	0.23
13	9	11	0.00	0.00	-0.00	-0.00	0.000	0.00
14	9	10	7.27	-8.54	-7.27	8.68	0.000	0.14
15	4	12	11.06	-15.23	-11.06	16.20	0.000	0.97
16	12	13	-16.20	-34.00	16.20	35.92	0.000	1.92
17	12	14	4.68	-2.08	4.65	-2.01	0.030	0.07
18	12	15	6.07	3.18	-6.04	-3.12	0.032	0.06
19	12	16	5.31	5.04	-5.26	-4.94	0.047	0.10
20	14	15	-1.55	0.41	1.55	-0.41	0.006	0.01
21	16	17	1.76	3.14	-1.75	-3.11	0.010	0.02
22	15	18	7.20	3.75	-7.13	-3.60	0.071	0.14
23	18	19	3.93	2.70	-3.92	-2.67	0.014	0.03
24	19	20	-5.58	-0.73	5.59	0.75	0.010	0.02
25	10	20	7.85	1.58	-7.79	-1.45	0.058	0.13
26	10	17	7.27	2.73	-7.25	-2.69	0.018	0.05
27	10	21	-4.43	-11.57	4.48	4.48	0.046	0.11
28	10	22	-5.06	-8.40	5.13	8.54	0.067	0.14
29	21	22	-21.98	-22.88	22.07	23.07	0.099	0.20
30	15	23	-10.92	-2.72	11.04	2.97	0.124	0.25
31	22	24	-4.46	2.59	4.49	-2.54	0.031	0.05
32	23	24	2.03	2.39	-2.01	-2.37	0.012	0.03
33	24	25	-11.18	-1.75	11.41	2.16	0.235	0.41
34	25	26	3.54	2.36	-3.50	-2.30	0.042	0.06
35	25	27	-14.96	-4.52	15.20	4.99	0.246	0.47
36	28	27	-11.45	-21.09	11.45	23.48	0.000	2.39
37	27	29	6.16	1.65	-6.08	-1.50	0.078	0.15
38	27	30	7.10	1.63	-6.95	-1.36	0.149	0.28
39	29	30	3.68	0.60	-3.65	-0.54	0.030	0.06
40	8	28	-6.29	-9.07	6.35	7.41	0.069	0.23
41	6	28	-5.05	-14.50	5.09	13.69	0.047	0.14
Total:							2.861	13.33

V: CONCLUSION

This paper presents a method to solve **optimal power flow problem of IEEE 30** bus system using **Newton's method**. From the above example & result, it is very clear that the Converged in **0.44 seconds** and the total active power loss is 2.861 and the total reactive power losses are 13.33. The total generation and load of the electric system active and reactive power losses are respectively 192.06, 105.08 and 189.20, 107.20.

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