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A Newton-Based Optimal Power Flow In to a Power System Simulation Environment

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Abstract: *This paper proposes an approach to solve the Optimal Power Flow (OPF) problem with an aim to enhancing the power system reliability. A Newton-based optimal power flow (OPF) is developed for implementation into a power system simulation environment. The OPF performs all system control while maintaining system security. System controls include generator megawatt outputs, transformer taps, and transformer phase shifts, while maintenance of system security ensures that no power system component's limits are violated. Special attention is paid to the heuristics important to creating an OPF which achieves solution in a rapid manner. Finally, sample applications of the OPF are discussed. These include transmission line overload removal, transmission system control, available transfer capability calculation (ATC), real and reactive power pricing, transmission component valuation, and transmission system marginal pricing.*
Keywords: *OPF, Available Transfer Capability (ATC), Short Run Marginal Cost (SRMC), Marginal Pricing, Power World Simulator.*

I. Introduction

The efficient and optimum economic operation and planning of electric power generation systems have always occupied an important position in the electric power industry. A small percent saving in the operation of the power system causes a significant reduction in operating cost, and also reduces the required fuel consumption. A periodic change in basic fuel price levels serves to accentuate the problem and increases its economic significance Inflation also plays a key role. Recently there has been a rapid growth in applied mathematical methods and the availability of computational capability for solving problems of this nature so that more involved problems has been successfully solved. There is a need to expand the limited economic optimization problem to incorporate constraints on system operation.

Optimal power-flow means an operating condition in which the power-flow in an electrical power system occurs optimally. Conceptually, it is one, among the many feasible power-flow conditions in which a certain objective is optimized as well as the operating constraints of the system are satisfied. The objective of OPF might be any one of the following –

1. Economic load dispatch.
2. Minimal transmission loss.
3. Optimal load scheduling..
4. Minimally proportioned reactive generating units

The work presented in this thesis utilizes an optimal power flow program, OPF, as the tool for solving these problems. The OPF is a natural choice for addressing these concerns because it is basically an optimal control problem. The OPF utilizes all control variables to help minimize the costs of the power system operation. It also yields valuable economic information and insight into the power system. In these ways, the OPF addresses both the control and economic problems

II. Overview On Optimal Power Flow

Before beginning the creation of an OPF, it is useful to consider the goals that the OPF will need to accomplish. The primary goal of a generic OPF is to minimize the costs of meeting the load demand for a power system while maintaining the security of the system. The costs associated with the power system may depend on the situation, but in general they can be attributed to the cost of generating power (megawatts) at each generator. From the viewpoint of an OPF, the maintenance of system security requires keeping each device in the power system within its desired operation range at steady-state. This will include maximum and minimum outputs for generators, maximum MVA flows on transmission lines and transformers, as well as keeping system bus voltages within specified ranges. It should be noted that the OPF only addresses steady-state operation of the power system. Topics such as transient stability, dynamic stability, and steady-state contingency analysis are not addressed. To achieve these goals, the OPF will perform all the steady-state control functions of the power system. These functions may include generator control and transmission system control. For generators, the OPF will control generator MW outputs as well as generator voltage. For the transmission system, the OPF may control the tap ratio or phase shift angle for variable transformers, switched shunt control, and all other flexible ac transmission system (FACTS) devices.

III. Optimal Power Flow :Methodology(11 Bold)

Newton's Method:

The optimal power flow problem 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.

Problem formulation:

Optimal power flow(OPF) is formulated to minimize the operating cost of power station

$$F = \sum_{i=1}^{NG} F_i = \sum_{i=1}^{NG} a_i P_{gi}^2 + b_i P_{gi} + c_i \quad \text{Rs /h} \qquad (1)$$

Subject to the operational constraints-

- Active power balance in the network

$$P_i(V, \delta) - P_{gi} + Pd_i = 0 \qquad (i=1, 2 \ldots NB) \qquad (2)$$

- Reactive power balance in the network

$$Q_i(V, \delta) - Q_{gi} + Qd_i = 0 \quad (i=NV+1, NV+2 \ldots NB) \qquad (3)$$

- Real power generation limits

$$P_{g_i}^{\min} \le P_{gi} \le P_{gi}^{\max} \qquad (i=1, 2 \ldots NG) \qquad (4)$$

- Reactive power generation limits

$$Q_{g_i}^{\min} \le Q_{gi} \le Q_{gi}^{\max} \qquad (i=1, 2 \ldots NG) \qquad (5)$$

- Voltage limits

$$V_i^{\min} \le V_i \le V_i^{\max} \quad (i=NV+1, NV+2 \ldots NG)$$

- Voltage angle limits

$$\delta_i^{\min} \le \delta_i \le \delta_i^{\max} \quad (i=2 \ldots NB)$$

- Active power flow equations are

$$P_i(V, \delta) = \sum_{i=1}^{NB} | V_i \| V_j \| Y_{ij} | \cos(\theta_{ij} - \delta_i + \delta_j)$$

- Reactive power flow equations are

$$Q_i(V, \delta) = \sum_{i=1}^{NB} | V_i \| V_j \| Y_{ij} | \sin(\theta_{ij} - \delta_i + \delta_j)$$

The constraint minimization problem can be transformed into an unconstrained by adding the load flow constraint into objective function. The additional variables are known as Lagrange multiplier functions in power system terminology. The cost function becomes

$$L(P_g, V, \delta) = F(P_{g_i}) + \sum_{i=1}^{NB} \lambda_{pi} \left[P_i(Vi, \delta) - P_{gi} + Pd_i\right] + \sum_{i=NV+1}^{NB} \lambda_{qi} \left[Q_i(V, \delta) - Q_{gi} + Qd_i\right]$$

The optimization problem is solved, if following equations of optimality are satisfied.

$$\frac{\partial L}{\partial P_{gi}} = \frac{\partial F}{\partial P_{gi}} - \lambda p_i \quad (i=1,2,\ldots..NG)$$

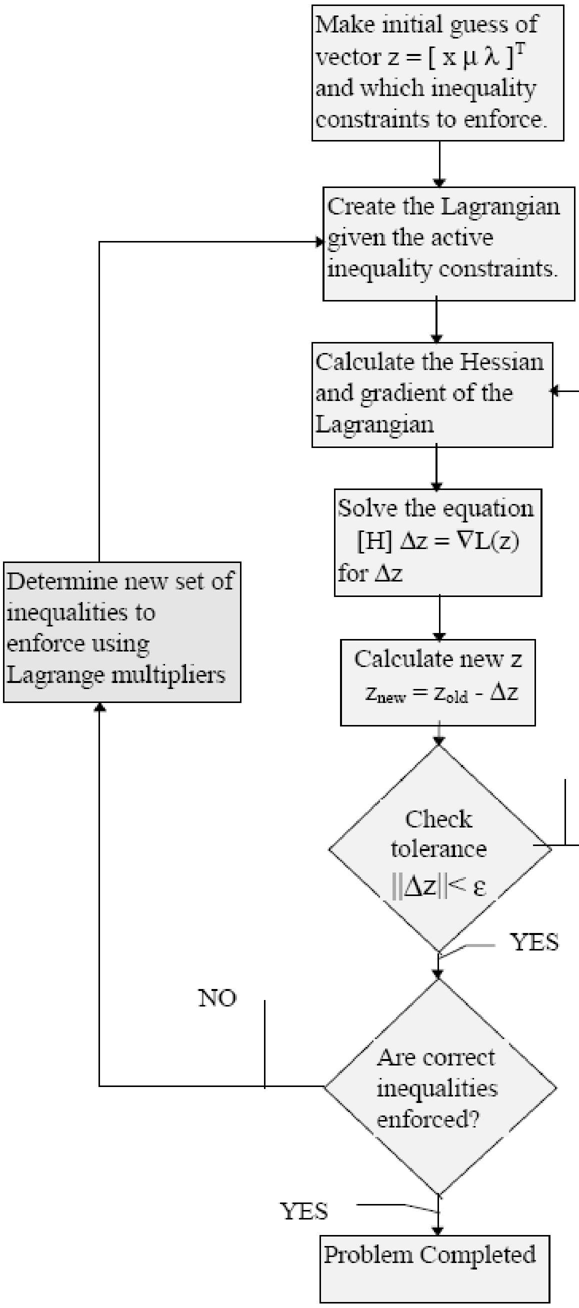
$$\frac{\partial L}{\partial \delta_i} = \sum_{j=1}^{NB} \left[\lambda p_j \frac{\partial P_j}{\partial \delta_i} \right] + \sum_{j=NV+1}^{NB} \left[\lambda q_j \frac{\partial Q_j}{\partial \delta_i} \right] \quad (i=1, 2 \ldots NG)$$

$$\frac{\partial L}{\partial V_i} = \sum_{j=1}^{NB}\left[\lambda p_j \frac{\partial P_j}{\partial V_i}\right] + \sum_{j=NV+1}^{NB}\left[\lambda q_j \frac{\partial Q_j}{\partial V_i}\right] \quad (i=NV+1, NV+2\ldots NG)$$

$$\frac{\partial L}{\partial \lambda p_i} = P_i(V,\delta) - P_{gi} + Pd_i \quad (i=1,2,\ldots..NB)$$

$$\frac{\partial L}{\partial \lambda q_i} = Q_i(V,\delta) - Q_{gi} + Qd_i \quad (i=NV+1,NV+2,\ldots..NB)$$

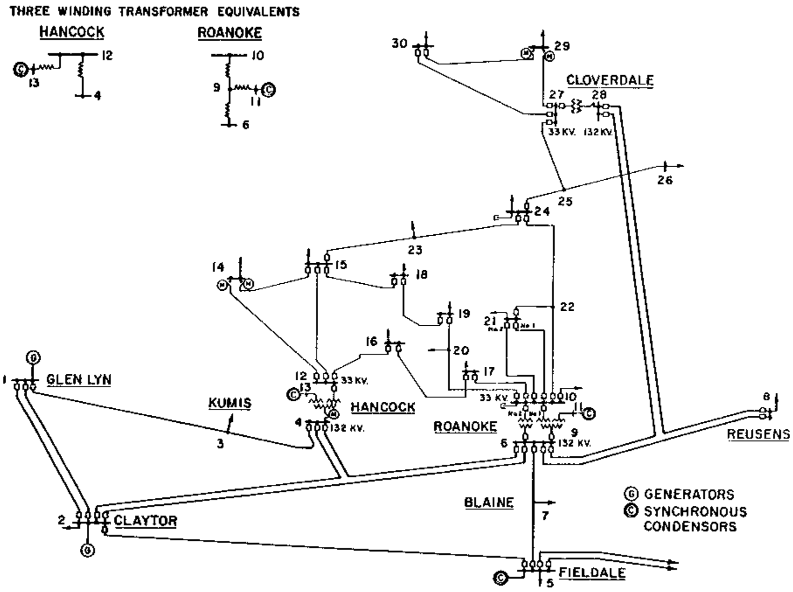
Flowchart:



IV. Case Study

IEEE Thirty Bus System:

An IEEE standard 30 bus system is shown in fig 4.1. the voltage values for all buses are set between 0.95 and 1.05.also the real power flow in line puts some limits. The main loads are at buses 5,7 and8 while the four generators are located at buses 1, 2, 22 and27.



V. Result &Conclusion

OPTIMAL POWER FLOW- IEEE 30-bus standard test system

Bus No.	Volt(Kv)	ANG(rad)	Pg	Qg
1	104	0.0465	1.1000	0.0276
2	103.0814	0.0062	0.5000	0.2127
3	102.0261	-0.0102	0	0
4	101.4156	-0.0209	0	0
5	99.7713	-0.1082	0	0
6	100.8177	-0.0326	0	0
7	100.5262	-0.0638	0	0
8	99.5261	-0.0406	0	0
9	101.4937	-0.0176	0	0
10	100.8196	-0.0099	0	0
11	105.0000	-0.0176	0	0
12	99.0808	-0.0482	0	0
13	101.2245	-0.0482	0	0
14	97.8532	-0.0533	0	0
15	98.1895	-0.0443	0	0
16	99.1158	-0.0376	0	0
17	99.7672	-0.0222	0	0
18	97.8445	-0.0454	0	0
19	97.9681	-0.0424	0	0
20	98.6024	-0.0353	0	0
21	100.8483	0.0149	0	0
22	101.3539	0.0255	0.6913	-0.0023
23	98.5140	-0.0155	0	0
24	99.9479	0.0289	0	0
25	102.5636	0.1091	0	0
26	101.3845	0.1281	0	0
27	105.0000	0.1483	0.4000	0.0281
28	100.6559	-0.0348	0	0
29	103.0719	0.1279	0	0
30	101.9565	0.1133	0	0

Iter	F-count	F(x)	Max. constraints	Step size	Directional derivative	First order optimality procedure
0	61	73.4149	1.1	1	50.6	2.08e+003
1	123	74.0602	0.04019	1	0.721	2.15e+003
2	185	73.7753	0.01486	0.5	-0.938	2.13e+003
3	248	74.263	0.009651	1	0.516	2.21e+003
4	310	74.263	0.002678	0.5	-0.272	2.25e+003
5	373	74.1709	0.002221	1	0.0613	2.32e+003
6	435	74.2172	0.00201	1	0.0152	2.32e+003
7	497	74.2302	3.641e-05	1	-0.00090	2.32e+003
8	559	74.2302	2.115e-05	1	0.0005	2.32e+003
9	621	74.2311	7.987e-06	1	0.00024	Hessian modified
10	683	74.2314	2.172e-06	1	6.64e-005	Hessian modified
11	745	74.2315	6.179e-07	1	1.9e-005	Hessian modified
12	807	74.2315	1.76e-07	1	5.38e-005	Hessian modified
13	869	74.2315	5.007e-08	1	1.53e-005	Hessian modified
14	931	74.2315	1.425e-08	1	1.54e-005	Hessian modified

VI. Conclusion

The OPF written in this paper has been very successful in achieving the goals set forth for an OPF. Minimization of system costs, while maintaining system security, was accomplished through the implementation of Newton's method to the OPF problem. Newton's method has proven to be very adaptive in solving the OPF problem. The optimal power flow developed for IEEE standard 30 bus system using MATLAB has produced results to the expectations. These developed generalized programs can be modified to work for real life practical system.

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