

OPTIMUM POWER GENERATION FOR IRAQI SUPER HIGH VOLTAGE SYSTEM

Dr. Samir S. Mustafa
Kirkuk Technical Institute

Abstract

Iraqi super grid power system consists of six generating power plants : Baji, Sad Al-Mosul, Haditha, Mussayab, Nasiriya and Hartha. A Matlab5.3 package has been used to calculate the optimum generation of the system generators which gives minimum losses in comparison with the total losses according to the same data which were recorded in National Control Center. The losses reduction became 30.96% . Gradient method has been employed for the solution of optimal power flow. The partial derivative of active and reactive losses with respect to injected power were used as an indicator on optimum power generation.

Keywords- Optimum, Power Generation.

التوليد الأمثل للقدرة لمنظومة الضغط ألفتانق في العراق

د . سمير سعدون مصطفى
المعهد التقني / كركوك

الخلاصة

منظومة الضغط ألفتانق في العراق تتكون من ست محطات توليد : بيجي ، سد الموصل ، حديثة ، المسيب ، الأنصارية وأهارة . تم استخدام برنامج جاهز بلغة Matlab ٥.٣ والتوصل إلى أمثل توليد في تلك المحطات والذي يعطي أقل خسائر في المنظومة مقارنة مع الخسائر المحسوبة بموجب نفس البيانات المسجلة في مركز السيطرة الوطنية فانخفضت الخسائر الكلية بمقدار ٣٠.٩٦ % . تم استخدام طريقة التدرج للحصول ألامثلية في التوليد في المحطات أعلاه. تم استخدام ألاشتقاق الجزئي لخسائر القدرة الفعالة والمتفاعلة نسبة إلى القدرة المحقونة في جميع العموميات كمؤشر على أمثل قدرة يمكن توليدها.

Introduction

Many different mathematical techniques have been employed for the solution of optimal power flow. The majority of the techniques in the references (Selman2005), (Antonio2002), (Quek2002), (Pjiac2003), (Kristiansen2002) and (Stevenson1985) use one of the following methods:

- 1- Lambda iteration method.
- 2- Gradient method.
- 3- Newton's method.
- 4- Linear programming method.
- 5- Interior point method.

Optimal power flow (OPF) has been widely used in planning and real-time operation of power systems for active and reactive power dispatch to minimize generation costs and system losses and improve voltage profiles.

The primary goal of OPF is to minimize the costs of meeting the load demand for a power system while maintaining the security of the system (Claudio2001). The cost associated with the power system can be attributed to the cost of generating power (megawatts) at each generator, keeping each device in the power system within its desired operation range. 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.

OPF program is to determine the optimal Operation State of a power system by optimizing a particular objective while satisfying certain specified physical and operating constraints to achieve these goals, OPF will perform all the steady-state control functions of 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. Optimization and security are often conflicting requirements and should be considered together. All the optimization problems can easily be transcribed into the following standard form (Yong1999) and (John2003):

$$\begin{aligned} & \min f(\underline{x}) \\ & \text{subject to:} \\ & g_i(\underline{x}) \leq 0 \quad i = 1, \dots, n_g \\ & h_k(\underline{x}) = 0 \quad k = 1, \dots, m_h \\ & \text{Where } \underline{x} = \{x_1 \dots x_n\} \in \mathfrak{R} \text{ (design variables).} \\ & f(x) \text{ the objective function.} \\ & g_i(x) \text{ inequality constraints.} \\ & h_k(x) \text{ equality constraints.} \end{aligned}$$

We assume that only part (P_{Gi}) of the total net power is controllable for the purpose of optimization. The objective function can then be defined as the sum of instantaneous operating costs over all controllable power generation:

$$f(x) = \sum_i c_i(P_{Gi}) \quad (1)$$

where c_i is the cost of producing P_{Gi} .

The minimization of system losses is achieved by minimizing the power injected at the slack node. Note that Baji generator has been chosen as slack node. The minimization of the objective function $f(x)$ can be achieved with reference to the Lagrange function (L).

The nonlinear power loss equation is:

$$P_{\text{loss}} = \sum_{i=1}^N \sum_{j=1}^N G_{ij} [|V_i|^2 + |V_j|^2 - 2|V_i||V_j| \cos(\delta_i - \delta_j)] \quad (2)$$

The linearized sensitivity model relating the dependent and control variables can be obtained by linearizing the power equations around the operating state. Despite the fact that any load flow techniques can be used, N-R load flow is most convenient to use to find the incremental losses. The change in power system losses, ΔP_L , is related to the control variables by the following equation (Selman2005)

$$\Delta P_L = \begin{bmatrix} \frac{\partial P_L}{\partial V_1} & \frac{\partial P_L}{\partial V_m} & \frac{\partial P_L}{\partial Q_{m+1}} & \frac{\partial P_L}{\partial Q_{m+w}} \end{bmatrix} \begin{bmatrix} \Delta V_1 \\ \vdots \\ \Delta V_m \\ \Delta Q_{m+1} \\ \Delta Q_{m+w} \end{bmatrix} \quad (3)$$

Electric power systems designed with generating units that are widely scattered and interconnected by long transmission lines may suffer significant losses. The losses depend on the line resistance and currents and are usually referred to as thermal losses. While the line resistances are fixed, the currents are a complex function of the system topology and the location of generation and load. Using the load data collected on 2/1/2003 in **Table 1** which can be obtained from the Iraqi Control Center (Afaneen2004) algorithm was applied to determine the best placement of new units in order to maximize power available and minimize losses on the system for a given load (William2002) The analysis objective is to find the partial derivatives (sensitivity) of active power loss with respect to active and reactive power injected at all buses except slack bus.

$$[SEN] = [\partial P_L / \partial P \quad \partial P_L / \partial Q] \quad (4)$$

The results of sensitivity vector $[SEN]$ are used as an indicator to the efficiency of the system to reduce losses in case of installing generation units or shunt capacitors at these buses. The following matrix $[D]$ is the partial derivative of real losses with respect to voltage magnitude at load buses and voltage angles at all buses except slack bus (samir2007).

$$[D] = \frac{\partial f}{\partial x} = \begin{bmatrix} \partial P_{loss} / \partial \delta_2 \\ \partial P_{loss} / \partial \delta_3 \\ \vdots \\ \partial P_{loss} / \partial \delta_N \\ \partial P_{loss} / \partial V_2 \\ \partial P_{loss} / \partial V_3 \\ \vdots \\ \partial P_{loss} / \partial V_{NL+1} \end{bmatrix} \quad (5)$$

The components of $[D]$ are calculated as follows:

$$\partial P_{loss} / \partial \delta_i = 2 \sum_{\substack{j=1 \\ j \neq i}}^N G_{ij} [V_i | V_j | \sin(\delta_i - \delta_j)] \quad (6)$$

$$\frac{\partial P_{loss}}{\partial V_i} = 2 \sum_{\substack{j=1 \\ j \neq i}}^N G_{ij} [|V_i| - |V_j| \cos(\delta_i - \delta_j)] \quad (7)$$

The mathematical analysis needs also Jacobian matrix $[Jac]$ which is used before in power flow problem, then:

$$[Jac]^T [SEN] = [D] \quad (8)$$

$$\text{then } [SEN] = [Jac]^{T^{-1}} [D] \quad (9)$$

$$\begin{bmatrix} P_{sen} \\ Q_{sen} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_L}{\partial P} \\ \frac{\partial P_L}{\partial Q} \end{bmatrix} = [Jac]^{T^{-1}} \begin{bmatrix} \frac{\partial P_L}{\partial \delta} \\ \frac{\partial P_L}{\partial V} \end{bmatrix} \quad (10)$$

where

P_{sen} = partial derivative of real losses with respect to real power injected at load buses.

Q_{sen} = partial derivative of real losses with respect to reactive power injected at load buses.

$[J]$ is the Jacobian matrix of Newton-Raphson load flow.

$$\text{Then } P_{sen} = \begin{bmatrix} \frac{\partial P_{loss}}{\partial P_2} \\ \frac{\partial P_{loss}}{\partial P_{NL+1}} \end{bmatrix} \quad (11)$$

$$\text{And } Q_{sen} = \begin{bmatrix} \frac{\partial P_{loss}}{\partial Q_2} \\ \frac{\partial P_{loss}}{\partial Q_{NL+1}} \end{bmatrix} \quad (12)$$

Iraqi National Super Grid

Iraqi national super grid contains six generating sets of various types units, thermal and hydro turbine kinds, with different capabilities of MW and MVAR generation and absorption. The load and generation of INSG system on the 2nd of January 2003 are tabulated in **Table 1** machines parameters and lines are tabulated in **Tables 2 and 3** (Afaneen1998)

A software package under Matlab5.3 has been developed to perform electrical power system analysis on a personal computer. The software is capable of performing admittance calculations, load flow studies, optimal load flow studies of electric power systems. The sensitivity of each power plant to reduce losses with respect to power generation is calculated according to equation (10). The results were shown in **Tables (1-5)**.

As shown in these Figures, increasing power generation at each bus reduces system losses if sensitivity value at that bus is negative. On the other hand increases power generation at each bus increases system losses if sensitivity value is positive.

The values of power generation which give minimum losses at SDM, HAD, MSB, NSR, and HRT power plants are 250, 425, 950, 700, and 450 Mw respectively.

Notice that increasing power generation at each bus reduce system losses if sensitivity value at that bus is negative, and increase system losses if sensitivity is positive.

System power losses with respect to sensitivity of each power plant shown in **Figures 6, 7, 8 & 9**.

Calculations of optimal power generation

Optimal power generation for all generation plants can be obtained by increasing real power of each generator with small amounts at the same time, as shown in **Figure 11**.

Increasing active power for each generator is stopped when sensitivity at that generator bus becomes zero or positive. The over all process continues until the sensitivities for all buses become zero or positive. The procedure is done using the package under Matlab.

The results show that optimum power generations give minimum losses equal to 25.95Mw where shown in **Table 4**.

Also the results show that total losses with ordinary generation is equal to 37.592Mw using the data of ordinary generation and loads on the 2nd of Jan. 2003.

Optimal losses reduction =

$$\begin{aligned} & (\text{losses with ordinary } P_g - \text{losses with optimum } P_g) / \text{losses with ordinary } P_g \times 100\% \\ & = 37.592 - 25.95 / 37.592 \\ & = 30.96 \% \end{aligned}$$

Conclusions

Using sensitivity analyzing gives us a good indicator about the buses which are sensitive to reduce system total losses .Increasing power generation at each generation plant reduces system losses if sensitivity value at that bus is negative. On the other hand increasing power generation at each bus increases system losses if sensitivity value is positive.

The results show us that optimum generation in the generation plants give minimum total losses in the Iraqi national super grid without exceeding the constrains of voltages, active and reactive power, as shown in **Table 5**.

References

- Afaneen A. Abood Automated Mapping Facilities Management Geographic Information System of a Power System, M. Sc. Thesis, University of Technology, Baghdad, 1998.
- Afaneen A. Abood, Implementation of Geographic Information System (GIS) in Real-Time Transient Stability, Ph.D. thesis, University of Technology, Baghdad, 2004.
- Antonio J. and Maria J., “Optimal Power Flow Algorithm Based on TABU Search for Meshed Distribution Networks”, www.pscoc2.org, 2002.
- Claudio C., “Comparison of Voltage Security Constrained Optimal Power Flow Techniques”, Proc. IEEE-PES Summer meeting Vancouver, BC, July 2001.
- Etienne J., “A Reduced Gradient Method with Variable Base Using Second Order Information, Applied to the Constrained and Optimal Power Flow”, www.system.seurope.be/pdf, 2000.
- John R., “Engineering Design Optimization”, www.me.uprm.edu/vgoyal/inme 4058, 2003.
- Kristiansen T., “Utilizing Mat Power in Optimal Power Flow”, www.ksg.haward.edu, 2002.
- Pajic S., “Sequential Quadratic Programming-Based Contingency Constrained Optimal Power Flow”, M. Sc. Thesis, Worcester polytechnic institute, www.wpi.edu. April 2003.

- Quek R., "Power Transfer Capability Assessment", www.innovexpo.itee.uq.edu.au/ 2002.
- Samir S. Mustafa, Minimum Power Losses Based Optimal Power Flow Iraqi National Super Grid and its Effect on Transient Stability, Ph.D thesis, University of Technology, Baghdad, 2007.
- Stevenson W. D., "Elements of Power System Analysis", McGraw-Hill Book co. 4th edition, 1985.
- William R., "Optimal Placement of Distributed Generation", www.pscoc2.org, 2002, USA.
- Yong T. and Lasseter R., "OPF Formulation in Market of Retail Wheeling", www.pserc.cornell.edu, 1999.

Table1: INSG System Load Data

Bus Bar Number	Bus Bar Name	Type	Generation		Load	
			MW	M _{VAR}	MW	M _{VAR}
1	BAJ	Slack	570.592	100.4455	200.00	98.00
2	SDM	P,V	700.00	- 23.2248	5.00	2.00
3	HAD	P,V	500.00	- 0.8474	100.00	60.00
4	QAM	P,Q	.00	.00	60.00	40.00
5	MOS	P,Q	.00	.00	300.00	180.00
6	KRK	P,Q	.00	.00	70.00	40.00
7	BQB	P,Q	.00	.00	150.00	80.00
8	BGW	P,Q	.00	.00	500.00	360.00
9	BGE	P,Q	.00	.00	500.00	360.00
10	BGS	P,Q	.00	.00	100.00	50.00
11	BGN	P,Q	.00	.00	300.00	200.00
12	MSB	P,V	600.00	420.6564	120.00	70.00
13	BAB	P,Q	.00	.00	100.00	50.00
14	KUT	P,Q	.00	.00	100.00	60.00
15	KDS	P,Q	.00	.00	200.00	100.00
16	NAS	P,V	650.00	- 69.1434	100.00	54.00
17	KAZ	P,Q	.00	.00	350.00	200.00
18	HRT	P,V	380.00	35.9855	38.00	22.00
19	QRN	P,Q	.00	.00	70.00	30.00
Total			3400.592	463.8716	3363	2056

Table2: Machine's Parameters

Node Name	Armature ARG (Per)	Transient XD (Per)	Inertia Constant
BAJ4	0.0	0.0122242	132
SDM4	0.0	0.037	91.008
HAD4	0.0	0.04948	36.096
MSB4	0.0	0.017225	104
NSR4	0.0	0.0285	99.94
HRT4	0.0	0.0508	47.5

Table3: INSG System Line Data

From	To	R (P.U)	X (P.U)	B (P.U)
BAJ4	SDM4	0.00542	0.0487	1.4384
MOS4	SDM4	0.00143	0.0124	0.36439
MOS4	BAJ4	0.00399	0.03624	1.074
BAJ4	HAD4	0.00364	0.03024	0.8676
QAM4	HAD4	0.0035	0.03	0.7413
BGE4	BQB4	0.00076	0.00689	0.2043
BAJ4	KRK4	0.00182	0.01654	0.49031
BAJ4	BGW4-2	0.0055	0.05004	1.4826
BAJ4	BGW4-1	0.00483	0.04393	1.3017
HAD4	BGW4	0.00483	0.04393	1.3017
BGW4	BGN4	0.00093	0.00847	0.25099
BGN4	BGE4	0.00029	0.00265	0.0788
KRK4	BGE4	0.00481	0.04373	1.29581
BGE4	BGS4	0.00105	0.00955	0.28309
BGW4	BGS4	0.00144	0.0131	0.38816
BGS4	MSB4-1	0.00121	0.0102	0.30944
BGS4	MSB4-2	0.00121	0.0102	0.30944
BAB4	MSB4-1	0.00077	0.00648	0.19666
BAB4	MSB4-2	0.00077	0.00648	0.19666

BGS4	KUT4	0.00245	0.02236	0.6625
BGS4	KDS4	0.00292	0.02659	0.788
KDS4	NSR4	0.00383	0.03486	1.03314
KAZ4	NSR4	0.00439	0.03999	1.1849
KUT4	NSR4	0.00433	0.0394	1.1674
KAZ4	HRT4	0.00119	0.01083	0.32104
QRN4	HRT4	0.0013	0.01182	0.35022
QRN4	KUT4	0.00628	0.05713	1.6927

Table4: Active Power Generations which Give Optimal Losses Reduction

Generation Bus Number	Generation [Mw]
BAJ	571
SDM	250
HAD	350
MSB	1000
NSR	500
HRT	400

Table5: Limits of Generation and Load Buses

Bus Bar	Q _{generation} [M _{var}]		Voltage [P.V]	
	Q _{min}	Q _{max}	V _{min}	V _{max}
1	- 200	200	0.95	1.05
2	- 257.15	433.82	0.95	1.05
3	- 183.68	309.87	0.95	1.05
4	0	0	0.95	1.05
5	0	0	0.95	1.05
6	0	0	0.95	1.05
7	0	0	0.95	1.05
8	0	0	0.95	1.05
9	0	0	0.95	1.05
10	0	0	0.95	1.05
11	0	0	0.95	1.05
12	- 220.42	371.85	0.95	1.05

13	0	0	0.95	1.05
14	0	0	0.95	1.05
15	0	0	0.95	1.05
16	- 238.77	402.83	0.95	1.05
17	0	0	0.95	1.05
18	- 139.6	235.5	0.95	1.05
19	0	0	0.95	1.05

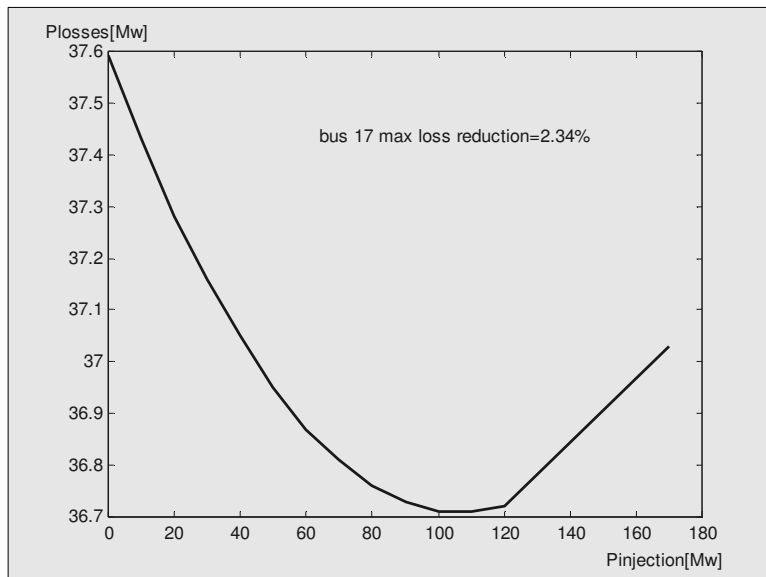


Figure (1): P_{loss} vs. $P_{injection}$ at Bus 17 (KAZ)

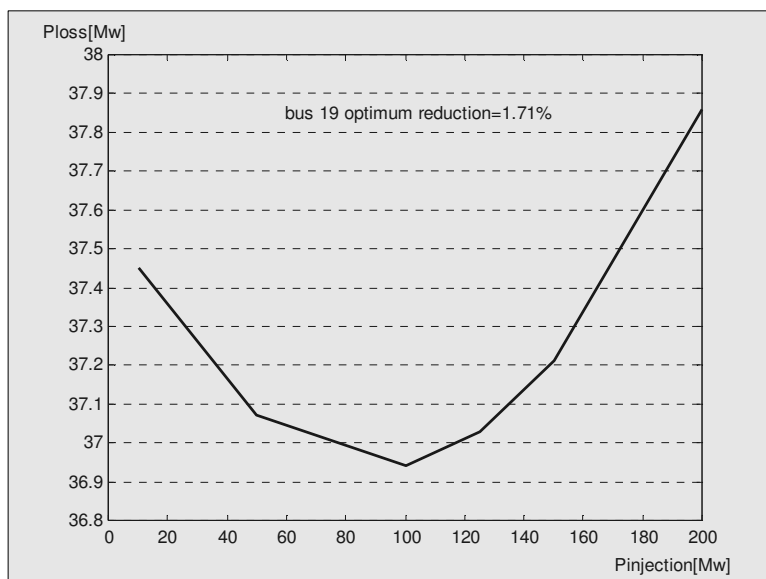


Figure (٢): P_{loss} vs. $P_{injection}$ at Bus 19 (QRN)

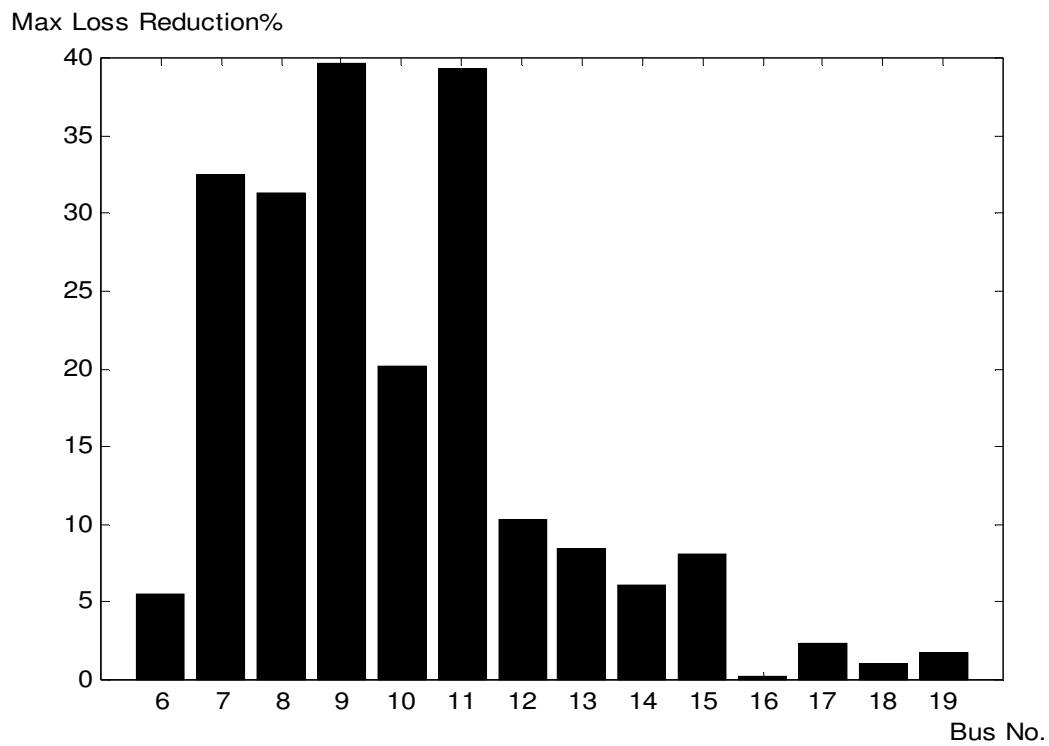


Figure3: Loss Reduction for Injecting Real Power at some Buses

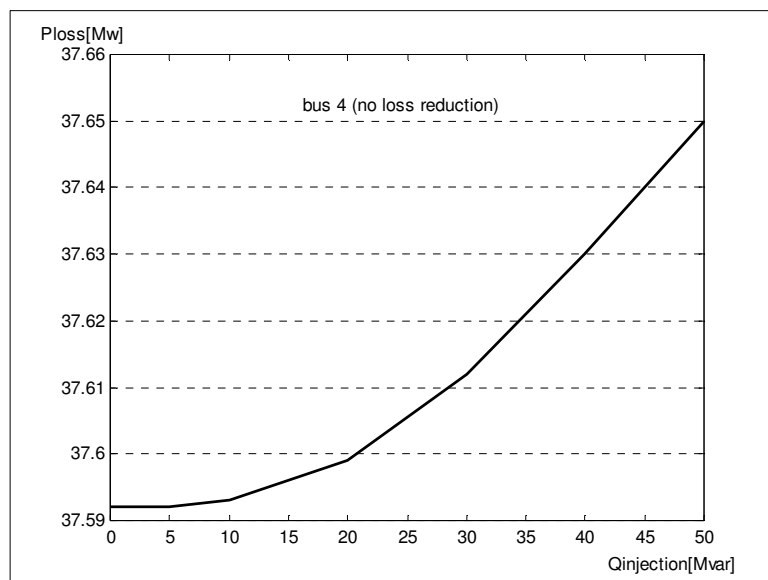


Figure4: P_{loss} vs. $Q_{injection}$ for Bus 4 (QAM)

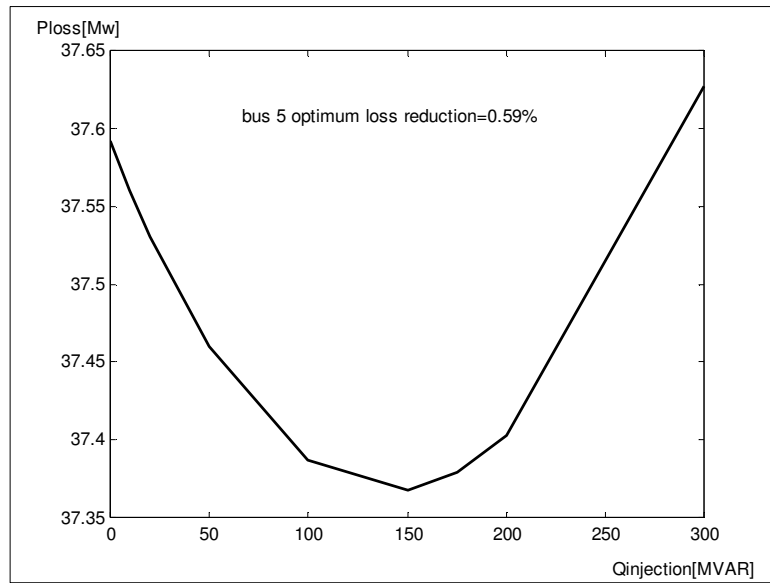


Figure5: P_{loss} vs. $Q_{injection}$ for Bus 5 (MOS)

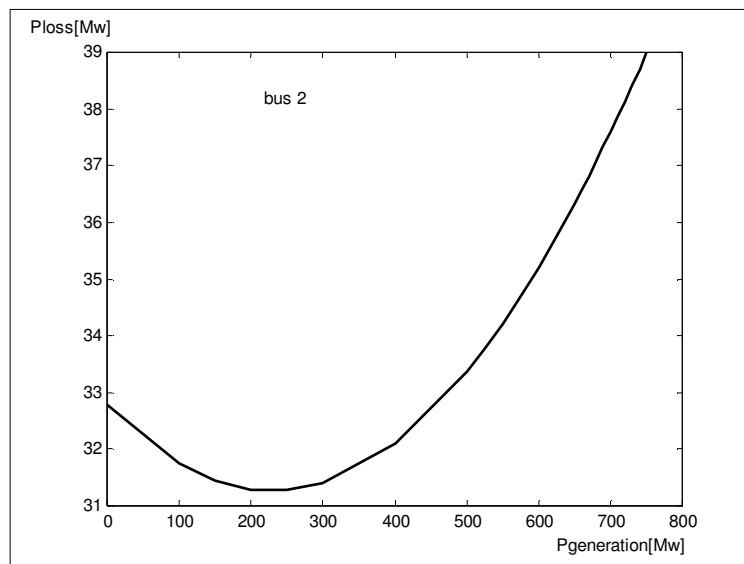


Figure 6: Relationship between Sensitivity and System Losses at Bus 2 (MOS)

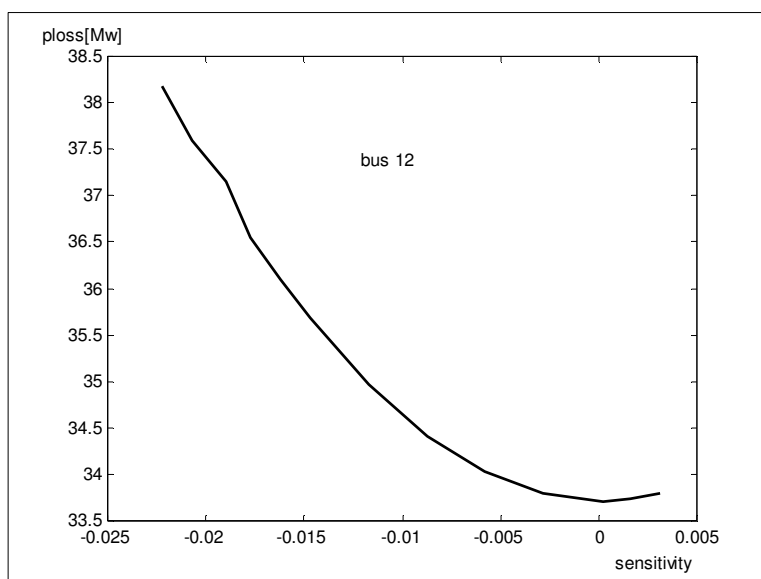


Figure 7: Relationship between Sensitivity and System Losses at Bus 3 (HAD)

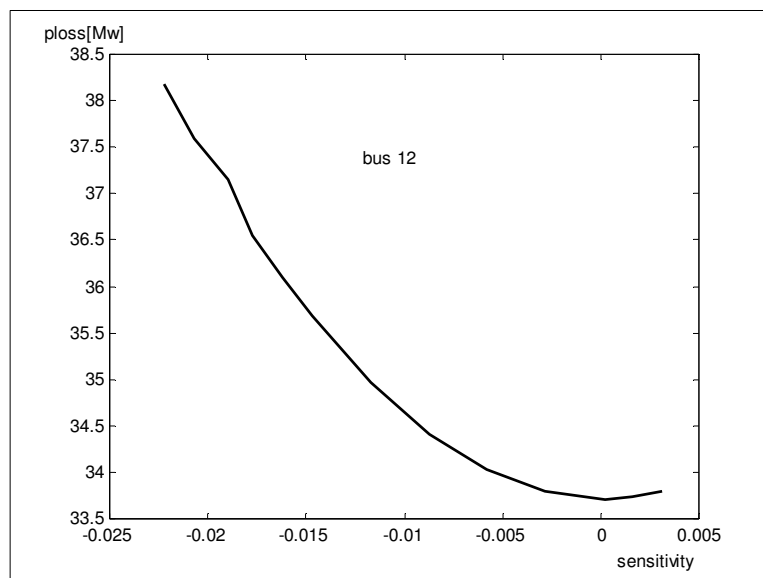


Figure 8: Relationship between Sensitivity and System Losses at Bus 12 (MSB)

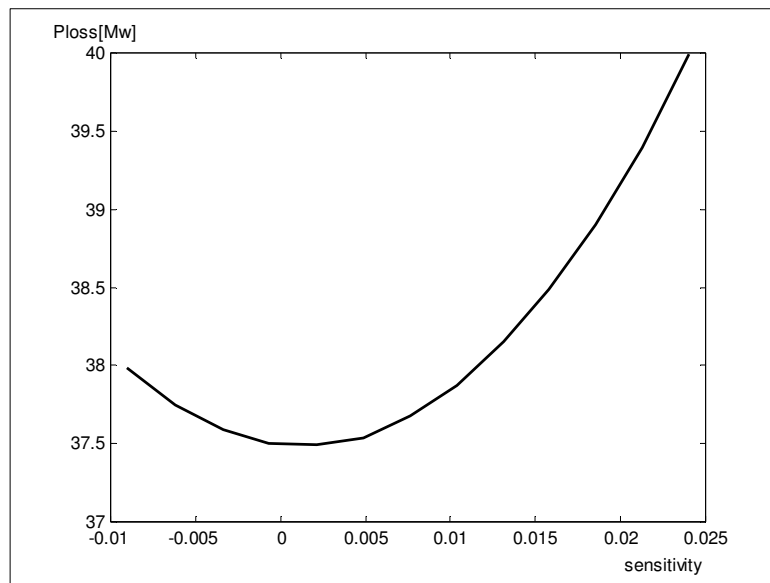


Figure 9: Relationship between Sensitivity and System Losses at Bus 16 (NSR)

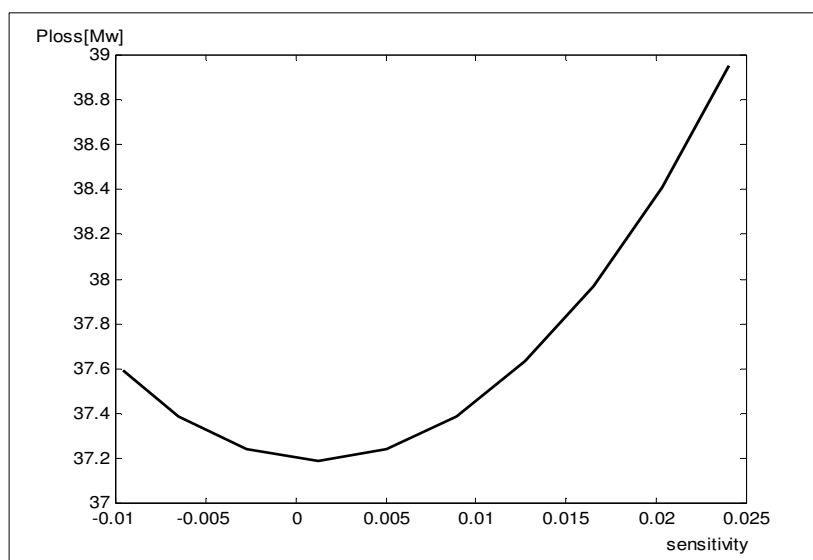


Figure10: Relationship between Sensitivity & System losses at Hartha Bus18(HRT)

From a **Subroutine** calculating losses using eq.۲

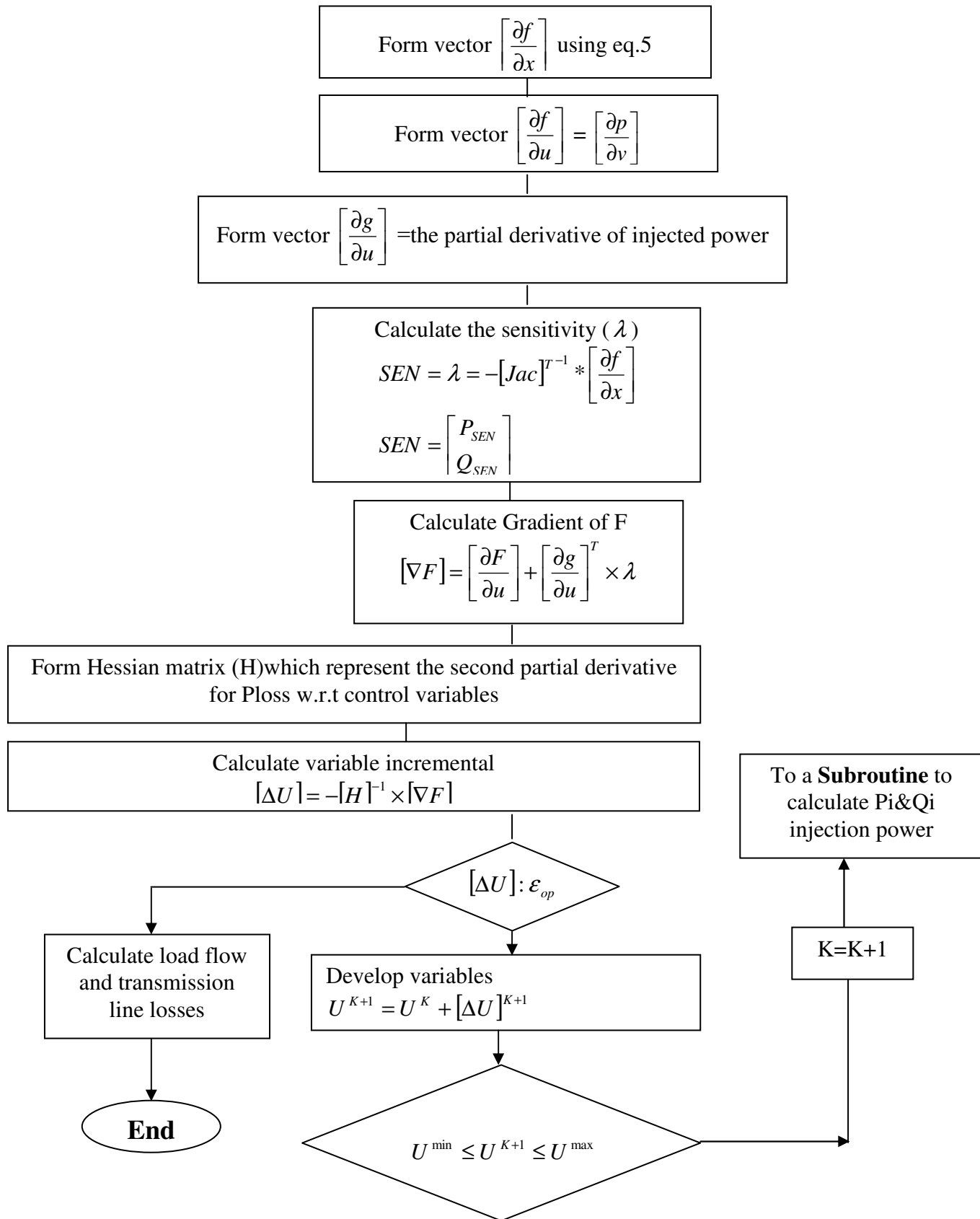


Figure11: Flow chart illustrating optimization program using sensitivity analyzing