ALLOCATION OF GENERATION PLANTS THAT GIVES MINIMUM LOSSES FOR IRAQI SUPER GRID NETWORK

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ABSTRACT

The main goal of this work is to determine optimal location for placing generating plants in the Iraqi National Super Grid which gives minimum total losses in the system. A package build under Matlab was used to allocate optimal placement of generating sets, calculating active and reactive power for these generators, .calculating system minimum losses, and determine the effect of varying the output of the generators used on losses reduction.

KEYWORDS

Allocation of the generating units, Minimum Losses, Iraqi supper grid network

تحديد مواقع إنشاء محطات التوليد التي تعطي اقل خسائر في القدرة لشبكة الضغط الفائق العراقية

ألخلاصة

تهدف هذه الدراسة إلى تحديد أفضل المواقع المستقبلية لمحطات التوليد لشبكة الضغط الفائق في العراق والتي تعطي اقل خسائر في المنظومة. استخدم لهذا الغرض برنامج جاهز بلغة Matlab حيث تم التوصل إلى تحديد أفضل الأماكن لنصب محطات التوليد، حساب القدرة الفعالة والمتفاعلة لكل محطة، اقل الخسائر التي يمكن الحصول عليها عند تحديد أماكن وقدرات تلك المحطات، و تأثير تغيير قدرات المحطات الحالية في التقليل من خسائر المنظومة .

INTRODUCTION

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. Proper placement of generation units will reduce losses also free available capacity for transmission of power and reduce equipment stress, while improper placement may actually increase system losses. In this work an algorithm was applied to determine the best placement of new units for the Iraqi super grid network in order to maximize power available and minimize losses on the system for a given load (William 2002).

Mathematical representation of the problem:

The main 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.

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

Where $[SEN]$ is the sensitivity factor.

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 (samir2007).

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.

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

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

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

$$\partial P_{loss} / \partial V_i = 2 \sum_{\substack{j=1 \\ j \neq i}}^{N} G_{ij} \left[|V_i| - |V_j| \cos(\delta_i - \delta_j) \right] \tag{3}$$

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

$$[Jac]^T[SEN]=[D] \tag{4}$$

Then $[SEN]=[Jac]^{T^{-1}}[D]$ (5)

$$\begin{bmatrix} P_{sen} \\ Q_{sen} \end{bmatrix} = \begin{bmatrix} \dfrac{\partial P_L}{\partial P} \\ \dfrac{\partial P_L}{\partial Q} \end{bmatrix} = [Jac]^{T^{-1}} \begin{bmatrix} \dfrac{\partial P_L}{\partial \delta} \\ \dfrac{\partial P_L}{\partial V} \end{bmatrix} \tag{6}$$

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

Then $P_{sen} = \begin{bmatrix} \dfrac{\partial Ploss}{\partial P_2} \\ \dfrac{\partial Ploss}{\partial P_{NL+1}} \end{bmatrix}$ (7)

And $Q_{sen} = \begin{bmatrix} \dfrac{\partial Ploss}{\partial Q_2} \\ \dfrac{\partial Ploss}{\partial Q_{NL+1}} \end{bmatrix}$ (8)

The following matrix represents derivative of active power losses w.r.t generation voltages:

$$\frac{\partial f}{\partial u} = \begin{bmatrix} \dfrac{\partial P_{loss}}{\partial V_1} \\ \dfrac{\partial P_{loss}}{\partial V_2} \\ \vdots \\ \dfrac{\partial P_{loss}}{\partial V_{NG}} \end{bmatrix} \tag{9}$$

Where $\dfrac{\partial P_{loss}}{\partial V_i} = 2\sum_{\substack{j=1 \\ j\neq 1}}^{NG} G_{ij}\left[|V_i| - |V_j|\cos(\delta_i - \delta_j)\right]$

$$\frac{\partial g}{\partial u} = \begin{bmatrix} \dfrac{\partial P_2}{\partial V_1} & \dfrac{\partial P_2}{\partial V_2} & \cdots & \dfrac{\partial P_2}{\partial V_N} \\ \vdots & & & \\ \dfrac{\partial P_N}{\partial V_1} & \dfrac{\partial P_N}{\partial V_2} & \cdots & \dfrac{\partial P_N}{\partial V_N} \\ \dfrac{\partial Q_2}{\partial V_1} & \dfrac{\partial Q_2}{\partial V_2} & \cdots & \dfrac{\partial Q_2}{\partial V_N} \\ \vdots & & & \\ \dfrac{\partial Q_{N_{L+1}}}{\partial V_1} & \dfrac{\partial Q_{N_{L+1}}}{\partial V_2} & & \dfrac{\partial Q_{N_{L+1}}}{\partial V_N} \end{bmatrix} \tag{10}$$

Where $\left[\frac{\partial g}{\partial u}\right]$ represents partial derivative of injected power to bus voltages.

Gradient $[\nabla f] = \left[\frac{\partial f}{\partial u}\right] + \left[\frac{\partial g}{\partial u}\right]^T * [SEN]$ (11)

Where $[\nabla f]$ represent the sensitivity of losses w.r.t control variables (Manadur 1981).

$$\text{Hessian } [H] = \frac{\partial_2 P_{loss}}{\partial V_i \partial V_j} = \begin{bmatrix} \frac{\partial_2 P_{loss}}{\partial V_1^2} & \cdots & \frac{\partial P_{loss}}{\partial V_1 \partial V_{NG}} \\ \frac{\partial_2 P_{loss}}{\partial V_2 \partial V_1} & \cdots & \frac{\partial P_{loss}}{\partial V_2 \partial V_{NG}} \\ \vdots & & \\ \frac{\partial_2 P_{loss}}{\partial V_{NG} \partial V_1} & \cdots & \frac{\partial P_{loss}}{\partial V_{NG}^2} \end{bmatrix} \quad (12)$$

Where $[H]$ represents the second partial derivative for P_{loss} w.r.t control variables.

$$[\Delta u] = \begin{bmatrix} \Delta V_1 \\ \Delta V_2 \\ \vdots \\ \Delta V_{NG} \end{bmatrix} = -[H]^{-1} * [\nabla f] \quad (13)$$

$[\Delta u] \le \in$ Optimum, where $\in$ opt. = 0.001, then P_{loss} represents minimum losses in the system. Otherwise control variables have to be developed as follows:

$$\begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_{NG} \end{bmatrix}^{K+1} = \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_{NG} \end{bmatrix}^{K} + \begin{bmatrix} \Delta V_1 \\ \Delta V_2 \\ \vdots \\ \Delta V_{NG} \end{bmatrix}^{K} \quad (14)$$

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 (Manadur 1981).

Iraqi National Super Grid (INSG) System:

INSG network consists of 19 busbars and 27 transmission lines; the total length of the lines is 3711 km., six generating stations are connected to the grid. They are of various types of generating units, thermal and hydro turbine kinds, with different capabilities of MW and MVAR generation and absorption. **Fig.1** shows the single line diagram of the INSG (400) kV system (Afaneen 2004).

The diagram shows all the bus bars, the transmission lines connecting the bus bars with their lengths in km marked on each one of them. The load and generation of INSG system on the 2nd of January 2003 are tabulated in **Table1**. Lines parameters were tabulated in **Table2** (Al-Rawi2002) and used for a program formulated under Matlab 5.3. For this study Baji was chosen as slack bus.

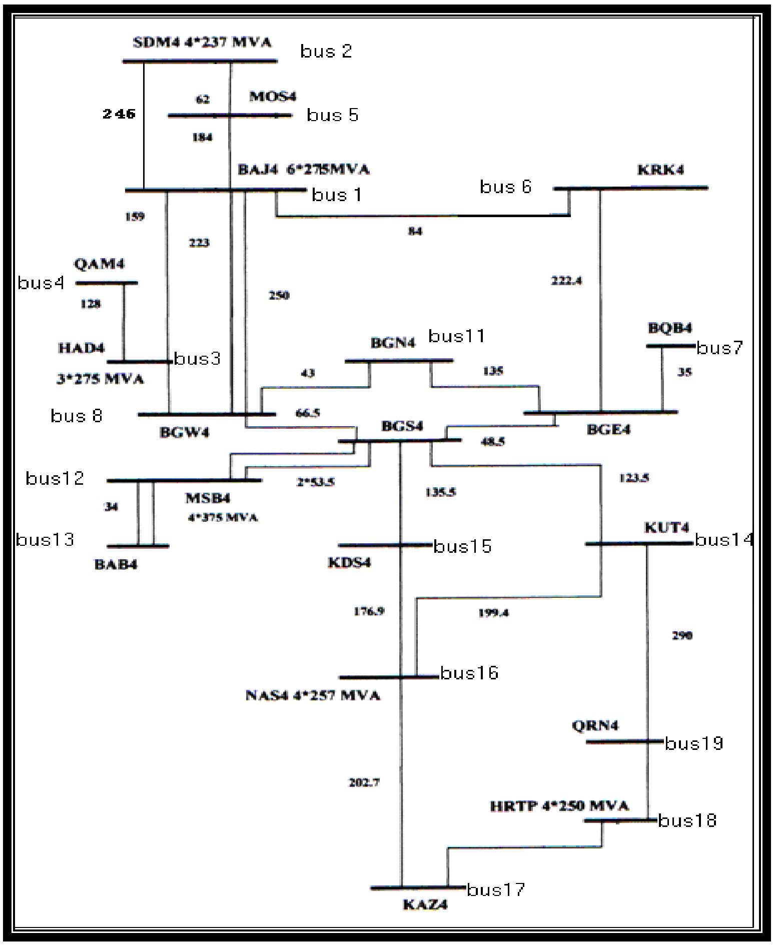

Figure1: Configuration of the 400 kV Network

Table1: The load & Generation of the Iraqi National Super Grid System (400 kV)

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	Total losses=37.592Mw		3400.592	463.8716	3363	2056

Table2: 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

Results and Discussion

The values of dPloss/dPi which represents the efficiency to reduce system power losses with respect to real power injecting at the buses except the slack bus, were tabulated in **Table3**.

High negative partial derivative at any bus means that the system has high efficiency to reduce active power losses when injecting active power in that bus. On the other hand positive partial derivative for example at buses (3, 5, and 2) means that system power losses increase in case of injecting real power in these buses. The best buses to accept injecting active power are those with high negative partial derivative. **Table4** and **Fig.2** show the values of active power injection at each load bus, which gives maximum real power loss reduction. Injecting real power at bus 9 (BGE) gives max system loss reduction equal to $\frac{37.592-22.67}{37.592}\times 100\%$ = 39.69%.On the other hand

Table 3: loss sensitivities for all buses

Bus No.	Bus Name	Loss sensitivity $\partial P_{loss} / \partial P_{injection}$
7	Baquba	- 0.0392
9	Baghdad East	- 0.0361
11	Baghdad North	- 0.0359
8	Baghdad West	- 0.0279
10	Baghdad South	- 0.0258
15	Kadissia	- 0.0230
13	Babel	- 0.0214
12	Mussayab	- 0.0207
14	KUT	- 0.0188
17	Khour-Al-Zubair	- 0.0152
19	Qurna	- 0.0126
6	Kirkuk	- 0.0110
18	Hartha	- 0.0096
16	Nasiriya	- 0.0034
4	Qaim	- 0.0004
1	Baji	0.0000
3	Haditha	0.0031
5	Mousil	0.0136
2	Sed Al-Mousil	0.0268

injecting real power at bus 16 (NSR) gives min system loss reduction equal to $\frac{37.592-37.49}{37.592}\times 100\%$ = 0.27%. For the other buses, loss reduction lies between these two values.

Table (4): The Injection of Real Power which Gives Max Loss Reduction

Bus No.	Bus Name	$P_{injection}$ [Mw]	Minimum losses [Mw]	Max. loss Reduction %
9	Baghdad East	800	22.67	39.69
11	Baghdad North	825	22.83	39.26
7	Baquba	625	25.37	32.51
8	Baghdad West	825	25.83	31.28
10	Baghdad South	550	30.35	20.19
12	Mussayab	350	33.71	10.32
13	Babel	200	34.406	8.47
15	Kadissia	250	34.56	8.06
14	KUT	225	35.30	6.09
6	Kirkuk	350	35.528	5.49
17	Khour-Al-Zubair	100	36.71	2.34
19	Qurna	100	36.946	1.71
18	Hartha	75	37.197	1.05
16	Nasiriya	50	37.49	0.27

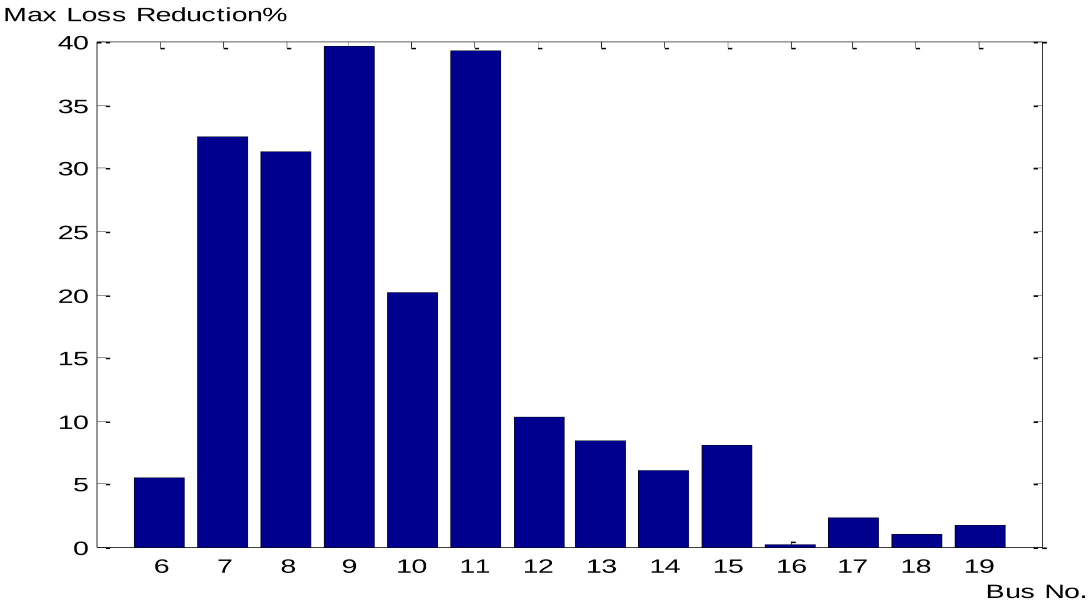

Figure2: maximum real power loss reduction

The optimal power injection at all buses is obtained by adding in steps small real power (U) equal to (5 Mw) in each step at the buses with the negative partial derivative of power losses with respect to real injection power (sensitivity) as shown before in **Table3**.

The addition of active power to each bus is stopped when sensitivity at that bus becomes zero or positive, the overall addition is stopped when sensitivity in all buses becomes zero or positive, at the same time this process must satisfy the constraints including reactive power limits of the generators as shown in **Table5** where the load bus voltage limit is pulse minus 0.05.

The injection of 180,200,210 and 300 Mw at the buses 7,8,9,11 respectively which are the best buses according to **Table3,** gives total system losses equal to 21.824 Mw. Total system losses according to **Table4** is equal to 37.592 So: Loss Reduction $= \frac{37.592 - 21.824}{37.592} \times 100\% = 41.94\%$.

Table5: INSG System Line Data Limits

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
20	- 200	200	0.95	1.05
21	- 257.15	433.82	0.95	1.05
22	- 183.68	309.87	0.95	1.05
23	- 220.42	371.85	0.95	1.05
24	- 238.77	402.83	0.95	1.05
25	- 139.6	235.5	0.95	1.05

CONTROL OF ACTIVE POWER AT GENERATION BUSES:

Optimal power generation for the present six generators in INSG, were calculated using procedure similar to that implemented for the other buses. Generation at each bus is increased by (10 Mw) at each step until the sensitivity at the bus becomes zero or positive, i.e. the system losses start to increase. **Table6** show active power generation at each generation bus which gives minimum losses equal to (25.95 Mw) with optimal losses reduction equal to (30.96 %).

Table 6: Active Power Generations which Give Optimal Losses Reduction

Generation Bus Number	Generation [Mw]
1 BAJ	571
2 SDM	250
3 HAD	350
12 MSB	1000
16 NSR	500
18 HRT	400

CONCLUSIONS

Proper placement of generation units will reduce losses, while improper placement may actually increase system losses. Each bus in the system has its sensitivity to decrease losses with respect to the power injection in that bus. From the obtained results it is very clear that the best buses for the placement of generation units are (7)Baquba, (8)Baghdad West, (9)Baghdad East, (10)Baghdad South and (11)Baghdad North which give maximum loss reduction and the best case to operate the present generation plants in Iraqi power system is to operate them at optimal power generation, which gives optimal loss reduction.

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