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Sensitivity Factor Analysis For Unit Commitment In Loaded Lines

Lata Chaudhary[1] Poonam Singhal[2]
[1]Post Graduate Student, EE Deptt. University of Science & Technology Faridabad, India
[2]Associate Prof. Electrical Engg. Deptt. YMCA University of Science & Technology Faridabad, India

ABSTRACT

In today's competitive electricity market, it is not possible to settle all contracted transactions of power because of congestion in transmission lines. Usually, the independent system operator seeks to eliminate congestion by rescheduling output power of the generators. But all generators may not have the same effect (sensitivity) on the power flow of the congested lines, so this is not an economical way to reschedule output power of all generators for managing congestion. Therefore, in this paper, active power generator sensitivity factor of the generators to the congested lines have been utilized to ascertain the number of generators participating in congestion management. The effectiveness and feasibility of the proposed algorithm have been tested on IEEE 30 bus system.

Keywords: congestion; load flow analysis; sensitivity index; rescheduling(key words)

I. INTRODUCTION

The restructuring of the electricity industry has brought huge changes in the planning, operations and management of power systems. The introduction of competitive markets did not only bring benefits, but also made the industry face unparalleled problems. Unlike other markets, the electricity market has crucial characteristics, which make the operation of competitive markets a major challenge. The lack of major storage capability, the in-time-manufacturing nature of electricity and the central role that is played by the transmission and distribution networks, are some of the principal complexities in electrical power system. With the increasing number of market participants in terms of generation, transmission and distribution owners, the number of desired transactions between the various players is also growing [5]. Each transaction requires energy to be transported from a sending point to a point of receipt. The sellers and buyers of electric energy are dependent on the transmission network for its transportation. Before restructuring, the power grid used to be operated by vertically integrated utilities, who had control over both generation and transmission facilities. Due to the unbundling of generation and transmission and the advent of more decentralized decision-making, it has become a challenge to operate the system in synchronism. The current transmission networks were not initially planned for trading in a competitive market. A problem that is becoming more and more significant nowadays is transmission congestion In addition, one of the key features of the electricity market is that the energy flow will occasionally take the direct route from the sender to the receiver, but will travel across the transmission system according to the laws of physics and is especially in a highly interconnected network likely to result in loop flows and affect various parts of the power system. If market participants aim to undertake a high number of transactions to transfer energy between various points in the network, the realization of all schedules might lead to violations of one or more limits of the transmission system. This situation is called transmission congestion. Whenever this is the case, not all of the desired transactions can be realized. The market players value the transmission of energy differently and the fact of not being able to realize certain transactions can have severe impacts and cause high additional costs. Energy that cannot be purchased from the supplier who offers it at the lowest price because the current state of the transmission system does not allow the transfer, has to be purchased from an alternative resource at a higher price. The situation is especially severe if an area with high demand does not possess sufficient generation and relies on the import of energy from neighboring systems to serve the network load. In this case, congestion on the tie lines between the two regions can significantly endanger the ability of the system to meet its demand [8].

In this paper, active power generator sensitivity factor of the generators to the congested lines have been utilized to ascertain the number of generators participating in congestion management.

II. COMPUTATIONAL METHODOLOGY

A) Determination of Congested Lines

AC load flow analysis in the IEEE 30 bus system (Appendix A) has been carried out using Newton-Raphson load flow method. For secure system, the power flow in the transmission line should not exceed their permissible limit. From the load flow results as shown in the table power flow in the transmission line 1-2 is exceeding its limits i.e. the line is overloaded and therefore this line is considered as congested line. Hence suitable corrective action should be carried out to alleviate the above said overloads. One of the methods to resolve this issue is to re-dispatch the generators based on the sensitivity factors. Participating generator buses are selected based on the sensitivity factor as calculated below.

B) Formulation of Generator Sensitivity Factors[4]

1) Linear sensitivity analysis:

The generator sensitivity (GS) technique indicates the change of active power flow due to change in active power generation. The generators in the system under consideration have different sensitivities to the power flow on the congested line. A change in real power flow in a transmission line k connected between bus i and bus j due to change in power generation by generator g can be termed as generator sensitivity to congested line (GS). Mathematically, GS for line k can be written as

$$GS_g = \frac{\Delta P_{ij}}{\Delta P_{Gg}} \qquad (1)$$

Where P_{ij} the real power is flow on congested line-k; P_{Gg} is the real power generated by the i_{th} generator.

The basic power flow equation on congested line can be written as

$$P_{ij} = -V_i^2 G_{ij} + V_i V_j G_{ij} \cos(\theta_i - \theta_j) + V_i V_j B_{ij} \sin(\theta_i - \theta_j) \qquad (2)$$

Where V_i and θ_i are voltage magnitude and phase angle respectively at the i_{th} bus; G_{ij} and B_{ij} represent, respectively, the conductance and susceptance of the line connected between buses i and j; neglecting P-V coupling, (1) can be expressed as

$$GS_g = \frac{\partial P_{ij}}{\partial \theta_i} * \frac{\partial \theta_i}{\partial P_{Gg}} + \frac{\partial P_{ij}}{\partial \theta_j} * \frac{\partial \theta_j}{\partial P_{Gg}} \qquad (3)$$

The first terms of the two products in (3) are obtained by differentiating (2) as follows:

$$\frac{\partial P_{ij}}{\partial \theta_i} = -V_i V_j G_{ij} \sin(\theta_i - \theta_j) + V_i V_j B_{ij} \cos(\theta_i - \theta_j)$$

(4)

$$\frac{\partial P_{ij}}{\partial \theta_j} = -V_i V_j G_{ij} \sin(\theta_i - \theta_j) - V_i V_j B_{ij} \cos(\theta_i - \theta_j)$$

(5)

$$\frac{\partial P_{ij}}{\partial \theta_j} = -\frac{\partial P_{ij}}{\partial \theta_i}$$

(6)

The active power injected at a bus-s can be represented as

$$P_s = P_{Gs} - P_{Ds}$$

(7)

Where, P_{Ds} is the active load at bus s and P_s can be expressed as

$$P_s = |V_s| \sum_{t=1}^{n} ((G_{st} \cos(\theta_s - \theta_t) + B_{st} \sin(\theta_s - \theta_t))|V_t|) = |V_s|^2 G_{ss} + |V_s| \sum_{\substack{t=1 \\ t \neq s}}^{n} ((G_{st} \cos(\theta_s - \theta_t) + B_{st} \sin(\theta_s - \theta_t))V_t$$

(8)

Where n is the number of buses in the system.

$$\frac{\partial P_s}{\partial \theta_t} = |V_s| \; |V_t| \; [G_{st} \; (\theta_s - \theta_t) \; - \; B_{st}(\theta_s - \theta_t)]$$

(9)

$$\frac{\partial P_s}{\partial \theta_s} = |V_s| \sum_{\substack{t=1 \\ t \neq s}}^{n} [-G_{st} \sin(\theta_s - \theta_t) + B_{st} \cos(\theta_s - \theta_t) \; |V_t| \,]$$

(10)

Neglecting P-V coupling, the relation between incremental change in active power at system buses and the phase angles of voltages can be written in matrix form as

$$[\Delta P]_{n*1} = [H]_{n*n} [\Delta\theta]_{n*1} \qquad (11)$$

$$[H]_{n*n} = \begin{bmatrix} \frac{\partial P_1}{\partial \theta_1} & \frac{\partial P_1}{\partial \theta_2} & \cdots & \frac{\partial P_1}{\partial \theta_n} \\ \frac{\partial P_2}{\partial \theta_1} & \frac{\partial P_2}{\partial \theta_2} & \cdots & \frac{\partial P_2}{\partial \theta_n} \\ \frac{\partial P_3}{\partial \theta_1} & \frac{\partial P_3}{\partial \theta_2} & \cdots & \frac{\partial P_3}{\partial \theta_n} \end{bmatrix}$$

(12)

$$[\Delta\theta] = [H]^{-1} [\Delta P] \qquad (13)$$

$$=[M][\Delta P] \qquad (14)$$

Where
$$[M] = [H]^{-1} \qquad (15)$$

To find the value of $\frac{\partial \theta_i}{\partial P_{Gg}}$ and $\frac{\partial \theta_j}{\partial P_{Gg}}$ in (3), [M] needs to be found out. However, [H] is a singular matrix of rank one deficiency. So it is not directly invertible. The slack bus in the has been considered as the reference node and assigned as bus number 1. The elements of first row and first column of [H] can be eliminated to obtain a matrix [H-1] which can $(.)_{-1}$ be inverted to obtain a matrix [M-1], where represents a matrix with its first row and column deleted or a vector with the first element deleted. Using these relations the following equation can be obtained:

$$[\Delta\theta_{-1}] = [M_{-1}]\,[\Delta P_{-1}] \qquad (16)$$

The actual vector $[\Delta\theta]$ can be found by simply adding the element $[\Delta\theta_1]$ to (16) as shown by the following relation:

$$[\Delta\theta]_{n*1} = \begin{bmatrix} 0 & 0 \\ 0 & [M_{-1}] \end{bmatrix}_{n*n} [\Delta P]_{n*1} + \Delta\theta_1 \begin{bmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{bmatrix}$$
(17)

The second term of the sum in (17) vanishes as , being the change in phase angle of slack bus is zero. Accordingly, (17) reduces to

$$[\Delta\theta]_{n*1} = \begin{bmatrix} 0 & 0 \\ 0 & [M_{-1}] \end{bmatrix}_{n*n} [\Delta P]_{n*1} \qquad (18)$$

Thus required elements of $\frac{\partial \theta_i}{\partial P_{Gg}}$ and $\frac{\partial \theta_j}{\partial P_{Gg}}$ are found out from (18) It is to be noted that the generator sensitivity values thus obtained are with respect to the slack bus as the reference. So the sensitivity of the slack bus generator to any congested line in the system is always zero.

GS_g denotes how much active power flow over a transmission line connecting bus-i and bus-j would change due to active power injection by generator g. The system operator selects the generators having non uniform and large magnitudes of sensitivity values as the ones most sensitive to the power flow on the congested line and to participate in congestion management by rescheduling their power outputs.

2) Generator shift sensitivity factors (reactance method)

For the calculation of generator shift sensitivity factor, the linear load flow model is considered. This is equivalent to a 1 pu power increase at bus i with a compensating 1 pu power decrease at the reference bus. The $\Delta\theta$ values are equal to the derivative of the bus angle with respect to a change in power injection at bus *i*. Then, the required sensitivity factors for the change in power of line *l* with respect to a change in generation at bus *i* is:

$$\theta = [X]\ \mathrm{P} \qquad (19)$$

This is the standard matrix calculation for the DC load flow. Since the DC power-flow model is a linear model, the calculation of perturbations about a given set of system conditions by use of the same model can be done.

The incremental changes of the bus voltage angles for perturbations of power injections

$$\Delta\theta = [X]\ \Delta\mathrm{P} \qquad (20)$$

For calculating the generation shift sensitivity factors for the generator on bus *i*, the perturbation is set on bus *i* to + 1and the perturbation on all the other buses to zero. The change in bus phase angles is found using matrix calculations

$$\Delta\theta = \Delta[X] \begin{bmatrix} +1_{atrowi} \\ -1_{atrefrow} \end{bmatrix} \qquad (21)$$

This is equivalent to a 1 pu power increase at bus i with a compensating 1 pu power decrease at the reference bus. The $\Delta\theta$ values are equal to the derivative of the bus angle with respect to a change in power injection at bus i. Then, the required sensitivity factors for the change in power of line l with respect to a change in generation at bus i is:

$$GS_g = \frac{d\theta_l}{dP_i} = \frac{d}{dP_i}\left[\frac{1}{x_l}(\theta_n - \theta_m\right] \qquad (22)$$

$$= \frac{1}{x_l}\left[\frac{d}{dP_i}\theta_n - \frac{d}{dP_i}\,\theta_m\right] \qquad (23)$$

$$= \frac{1}{x_l}[X_{ni} - X_{mi}] \qquad (24)$$

Where

$X_{ni} = \frac{d}{dP_i}\theta_n = n^{th}$ element from the $\Delta\theta$ vector in Eq. 21

$X_{mi} = \frac{d}{d_{Pi}}\theta_m = m^{th}$ element from the $\Delta\theta$ vector in Eq. 21

θ_m = mth element from the $\Delta\theta$ vector in Eq. 21

x_l= line reactance for line *l*.

III. RESULTS AND DISCUSSION

Test Case 1: IEEE 30 Bus System

Considering IEEE 30 Bus System (given in Appendix) , which consist of 6 generator buses and 24 load buses. Slack node has been assigned as bus number 1. The IEEE - 30 bus test system is shown in figure 4.1. The system data is taken from appendix. The data is on 100 MVA base.

Optimal power flow is carried out on the given data using Newton-Raphson method and the results thus obtained are displayed in table 1 and 2 respectively.

Table 1 indicates load flow analysis results while table 2 indicates line flows and line losses. From the analysis of tables it can be deducted that transmission line 1(between buses 1 and 2) is congested as this line is exceeding its loading limits.To select the generators for re-dispatching, sensitivity factor of congested line is calculated with respect to all the generators in the given test system. Sensitivity factor is calculated by using two methods.

First method involves manual calculation by introducing a fixed change in the generation of one of the generators and observing a corresponding change in line flow in congested line. Second method is reactance method involving use of line reactances.

Results of both these methods have been placed in table 3.

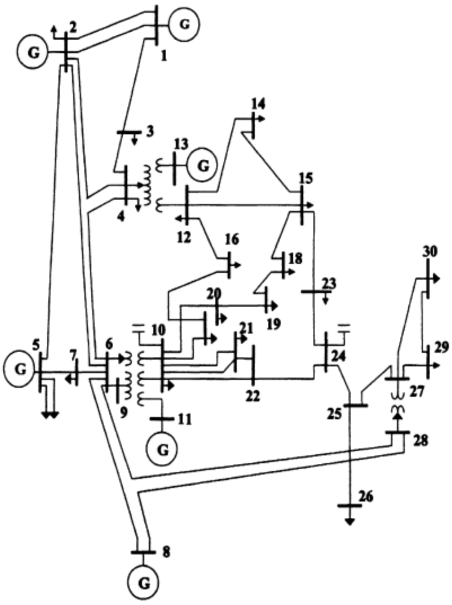

Fig.1 IEEE 30 bus system

TABLE I. LOAD FLOW ANALYSIS

BUS NO.	V (PU)	ANGLE(DEGREES)	INJECTION		GENERATION		LOAD	
			MW	MVAR	MW	MVAR	MW	MVAR
1	1.0600	0.0000	200.024	-6.335	200.024	-6.335	0.000	0.000
2	1.0430	-0.0717	22.626	21.690	44.326	34.390	21.700	12.700
3	1.0248	-0.1081	-2.400	-1.200	-0.000	0.000	2.400	1.200
4	1.0164	-0.1301	-7.600	-1.600	-0.000	-0.000	7.600	1.600
5	1.0100	-0.1963	-75.789	8.509	18.411	27.509	94.200	19.000
6	1.0143	-0.1536	-0.000	0.000	-0.000	0.000	0.000	0.000
7	1.0048	-0.1803	-22.800	-10.900	-0.000	-0.000	22.800	10.900
8	1.0100	-0.1615	-20.000	-8.498	10.00	21.502	30.000	30.000
9	1.0526	-0.1911.	0.000	0.000	0.000	0.000	0.000	0.000
10	1.0461	-0.2208	-5.800	17.00	0.000	19.000	5.800	2.000
11	1.0820	-0.1728	10.000	15.394	10.000	15.394	0.000	0.000
12	1.0598	-.2050	-11.200	-7.500	-0.000	0.000	11.200	7.500
13	1.071	-1.902	12.000	8.656	12.000	8.656	0.000	0.000
14	1.0449	-0.2210	-6.200	-1.600	12.000	-0.000	6.200	1.600
15	1.0400	-0.2231	-8.200	-2.500	-0.000	-0.000	8.200	2.500
BUS NO.	V (PU)	ANGLE (DEGREES)	INJECTION		GENERATION		LOAD	
			MW	MVAR	MW	MVAR	MW	MVAR
16	1.0468	-0.2164	-3.500	-1.800	-0.000	0.000	3.500	1.800
17	1.0414	-0.2231	-9.00	-5.800	-0.000	-0.000	9.000	5.800
18	1.0300	-0.2343	-3.200	-0.900	-0.000	0.000	3.200	0.900
19	1.0272	-0.2377	-9.500	-3.400	-0.000	-0.00	9.500	3.400
20	1.0312	-0.2345	-2.200	-0.700	-0.000	0.000	2.200	0.700
21	1.0339	-0.2287	-17.500	-11.200	-0.000	-0.000	17.500	11.200
22	1.0345	-0.2286	0.000	0.000	0.000	0.000	0.000	0.000
23	1.0292	-0.2311	-3.200	-1.600	-0.000	0.000	3.200	1.600
24	1.0232	-0.2360	-8.700	-2.400	-0.00	4.300	8.700	6.700
25	1.0199	-0.2330	0.000	0.000	0.000	0.000	0.000	0.000
26	1.0023	-0.2403	-3.500	-2.300	-0.000	-0.000	3.500	2.300
27	1.0264	-0.2266	-0.000	-0.000	-0.000	-0.000	0.000	0.000
28	1.0125	-0.1635	-0.000	-0.000	-0.000	-0.000	0.000	0.000
29	1.0066	-0.2480	-2.400	-0.900	-0.00	-0.00	2.400	0.900
30	0.9952	-0.2633	-10.600	-1.900	-0.000	0.000	10.600	1.900
TOTAL			11.362	-1.783	294.762	124.417	283.400	126.200

TABLE II LINE FLOW AND LOSSES

BUS		P (MW)	Q (MVar)	BUS		P (MW)	Q (MVar)	LOAD	
FROM	TO			FROM	TO			MW	MVAR
1	2	134.857	-8.749	2	1	-131.736	18.095	3.123	9.346
1	3	65.167	7.672	3	1	-63.435	-0.576	1.732	7.097
2	4	37.171	4.784	4	2	-36.435	-2.541	0.736	2.243
3	4	61.035	1.959	4	3	-60.566	-0.613	0.469	1.346
2	5	67.295	5.455	5	2	-63.317	2.855	1.978	8.309
2	6	49.896	2.538	6	2	-48.563	1.507	1.333	4.045
4	6	55.591	-10.039	6	4	-55.224	11.318	0.368	1.279
5	7	-10.471	8.827	7	5	10.556	-8.614	0.085	0.213
6	7	33.650	1.302	7	6	-33.356	-0.398	0.294	0.904
6	8	20.621	4.594	8	6	-20.569	-4.412	-0.052	0.812
6	9	19.701	-18.713	9	6	-19.701	20.173	-0.000	1.460
6	10	13.229	-5.548	10	6	-13.229	-6.625	0.000	1.078
9	11	-10.000	-14.796	11	9	10.000	15.394	0.000	0.5999
9	10	29.701	6.605	10	9	-29.701	-5.6860	0.000	0.9191
4	12	33.810	-17.201	12	4	-33.8102	0.524	0.000	3.323

BUS		P (MW)	Q (MVar)	BUS		P (MW)	Q (MVar)	LOAD	
FROM	TO			FROM	TO			MW	MVAR
12	13	-12.000	-8.389	13	12	12.000	8.656	0.000	0.267
12	14	8.052	2.365	14	12	-7.975	-2.204	0.077	0.160
12	15	18.667	6.781	15	12	-18.435	-6.323	0.232	0.458
12	16	7.891	3.231	16	12	-7.830	-3.102	0.061	0.129
14	15	1.775	0.604	15	14	-1.768	-0.598	0.007	0.006
16	17	4.330	1.302	17	16	-4.314	-1.266	0.015	0.036
15	18	6.344	1.659	18	15	-6.301	-1.572	0.043	0.087
18	19	3.101	0.672	19	18	-3.095	-0.659	0.006	0.012
19	20	-6.405	-2.741	20	19	6.421	2.772	0.016	0.031
10	20	8.697	3.642	20	10	-8.621	-3.472	0.076	0.170
10	17	4.699	4.567	17	10	-4.686	-4.534	0.013	0.033
10	21	15.987	9.732	21	10	-15.875	-9.493	0.111	0.240
10	22	7.748	4.416	22	10	-7.696	-4.307	0.053	0.109
21	22	-1.625	-1.707	22	21	1.625	1.709	0.001	0.001
15	23	5.659	2.762	23	15	-5.622	-2.688	0.037	0.074
22	24	6.070	2.599	24	22	-6.023	-2.526	0.047	0.073
23	24	2.422	1.088	24	23	-2.413	-1.070	0.009	0.018
24	25	-0.263	1.196	25	24	0.266	-1.191	0.003	0.005
25	26	3.544	2.366	26	25	-3.500	-2.300	0.044	0.066
25	27	-36.810	-1.175	27	25	3.827	1.207	0.017	0.032
28	27	17.107	-3.128	27	28	-17.107	4.259	0.000	1.131
27	29	6.189	1.667	29	27	-6.103	-1.505	0.086	0.162
27	30	7.091	1.661	30	27	-6.930	-1.358	0.161	0.303
29	30	3.703	0.605	30	29	-3.670	-0.542	0.033	0.063
8	28	0.569	-1.444	28	8	-0.567	1.449	0.002	0.005
6	28	16.585	-1.535	28	6	-16.540	1.696	0.046	0.162
TOTAL LOSSES								11.362	46.176

TABLE III Generator sensitivity factors of congested lines of IEEE 30-bus system

Congested lines	Generator at bus no. 1	Generator at bus no no. 2	Generator at bus no no. 5	Generator at bus no no. 8	Generator at bus no no. 11	Generator at bus no no. 13
1-2	0	-0.8785	-0.8426	-0.7303	-0.7208	-0.6543
	0	-0.8311	-0.7371	-0.6476	-0.6604	-0.6497

IV. CONCLUSIONS AND FUTURE SCOPE

A negative value of sensitivity factor of a generator indicates that an increase in generation for that generator decreases the power flow in the congested line; a positive sensitivity factor of a generator indicates that an increase in generation increases power flow in the congested line.

After analysis of sensitivity factors it can be concluded that since all the generators are exhibiting negative sensitivity factor all of them would be chosen to tackle congestion.

This work can be further extended by rescheduling of reactive power generation in addition to active power generation and then congestion management using PSO.

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APPENDIX

TABLE A.1 BUS DATA FOR IEEE 30-BUS

BUS	TYPE(*)	VOLTAGE	ANGLE	GEN (MW)	GEN (MVAR)	LOAD (MW)	LOAD (MVAR)	GEN (QMIN)	GEN (QMAX)
1	1	1.06	0	173.5227	0	0	0.0	0	0
2	2	1.043	0	44.3263	50	21.7	12.7	-40	50
3	3	1.0	0	0	0	2.4	1.2	0	0
4	3	1.06	0	0	0	7.6	1.6	0	0
5	2	1.01	0	18.4114	37	94.2	19	-40	40
6	3	1.0	0	0	0	0	0.0	0	0
7	3	1.0	0	0	0	22.8	10.9	0	0
8	2	1.01	0	10	37.3	30	30	-10	40
9	3	1.0	0	0	0	0	0.0	0	0
10	3	1.0	0	0	0	5.8	2	0	0
11	2	1.082	0	10	16.2	0	0.0	-6	24
12	3	1.0	0	0	0	11.2	7.5	0	0
13	2	1.071	0	12	10.6	0	0.0	-6	24
14	3	1.0	0	0	0	6.2	1.6	0	0
15	3	1.0	0	0	0	8.2	2.5	0	0
16	3	1.0	0	0	0	3.5	1.8	0	0
17	3	1.0	0	0	0	9.0	5.8	0	0
18	3	1.0	0	0	0	3.2	0.9	0	0
19	3	1.0	0	0	0	9.5	3.4	0	0
20	3	1.0	0	0	0	2.2	0.7	0	0
21	3	1.0	0	0	0	17.5	11.2	0	0
22	3	1.0	0	0	0	0.0	0.0	0	0
23	3	1.0	0	0	0	3.2	1.6	0	0
24	3	1.0	0	0	0	8.7	6.7	0	0
25	3	1.0	0	0	0	0.0	0.0	0	0
26	3	1.0	0	0	0	3.5	2.3	0	0
27	3	1.0	0	0	0	0.0	0.0	0	0
28	3	1.0	0	0	0	0.0	0.0	0	0
29	3	1.0	0	0	0	2.4	0.9	0	0
30	3	1.0	0	0	0	10.6	1.9	0	0

*1- slack bus , 2- PV bus , 3- PQ bus

TABLE A.2 LINE DATA FOR IEEE 30-BUS

FROM BUS	TOBUS	R(PU)	X(PU)	B/2(PU)	TRANSFORMER TAP (a)	LINE FLOW LIMIT (MVA)
1	2	0.0192	0.0575	0.0264	1	130
1	3	0.0452	0.1852	0.0204	1	130
2	4	0.0570	0.1737	0.0184	1	65
3	4	0.0132	0.0379	0.0042	1	130
2	5	0.0472	0.1983	0.0209	1	130
2	6	0.0581	0.1763	0.0187	1	65
4	6	0.0119	0.0414	0.0045	1	90
5	7	0.0460	0.1160	0.0102	1	70
6	7	0.0267	0.0820	0.0085	1	130
6	8	0.0120	0.0420	0.0045	1	32
6	9	0.0	0.2080	0.0	0.978	65
6	10	0.0	0.5560	0.0	0.969	32
9	11	0.0	0.2080	0.0	1	65
9	10	0.0	0.1100	0.0	1	65
4	12	0.0	0.2560	0.0	0.932	65
12	13	0.0	0.1400	0.0	1	65
12	14	0.1231	0.2559	0.0	1	32
12	15	0.0662	0.1304	0.0	1	32
12	16	0.0945	0.1987	0.0	1	32
14	15	0.2210	0.1997	0.0	1	16
16	17	0.0824	0.1923	0.0	1	16
FROM BUS	TO BUS	R (PU)	X (PU)	B/2 (PU)	TRANSFORMER TAP (a)	LINE FLOW LIMIT (MVA)
15	18	0.1073	0.2185	0.0	1	16
18	19	0.0639	0.1292	0.0	1	16
19	20	0.0340	0.0680	0.0	1	32
10	20	0.0936	0.2090	0.0	1	32
10	17	0.0324	0.0845	0.0	1	32
10	21	0.0348	0.0749	0.0	1	32
10	22	0.0727	0.1499	0.0	1	32
21	22	0.0116	0.0236	0.0	1	32
15	23	0.1000	0.2020	0.0	1	16
22	24	0.1150	0.1790	0.0	1	16
23	24	0.1320	0.2700	0.0	1	16
24	25	0.1885	0.3292	0.0	1	16
25	26	0.2544	0.3800	0.0	1	16
25	27	0.1093	0.2087	0.0	1	16
28	27	0.0	0.3960	0.0	1	65
27	29	0.2198	0.4153	0.0	1	16
27	30	0.3202	0.6027	0.0	1	16
29	30	0.2399	0.4533	0.0	1	16
8	28	0.0636	0.2000	0.0214	1	32
6	28	0.0169	0.0599	0.065	1	32