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Araştırma Makalesi / Research Article

A New Program Design Developed for AC Load Flow Analysis Problems

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Abstract

The Newton-Raphson method is generally used for iterative solutions of power systems in load flow analysis. This study focuses on a new program structure designed to solve large size power systems accurately and quickly using AC load flow analysis technique. This program structure will provide both easy and accurate data input in solutions of high-capacity data input problems. The data required for solving the problem at hand was obtained from an Excel, and coded in Matlab R2015b and solutions were printed onto a solution file.

Key Words

“Electrical power generation, AC load flow, Newton-Raphson Method.”

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1. INTRODUCTION

With the increasing demand for electricity, the planning and optimal operation of power generation systems have recently become a very important issue. In order to carry out these operations, it is necessary to analyze AC load flow in power systems. In order to perform AC load flow analysis of a power system, net active and reactive powers of all buses and voltage magnitude and angle of the slack bus should be input into the system. If there are voltage-controlled buses in the system, they should be introduced to the system as buses, the voltage amplitudes of which will be kept constant. The power flow solution provides the voltages, amplitudes and phase angles of all buses. Afterwards, active and reactive powers of the slack, power flows and line losses are calculated.

There are many studies on AC load flow analysis in the literature. While some of these studies deal with newly developed methods, some others focus on interface designs to make a given program easier to use. The latter address load flow analysis using a modified Newton-Raphson method (Panosyan et al., 2004), use of probability techniques for AC load flow analysis (Allan et al., 1977), (Dagur et al., 2014), linearized AC load flow applications (Rosoni et al, 2016) and use of evolutionary computation methods in load flow solutions (Revanthi, 2008).

This study used the Newton-Raphson method for load flow analysis. When using this method, it is very important that problem data are input correctly into load flow programs. If data are input incorrectly, it is unlikely that solutions will be correct. Therefore, data input becomes very important, especially in high-dimensional systems. For this reason, this study focused on a new data input design. Data was extracted from an Excel file and coded, and the program software was run using Matlab R2015b. The system used as a sample application consists of 118 buses and 54 generators.

This paper summarizes the load flow method, provides information on the software developed to provide ease of use, and presents the solution to a multi-dimensional sample system to demonstrate the advantage of the software.

2. LOAD FLOW ANALYSIS

Load flow refers to determination of the best mode of operation of existing power systems and calculation of voltage magnitude and phase angle of each bus in a power system. Once the information on buses has been obtained, active and reactive power flows and transmission line losses that occur in transmission lines in the system are calculated (Wood et al., 2013), (Kothari & Dhillon, 2007), (Özyön,2009).

In power flow in a power system, net active and reactive powers for all buses except one bus are determined. Net power (active Pk and reactive Qk) is equal to the difference between the power supplied to the system and the power drawn from the system, which means that it is the difference between the power supplied by the generator and the power the load consumes depending on the bus. If there is a voltage-controlled bus in the system, the bus voltage magnitude that will be kept constant at this bus should be determined. The generation of the bus-dependent reactive power generator and the bus voltage angle are calculated at the end of power flow solution (Wood et al., 2013), (Kothari & Dhillon, 2007), (Özyön,2009).

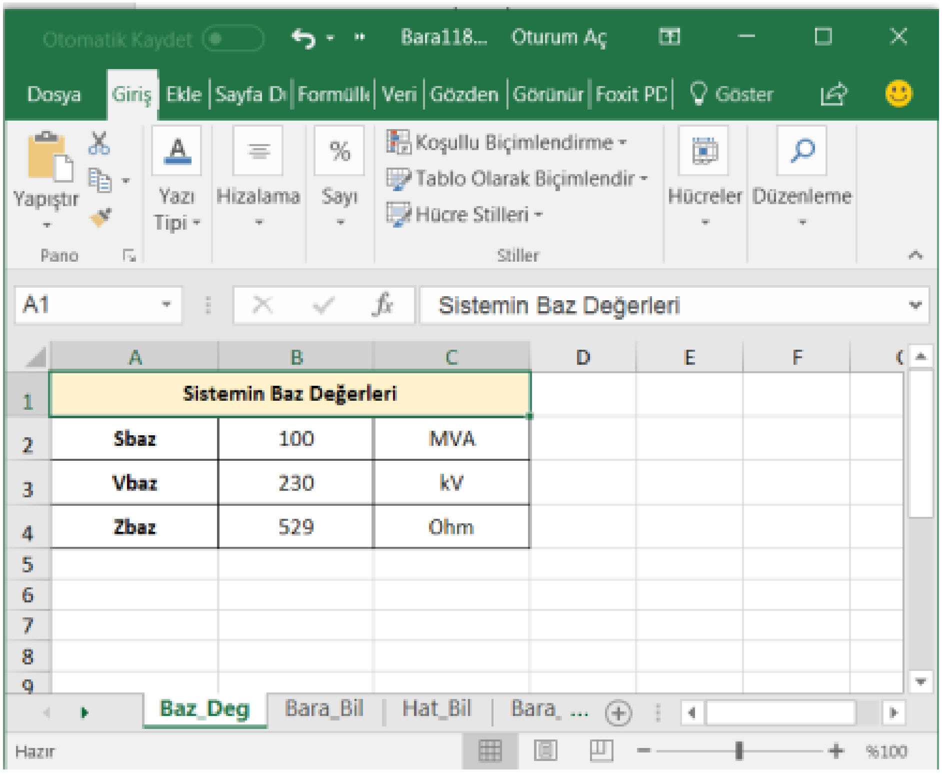
Buses in a power system are divided into various types as load bus, voltage-controlled bus and slack bus. A system has only one slack bus.

Each bus *k* in a system is defined by active power P_k, reactive power Q_k, voltage magnitude $|V_k|$ and voltage angle δ_k. Depending on each bus *k*, two of P_k, Q_k, δ_k and $|V_k|$ values are known and the other two are calculated. The purpose of power flow solutions is to find the two unknown values when the difference between the values of P_k and Q_k and the calculated values are approximated to zero (Wood et al., 2013).

In power flow studies, bus voltage magnitudes |Vk| and angles δk are unknown parameters expect for slack buses. They are, mathematically, independent variables, as their values determine the state of a system. Therefore, a power flow problem can be defined as the determination of values of all state variables using equal number of power flow equations based on input data. Once the values of state variables have been calculated, the entire state of the system is known and all values depending on the state variables can be calculated.

3. DESIGNED PROGRAM AND DATA INPUT

This study focused on designing a new program that facilitates data input in the load flow program. Data input was performed using Excel, and transferred to Matlab R2015b. The load flow solution was obtained by forming the coding of the program as distinct subprograms and results were printed to a file. The data input sheets in Excel are given in Figures 1, 2 and 3. Power base (S_{base}), voltage base (V_{base}) and impedance base (Z_{base}) values used in the system solution are entered in the *Baz_Deg* sheet in Figure 1.

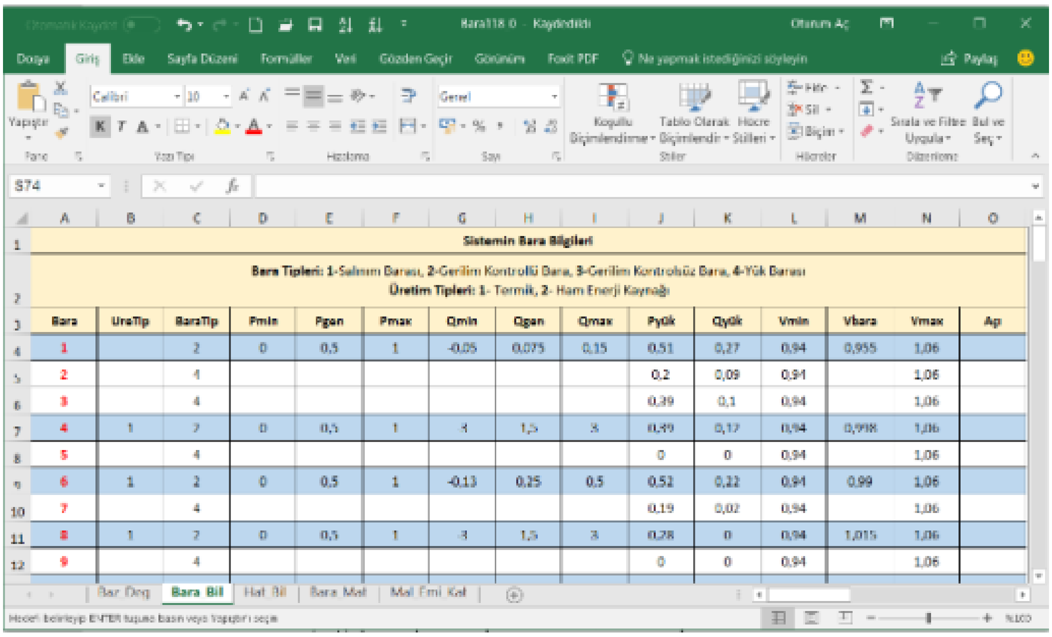


Sistemin Baz Değerleri		
Sbaz	100	MVA
Vbaz	230	kV
Zbaz	529	Ohm

Figure 1. System base values input sheet

The bus numbers, generator bus types (*UreTip*), bus types (*BusTip*), active power generation limits of generators (P_{min}, P_{max}), initial value of active power generation (P_{Gen}), reactive power generation limits of generators (Q_{min}, Q_{max}), initial value of reactive power generation (Q_{Gen}), active and reactive load values at buses (P_{load}, Q_{load}), voltage limits of buses (V_{min}, V_{max}), voltage values of voltage-controlled buses (V_{bus}) and bus angles (*Açı*) used in the solution of the problem are entered in the *Bus_Bil* sheet given in Figure 2.

The line numbers, serial impedance between lines (*R*), parallel admittance (*X*), capacitance values (*B*), transformer transfer ratio (*Tap*), transmission line carrying capacities (S_{limit}) and maximum angle difference between buses (*MaxAf*), which are the transmission line information of the system, are entered in the *Hat_Bil* sheet given in Figure 3.

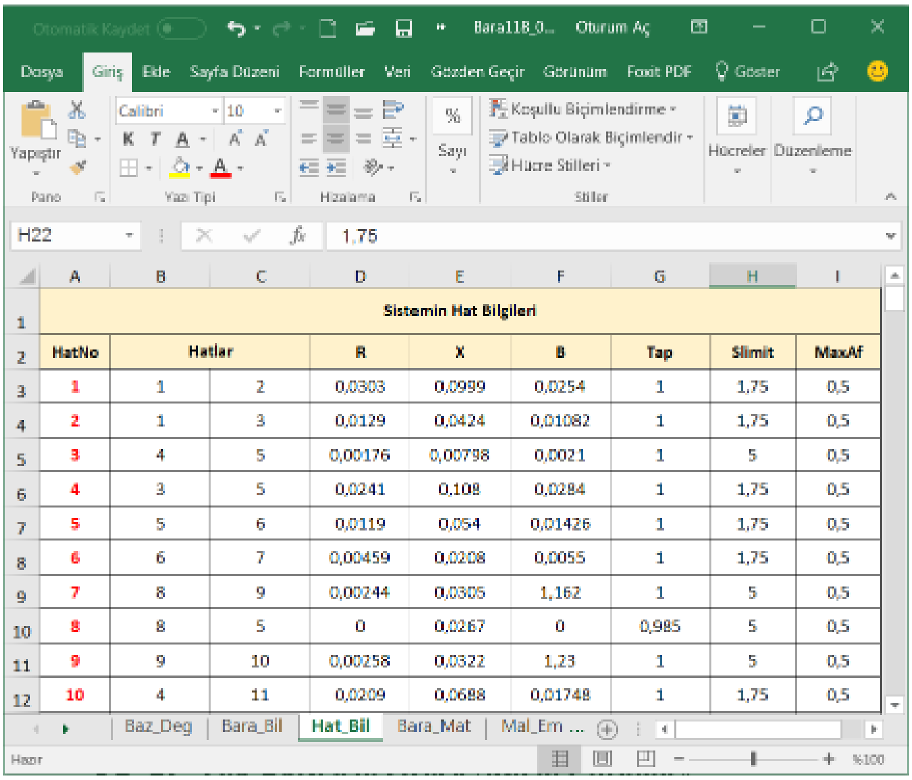


Sistemin Bara Bilgileri

Bara Tipleri: 1-Salınım Barası, 2-Gerilim Kontrollü Bara, 3-Gerilim Kontrolsüz Bara, 4-Yük Barası
Üretim Tipleri: 1- Termik, 2- Ham Enerji Kaynağı

Bara	UreTip	BaraTip	Pmin	Pgen	Pmax	Qmin	Qgen	Qmax	Pyük	Qyük	Vmin	Vbara	Vmax	Açı
1		2	0	0,5	1	-0,05	0,075	0,15	0,51	0,27	0,94	0,955	1,06	
2		4							0,2	0,09	0,94		1,06	
3		4							0,39	0,1	0,94		1,06	
4	1	2	0	0,5	1	-3	1,5	3	0,39	0,17	0,94	0,998	1,06	
5		4							0	0	0,94		1,06	
6	1	2	0	0,5	1	-0,13	0,25	0,5	0,52	0,22	0,94	0,99	1,06	
7		4							0,19	0,02	0,94		1,06	
8	1	2	0	0,5	1	-3	1,5	3	0,28	0	0,94	1,015	1,06	
9		4							0	0	0,94		1,06	

Figure 2. System bus information input sheet



Sistemin Hat Bilgileri								
HatNo	Hatlar		R	X	B	Tap	Slimit	MaxAf
1	1	2	0,0303	0,0999	0,0254	1	1,75	0,5
2	1	3	0,0129	0,0424	0,01082	1	1,75	0,5
3	4	5	0,00176	0,00798	0,0021	1	5	0,5
4	3	5	0,0241	0,108	0,0284	1	1,75	0,5
5	5	6	0,0119	0,054	0,01426	1	1,75	0,5
6	6	7	0,00459	0,0208	0,0055	1	1,75	0,5
7	8	9	0,00244	0,0305	1,162	1	5	0,5
8	8	5	0	0,0267	0	0,985	5	0,5
9	9	10	0,00258	0,0322	1,23	1	5	0,5
10	4	11	0,0209	0,0688	0,01748	1	1,75	0,5

Figure 3. System line information input sheet

In this design used to input system data, the program can easily be integrated into the new state by adding a sheet or column to the data file for additional information required for a new problem or a new system.

After the system data is uploaded to an Excel file, the following code block generated in Matlab is used to convert the data into a matrix form with a .mat extension. The data converted into a matrix form is uploaded to the Matlab application and their load flow is performed and results are printed.

4. SAMPLE SYSTEM SOLUTION

```
format compact
clear, clc
s = 'Bara118_0';
file = [s,'.mat'];
if exist(file,'file') ~= 2
tic
f = [s,'.xlsx'];
Baz = xlsread(f,1);
Bara = xlsread(f,2);
Hat = xlsread(f,3);
BMat = xlsread(f,4);
MalEmKat = xlsread(f,5);
clear s f
save(file)
toc
end
Data = load(file)
```

A sample power system consisting of IEEE 118 buses, 54 thermal power generation units and 179 transmission lines referred to as single-line diagram in Appendix Figure 1 was selected in order to test the load flow analysis in this section (Power Systems Test Case Archieve, 2017), (MatPower, 2017), (Zahlay, 2016).

This system is one of the high dimensional systems in the literature. Bus no 69 in the system is a slack bus and its voltage is $1.035\angle 0^0$ *pu*. All 54 generators in the system consist of voltage-controlled buses. 9 transmission lines in the system have transformers. The base values of the system were designated as S_{base}=100 *MVA*, U_{base}=230 *kVA* and Z_{base}=529 *Ohm*.

Appendix Table 1 shows the serial impedance, parallel admittance, capacitance values, transformer transfer ratios and line carrying capacities of the nominal π equivalent circuits of the transmission lines in the sample system. 91 buses and their active and reactive load values that remain unchanged at a period of time in the system are given as *pu* in Appendix Table 2. Appendix Table 3 presents the initial values of the load flow of the generation units. The 54 generators in the system are voltage-controlled buses and the bus voltages of these buses are kept constant at the values given in Appendix Table 3. The working limit values of the generation units in the system are given in Appendix Table 4 (Power Systems Test Case Archieve, 2017), (MatPower,2017), (Zahlay, 2016)

The bus voltage magnitude and angle values (V_k, δ_k), active and reactive power generation values (P_k, Q_k) as *pu* in the generation units and transmission line losses obtained from AC load flow in the sample system are given in Annex Table 5. The transmission line losses that occured as a result of AC load flow in the sample system were P_{loss}=0,614601 *pu*. The voltage magnitudes of the buses in the system ranged from 0.94 to 1.06 *pu*. The voltage profile of all the buses showing this state is given in Figure 4. The load flow solution time of the large size sample system at the work statiton with Intel Xeon E5-2637 v4 3.50 GHz processor and 128 GB RAM memory was 0.0719492 sec.

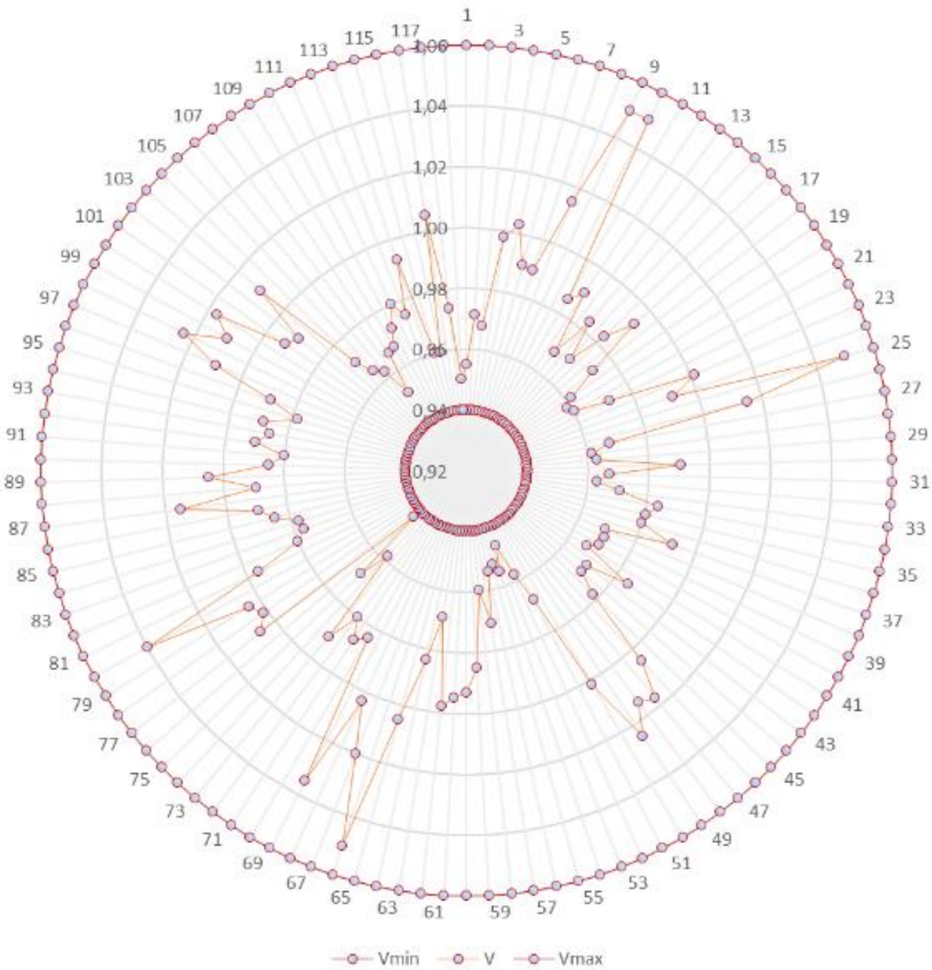


Figure 4. Voltage profile of IEEE 118 bus system at solution point

5. CONCLUSION

In this study, the Newton-Raphson method was used to perform load flow analysis and the new program facilitates the data input for the process. On a different sample system, this new data input method can be used to provide data input without running the load flow program. This new method makes it easier to correctly input data for the solutions to high-dimensional systems. It also prevents erroneous data input. The data input innovation developed in this study can also be improved for future studies and used for economic power distribution and short term hydrothermal coordination problems.

ACKNOWLEDGMENT

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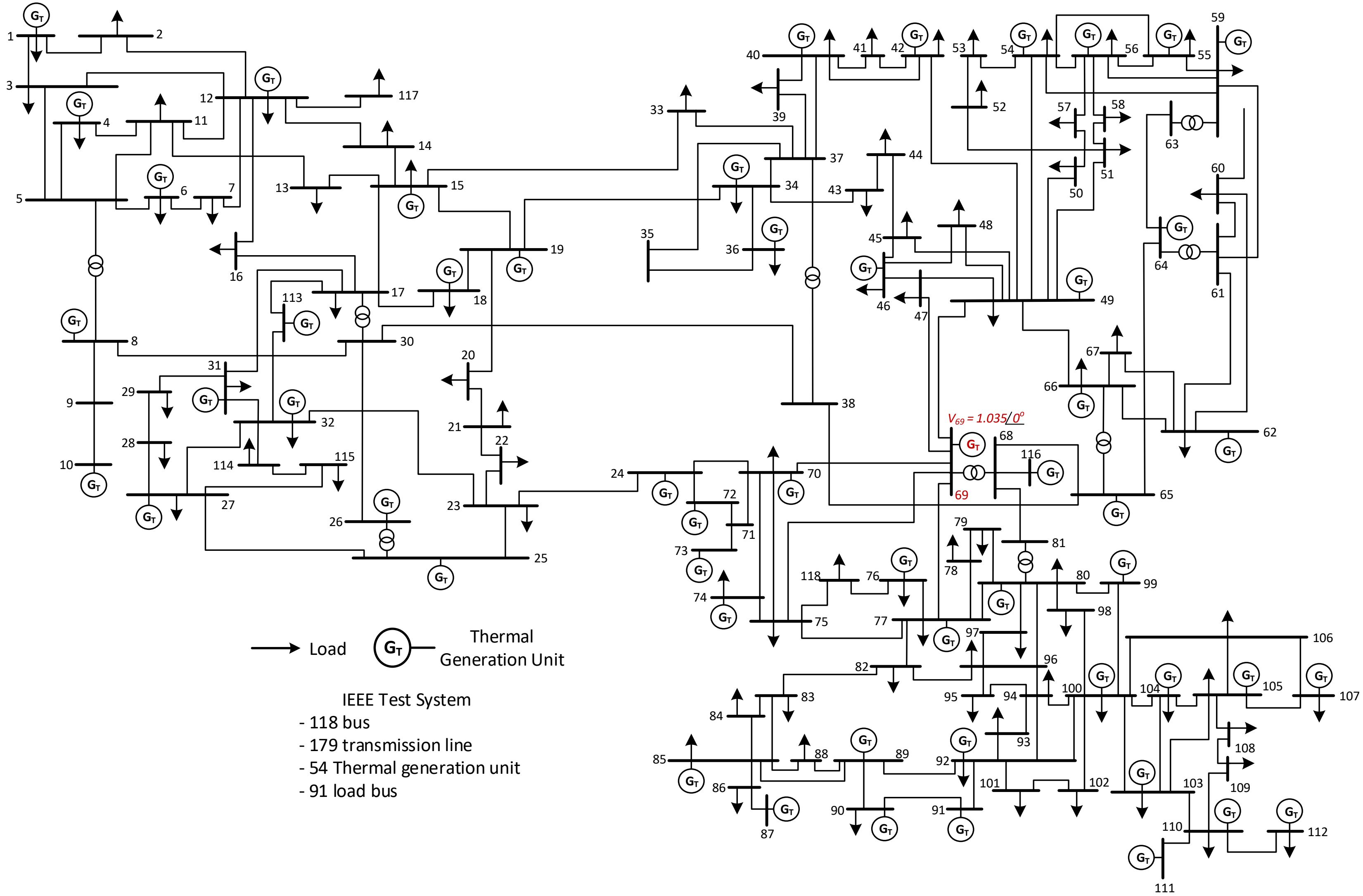
Appendix



Appendix Figure 1. Single line diagram of the test system.

Appendix Table 1. Values of nominal π equivalent circuits of transmission lines in the sample system

Line no	From bus	To bus	R (pu)	X (pu)	B (pu)	Tap	S_L^{max}
1	1	2	0,03030	0,09990	0,02540	-	1,750
2	1	3	0,01290	0,04240	0,01082	-	1,750
3	4	5	0,00176	0,00798	0,00210	-	5,000
4	3	5	0,02410	0,10800	0,02840	-	1,750
5	5	6	0,01190	0,05400	0,01426	-	1,750
6	6	7	0,00459	0,02080	0,00550	-	1,750
7	8	9	0,00244	0,03050	1,16200	-	5,000
8	8	5	-	0,02670	-	0,985	5,000
9	9	10	0,00258	0,03220	1,23000	-	5,000
10	4	11	0,02090	0,06880	0,01748	-	1,750
11	5	11	0,02030	0,06820	0,01738	-	1,750
12	11	12	0,00595	0,01960	0,00502	-	1,750
13	2	12	0,01870	0,06160	0,01572	-	1,750
14	3	12	0,04840	0,16000	0,04060	-	1,750
15	7	12	0,00862	0,03400	0,00874	-	1,750
16	11	13	0,02225	0,07310	0,01876	-	1,750
17	12	14	0,02150	0,07070	0,01816	-	1,750
18	13	15	0,07440	0,24440	0,06268	-	1,750
19	14	15	0,05950	0,19500	0,05020	-	1,750
20	12	16	0,02120	0,08340	0,02140	-	1,750
21	15	17	0,01320	0,04370	0,04440	-	5,000
22	16	17	0,04540	0,18010	0,04660	-	1,750
23	17	18	0,01230	0,05050	0,01298	-	1,750
24	18	19	0,01119	0,04930	0,01142	-	1,750
25	19	20	0,02520	0,11700	0,02980	-	1,750
26	15	19	0,01200	0,03940	0,01010	-	1,750
27	20	21	0,01830	0,08490	0,02160	-	1,750
28	21	22	0,02090	0,09700	0,02460	-	1,750
29	22	23	0,03420	0,15900	0,04040	-	1,750
30	23	24	0,01350	0,04920	0,04980	-	1,750
31	23	25	0,01560	0,08000	0,08640	-	5,000
32	26	25	-	0,03820	-	0,960	5,000
33	25	27	0,03180	0,16300	0,17640	-	5,000
34	27	28	0,01913	0,08550	0,02160	-	1,750
35	28	29	0,02370	0,09430	0,02380	-	1,750
36	30	17	-	0,03880	-	0,960	5,000
37	8	30	0,00431	0,05040	0,51400	-	1,750
38	26	30	0,00799	0,08600	0,90800	-	5,000
39	17	31	0,04740	0,15630	0,03990	-	1,750
40	29	31	0,01080	0,03310	0,00830	-	1,750
41	23	32	0,03170	0,11530	0,11730	-	1,40
42	31	32	0,02980	0,09850	0,02510	-	1,750
43	27	32	0,02290	0,07550	0,01926	-	1,750
44	15	33	0,03800	0,12440	0,03194	-	1,750
45	19	34	0,07520	0,24700	0,06320	-	1,750
46	35	36	0,00224	0,01020	0,00268	-	1,750
47	35	37	0,01100	0,04970	0,01318	-	1,750
48	33	37	0,04150	0,14200	0,03660	-	1,750
49	34	36	0,00871	0,02680	0,00568	-	1,750
50	34	37	0,00256	0,00940	0,00984	-	5,000
51	38	37	-	0,03750	-	0,935	5,000
52	37	39	0,03210	0,10600	0,02700	-	1,750

53	37	40	0,05930	0,16800	0,04200	-	1,750
54	30	38	0,00464	0,05400	0,42200	-	1,750
55	39	40	0,01840	0,06050	0,01552	-	1,750
56	40	41	0,01450	0,04870	0,01222	-	1,750
57	40	42	0,05550	0,18300	0,04660	-	1,750
58	41	42	0,04100	0,13500	0,03440	-	1,750
59	43	44	0,06080	0,24540	0,06068	-	1,750
60	34	43	0,04130	0,16810	0,04226	-	1,750
61	44	45	0,02240	0,09010	0,02240	-	1,750
62	45	46	0,04000	0,13560	0,03320	-	1,750
63	46	47	0,03800	0,12700	0,03160	-	1,750
64	46	48	0,06010	0,18900	0,04720	-	1,750
65	47	49	0,01910	0,06250	0,01604	-	1,750
66	42	49	0,03575	0,16150	0,17200	-	2,300
67	45	49	0,06840	0,18600	0,04440	-	1,750
68	48	49	0,01790	0,05050	0,01258	-	1,750
69	49	50	0,02670	0,07520	0,01874	-	1,750
70	49	51	0,04860	0,13700	0,03420	-	1,750
71	51	52	0,02030	0,05880	0,01396	-	1,750
72	52	53	0,04050	0,16350	0,04058	-	1,750
73	53	54	0,02630	0,12200	0,03100	-	1,750
74	49	54	0,03993	0,14507	0,14680	-	2,300
75	54	55	0,01690	0,07070	0,02020	-	1,750
76	54	56	0,00275	0,00955	0,00732	-	1,750
77	55	56	0,00488	0,01510	0,00374	-	1,750
78	56	57	0,03430	0,09660	0,02420	-	1,750
79	50	57	0,04740	0,13400	0,03320	-	1,750
80	56	58	0,03430	0,09660	0,02420	-	1,750
81	51	58	0,02550	0,07190	0,01788	-	1,750
82	54	59	0,05030	0,22930	0,05980	-	1,750
83	56	59	0,04070	0,12243	0,11050	-	2,300
84	55	59	0,04739	0,21580	0,05646	-	1,750
85	59	60	0,03170	0,14500	0,03760	-	1,750
86	59	61	0,03280	0,15000	0,03880	-	1,750
87	60	61	0,00264	0,01350	0,01456	-	5,000
88	60	62	0,01230	0,05610	0,01468	-	1,750
89	61	62	0,00824	0,03760	0,00980	-	1,750
90	63	59	-	0,03860	-	0,960	5,000
91	63	64	0,00172	0,02000	0,21600	-	5,000
92	64	61	-	0,02680	-	0,985	5,000
93	38	65	0,00901	0,09860	1,04600	-	5,000
94	64	65	0,00269	0,03020	0,38000	-	5,000
95	49	66	0,00900	0,04595	0,04960	-	8,000
96	62	66	0,04820	0,21800	0,05780	-	1,750
97	62	67	0,02580	0,11700	0,03100	-	1,750
98	65	66	-	0,03700	-	0,935	5,000
99	66	67	0,02240	0,10150	0,02682	-	1,750
100	65	68	0,00138	0,01600	0,63800	-	5,000
101	47	69	0,08440	0,27780	0,07092	-	1,750
102	49	69	0,09850	0,32400	0,08280	-	1,750
103	68	69	-	0,03700	-	0,935	5,000
104	69	70	0,03000	0,12700	0,12200	-	5,000
105	24	70	0,00221	0,41150	0,10198	-	1,750
106	70	71	0,00882	0,03550	0,00878	-	1,750
107	24	72	0,04880	0,19600	0,04880	-	1,750

108	71	72	0,04460	0,18000	0,04444	-	1,750
109	71	73	0,00866	0,04540	0,01178	-	1,750
110	70	74	0,04010	0,13230	0,03368	-	1,750
111	70	75	0,04280	0,14100	0,03600	-	1,750
112	69	75	0,04050	0,12200	0,12400	-	5,000
113	74	75	0,01230	0,04060	0,01034	-	1,750
114	76	77	0,04440	0,14800	0,03680	-	1,750
115	69	77	0,03090	0,10100	0,10380	-	1,750
116	75	77	0,06010	0,19990	0,04978	-	1,750
117	77	78	0,00376	0,01240	0,01264	-	1,750
118	78	79	0,00546	0,02440	0,00648	-	1,750
119	77	80	0,01088	0,03321	0,07000	-	8,000
120	79	80	0,01560	0,07040	0,01870	-	1,750
121	68	81	0,00175	0,02020	0,80800	-	5,000
122	81	80	-	0,03700	-	0,935	5,000
123	77	82	0,02980	0,08530	0,08174	-	2,000
124	82	83	0,01120	0,03665	0,03796	-	2,000
125	83	84	0,06250	0,13200	0,02580	-	1,750
126	83	85	0,04300	0,14800	0,03480	-	1,750
127	84	85	0,03020	0,06410	0,01234	-	1,750
128	85	86	0,03500	0,12300	0,02760	-	5,000
129	86	87	0,02828	0,20740	0,04450	-	5,000
130	85	88	0,02000	0,10200	0,02760	-	1,750
131	85	89	0,02390	0,17300	0,04700	-	1,750
132	88	89	0,01390	0,07120	0,01934	-	5,000
133	89	90	0,01638	0,06517	0,15880	-	8,000
134	90	91	0,02540	0,08360	0,02140	-	1,750
135	89	92	0,00799	0,03829	0,09620	-	8,000
136	91	92	0,03870	0,12720	0,03268	-	1,750
137	92	93	0,02580	0,08480	0,02180	-	1,750
138	92	94	0,04810	0,15800	0,04060	-	1,750
139	93	94	0,02230	0,07320	0,01876	-	1,750
140	94	95	0,01320	0,04340	0,01110	-	1,750
141	80	96	0,03560	0,18200	0,04940	-	1,750
142	82	96	0,01620	0,05300	0,05440	-	1,750
143	94	96	0,02690	0,08690	0,02300	-	1,750
144	80	97	0,01830	0,09340	0,02540	-	1,750
145	80	98	0,02380	0,10800	0,02860	-	1,750
146	80	99	0,04540	0,20600	0,05460	-	2,000
147	92	100	0,06480	0,29500	0,04720	-	1,750
148	94	100	0,01780	0,05800	0,06040	-	1,750
149	95	96	0,01710	0,05470	0,01474	-	1,750
150	96	97	0,01730	0,08850	0,02400	-	1,750
151	98	100	0,03970	0,17900	0,04760	-	1,750
152	99	100	0,01800	0,08130	0,02160	-	1,750
153	100	101	0,02770	0,12620	0,03280	-	1,750
154	92	102	0,01230	0,05590	0,01464	-	1,750
155	101	102	0,02460	0,11200	0,02940	-	1,750
156	100	103	0,01600	0,05250	0,05360	-	5,000
157	100	104	0,04510	0,20400	0,05410	-	1,750
158	103	104	0,04660	0,15840	0,04070	-	1,750
159	103	105	0,05350	0,16250	0,04080	-	1,750
160	100	106	0,06050	0,22900	0,06200	-	1,750
161	104	105	0,00994	0,03780	0,00986	-	1,750
162	105	106	0,01400	0,05470	0,01434	-	1,750

163	105	107	0,05300	0,18300	0,04720	-	1,750
164	105	108	0,02610	0,07030	0,01844	-	1,750
165	106	107	0,05300	0,18300	0,04720	-	1,750
166	108	109	0,01050	0,02880	0,00760	-	1,750
167	103	110	0,03906	0,18130	0,04610	-	1,750
168	109	110	0,02780	0,07620	0,02020	-	1,750
169	110	111	0,02200	0,07550	0,02000	-	1,750
170	110	112	0,02470	0,06400	0,06200	-	1,750
171	17	113	0,00913	0,03010	0,00768	-	1,750
172	32	113	0,06150	0,20300	0,05180	-	5,000
173	32	114	0,01350	0,06120	0,01628	-	1,750
174	27	115	0,01640	0,07410	0,01972	-	1,750
175	114	115	0,00230	0,01040	0,00276	-	1,750
176	68	116	0,00034	0,00405	0,16400	-	5,000
177	12	117	0,03290	0,14000	0,03580	-	1,750
178	75	118	0,01450	0,04810	0,01198	-	1,750
179	76	118	0,01640	0,05440	0,01356	-	1,750

Appendix Table 2. Active and reactive load values in the sample system.

Bus No	P_{load} (*pu*)	Q_{load} (*pu*)	***Bus No***	P_{load} (*pu*)	Q_{load} (*pu*)
1	0,5100	0,2700	**60**	0,7800	0,0300
2	0,2000	0,0900	**61**	-	-
3	0,3900	0,1000	**62**	0,7700	0,1400
4	0,3900	0,1200	**63**	-	-
5	-	-	**64**	-	-
6	0,5200	0,2200	**65**	-	-
7	0,1900	0,0200	**66**	0,3900	0,1800
8	0,2800	0,0000	**67**	0,2800	0,0700
9	-	-	**68**	-	-
10	-	-	**69**	-	-
11	0,7000	0,2300	**70**	0,6600	0,2000
12	0,4700	0,1000	**71**	-	-
13	0,3400	0,1600	**72**	0,1200	-
14	0,1400	0,0100	**73**	0,0600	-
15	0,9000	0,3000	**74**	0,6800	0,2700
16	0,2500	0,1000	**75**	0,4700	0,1100
17	0,1100	0,0300	**76**	0,6800	0,3600
18	0,6000	0,3400	**77**	0,6100	0,2800
19	0,4500	0,2500	**78**	0,7100	0,2600
20	0,1800	0,0300	**79**	0,3900	0,3200
21	0,1400	0,0800	**80**	1,3000	0,2600
22	0,1000	0,0500	**81**	-	-
23	0,0700	0,0300	**82**	0,5400	0,2700
24	0,1300	-	**83**	0,2000	0,1000
25	-	-	**84**	0,1100	0,0700
26	-	-	**85**	0,2400	0,1500
27	0,7100	0,1300	**86**	0,2100	0,1000
28	0,1700	0,0700	**87**	-	-
29	0,2400	0,0400	**88**	0,4800	0,1000
30	-	-	**89**	-	-
31	0,4300	0,2700	**90**	1,6300	0,4200
32	0,5900	0,2300	**91**	0,1000	-
33	0,2300	0,0900	**92**	0,6500	0,1000
34	0,5900	0,2600	**93**	0,1200	0,0700

35	0,3300	0,0900	**94**	0,3000	0,1600
36	0,3100	0,1700	**95**	0,4200	0,3100
37	-	-	**96**	0,3800	0,1500
38	-	-	**97**	0,1500	0,0900
39	0,2700	0,1100	**98**	0,3400	0,0800
40	0,6600	0,2300	**99**	0,4200	-
41	0,3700	0,1000	**100**	0,3700	0,1800
42	0,9600	0,2300	**101**	0,2200	0,1500
43	0,1800	0,0700	**102**	0,0500	0,0300
44	0,1600	0,0800	**103**	0,2300	0,1600
45	0,5300	0,2200	**104**	0,3800	0,2500
46	0,2800	0,1000	**105**	0,3100	0,2600
47	0,3400	-	**106**	0,4300	0,1600
48	0,2000	0,1100	**107**	0,5000	0,1200
49	0,8700	0,3000	**108**	0,0200	0,0100
50	0,1700	0,0400	**109**	0,0800	0,0300
51	0,1700	0,0800	**110**	0,3900	0,3000
52	0,1800	0,0500	**111**	-	-
53	0,2300	0,1100	**112**	0,6800	0,1300
54	1,1300	0,3200	**113**	0,0600	-
55	0,6300	0,2200	**114**	0,0800	0,0300
56	0,8400	0,1800	**115**	0,2200	0,0700
57	0,1200	0,0300	**116**	1,8400	-
58	0,1200	0,0300	**117**	0,2000	0,0800
59	2,7700	1,1300	**118**	0,3300	0,1500
Total Load		***P_{load}*:** 42,4200		***Q_{load}*:** 14,3800	

Appendix Table 3. AC load flow initial values of the generation units in the sample system

Gen. Unit	*Bus*	*P_i (pu)*	*Q_i (pu)*	*V (pu)*	*Gen. Unit*	*Bus*	*P_i (pu)*	*Q_i (pu)*	*V (pu)*
1	1	0,500	0,075	0,995	**28**	65	2,000	1,000	1,005
2	4	0,500	1,500	0,998	**29**	66	2,000	1,000	1,050
3	6	0,500	0,250	0,990	**30**	69	-	-	1,035
4	8	0,500	1,500	1,015	**31**	70	0,500	0,150	0,984
5	10	2,000	1,000	1,050	**32**	72	0,500	0,500	0,980
6	12	1,000	0,600	0,990	**33**	73	0,500	0,500	0,991
7	15	0,500	0,150	0,970	**34**	74	0,500	0,045	0,958
8	18	0,500	0,250	0,973	**35**	76	0,500	0,120	0,943
9	19	0,500	0,120	0,962	**36**	77	0,500	0,350	1,006
10	24	0,500	1,500	0,992	**37**	80	2,000	1,400	1,040
11	25	1,000	0,700	1,050	**38**	85	0,500	0,120	0,985
12	26	2,000	5,000	1,015	**39**	87	0,500	5,000	1,015
13	27	0,500	1,500	0,968	**40**	89	2,000	1,500	1,005
14	31	0,500	1,500	0,967	**41**	90	0,500	1500	0,985
15	32	0,500	0,210	0,963	**42**	91	0,500	0,500	0,980
16	34	0,500	0,120	0,984	**43**	92	0,500	0,045	0,990
17	36	0,500	0,120	0,980	**44**	99	0,500	0,500	1,010
18	40	0,500	1,500	0,970	**45**	100	1,000	0,750	1,017
19	42	0,500	1,500	0,985	**46**	103	0,500	0,200	1,010
20	46	0,500	0,500	1,005	**47**	104	0,500	0,120	0,971
21	49	1,000	1,000	1,025	**48**	105	0,500	0,120	0,965
22	54	0,500	1,500	0,955	**49**	107	0,500	1,000	0,952
23	55	0,500	0,120	0,952	**50**	110	0,500	0,120	0,973
24	56	0,500	0,075	0,954	**51**	111	0,500	5,000	0,980
25	59	1,000	0,900	0,985	**52**	112	0,500	5,000	0,975

26	61	1,000	1,500	0,995	**53**	113	0,500	1,000	0,993
27	62	0,500	0,100	0,998	**54**	116	0,500	5,000	1,005

Appendix Table 4. Operating limit values of generation units in the sample system.

Gen. Unit	***Bus***	***P_{min} (pu)***	***P_{max} (pu)***	***Q_{min} (pu)***	***Q_{max} (pu)***	***V_{min} (pu)***	***V_{max} (pu)***
1	1	0,0000	1,0000	-0,0500	0,1500	0,9400	1,0600
2	4	0,0000	1,0000	-3,0000	3,0000	0,9400	1,0600
3	6	0,0000	1,0000	-0,1300	0,5000	0,9400	1,0600
4	8	0,0000	1,0000	-3,0000	3,0000	0,9400	1,0600
5	10	0,0000	5,5000	-1,4700	2,0000	0,9400	1,0600
6	12	0,0000	1,8500	-0,3500	1,2000	0,9400	1,0600
7	15	0,0000	1,0000	-0,1000	0,3000	0,9400	1,0600
8	18	0,0000	1,0000	-0,1600	0,5000	0,9400	1,0600
9	19	0,0000	1,0000	-0,0800	0,2400	0,9400	1,0600
10	24	0,0000	1,0000	-3,0000	3,0000	0,9400	1,0600
11	25	0,0000	3,2000	-0,4700	1,4000	0,9400	1,0600
12	26	0,0000	4,1400	-10,0000	10,0000	0,9400	1,0600
13	27	0,0000	1,0000	-3,0000	3,0000	0,9400	1,0600
14	31	0,0000	1,0700	-3,0000	3,0000	0,9400	1,0600
15	32	0,0000	1,0000	-0,1400	0,4200	0,9400	1,0600
16	34	0,0000	1,0000	-0,0800	0,2400	0,9400	1,0600
17	36	0,0000	1,0000	-0,0800	0,2400	0,9400	1,0600
18	40	0,0000	1,0000	-3,0000	3,0000	0,9400	1,0600
19	42	0,0000	1,0000	-3,0000	3,0000	0,9400	1,0600
20	46	0,0000	1,1900	-1,0000	1,0000	0,9400	1,0600
21	49	0,0000	3,0400	-0,8500	2,1000	0,9400	1,0600
22	54	0,0000	1,4800	-3,0000	3,0000	0,9400	1,0600
23	55	0,0000	1,0000	-0,0800	0,2300	0,9400	1,0600
24	56	0,0000	1,0000	-0,0800	0,1500	0,9400	1,0600
25	59	0,0000	2,5500	-0,6000	1,8000	0,9400	1,0600
26	61	0,0000	2,6000	-1,0000	3,0000	0,9400	1,0600
27	62	0,0000	1,0000	-0,2000	0,2000	0,9400	1,0600
28	65	0,0000	4,9100	-0,6700	2,0000	0,9400	1,0600
29	66	0,0000	4,9200	-0,6700	2,0000	0,9400	1,0600
30	69	0,0000	8,0520	-3,0000	3,0000	0,9400	1,0600
31	70	0,0000	1,0000	-0,1000	0,3200	0,9400	1,0600
32	72	0,0000	1,0000	-1,0000	1,0000	0,9400	1,0600
33	73	0,0000	1,0000	-1,0000	1,0000	0,9400	1,0600
34	74	0,0000	1,0000	-0,0600	0,0900	0,9400	1,0600
35	76	0,0000	1,0000	-0,0800	0,2300	0,9400	1,0600
36	77	0,0000	1,0000	-0,2000	0,7000	0,9400	1,0600
37	80	0,0000	5,7700	-1,6500	2,8000	0,9400	1,0600
38	85	0,0000	1,0000	-0,0800	0,2300	0,9400	1,0600
39	87	0,0000	1,0400	-1,0000	10,0000	0,9400	1,0600
40	89	0,0000	7,0700	-2,1000	3,0000	0,9400	1,0600
41	90	0,0000	1,0000	-3,0000	3,0000	0,9400	1,0600
42	91	0,0000	1,0000	-1,0000	1,0000	0,9400	1,0600
43	92	0,0000	1,0000	-0,0300	0,0900	0,9400	1,0600
44	99	0,0000	1,0000	-1,0000	1,0000	0,9400	1,0600
45	100	0,0000	3,5200	-0,5000	1,5500	0,9400	1,0600
46	103	0,0000	1,4000	-0,1500	0,4000	0,9400	1,0600

47	104	0,0000	1,0000	-0,0800	0,2300	0,9400	1,0600
48	105	0,0000	1,0000	-0,0800	0,2300	0,9400	1,0600
49	107	0,0000	1,0000	-2,0000	2,0000	0,9400	1,0600
50	110	0,0000	1,0000	-0,0800	0,2300	0,9400	1,0600
51	111	0,0000	1,3600	-1,0000	10,0000	0,9400	1,0600
52	112	0,0000	1,0000	-1,0000	10,0000	0,9400	1,0600
53	113	0,0000	1,0000	-1,0000	2,0000	0,9400	1,0600
54	116	0,0000	1,0000	-10,0000	10,0000	0,9400	1,0600

Appendix Table 5. The values obtained as a result of AC load flow of all the buses in the sample system.

Bus No	***V (pu)***	δ ***(R)***	P_{gen} ***(pu)***	Q_{gen} ***(pu)***	***Bus No***	***V (pu)***	δ ***(R)***	P_{gen} ***(pu)***	Q_{gen} ***(pu)***
1	0,9550	-0,0326	0,5000	-0,1882	**60**	0,9932	-0,1631	-	-
2	0,9715	-0,0401	-	-	**61**	0,9950	-0,1496	1,0000	-0,3185
3	0,9678	-0,0351	-	-	**62**	0,9980	-0,1523	0,5000	-0,1092
4	0,9980	-0,0012	0,5000	-0,3627	**63**	0,9688	-0,1656	-	-
5	1,0028	0,0007	-	-	**64**	0,9836	-0,1365	-	-
6	0,9900	-0,0185	0,5000	0,0169	**65**	1,0050	-0,0788	2,0000	0,8208
7	0,9893	-0,0265	-	-	**66**	1,0500	-0,1034	2,0000	0,1283
8	1,0150	0,0428	0,5000	-0,2691	**67**	1,0200	-0,1396	-	-
9	1,0500	0,0973	-	-	**68**	1,0032	-0,0699	-	-
10	1,0500	0,1560	2,0000	-0,7807	**69**	1,0350	0,0000	4,5346	-0,5042
11	0,9855	-0,0324	-	-	**70**	0,9840	0,0156	0,5000	-0,1494
12	0,9900	-0,0331	1,0000	0,8467	**71**	0,9869	0,0444	-	-
13	0,9687	-0,0519	-	-	**72**	0,9800	0,1112	0,5000	-0,2242
14	0,9836	-0,0426	-	-	**73**	0,9910	0,0647	0,5000	0,0042
15	0,9700	-0,0394	0,5000	-0,0458	**74**	0,9580	-0,0318	0,5000	-0,1250
16	0,9833	-0,0397	-	-	**75**	0,9686	-0,0436	-	-
17	0,9933	-0,0111	-	-	**76**	0,9430	-0,0703	0,5000	-0,1319
18	0,9730	-0,0244	0,5000	0,1853	**77**	1,0060	-0,0802	0,5000	0,1428
19	0,9620	-0,0345	0,5000	-0,2941	**78**	1,0015	-0,0898	-	-
20	0,9588	-0,0335	-	-	**79**	1,0043	-0,0931	-	-
21	0,9606	-0,0162	-	-	**80**	1,0400	-0,0805	2,0000	1,7349

22	0,9723	0,0164	-	-	**81**	0,9962	-0,0736	-	-
23	1,0012	0,0834	-	-	**82**	0,9801	-0,0946	-	-
24	0,9920	0,0978	0,5000	-0,2436	**83**	0,9767	-0,0823	-	-
25	1,0500	0,1334	1,0000	0,5919	**84**	0,9775	-0,0538	-	-
26	1,0150	0,1484	2,0000	-0,0189	**85**	0,9850	-0,0344	0,5000	-0,0683
27	0,9680	0,0374	0,5000	-0,1697	**86**	0,9898	0,0027	-	-
28	0,9616	0,0154	-	-	**87**	1,0150	0,1038	0,5000	0,0570
29	0,9631	0,0072	-	-	**88**	0,9893	-0,0430	-	-
30	0,9907	0,0161	-	-	**89**	1,0050	-0,0157	2,0000	0,4733
31	0,9670	0,0124	0,5000	0,2063	**90**	0,9850	-0,0655	0,5000	0,4176
32	0,9630	0,0351	0,5000	-0,3544	**91**	0,9800	-0,0304	0,5000	-0,2758
33	0,9709	-0,0858	-	-	**92**	0,9900	-0,0398	0,5000	-0,3647
34	0,9840	-0,1063	0,5000	-0,2759	**93**	0,9858	-0,0624	-	-
35	0,9807	-0,1089	-	-	**94**	0,9889	-0,0741	-	-
36	0,9800	-0,1062	0,5000	-0,0869	**95**	0,9781	-0,0917	-	-
37	0,9921	-0,1060	-	-	**96**	0,9885	-0,0953	-	-
38	0,9694	-0,0608	-	-	**97**	1,0093	-0,0940	-	-
39	0,9705	-0,1643	-	-	**98**	1,0234	-0,0879	-	-
40	0,9700	-0,1828	0,5000	0,1216	**99**	1,0100	-0,0464	0,5000	-0,2875
41	0,9668	-0,2044	0,0000	0,0000	**100**	1,0170	-0,0433	1,0000	1,2848
42	0,9850	-0,2143	0,5000	0,1998	**101**	0,9927	-0,0570	-	-
43	0,9704	-0,1649	-	-	**102**	0,9901	-0,0474	-	-
44	0,9704	-0,2063	-	-	**103**	1,0100	-0,0200	0,5000	0,5789
45	0,9782	-0,2071	-	-	**104**	0,9710	-0,0125	0,5000	-0,1276
46	1,0050	-0,1707	0,5000	0,0329	**105**	0,9650	-0,0128	0,5000	-0,1532
47	1,0173	-0,1611	-	-	**106**	0,9624	-0,0345	-	-
48	1,0149	-0,1778	-	-	**107**	0,9520	-0,0201	0,5000	-0,0441
49	1,0250	-0,1714	1,0000	1,3987	**108**	0,9664	-0,0016	-	-
50	1,0015	-0,2010	-	-	**109**	0,9672	0,0036	-	-

51	0,9677	-0,2393	-	-	**110**	0,9730	0,0233	0,5000	-0,0481
52	0,9577	-0,2542	-	-	**111**	0,9800	0,0639	0,5000	-0,0540
53	0,9464	-0,2665	-	-	**112**	0,9750	0,0085	0,5000	0,2021
54	0,9550	-0,2471	0,5000	0,0191	**113**	0,9930	0,0064	0,5000	-0,0190
55	0,9520	-0,2456	0,5000	-0,0980	**114**	0,9601	0,0263	-	-
56	0,9540	-0,2461	0,5000	-0,2127	**115**	0,9600	0,0256	-	-
57	0,9710	-0,2337	-	-	**116**	1,0050	-0,0755	0,5000	0,4698
58	0,9595	-0,2474	-	-	**117**	0,9738	-0,0600	-	-
59	0,9850	-0,2213	1,0000	0,8911	**118**	0,9501	-0,0640	-	-

Total Active Power	43,034601	***Total P Load***	42,420000	***P_{loss}***	0,614601
Total Reactive Power	4,419482	***Total Q Load***	14,380000	***Q_{loss}***	-9,961833
***Time (sec)*:** 0,034583					