CONTINGENCY ANALYSIS OF THE 26-BUS TEST POWER SYSTEM: DATA, RESULTS AND ILLUSTRATION

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Abstract

This report presents contingency analysis results of the 26-bus test power system. The outage of twenty four transmission lines of this system, one at a time, are considered. All the results presented were obtained by performing an exact AC load flow solution for each contingency and using the computer packages TTM1, CTTM1, CNTL and formatted data files.

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I. INTRODUCTION

Contingency analysis of a power system is a study of the system under certain emergency conditions, i.e., line outage, generator outage, etc. The main goal of this analysis is to determine which contingencies cause component limit violations and also to determine severity of any such violations, i.e., branch flow limits, bus voltage limits and generator VAR limits. The direct approach to this problem involves an exact AC load flow for each contingency and checking the limit violations. For practical reasons this analysis is limited to single component contingencies. A more efficient approach is to perform a full AC load flow on only those cases which are able to cause limit violations. This approach is called contingency selection. One set of these methods is called ranking methods [1-4]. Contingencies are ranked based on the value of a scalar performance index. Another set of methods, called screening methods, employs an approximate system solution to identify cases causing limit violations [5-7].

In this report we present numerical results of the contingency analysis of the 26-bus test power system [8]. These results were obtained performing full AC load flow for each contingency, i.e., when single lines are removed, one at a time. All calculations have been performed using packages TTM1 [9], CTTM1 [10], CNTL [11] and formatted data files [8,12].

II. A 26-BUS TEST POWER SYSTEM

The Saskatchewan Power Corporation 26-bus system has been considered in many relevant steady-state power system analyses. The single line diagram of this system is shown in Fig. 1. The line data, operating bus data and load flow solution are shown in Tables I, II and III, respectively. All values shown are in per unit. It is assumed that the model of a transmission line of this system is as in Fig. 2.

For this 26-bus system using the computer package CTTM1 [10] a single line outage cases involving lines (13,26), (23,26), (16,23), (9,10), (9,12), (12,26), (9,14), (11,14), (19,26), (6,26), (6,19), (7,19), (6,7), (11,22), (8,11), (17,22), (8,21), (17,21), (1,4), (4,21), (20,21), (15,1),

(2,13), (1,7) and (15,20) were simulated. The obtained load flow solutions for all these studies are presented in [12].

For each line outage we calculated using package CNTL [11] real and reactive power flow in lines of the system, deviation of the power flow in the lines of the system under a contingency, the changes of bus voltages and the changes of the reactive power generation at PV buses. All obtained results are summarized in Tables V-XXIX.

Each table demonstrates:

- real (P_ℓ^B, P_ℓ^C) and reactive (Q_ℓ^B, Q_ℓ^C) power flow in selected lines of the system for pre-contingency (B) and post-contingency (C) states. For each contingency we have selected only overloaded lines. It is assumed that a line of the studied system will be treated as overloaded if the relative deviation $(P_\ell^C - P_\ell^B)/P_\ell^B$ of the real power injected in this line after a contingency is greater than 2%.
- deviation $\Delta P_\ell = P_\ell^C - P_\ell^B$ an injected real power in the ℓth line of the system under a contingency.
- relative deviation $\Delta P_\ell/P_\ell^B$ of the injected real power in the ℓth line of the system under a contingency.
- the buses with a deviation of the bus voltage magnitude from the base case greater than 2%. This deviation was selected as the definition of significant voltage change.
- reactive power generation (Q_m^B, Q_m^C) at selected PV buses for pre- contingency and post-contingency states, deviation $\Delta Q_m = Q_m^C - Q_m^B$ and the relative deviation at these buses. For each line outage we have selected only those PV buses for which the modulus of the deviation of the reactive power generation from base case is greater than 2%.

For each line outage the changes of the real power injected in the selected lines of the studied system, the changes of the bus voltage magnitude for the selected buses and the changes of the reactive power generation at selected buses are illustrated in Figures 3-27. The meaning of symbols used is explained in Table IV.

III. REFERENCES

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TABLE I

LINE DATA FOR THE 26-BUS POWER SYSTEM

No.	Terminal Buses	Resistance R_t (p.u.)	Reactance X_t (p.u.)	1/2 Shunt Susceptance B	Transformer Tap
1	13,26	0.0	0.0131	0.0	1.03
2	26,16	0.0	0.0392	0.0	0.96
3	16,23	0.0	0.4320	0.0	1.0
4	23,26	0.0	0.3140	0.0	1.0
5	2,10	0.0	0.0150	0.0	1.03
6	9,10	0.1494	0.3392	0.4120	1.0
7	9,12	0.0658	0.1494	0.0182	1.0
8	12,26	0.0533	0.1210	0.0147	1.0
9	9,14	0.0618	0.2397	0.0319	1.0
10	11,14	0.0676	0.2620	0.0349	1.0
11	19,26	0.0610	0.2521	0.0295	1.0
12	6,26	0.0513	0.1986	0.0265	1.0
13	6,19	0.0129	0.0532	0.0074	1.0
14	7,19	0.0906	0.3742	0.0437	1.0
15	6,7	0.0921	0.3569	0.0475	1.0
16	11,22	0.0513	0.2118	0.0248	1.0
17	8,11	0.0865	0.3355	0.0447	1.0
18	17,22	0.0281	0.1869	0.0237	1.0
19	8,21	0.0735	0.2847	0.0379	1.0
20	17,21	0.0459	0.3055	0.0387	1.0
21	1,4	0.0619	0.2401	0.0319	1.0
22	4,21	0.0610	0.2365	0.0315	1.0
23	20,21	0.0	0.0305	0.0	0.97
24	15,1	0.0	0.0147	0.0	0.89
25	2,13	0.0086	0.0707	0.3017	1.0
26	1,7	0.0199	0.0785	0.0404	1.0
27	15,20	0.0107	0.0617	0.4471	1.0
28	2,18	0.0074	0.0608	0.2593	1.0
29	1,3	0.0	0.0392	0.0	0.98
30	24,3	0.0	0.1450	0.0	0.98
31	5,21	0.0	0.1750	0.0	0.99
32	5,25	0.0	0.154	0.0	1.03

TABLE II

BUS DATA FOR LOAD FLOW ANALYSIS OF THE 26-BUS SYSTEM

Bus	Injected Power		Bus Voltage	
	P_m	Q_m	$\|V_m\|$	δ_m
1	−0.82	−0.21	–	–
2	0.0	0.0	–	–
3	−0.57	−0.17	–	–
4	−0.48	−0.21	–	–
5	−0.43	−0.11	–	–
6	−0.40	−0.10	–	–
7	−1.11	−0.27	–	–
8	−0.23	−0.06	–	–
9	−0.67	−0.21	–	–
10	−1.02	−0.27	–	–
11	−0.43	−0.14	–	–
12	−0.43	−0.12	–	–
13	0.0	0.0	–	–
14	0.0	0.0	–	–
15	0.0	0.0	–	–
16	−1.31	−0.30	–	–
17	−0.03	−0.01	–	–
18	2.80	–	1.07	–
19	1.45	–	1.05	–
20	2.80	–	1.00	–
21	1.10	–	1.02	–
22	−0.56	–	0.89	–
23	−0.04	–	1.00	–
24	−0.05	–	1.00	–
25	0.63	–	1.00	–
26	0.0	–	1.01	0.0

TABLE III

LOAD FLOW SOLUTION OF THE 26-BUS SYSTEM

Load Buses					
$\|V_1\|$	=	1.0357	δ_1	=	0.0747
$\|V_2\|$	=	1.0685	δ_2	=	0.0884
$\|V_3\|$	=	1.0438	δ_3	=	0.0527
$\|V_4\|$	=	0.9908	δ_4	=	0.0989
$\|V_5\|$	=	1.0081	δ_5	=	0.2607
$\|V_6\|$	=	1.0339	δ_6	=	0.0536
$\|V_7\|$	=	1.0133	δ_7	=	0.0178
$\|V_8\|$	=	0.9450	δ_8	=	0.0426
$\|V_9\|$	=	0.9675	δ_9	=	−0.1127
$\|V_{10}\|$	=	1.0393	δ_{10}	=	0.0667
$\|V_{11}\|$	=	0.9037	δ_{11}	=	−0.1100
$\|V_{12}\|$	=	0.9699	δ_{12}	=	−0.0764
$\|V_{13}\|$	=	1.0465	δ_{13}	=	0.0150
$\|V_{14}\|$	=	0.9449	δ_{14}	=	−0.1136
$\|V_{15}\|$	=	0.9324	δ_{15}	=	0.1042
$\|V_{16}\|$	=	1.0363	δ_{16}	=	−0.0455
$\|V_{17}\|$	=	0.9322	δ_{17}	=	0.0298
Generator Buses					
$\|Q_{18}\|$	=	−0.4004	δ_{18}	=	0.2385
$\|Q_{19}\|$	=	0.1872	δ_{19}	=	0.0921
$\|Q_{20}\|$	=	0.7795	δ_{20}	=	0.2432
$\|Q_{21}\|$	=	−0.0294	δ_{21}	=	0.2270
$\|Q_{22}\|$	=	−0.1775	δ_{22}	=	−0.0996
$\|Q_{23}\|$	=	−0.1144	δ_{23}	=	−0.0266
$\|Q_{24}\|$	=	−0.1645	δ_{24}	=	0.0459
$\|Q_{25}\|$	=	0.1691	δ_{25}	=	0.3599
Slack Bus					
P_{26}	=	0.1334	Q_{26}	=	−0.0513

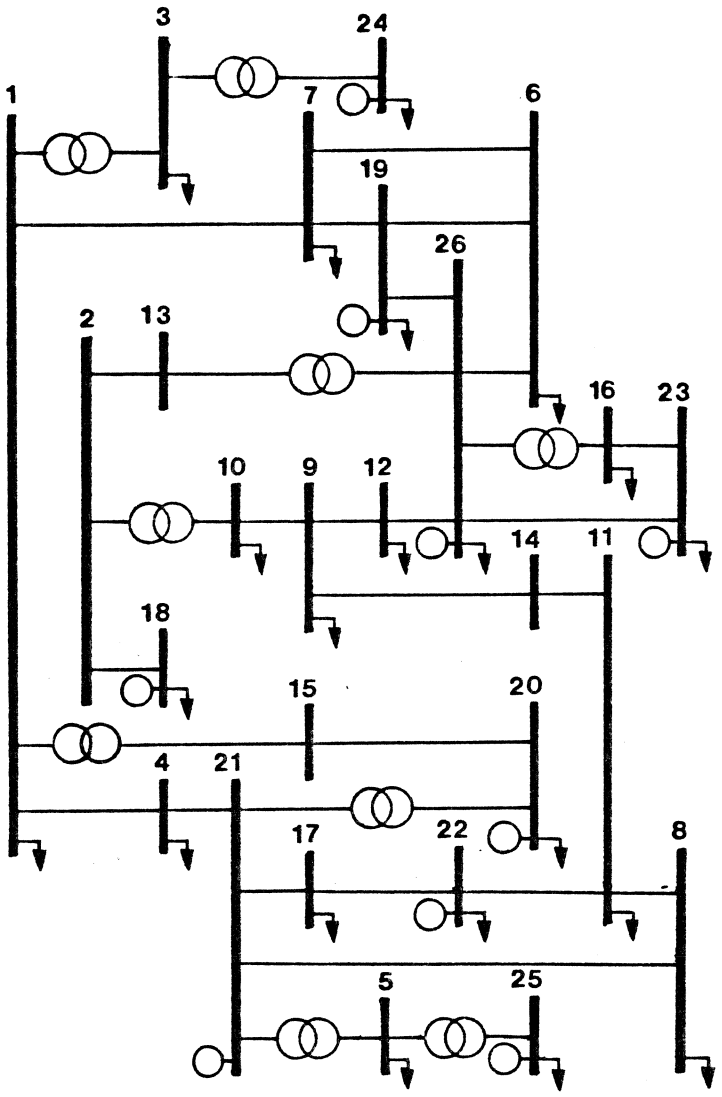

Fig. 1 The 26-bus power system.

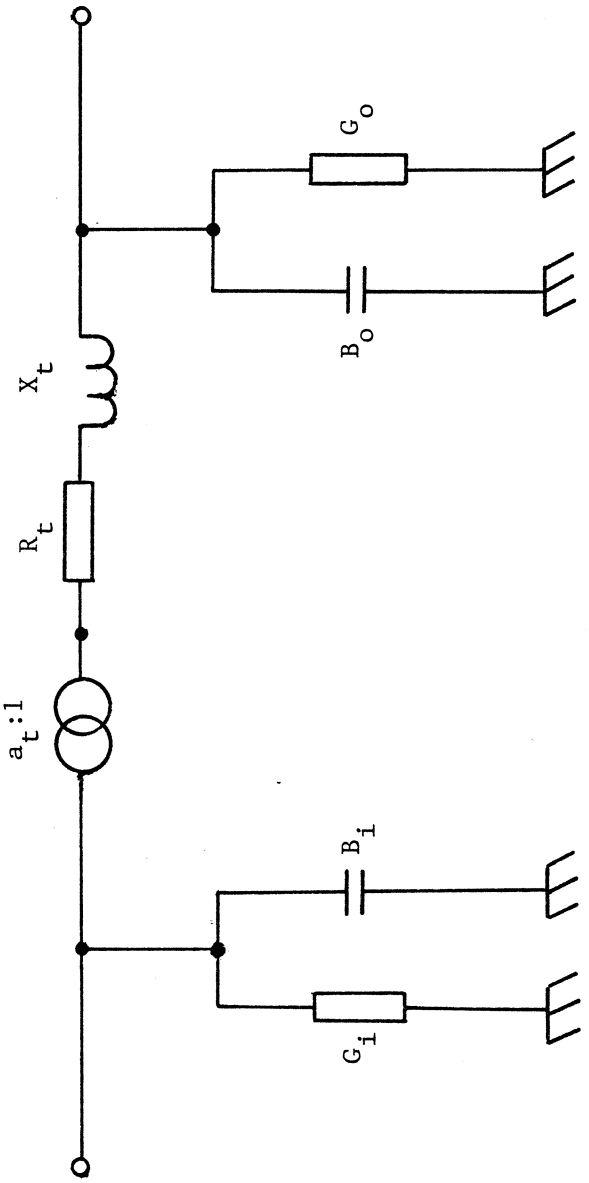

Fig.2 Transmission line model.

TABLE IV

THE MEANING OF SYMBOLS

Symbol	$\bar{a} = \lvert \Delta V_m / V_m^B \rvert$ %	$\bar{b} = \lvert \Delta Q_m / Q_m^B \rvert$ %	$\bar{c} = \Delta P_\ell / P_\ell^B$ %
a	$2 < \bar{a} \leq 5$	$2 < \bar{b} \leq 20$	$2 < \bar{c} \leq 20$
b	$5 < \bar{a} \leq 10$	$20 < \bar{b} \leq 50$	$20 < \bar{c} \leq 50$
c	$10 < \bar{a} \leq 15$	$50 < \bar{b} \leq 100$	$50 < \bar{c} \leq 100$
d	$15 < \bar{a} \leq 20$	$100 < \bar{b} \leq 200$	$100 < \bar{c} \leq 200$
e	$\bar{a} > 20$	$\bar{b} > 200$	$\bar{c} > 200$

where

$$\Delta V_m = \lvert V_m^C \rvert - \lvert V_m^B \rvert ,$$

$$\Delta Q_m = Q_m^C - Q_m^B ,$$

$$\Delta P_\ell = P_\ell^C - P_\ell^B ,$$

and

V_m^B and V_m^C are complex voltages at the mth bus,

Q_m^B and Q_m^C are reactive generator injections at the mth bus,

P_ℓ^B and P_ℓ^C are injected real powers in the ℓth line, and indices B and C refer to pre-contingency and post-contingency states, respectively.

The sign + or − at a generator bus denotes that, after a line outage, the reactive power generation at this bus changes sign to + or to −, respectively.

TABLE V

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (13,26) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell / P_\ell^B$
5	2,10	1.562	−0.112	2.747	0.199	1.186	76.0
6	9,10	−0.501	−0.322	−1.314	0.336	1.186	218.9
7	9,12	−0.195	0.058	0.462	−0.456	0.269	133.9
9	9,14	0.026	0.055	0.181	−0.089	0.156	611.5
10	11,14	−0.023	−0.165	−0.176	0.007	0.153	614.4
11	19,26	0.408	0.053	0.480	0.043	0.072	17.8
12	6,26	0.296	0.027	0.384	0.009	0.088	30.0
16	11,22	−0.024	0.044	0.045	−0.056	0.021	86.3
21	1,4	−0.050	0.174	−0.080	0.182	0.030	57.4
22	4,21	−0.533	0.190	0.563	0.026	0.032	5.9
24	15,1	2.179	0.881	2.311	0.866	0.132	6.0
26	1,7	0.789	0.072	0.952	0.041	0.162	20.6
27	15,20	−2.179	−0.887	−2.312	−0.864	0.140	6.2

Bus No.	Deviation $\lvert V_m^C\rvert - \lvert V_m^B\rvert$
9	−0.0850
11	−0.0199
12	−0.0403
13	0.0627
14	−0.0560

TABLE V

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (13,26) IS REMOVED (cont'd)

Bus No.	Base Case State Q_m^B	Post-Contingency State Q_m^C	Deviation ΔQ_m	Relative Deviation % $\Delta Q_m/Q_m^B$
18	−0.4004	−0.6971	−0.2967	74.1
19	0.1872	0.2010	0.0138	7.4
20	0.7795	0.7974	0.0179	2.3
21	−0.0294	−0.0186	0.0108	−36.7
22	−0.1775	−0.1106	0.0669	−37.7
24	−0.1645	−0.1568	0.0077	−4.7

Contingency analysis of the 26-bus power system

Index of the line removed: 1 terminal buses: 13,26

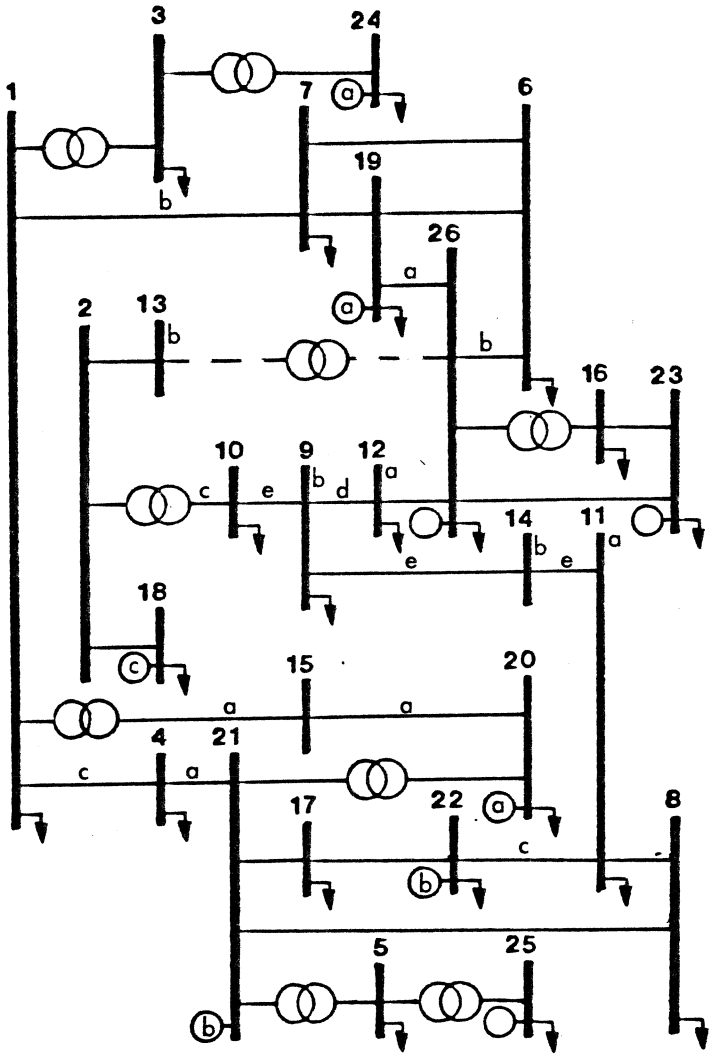

Fig. 3 The 26 - bus power system.

TABLE VI

CONTINGENCY ANALYSIS OF THE 26 - BUS POWER SYSTEM

LINE (23,26) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell / P_\ell^B$
2	26,16	1.265	0.451	1.350	0.458	0.085	6.8

Bus No.	Base Case State	Post-Contingency State	Deviation	Relative Deviation %
	Q_m^B	Q_m^C	ΔQ_m	$\Delta Q_m / Q_m^B$
23	−0.1144	−0.084	0.0304	−26.6

Contingency analysis of the 26-bus power system

Index of the line removed: 4 terminal buses: 23,26

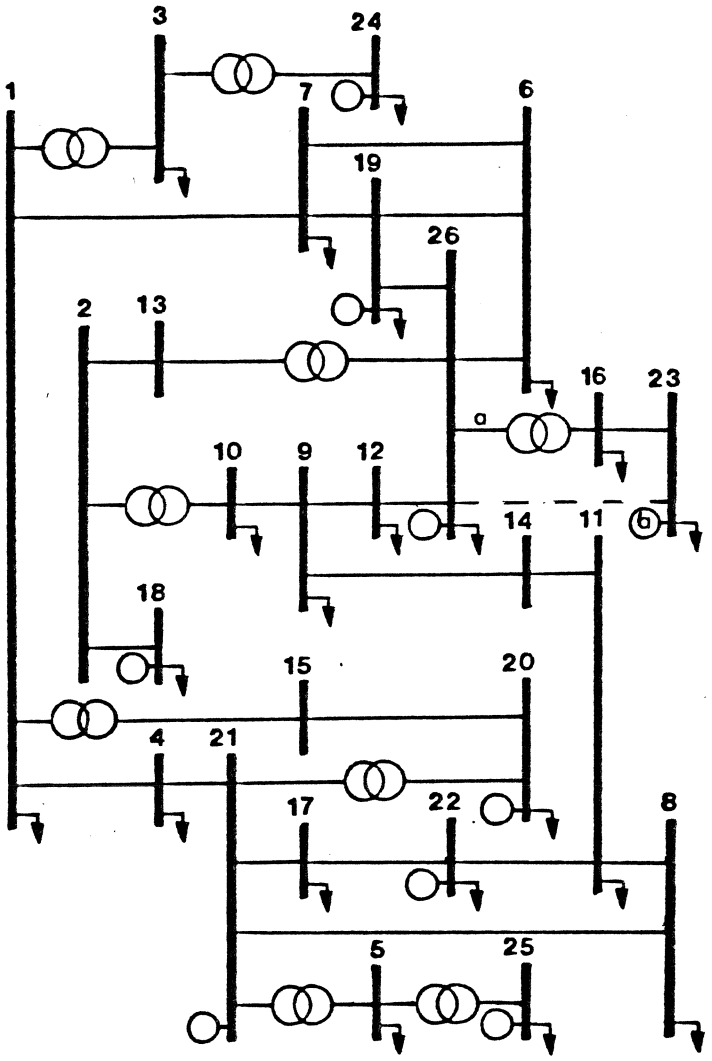

Fig. 4 The 26-bus power system.

TABLE VII

CONTINGENCY ANALYSIS OF THE 26 - BUS POWER SYSTEM

LINE (16,23) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell / P_\ell^B$
2	26,16	1.265	0.451	1.310	0.364	0.045	3.6

Bus No.	Base Case State	Post-Contingency State	Deviation	Relative Deviation %
	Q_m^B	Q_m^C	ΔQ_m	$\Delta Q_m / Q_m^B$
23	−0.1144	−0.0316	0.0828	−72.3

Contingency analysis of the 26-bus power system

Index of the line removed: 3 terminal buses: 16,23

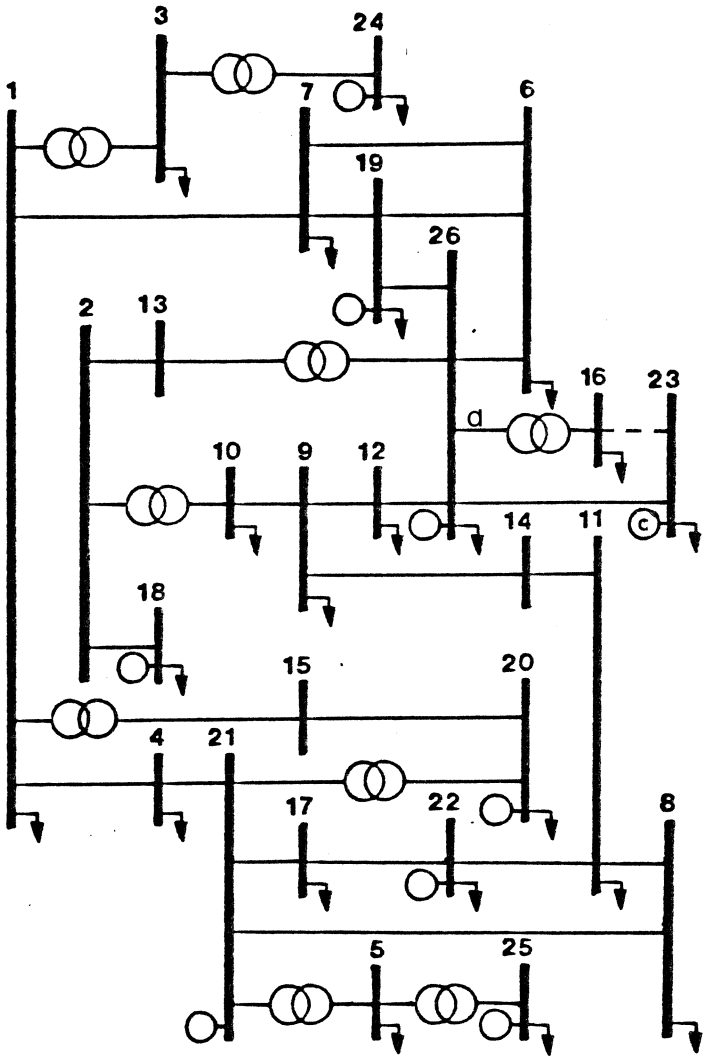

Fig. 5 The 26-bus power system.

TABLE VIII

CONTINGENCY ANALYSIS OF THE 26 - BUS POWER SYSTEM

LINE (9,10) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell / P_\ell^B$
1	13,26	1.177	0.472	1.706	0.202	0.529	45.0
7	9,12	−0.195	0.058	−0.602	−0.102	0.441	222.9
8	12,26	−0.628	−0.035	−1.068	−0.295	0.498	76.7
9	9,14	0.026	0.055	−0.068	−0.090	0.043	168.7
10	11,14	−0.023	−0.165	0.069	−0.002	0.044	176.3
14	7,19	−0.220	−0.083	−0.270	−0.065	0.052	23.1
15	6,7	0.113	−0.019	0.167	−0.031	0.053	47.1
16	11,22	−0.024	0.044	−0.078	−0.100	0.054	222.6
17	8,11	0.398	0.003	0.442	−0.046	0.044	11.0
18	17,22	0.597	0.137	0.653	0.123	0.056	9.4
19	8,21	−0.628	−0.063	−0.672	−0.106	0.051	7.6
20	17,21	−0.627	−0.147	−0.683	−0.133	0.060	9.3
23	20,21	0.560	0.374	0.649	0.375	0.090	16.1
25	2,13	1.188	−0.113	1.729	−0.275	0.541	45.6

Bus No.	Deviation $\lvert V_m^C\rvert - \lvert V_m^B\rvert$
8	−0.0212
9	−0.1396
10	−0.0196
11	−0.0384
12	−0.0690
14	−0.0921

TABLE VIII

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (9,10) IS REMOVED (cont'd)

Bus No.	Base Case State Q_m^B	Post-Contingency State Q_m^C	Deviation ΔQ_m	Relative Deviation % $\Delta Q_m/Q_m^B$
18	−0.4004	−0.1555	0.2449	−61.2
19	0.1872	0.1841	−0.0031	−2.0
21	−0.0294	0.0547	0.0840	~
22	−0.1775	−0.0004	0.1771	−100.0
24	−0.1645	−0.1679	−0.0034	2.0

Contingency analysis of the 26-bus power system

Index of the line removed: 6 terminal buses: 9,10

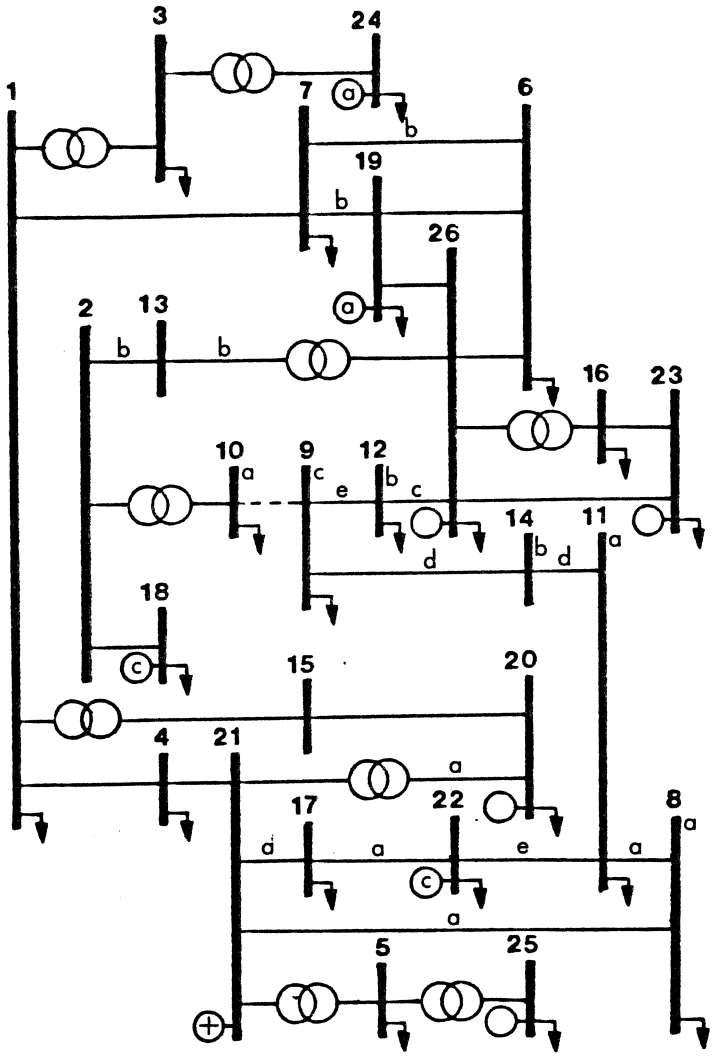

Fig. 6 The 26-bus power system.

TABLE IX

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (9,12) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell / P_\ell^B$
5	2,10	1.561	−0.112	1.734	−0.091	0.173	11.1
6	9,10	−0.501	−0.322	−0.643	−0.254	0.173	31.9
9	9,14	0.026	0.055	−0.027	0.044	0.002	7.1
10	11,14	0.023	−0.165	0.029	−0.152	0.004	14.8
14	7,19	−0.220	−0.083	−0.247	−0.073	0.028	12.9
15	6,7	0.113	−0.019	0.143	−0.025	0.029	25.7
16	11,22	−0.024	0.044	−0.051	0.023	0.027	109.7
17	8,11	0.398	0.033	0.426	0.005	0.028	7.0
18	17,22	0.597	0.137	0.624	0.131	0.028	4.6
19	8,21	−0.628	−0.063	−0.656	−0.065	0.031	4.7
20	17,21	−0.627	−0.147	−0.654	−0.140	0.030	4.6
23	20,21	0.559	0.374	0.603	0.373	0.049	8.8

Bus No.	Deviation $\lvert V_m^C \rvert - \lvert V_m^B \rvert$
9	−0.0195

TABLE IX

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (9,12) IS REMOVED (cont'd)

Bus No.	Base Case State Q_m^B	Post-Contingency State Q_m^C	Deviation ΔQ_m	Relative Deviation % $\Delta Q_m/Q_m^B$
18	−0.4004	−0.3827	0.0177	−4.4
21	−0.0294	−0.0077	0.0217	−73.8
22	−0.1775	−0.1425	0.0350	−19.7

Contingency analysis of the 26-bus power system

Index of the line removed: 7 terminal buses: 9,12

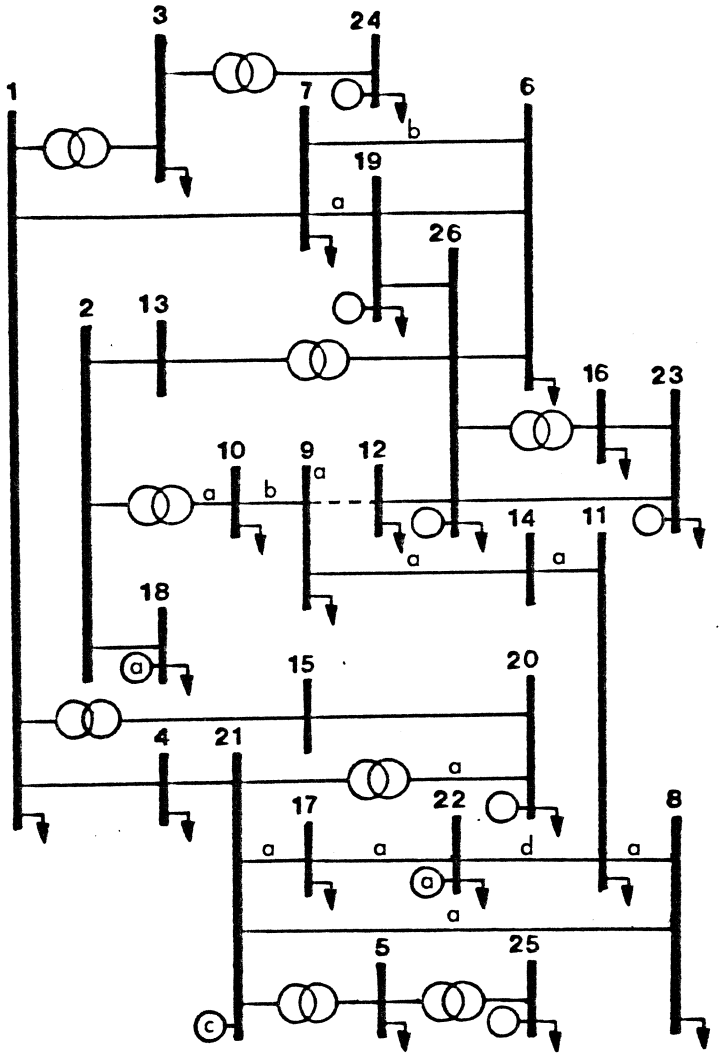

Fig. 7 The 26-bus power system.

TABLE X

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (12,26) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell / P_\ell^B$
5	2,10	1.562	−0.112	2.332	0.796	0.771	49.4
6	9,10	−0.501	−0.322	−0.927	−0.181	0.746	137.8
7	9,12	−0.195	0.058	0.454	0.201	0.256	130.0
9	9,14	0.025	0.055	−0.204	−0.199	0.192	152.7
10	11,14	−0.023	−0.165	0.235	0.234	0.210	840.0
14	7,19	−0.220	−0.083	−0.371	−0.029	0.158	70.3
15	6,7	0.113	−0.019	0.276	0.051	0.163	143.6
16	11,22	−0.024	0.044	−0.177	−0.318	0.162	667.0
17	8,11	0.398	0.003	0.522	0.116	0.124	31.0
18	17,22	0.597	0.137	0.766	0.096	0.169	28.3
19	8,21	−0.628	−0.063	−0.753	−0.173	0.148	22.3
20	17,21	−0.627	−0.147	−0.796	−0.102	0.182	28.1
23	20,21	0.559	0.374	0.829	0.380	0.270	48.2

Bus No.	Deviation $\lvert V_m^C\rvert - \lvert V_m^B\rvert$
2	−0.0331
8	−0.0600
9	−0.3707
10	−0.0452
11	−0.1055
12	−0.4668
14	−0.2485

TABLE X

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (12,26) IS REMOVED (cont'd)

Bus No.	Base Case State Q_m^B	Post-Contingency State Q_m^C	Deviation ΔQ_m	Relative Deviation % $\Delta Q_m/Q_m^B$
18	−0.4404	0.1772	0.5776	~
19	0.1872	0.1935	0.0063	3.4
21	−0.0294	0.2185	0.2479	~
22	−0.1775	0.3193	0.4967	~
24	−0.1645	−0.1714	−0.0069	4.2

Contingency analysis of the 26-bus power system

Index of the line removed: 8 terminal buses: 12,26

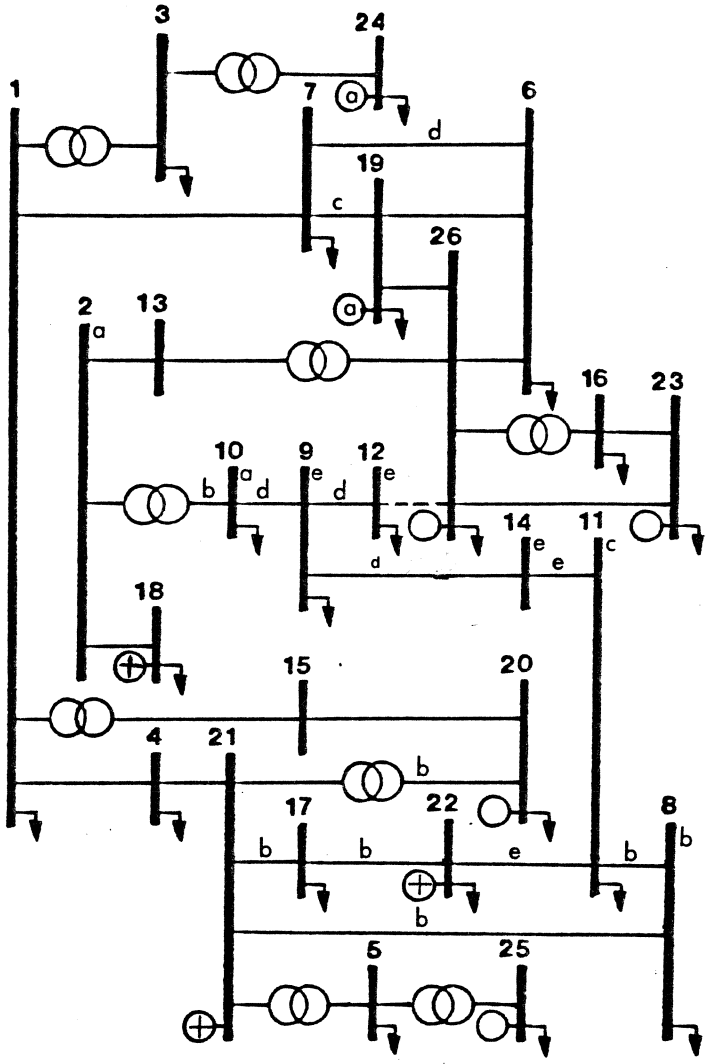

Fig. 8 The 26-bus power system.

TABLE XI

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (9,14) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell / P_\ell^B$
14	7,19	−0.220	−0.083	−0.230	−0.078	0.013	5.9
15	6,7	0.113	−0.018	0.127	−0.022	0.014	12.0
16	11,22	−0.024	0.044	−0.040	−0.045	0.016	66.4
17	8,11	0.398	0.003	0.407	0.033	0.009	2.2
18	17,22	0.597	0.137	0.613	0.133	0.017	2.8
20	17,21	−0.627	−0.147	−0.642	−0.143	0.018	2.7
23	20,21	0.559	0.347	0.582	0.374	0.023	4.2

Bus No.	Deviation $\lvert V_m^C\rvert - \lvert V_m^B\rvert$
11	−0.0221
14	−0.0552

Bus No.	Base Case State Q_m^B	Post-Contingency State Q_m^C	Deviation ΔQ_m	Relative Deviation % $\Delta Q_m / Q_m^B$
18	−0.4004	−0.4192	−0.0188	4.7
21	−0.0294	0.0121	0.0415	~
22	−0.1775	−0.0801	0.0974	−54.9

Contingency analysis of the 26-bus power system

Index of the line removed: 9 terminal buses: 9,14

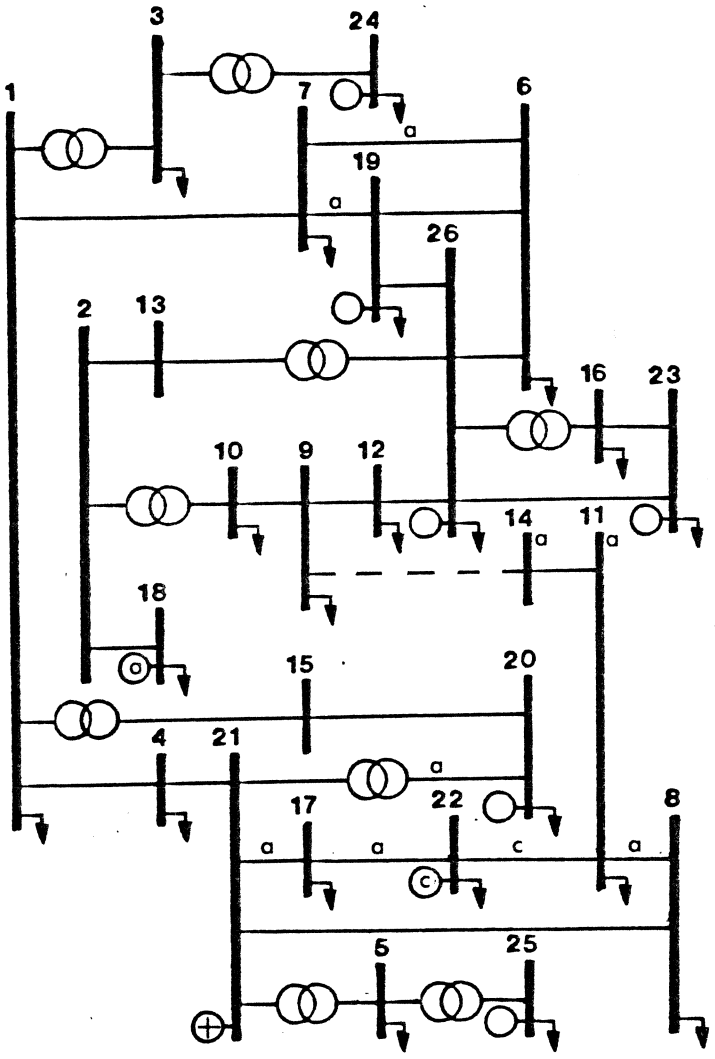

Fig. 9 The 26-bus power system.

TABLE XII

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (11,14) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell / P_\ell^B$
14	7,19	−0.220	−0.083	−0.233	0.078	0.014	6.1
15	6,7	0.113	−0.019	0.128	−0.022	0.014	12.5
16	11,22	−0.024	0.044	−0.042	−0.086	0.019	76.4
18	17,22	0.597	0.137	0.616	0.133	0.019	3.2
20	17,21	−0.627	−0.147	−0.646	−0.143	0.021	3.2
23	20,21	0.559	0.374	0.374	0.374	0.024	4.3

Bus No.	Deviation $\lvert V_m^C\rvert - \lvert V_m^B\rvert$
9	0.0248
11	−0.0325
14	0.0550

Bus No.	Base Case State Q_m^B	Post-Contingency State Q_m^C	Deviation ΔQ_m	Relative Deviation % $\Delta Q_m / Q_m^B$
18	−0.4004	−0.4381	−0.0377	9.4
21	−0.0294	0.0295	0.0589	~
22	−0.1775	−0.0357	0.1417	−79.8

Contingency analysis of the 26-bus power system

Index of the line removed: 10 terminal buses: 11,14

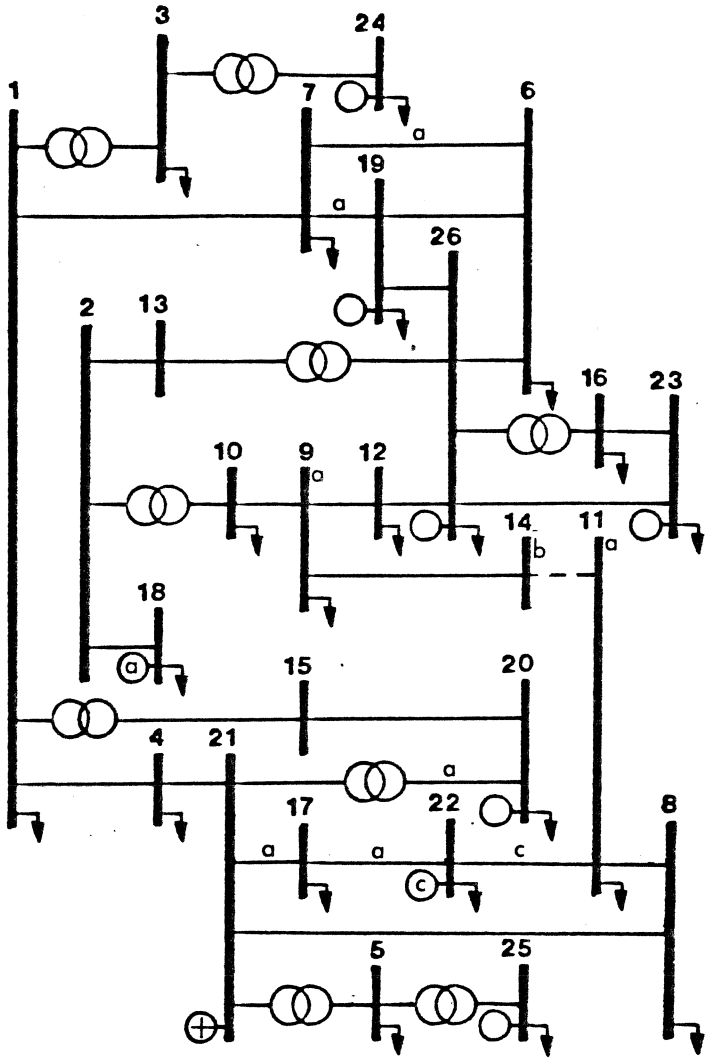

Fig. 10 The 26-bus power system.

TABLE XIII

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (19,26) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell / P_\ell^B$
12	6,26	0.296	0.027	0.643	−0.038	0.346	117.0
13	6,19	−0.810	−0.109	−1.157	−0.038	0.356	43.5
14	7,19	−0.220	−0.083	−0.270	−0.067	0.052	23.0
16	11,22	−0.024	0.044	−0.047	0.046	0.023	96.0
17	8,11	0.398	0.003	0.425	−0.002	0.027	6.7
18	17,22	0.591	0.137	0.621	0.131	0.024	4.0
19	8,21	−0.628	−0.063	−0.655	−0.058	0.029	4.4
20	17,21	−0.627	−0.147	−0.651	−0.141	0.026	4.0
23	20,21	0.559	0.374	0.604	0.375	0.045	8.1

Bus No.	Base Case State	Post-Contingency State	Deviation	Relative Deviation %
	Q_m^B	Q_m^C	ΔQ_m	$\Delta Q_m / Q_m^B$
19	0.187	0.090	−0.097	−52.0
21	−0.029	−0.018	0.012	−41.3
22	−0.176	−0.167	0.011	−6.2

Contingency analysis of the 26-bus power system

Index of the line removed: 11 terminal buses: 19,26

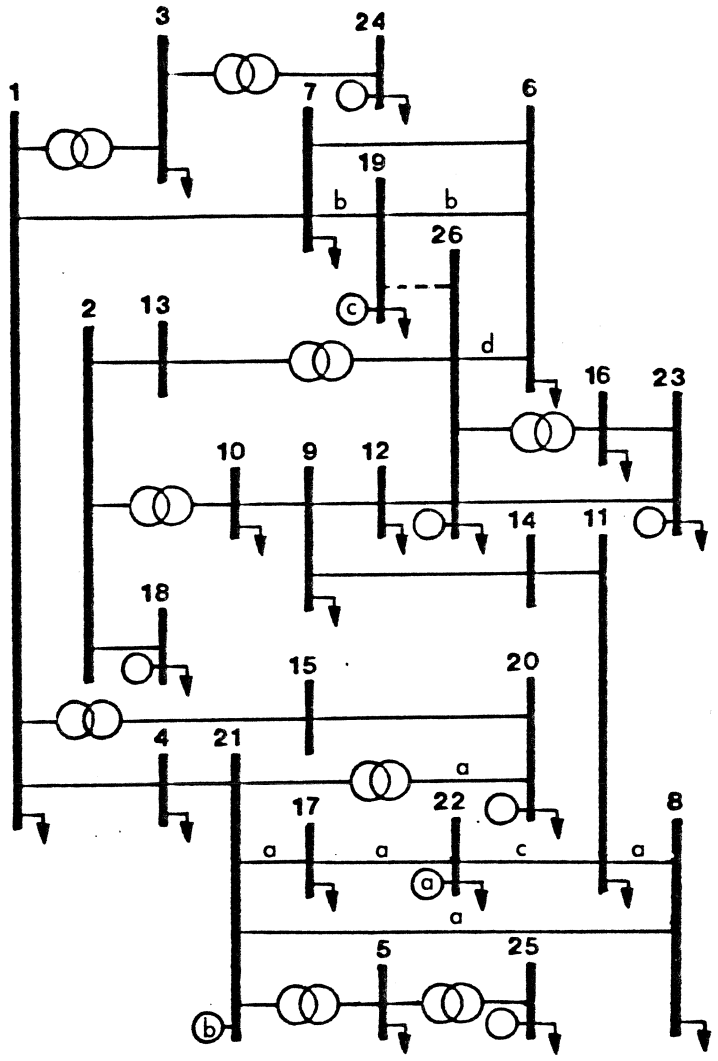

Fig. 11 The 26-bus power system.

TABLE XIV

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (6,26) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell / P_\ell^B$
11	19,26	0.408	0.053	0.662	0.243	0.254	62.4
15	6,7	0.113	−0.185	0.156	−0.017	0.042	37.2
16	11,22	−0.024	0.044	−0.045	0.046	0.021	85.4
17	8,11	0.398	0.003	0.442	−0.002	0.024	5.9
18	17,22	0.597	0.137	0.618	0.132	0.022	3.6
19	8,21	−0.628	−0.063	−0.652	−0.058	0.026	4.0
20	17,21	−0.627	−0.147	−0.648	−0.142	0.023	3.6
23	20,21	0.559	0.374	0.599	0.375	0.040	7.1

Bus No.	Base Case State	Post-Contingency State	Deviation	Relative Deviation %
	Q_m^B	Q_m^C	ΔQ_m	$\Delta Q_m / Q_m^B$
19	0.1872	0.1099	−0.0773	−41.3
21	−0.0294	−0.0203	0.0091	−31.0
22	−0.1775	−0.1678	0.0096	−5.4
24	−0.1645	−0.1688	−0.0042	2.6

Contingency analysis of the 26-bus power system

Index of the line removed: 12 terminal buses: 6,26

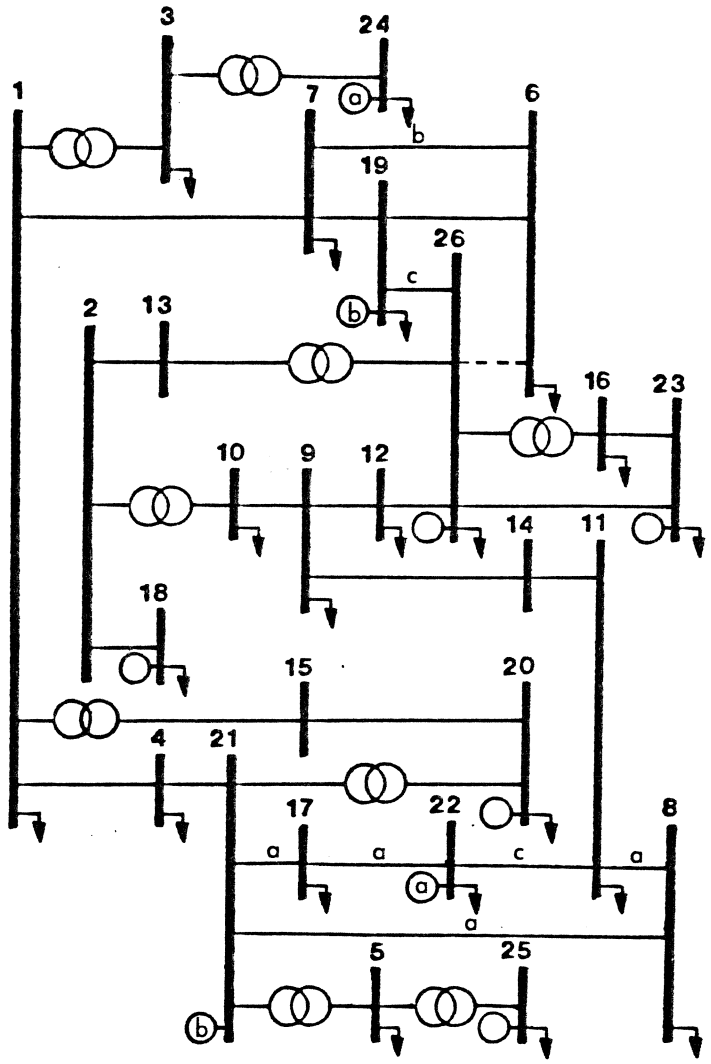

Fig. 12 The 26-bus power system.

TABLE XV

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (6,19) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell / P_\ell^B$
11	19,26	0.408	0.053	0.906	0.011	0.498	122.2
14	7,19	−0.220	−0.083	−0.519	−0.002	0.319	142.2
15	6,7	0.113	−0.018	−0.178	0.026	0.068	60.2
16	11,22	−0.024	0.044	−0.026	0.044	0.002	7.8

Bus No.	Deviation $\lvert V_m^C \rvert - \lvert V_m^B \rvert$
6	−0.046

Bus No.	Base Case State Q_m^B	Post-Contingency State Q_m^C	Deviation ΔQ_m	Relative Deviation % $\Delta Q_m / Q_m^B$
19	0.1872	0.023	−0.1642	−87.7
20	0.7795	0.8491	0.0696	8.9
21	−0.0294	−0.0159	0.0135	−46.0
24	−0.1645	−0.1316	0.0329	−20.0

Contingency analysis of the 26-bus power system

Index of the line removed: 13 terminal buses: 6,19

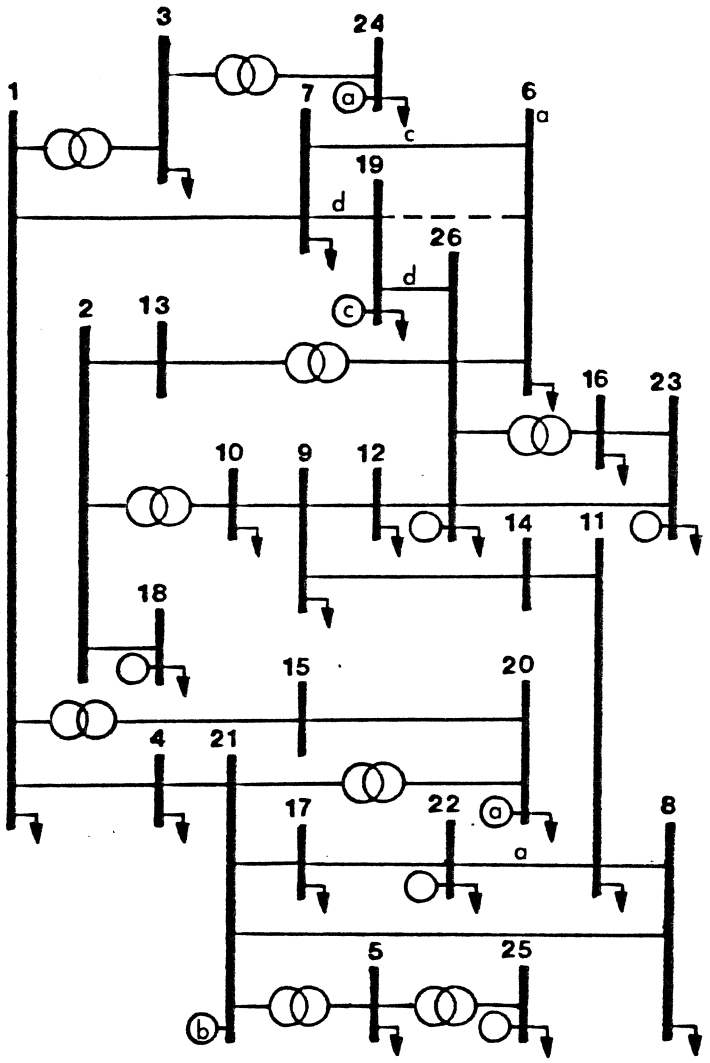

Fig. 13 The 26-bus power system.

TABLE XVI

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (7,19) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell/P_\ell^B$
6	9,10	−0.501	−0.322	−0.518	−0.316	0.020	3.7
7	9,12	−0.195	0.058	−0.222	0.065	0.028	14.3
8	12,26	−0.628	0.035	−0.656	−0.030	0.030	4.7
9	9,14	0.026	0.055	0.070	0.039	0.044	174.4
10	11,14	−0.023	−0.165	−0.068	−0.148	0.044	177.4
11	19,26	0.408	0.053	0.447	0.048	0.039	9.6
13	6,19	−0.810	−0.109	−0.991	−0.104	0.186	22.7
15	6,7	0.113	−0.019	0.296	−0.011	0.182	160.7
21	1,4	−0.050	0.174	−0.061	0.162	0.011	20.6
22	4,21	−0.533	0.019	−0.544	0.007	0.012	2.1
26	1,7	0.789	0.072	0.836	0.187	0.047	5.9

Bus No.	Base Case State	Post-Contingency State	Deviation	Relative Deviation %
	Q_m^B	Q_m^C	ΔQ_m	$\Delta Q_m/Q_m^B$
19	0.1872	0.1880	0.0018	4.3
20	0.7795	0.8664	0.0869	11.1
21	−0.0294	−0.0217	0.0077	−26.2
22	−0.1775	−0.1855	−0.0080	4.5
24	−0.1645	−0.1232	0.0413	−25.1

Contingency analysis of the 26-bus power system

Index of the line removed: 14 terminal buses: 7,19

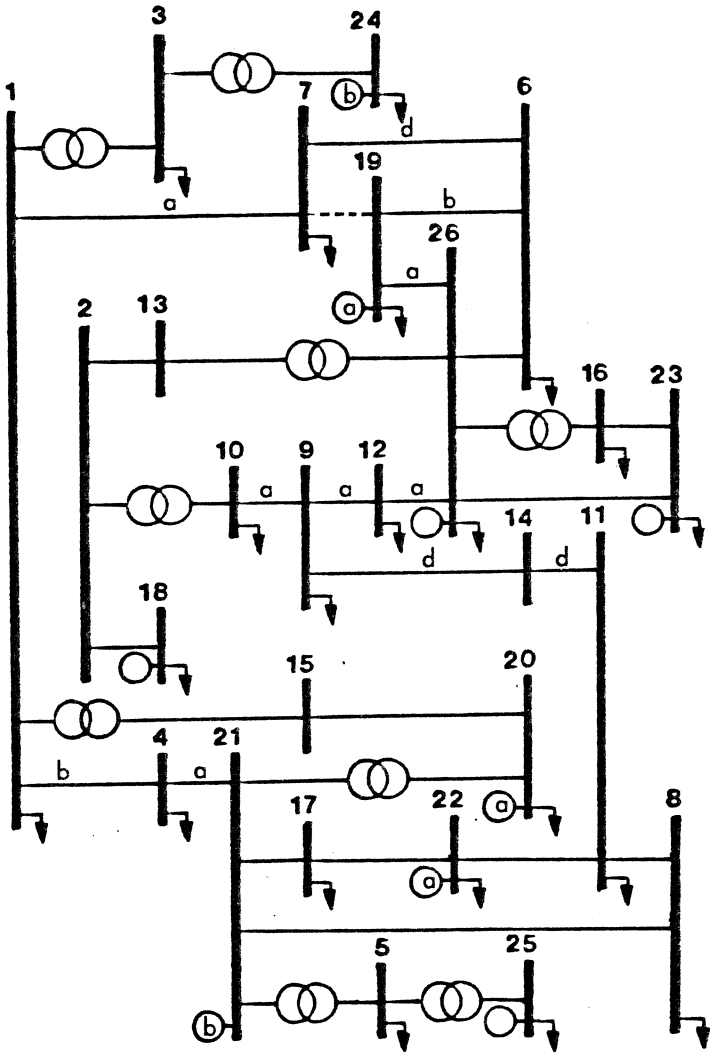

Fig. 14 The 26-bus power system.

TABLE XVII

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (6,7) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell/P_\ell^B$
7	9,12	−0.195	0.057	−0.209	0.062	0.015	7.5
8	12,26	−0.628	−0.035	−0.642	−0.032	0.016	2.5
9	9,14	0.026	0.055	0.049	0.046	0.023	91.5
10	11,14	−0.023	−0.165	−0.047	−0.156	0.023	93.5
12	6,26	0.296	0.027	0.319	0.025	0.023	7.7
14	7,19	−0.220	−0.083	−0.309	−0.083	0.093	41.6
21	1,4	−0.050	0.173	0.056	−0.165	0.006	11.6
26	1,7	0.789	0.072	0.814	0.156	0.025	3.1

Bus No.	Base Case State	Post-Contingency State	Deviation	Relative Deviation %
	Q_m^B	Q_m^C	ΔQ_m	$\Delta Q_m/Q_m^B$
19	0.1872	0.2160	0.0288	15.4
20	0.7795	0.8425	0.0629	8.0
21	−0.0294	−0.0256	0.0038	−13.0
22	−0.1775	−0.1820	−0.0045	2.5
24	−0.1645	−0.1358	0.0287	−17.4

Contingency analysis of the 26-bus power system

Index of the line removed: 15 terminal buses: 6,7

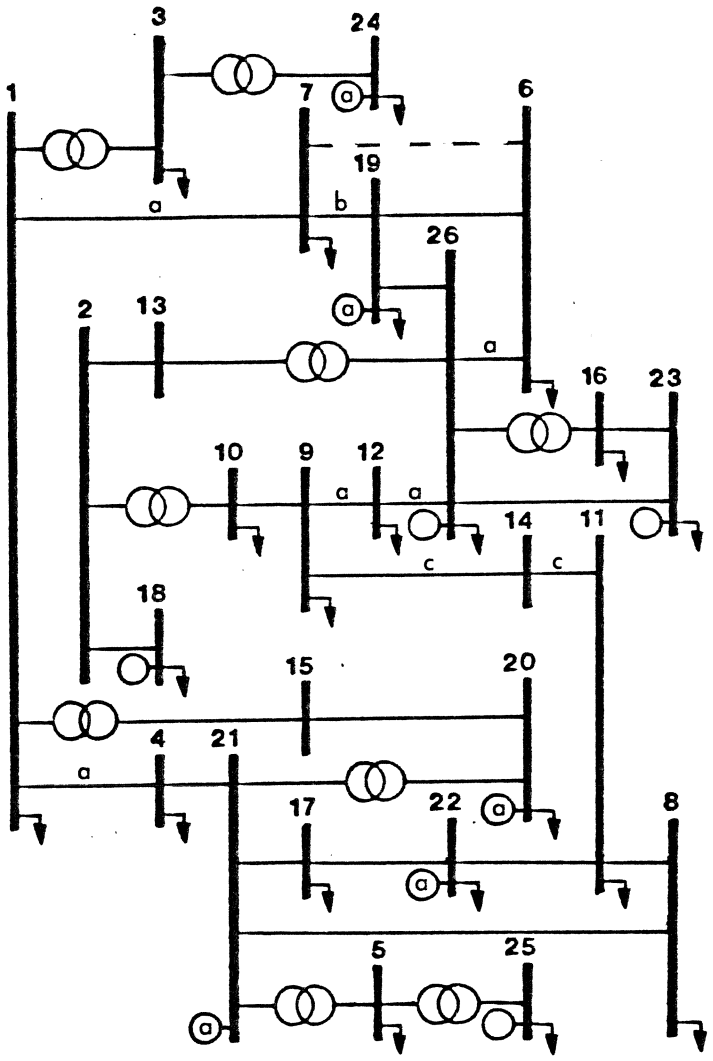

Fig. 15 The 26-bus power system.

TABLE XVIII

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (11,22) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell / P_\ell^B$
9	9,14	0.025	0.055	0.032	0.033	0.007	26.3
10	11,14	−0.023	−0.165	−0.031	−0.148	0.007	27.6
17	8,11	0.398	0.003	0.416	−0.021	0.018	4.5
19	8,21	−0.628	−0.063	−0.646	−0.039	0.019	2.9
21	1,4	−0.050	0.174	−0.051	0.174	0.001	2.5

Bus No.	Base Case State	Post-Contingency State	Deviation	Relative Deviation %
	Q_m^B	Q_m^C	ΔQ_m	$\Delta Q_m / Q_m^B$
21	−0.0294	−0.0534	−0.0240	81.6
22	−0.1775	−0.1071	0.0704	−39.6

Contingency analysis of the 26-bus power system

Index of the line removed: 16 terminal buses: 11,22

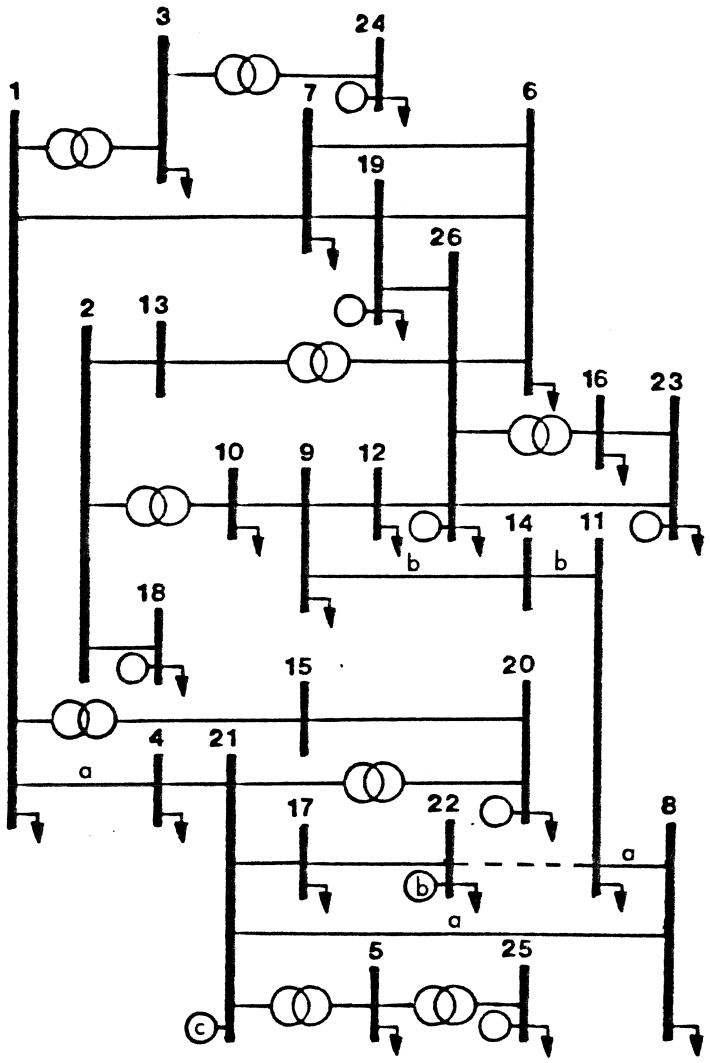

Fig. 16 The 26-bus power system.

TABLE XIX

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (8,11) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell / P_\ell^B$
6	9,10	−0.501	−0.322	−0.561	−0.309	0.072	13.4
7	9,12	−0.195	0.058	−0.297	0.056	0.106	53.7
8	12,26	−0.628	−0.035	−0.734	−0.046	0.115	17.7
9	9,14	0.026	0.055	0.188	0.043	0.163	638.1
10	11,14	−0.023	−0.165	−0.182	−0.130	0.160	642.3
11	19,26	0.408	0.053	0.478	0.044	0.071	17.3
12	6,26	0.296	0.027	0.382	0.009	0.085	28.8
16	11,22	−0.024	0.044	−0.249	−0.010	0.228	940.2
18	17,22	0.597	0.137	0.836	0.074	0.240	40.2
20	17,21	−0.627	−0.147	−0.866	−0.084	0.259	40.0
21	1,4	−0.050	0.174	−0.079	0.182	0.029	55.9
22	4,21	−0.533	−0.019	−0.562	0.025	0.032	5.7
24	15,1	2.179	0.887	2.309	0.863	0.129	5.9
26	1,7	0.789	0.072	0.947	0.042	0.158	20.1
27	15,20	−2.179	−0.887	−2.308	0.864	0.136	6.1

Bus No.	Deviation $\lvert V_m^C \rvert - \lvert V_m^B \rvert$
8	0.0496
11	−0.0283
14	−0.0236

TABLE XIX

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (8,11) IS REMOVED (cont'd)

Bus No.	Base Case State Q_m^B	Post-Contingency State Q_m^C	Deviation ΔQ_m	Relative Deviation % $\Delta Q_m/Q_m^B$
18	−0.4004	−0.3806	0.0198	−4.9
19	0.1872	0.1979	0.0107	5.7
20	0.7795	0.7970	0.0174	2.2
21	−0.0294	−0.0794	−0.0500	170.0
22	−0.1775	0.0328	0.2102	~
24	−0.1645	−0.1570	0.0075	−4.6

Contingency analysis of the 26-bus power system

Index of the line removed: 17 terminal buses: 8,11

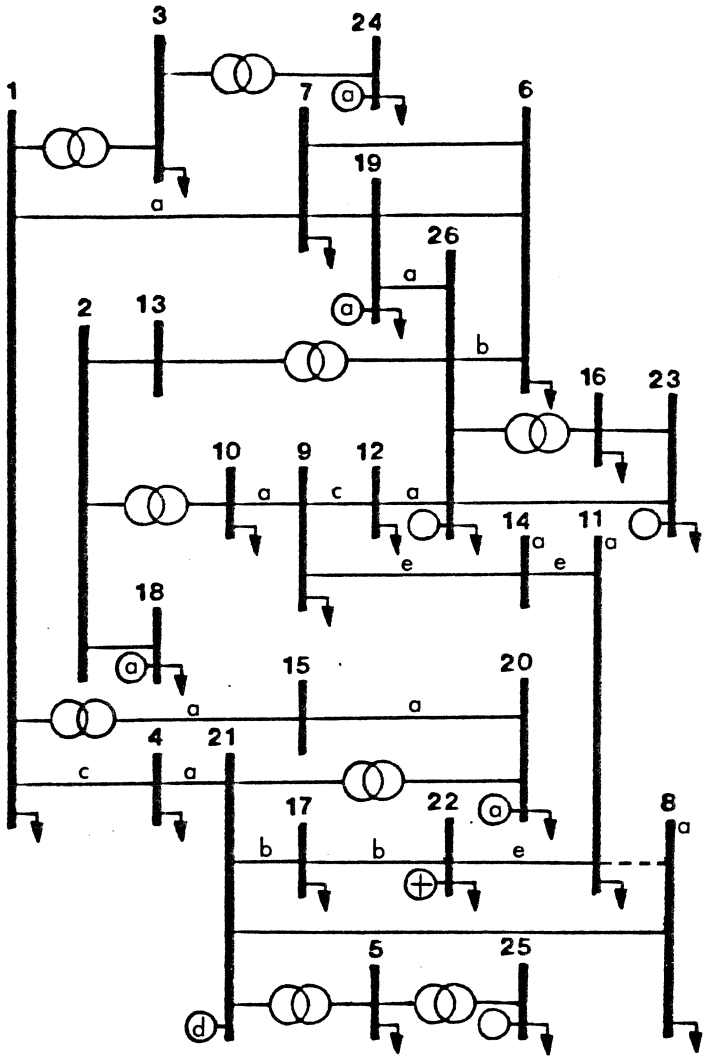

Fig. 17 The 26-bus power system.

TABLE XX

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (17,22) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell/P_\ell^B$
5	2,10	1.562	−0.112	1.700	0.043	0.138	8.8
6	9,10	−0.501	−0.322	−0.614	−0.300	0.138	25.5
7	9,12	−0.195	0.058	−0.389	0.048	0.203	102.6
8	12,26	−0.628	−0.035	−0.831	−0.067	0.221	34.1
9	9,14	0.026	0.055	0.333	0.043	0.307	1206.2
10	11,14	−0.023	−0.165	−0.315	−0.080	0.300	1200.4
11	19,26	0.408	0.053	0.485	0.043	0.077	18.9
12	6,26	0.296	0.027	0.389	0.008	0.093	31.4
16	11,22	−0.024	0.044	0.589	−0.267	0.565	2325.2
17	8,11	0.398	0.003	0.771	−0.016	0.372	93.5
19	8,21	−0.628	−0.063	−1.001	−0.044	0.435	65.8
21	1,4	−0.050	0.174	−0.082	0.182	0.032	61.1
22	4,21	−0.533	0.019	−0.565	0.026	0.034	6.3
24	15,1	2.179	0.887	2.320	0.863	0.140	6.5
26	1,7	0.789	0.072	0.962	0.040	0.172	21.8
27	15,20	2.179	−0.887	−2.320	−0.862	0.149	6.6

TABLE XX

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (17,22) IS REMOVED (cont'd)

Bus No.	Deviation $\lvert V_m^C \rvert - \lvert V_m^B \rvert$
8	−0.0657
9	−0.0357
11	−0.0553
14	−0.0496
17	0.0956

Bus No.	Base Case State Q_m^B	Post-Contingency State Q_m^C	Deviation ΔQ_m	Relative Deviation % $\Delta Q_m / Q_m^B$
18	−0.4004	−0.3552	0.0452	−11.3
19	0.1872	0.2001	0.0129	6.9
20	0.7795	0.7992	0.0197	2.5
21	−0.0294	−0.0885	−0.0591	201.0
22	−0.1775	0.350	0.528	~
24	−0.1645	−0.1564	0.0081	4.9

Contingency analysis of the 26-bus power system

Index of the line removed: 18 terminal buses: 17,22

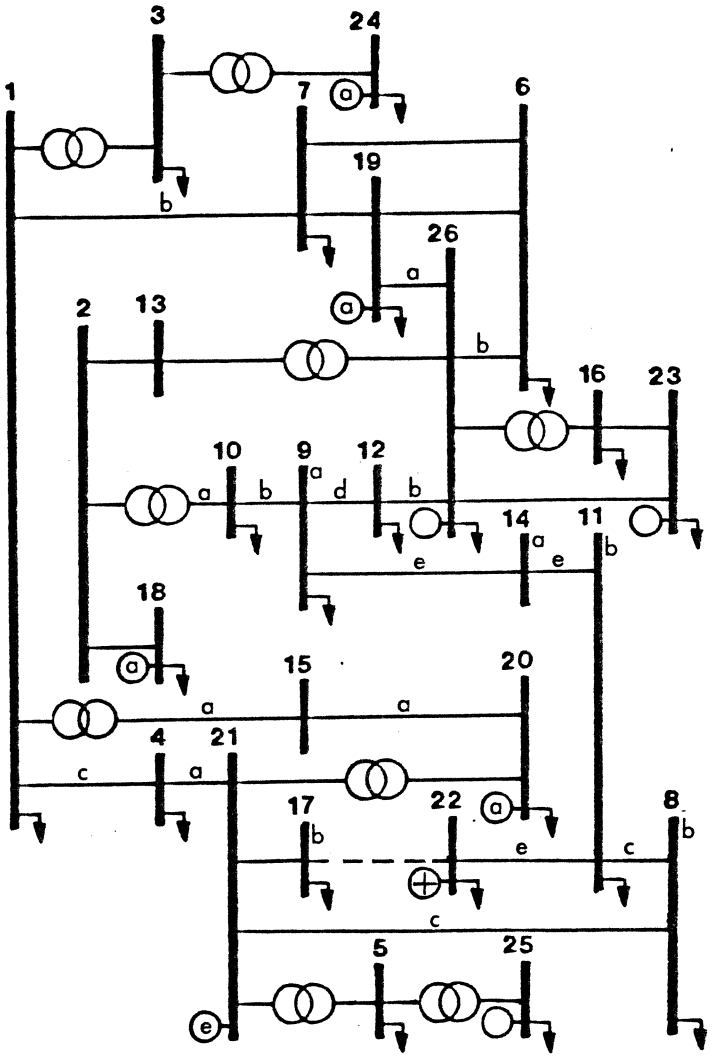

Fig. 18 The 26-bus power system.

TABLE XXI

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (8,21) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell / P_\ell^B$
5	2,10	1.562	−0.112	1.685	−0.043	0.124	7.9
6	9,10	−0.501	−0.322	−0.603	−0.304	0.124	23.0
7	9,12	−0.195	0.058	−0.370	0.046	0.183	92.6
8	12,26	−0.628	−0.035	−0.811	−0.066	0.199	30.1
9	9,14	0.026	0.055	0.303	0.048	0.278	1089.4
10	11,14	−0.023	−0.164	−0.2880	−0.096	0.271	1086.2
11	19,26	0.408	0.053	0.508	0.038	0.100	24.5
12	6,26	0.296	0.027	0.417	0.002	0.121	40.8
16	11,22	−0.024	0.044	−0.379	−0.070	0.365	1504.3
18	17,22	0.597	0.137	0.983	0.030	0.368	64.1
20	17,21	−0.627	−0.147	−1.013	−0.040	0.422	65.1
21	1,4	−0.50	0.174	−0.091	0.185	0.042	79.6
22	4,21	−0.533	0.019	0.575	0.028	0.045	8.2
24	15,1	2.179	0.887	2.363	0.857	0.183	8.4
26	1,7	0.789	0.072	1.014	0.030	0.225	28.5
27	15,20	−2.179	−0.887	−2.363	−0.856	0.194	8.6

Bus No.	Deviation $\lvert V_m^C \rvert - \lvert V_m^B \rvert$
8	−0.1381
9	−0.0328
11	−0.0543
14	−0.0468
17	−0.0246

TABLE XXI

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (8,21) IS REMOVED (cont'd)

Bus No.	Base Case State Q_m^B	Post-Contingency State Q_m^C	Deviation ΔQ_m	Relative Deviation % $\Delta Q_m/Q_m^B$
18	−0.4004	−0.3611	0.0394	−9.9
19	0.1872	0.2061	0.0189	10.1
20	0.7795	0.8068	0.0273	3.5
21	−0.0294	−0.0141	0.0153	−52.0
22	−0.1775	0.2271	0.4045	~
24	−0.1645	−0.1531	0.0114	−6.7

Contingency analysis of the 26-bus power system

Index of the line removed: 19 terminal buses: 8,21

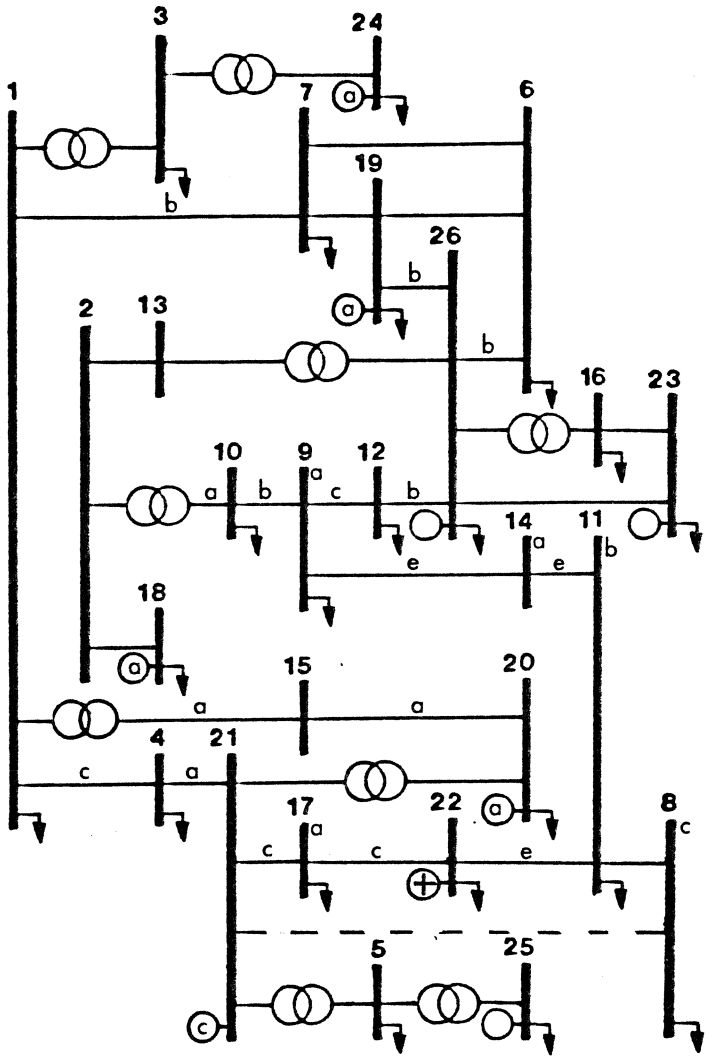

Fig. 19 The 26-bus power system.

TABLE XXII

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (17,21) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell / P_\ell^B$
5	2,10	1.562	−0.112	1.709	−0.029	0.148	9.5
6	9,10	−0.501	−0.322	−0.622	−0.300	0.148	27.3
7	9,12	−0.195	0.058	−0.403	0.044	0.218	110.2
8	12,26	−0.628	−0.035	−0.846	−0.072	0.238	36.6
9	9,14	0.026	0.055	0.355	0.046	0.329	1292.2
10	11,14	−0.023	−0.165	−0.335	−0.073	0.320	1283.4
11	19,26	0.408	0.053	0.487	0.043	0.079	19.5
12	6,26	0.296	0.027	0.392	0.007	0.096	32.4
16	11,22	−0.024	0.044	0.623	−0.290	0.599	2466.3
17	8,11	0.398	0.003	0.790	−0.013	0.392	98.3
19	8,21	−0.628	−0.063	−1.020	−0.047	0.459	69.5
21	1,4	−0.050	0.174	0.083	0.183	0.033	62.5
22	4,21	−0.533	0.019	−0.566	0.026	0.036	6.5
26	1,7	0.789	0.072	0.967	0.038	0.178	22.5
24	15,1	2.179	0.887	2.325	0.859	0.146	6.7
27	15,20	−2.179	−0.887	−2.324	−0.862	0.153	6.8

TABLE XXII

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (17,21) IS REMOVED (cont'd)

Bus No.	Deviation $\lvert V_m^C \rvert - \lvert V_m^B \rvert$
8	−0.0719
9	−0.0394
11	−0.0611
12	−0.0203
14	−0.0551
17	−0.0413

Bus No.	Base Case State Q_m^B	Post-Contingency State Q_m^C	Deviation ΔQ_m	Relative Deviation % $\Delta Q_m / Q_m^B$
18	−0.4004	−0.3502	0.0502	−12.5
19	0.1872	0.2012	0.0140	7.5
20	0.7795	0.7996	0.0201	2.6
21	−0.0294	0.005	0.0344	~
22	−0.1775	−0.3629	−0.1854	104.5
24	−0.1645	−0.1516	0.0085	−5.2

Contingency analysis of the 26-bus power system

Index of the line removed: 20 terminal buses: 17,21

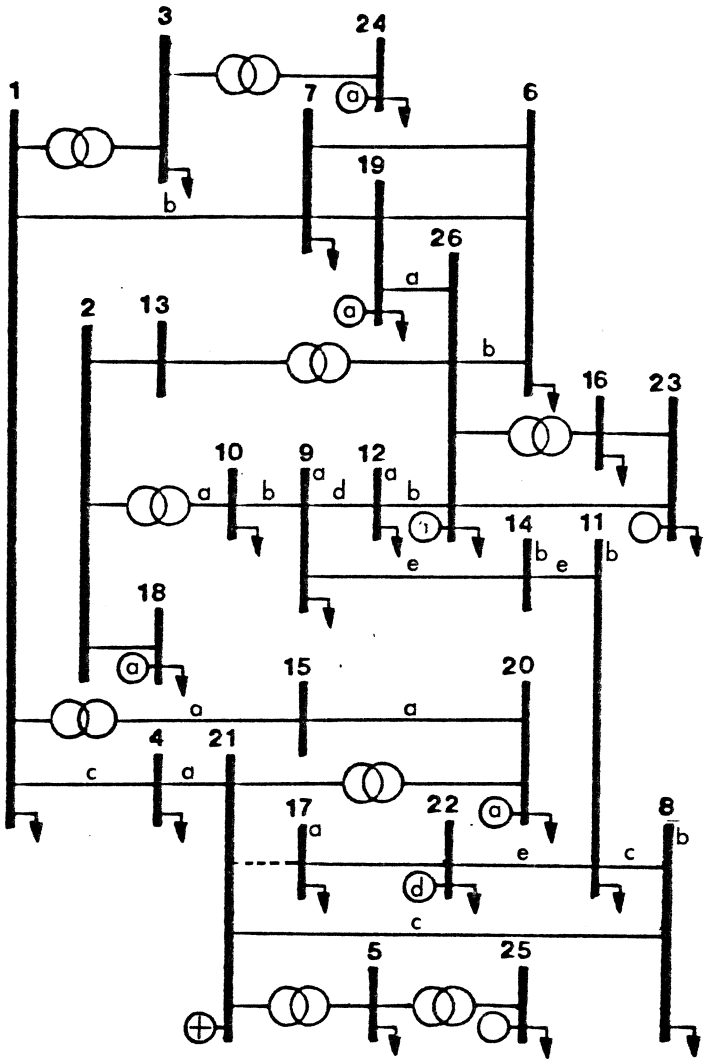

Fig. 20 The 26-bus power system.

TABLE XXIII

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (1,4) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow P_ℓ^B	Base Case Flow Q_ℓ^B	Post-Contingency Flow P_ℓ^C	Post-Contingency Flow Q_ℓ^C	Deviation ΔP_ℓ	Relative Deviation % $\Delta P_\ell/P_\ell^B$
16	11,22	−0.024	0.044	0.025	0.044	0.001	4.0
24	15,1	2.179	0.887	2.228	0.793	0.049	2.2
27	15,20	−2.179	0.887	2.228	0.791	0.050	2.2

Bus No.	Deviation $\lvert V_m^C\rvert - \lvert V_m^B\rvert$
4	−0.054

Bus No.	Base Case State Q_m^B	Post-Contingency State Q_m^C	Deviation ΔQ_m	Relative Deviation % $\Delta Q_m/Q_m^B$
19	0.1872	0.1591	−0.0281	−15.0
20	0.7795	0.6826	−0.0969	−12.4
21	−0.0294	0.2044	0.2338	~
24	−0.1645	−0.2103	−0.0458	27.8

Contingency analysis of the 26-bus power system

Index of the line removed: 21 terminal buses: 1,4

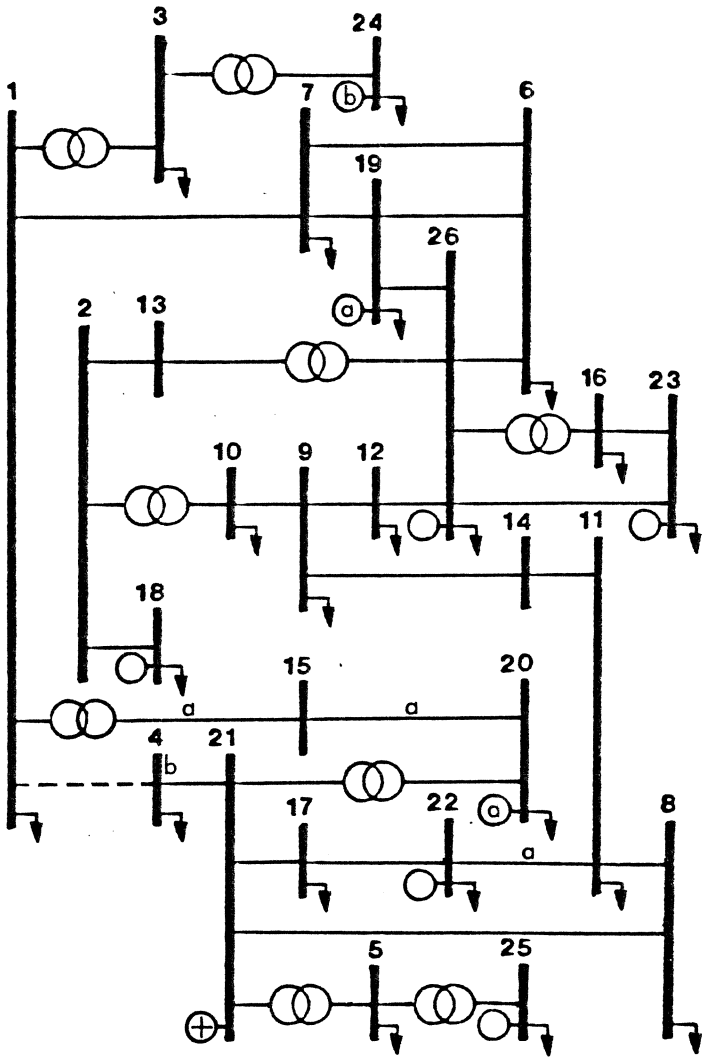

Fig. 21 The 26-bus power system.

TABLE XXIV

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (4,21) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell / P_\ell^B$
14	7,19	−0.220	−0.083	−0.250	−0.096	0.031	13.8
15	6,7	0.113	−0.019	0.146	−0.003	0.033	29.0
16	11,22	−0.024	−0.044	0.038	0.045	0.014	59.4
17	8,11	0.398	0.003	0.415	0.000	0.016	4.1
18	17,22	0.597	0.137	0.612	0.134	0.015	2.5
19	8,21	−0.628	−0.063	−0.645	−0.060	0.018	2.7
20	17,21	−0.627	−0.147	−0.642	−0.144	0.016	2.5
21	1,4	−0.050	0.174	0.499	0.220	0.446	846.6
24	15,1	2.179	0.887	2.664	0.867	0.485	22.3
27	15,20	−2.179	−0.887	−2.665	0.866	0.516	23.0

Bus No.	Deviation $\lvert V_m^C \rvert - \lvert V_m^B \rvert$
4	−0.0511

TABLE XXIV

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (4,21) IS REMOVED (cont'd)

Bus No.	Base Case State Q_m^B	Post-Contingency State Q_m^C	Deviation ΔQ_m	Relative Deviation % $\Delta Q_m/Q_m^B$
19	−0.1872	−0.2289	−0.0418	22.3
20	0.7795	0.9417	0.1622	21.0
21	−0.0294	−0.0230	0.0006	−2.0
22	−0.1775	−0.1710	0.0065	−3.7
24	−0.1645	−0.0971	0.0674	−40.9

Contingency analysis of the 26-bus power system

Index of the line removed: 22 terminal buses: 4,21

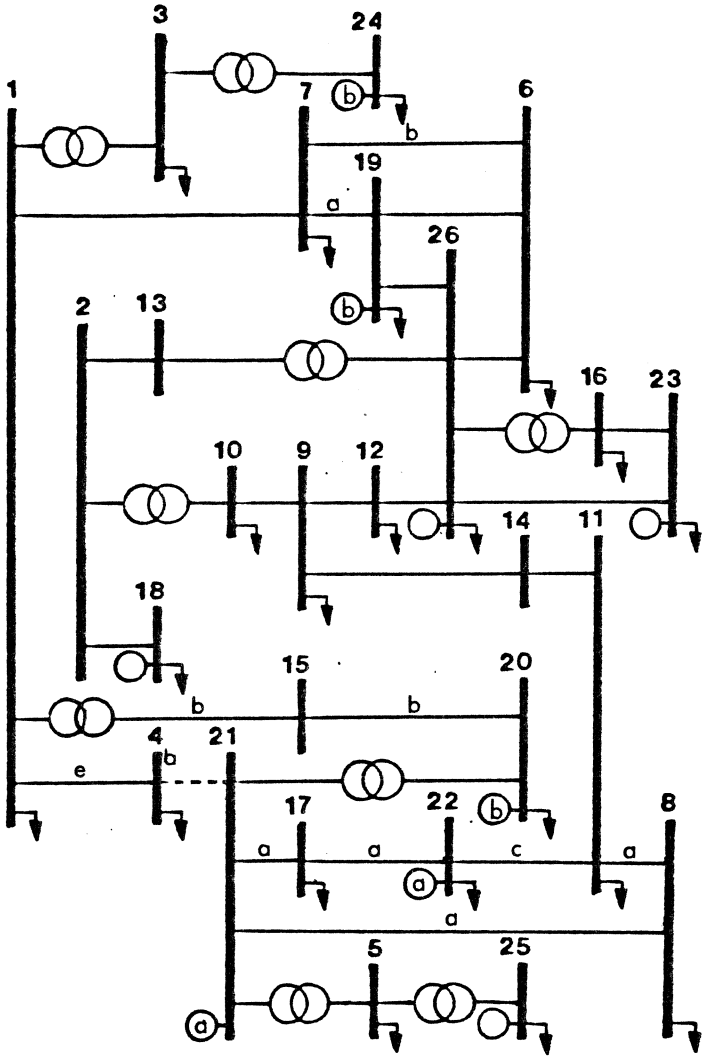

Fig. 22 The 26-bus power system.

TABLE XXV

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (20,21) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell/P_\ell^B$
5	2,10	1.562	−0.112	1.619	−0.100	0.057	3.6
6	9,10	−0.501	−0.322	−0.549	−0.301	0.058	10.6
7	9,12	−0.195	0.058	−0.273	0.078	0.081	41.1
8	12,26	−0.628	−0.035	−0.709	−0.022	0.088	13.5
9	9,14	0.026	0.055	0.152	0.013	0.127	498.1
10	11,14	−0.023	−0.165	−0.148	−0.115	0.126	503.5
11	19,26	0.408	0.053	0.462	0.045	0.055	13.4
12	6,26	0.296	0.027	0.362	0.128	0.066	22.3
16	11,22	−0.024	0.044	0.036	0.032	0.012	48.5
21	1,4	−0.050	0.174	0.356	0.063	0.303	575.1
24	15,1	2.179	0.887	2.707	0.762	0.528	24.2
26	1,7	0.789	0.072	0.912	0.042	0.122	15.5
27	15,20	−2.179	−0.887	−2.707	−0.762	0.559	24.5

Bus No.	Base Case State	Post-Contingency State	Deviation	Relative Deviation %
	Q_m^B	Q_m^C	ΔQ_m	$\Delta Q_m/Q_m^B$
19	0.1872	0.2001	0.0129	6.9
20	0.7795	0.4640	−0.3145	40.3
21	−0.0294	0.2710	0.3004	~
22	−0.1775	−0.1943	−0.0169	9.5
24	−0.1645	−0.1493	0.0152	−9.2

Contingency analysis of the 26-bus power system

Index of the line removed: 23 terminal buses: 20,21

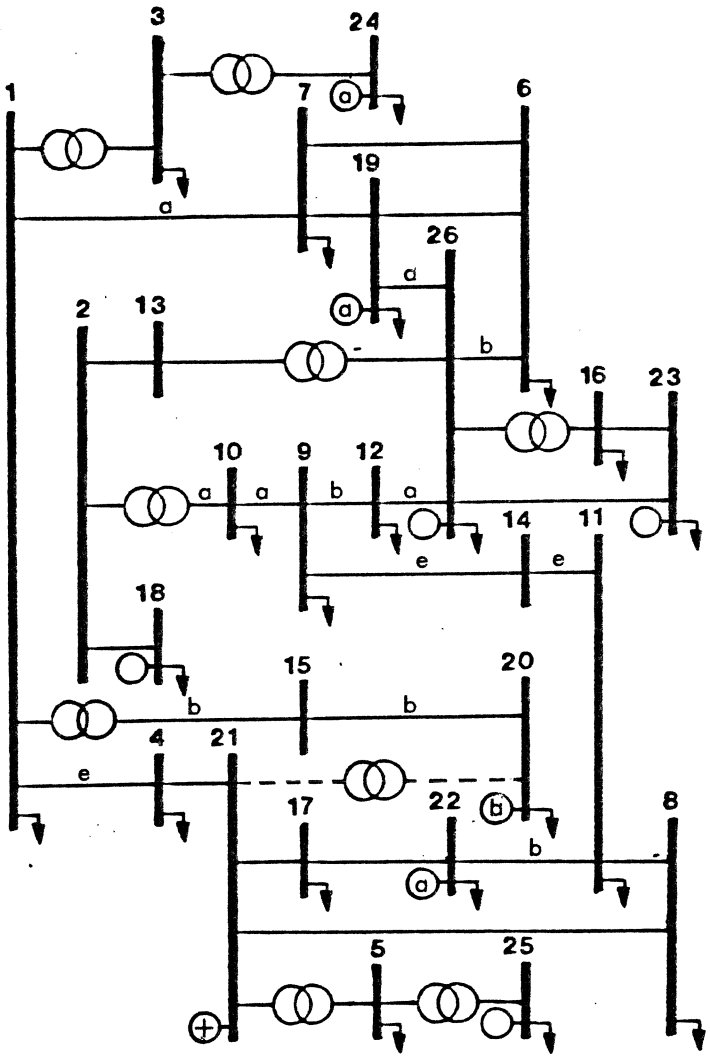

Fig. 23 The 26-bus power system.

TABLE XXVI

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (15,1) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell / P_\ell^B$
1	13,26	1.117	0.472	1.389	0.408	0.212	18.1
9	9,14	0.026	0.055	−0.458	0.337	0.456	1788.8
10	11,14	−0.023	−0.165	0.509	−0.251	0.484	1938.0
12	6,26	0.296	0.027	−0.536	0.095	0.255	86.2
14	7,19	−0.220	−0.083	−0.844	−0.271	0.745	331.5
15	6,7	0.113	−0.018	0.885	0.560	0.771	679.5
16	11,22	−0.024	0.041	−0.299	−0.035	0.281	1155.2
17	8,11	0.398	0.003	0.691	0.019	0.292	73.5
18	17,22	0.597	0.137	0.892	0.058	0.295	49.5
19	8,21	−0.628	−0.063	−0.921	−0.040	0.337	51.0
20	17,21	−0.627	−0.147	−0.922	−0.671	0.321	49.5
21	1,4	−0.050	0.174	−0.920	1.049	1.111	2100.2
22	4,21	−0.532	0.019	−1.648	−0.065	1.574	286.0
23	20,21	0.559	0.374	2.798	0.483	2.239	400.0
25	2,13	1.188	−0.113	1.404	−0.139	0.216	18.2

TABLE XXVI

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (15,1) IS REMOVED (cont'd)

Bus No.	Deviation $\lvert V_m^C \rvert - \lvert V_m^B \rvert$
1	−0.3261
3	−0.2639
4	−0.4010
6	−0.0336
7	−0.2649
8	−0.0456
11	−0.0384
14	−0.0349
15	0.0960

Bus No.	Base Case State Q_m^B	Post-Contingency State Q_m^C	Deviation ΔQ_m	Relative Deviation % $\Delta Q_m / Q_m^B$
18	−0.4004	−0.3626	0.0379	−9.5
19	0.1872	1.7291	1.5419	824.0
20	0.7792	−0.4238	−1.2033	~
21	−0.0294	2.2045	2.2339	~
22	−0.1775	0.1042	.2817	~
24	−0.1645	1.6929	1.8574	~

Contingency analysis of the 26-bus power system

Index of the line removed: 24 terminal buses: 15,1

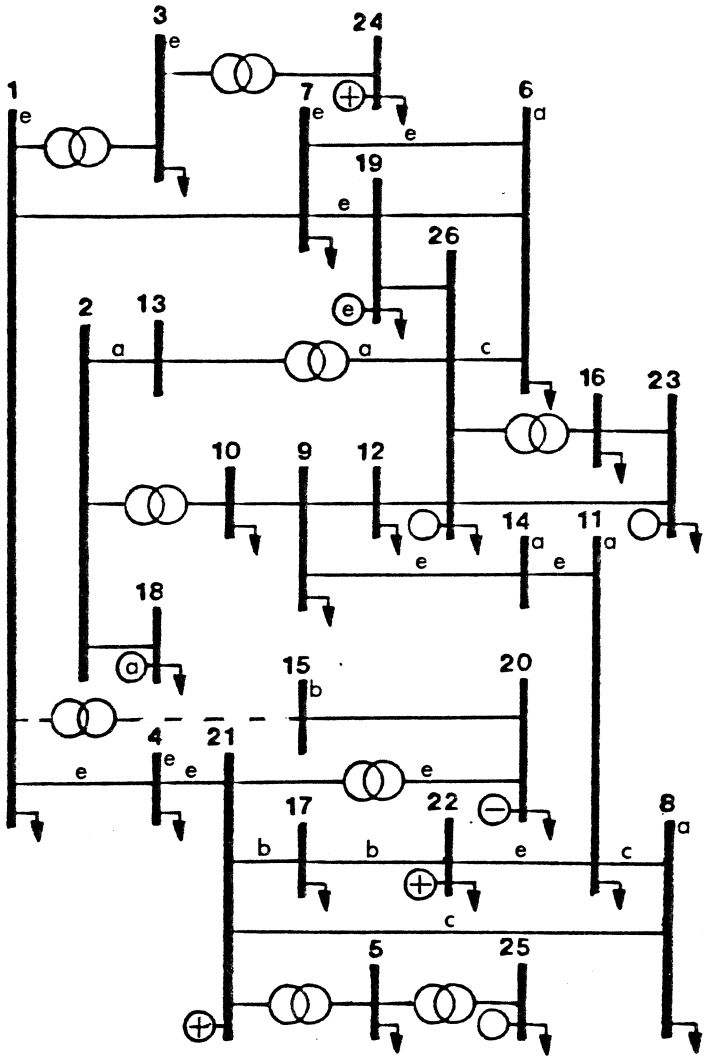

Fig. 24 The 26-bus power system.

TABLE XXVII

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (2,13) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell/P_\ell^B$
5	2,10	1.562	−0.112	2.748	0.245	1.187	76.0
6	9,10	−0.501	−0.322	−1.277	0.446	1.187	219.2
7	9,12	−0.195	0.058	0.429	−0.528	0.231	117.0
9	9,14	0.026	0.055	0.178	−0.125	0.152	598.2
10	11,14	−0.023	−0.165	−0.171	0.050	0.149	598.2
11	19,26	0.408	0.053	0.478	0.044	0.070	17.2
12	6,26	0.296	0.027	0.381	0.010	0.085	28.6
16	11,22	−0.024	0.044	0.042	−0.090	0.017	71.1
21	1,4	−0.050	0.174	−0.079	0.182	0.03	55.5
22	4,21	−0.533	0.019	−0.562	0.025	0.031	5.7
24	15,1	2.179	0.887	2.307	0.862	0.128	5.9
26	1,7	0.789	0.072	0.946	0.043	0.157	19.9
27	15,20	−2.179	0.887	−2.307	−0.864	0.135	6.0

Bus No.	Deviation $\lvert V_m^C\rvert - \lvert V_m^B\rvert$
2	−0.0282
9	−0.1179
10	−0.0320
11	−0.0285
12	−0.0556
14	−0.0777

TABLE XXVII

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (2,13) IS REMOVED (cont'd)

Bus No.	Base Case State Q_m^B	Post-Contingency State Q_m^C	Deviation ΔQ_m	Relative Deviation % $\Delta Q_m/Q_m^B$
18	−0.4004	0.0919	0.4923	~
19	0.1872	0.1977	0.0105	5.6
20	0.7795	0.7967	0.0172	2.2
21	−0.0294	−0.0038	0.0256	−87.1
22	−0.1775	−0.0732	0.1042	−58.7
24	−0.1645	−0.1572	0.0072	−4.4

Contingency analysis of the 26-bus power system

Index of the line removed: 25 terminal buses: 2,13

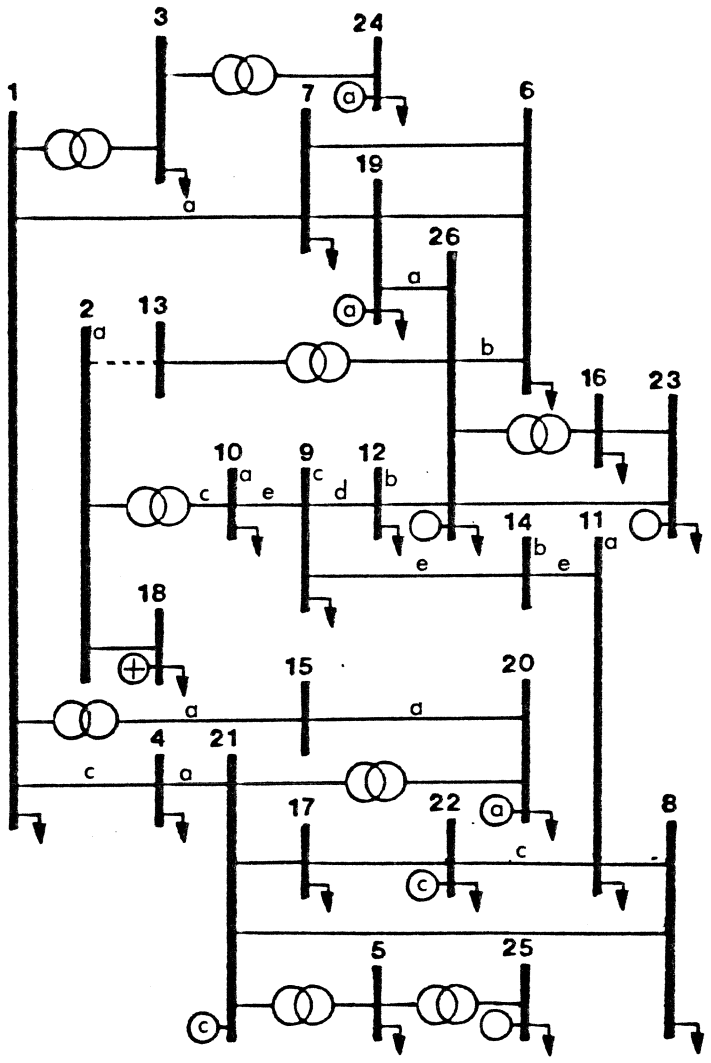

Fig. 25 The 26-bus power system.

TABLE XXVIII

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (1,7) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell / P_\ell^B$
1	13,26	1.177	0.418	1.431	0.380	0.254	21.6
9	9,14	0.026	0.055	−0.555	0.440	0.565	2216.6
10	11,14	−0.023	−0.165	0.633	−0.238	0.608	2433.7
14	7,19	−0.220	−0.083	−0.597	−0.146	0.411	182.8
15	6,7	0.113	−0.019	0.543	0.148	0.430	378.9
16	11,22	−0.024	0.044	−0.371	−0.091	0.357	1467.7
17	8,11	0.398	0.003	0.756	-0.008	0.358	89.8
18	17,22	0.597	0.137	0.973	0.033	0.377	63.1
19	8,21	−0.628	−0.063	−0.986	−0.052	0.417	63.1
20	17,21	−0.627	−0.147	−1.003	−0.043	0.411	63.4
21	1,4	0.050	0.174	0.100	0.161	0.048	90.5
23	20,21	0.559	0.374	1.229	0.391	0.670	119.7
25	2,13	1.188	−0.113	1.447	−0.155	0.259	21.8

Bus No.	Deviation $\lvert V_m^C \rvert - \lvert V_m^B \rvert$
7	−0.0922
8	−0.0654
9	−0.0171
11	−0.0590
14	−0.0587
17	−0.0237

TABLE XXVIII

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (1,7) IS REMOVED (cont'd)

Bus No.	Base Case State Q_m^B	Post-Contingency State Q_m^C	Deviation ΔQ_m	Relative Deviation % $\Delta Q_m/Q_m^B$
18	−0.4004	−0.3384	0.0620	−15.5
19	0.1872	0.7025	0.5152	275.2
20	0.7795	0.5941	−0.1854	−23.8
21	−0.0294	0.3168	0.3462	~
22	−0.1775	0.2399	0.4174	~
24	−0.1645	−0.2609	−0.0964	58.6

Contingency analysis of the 26-bus power system

Index of the line removed: 26 terminal buses: 1,7

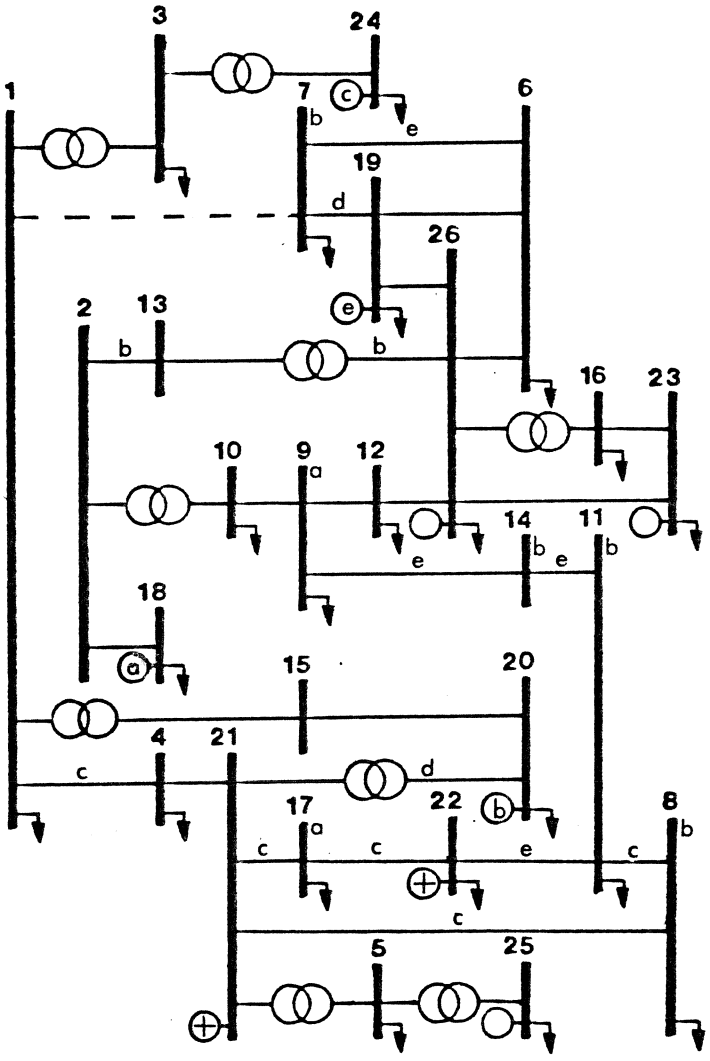

Fig. 26 The 26-bus power system.

TABLE XXIX

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (15,20) IS REMOVED

Overloaded Line No.	Terminal Buses	Base Case Flow		Post-Contingency Flow		Deviation	Relative Deviation %
		P_ℓ^B	Q_ℓ^B	P_ℓ^C	Q_ℓ^C	ΔP_ℓ	$\Delta P_\ell / P_\ell^B$
1	13,26	1.177	0.472	1.389	0.408	0.213	18.0
9	9,14	0.026	0.055	−0.459	0.338	0.457	1792.3
10	11,14	−0.023	−0.165	0.510	−0.251	0.458	1941.8
12	6,26	0.296	0.027	−0.536	0.095	0.255	86.1
14	7,19	−0.220	−0.083	−0.844	−0.271	0.745	331.4
15	6,7	0.113	−0.019	0.884	0.560	0.770	679.4
16	11,22	−0.024	0.044	−0.299	−0.036	0.281	1151.0
17	8,11	0.398	0.003	0.681	−0.019	0.293	73.6
18	17,22	0.597	0.137	0.892	0.058	0.286	49.6
19	8,21	−0.628	−0.063	−0.921	−0.040	0.338	51.1
20	17,21	−0.627	−0.147	−0.923	−0.067	0.321	49.6
21	1,4	−0.050	0.174	−0.920	1.050	1.111	2110.3
22	4,21	0.533	0.019	−1.648	0.064	1.574	286.0
23	20,21	0.559	0.374	2.800	0.483	2.241	400.7
25	2,13	1.188	−0.113	1.404	−0.139	0.217	18.3

TABLE XXIX

CONTINGENCY ANALYSIS OF THE 26-BUS POWER SYSTEM

LINE (15,20) IS REMOVED (cont'd)

Bus No.	Deviation $\|V_m^C\| - \|V_m^B\|$
1	−0.3262
3	−0.2640
4	−0.4013
6	−0.0336
7	−0.2649
8	−0.0457
11	−0.0385
14	−0.0350
15	−0.3010

Bus No.	Base Case State Q_m^B	Post-Contingency State Q_m^C	Deviation ΔQ_m	Relative Deviation % $\Delta Q_m / Q_m^B$
18	−0.4004	−0.3625	0.0379	−9.5
19	0.1872	1.7288	1.5416	824.0
20	0.7795	−0.4832	−1.262	~
21	−0.0294	2.2071	2.2365	~
22	−0.1775	0.1051	0.2826	~
24	−0.1645	1.6933	1.8578	~

Contingency analysis of the 26-bus power system

Index of the line removed: 27 terminal buses: 15,20

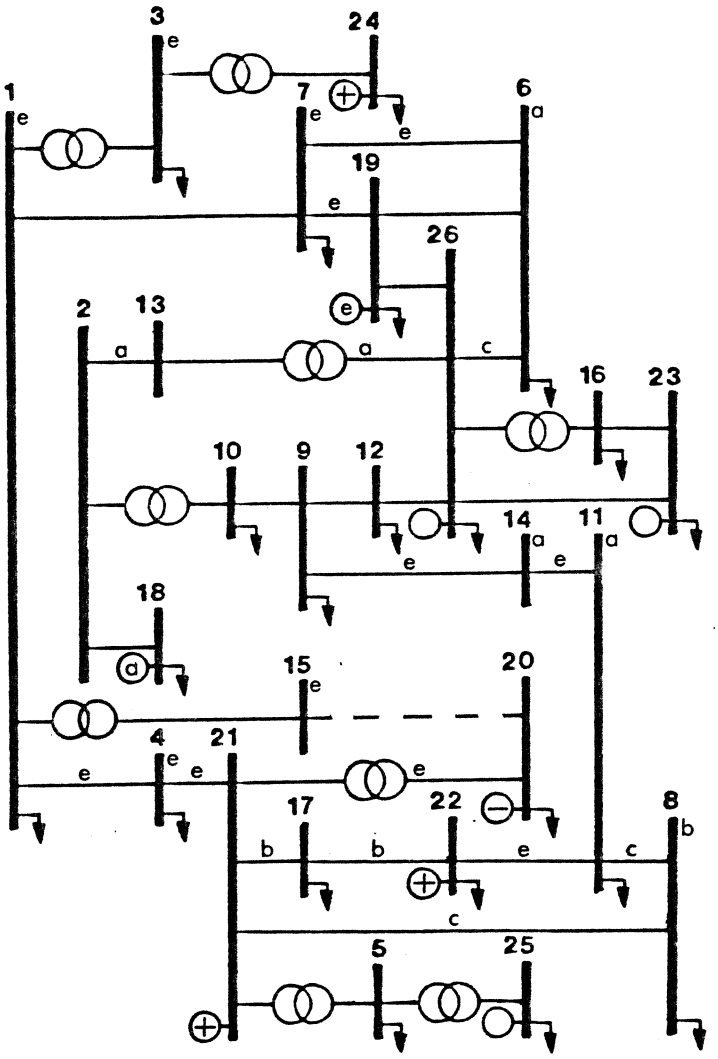

Fig. 27 The 26-bus power system.