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Contingency Selection and Ranking Approach for Power Systems

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Abstract: In this paper, an efficient technique based on ranking lines and generators outage contingencies according to their severity has been developed. The technique is based on a defined performance index (PI). The elements of this PI are obtained by calculating the generators and lines, outages distributing factors instead of repeating the load flow analysis. Results for the Saudi Electric Company (SEC) in the central operating area have been obtained with the proposed technique and are compared with those obtained by the conventional ac-dc load flow methods.

Keywords: Contingency ranking, Performance index, Generators and lines outages, Load flow

1. INTRODUCTION

The generation-transmission configuration is usually complicated and perhaps not possible to reduce it using conventional reduction methods. However, quantitative assessment of the adequacy of power systems can be performed using a contingency enumeration method [1-5]. A complete procedure for contingency analysis requires the assessment of all "credible" contingency cases. The computational burden that this procedure places on even the most advanced computer facilities has prompted the need for analytical techniques for the selection of meaningful contingency cases. This is dictated by various factors such as the size of the system, the severity of contingency events, their probabilities of occurrence, the criteria used, and the computation time required to evaluate such contingency cases. A basic and primary objective of e to determine which subset of contingencies taken from the set of all possible contingencies will cause system failure.

This paper presents a technique to contingency determination which is designated as contingency selection. The selection method can be used to examine both the quality and adequacy of power supply at major load centers for any type of contingency. The method is well suited for large power networks because of its efficiency, reduced computation time and storage requirements. contingency ranking and selection is to reduce the large number of possible cases and at the same time.

From the state of art in this area, it can be seen that most of the methods for ranking line outage contingencies from voltage stability point of view are either not sufficiently accurate or are computationally demanding. Hence, an effort is made in this paper to develop a computationally efficient procedure for calculation of RSI for contingency ranking. In order to overcome the limitations of the RSI approach, another voltage security index (VSI) is also proposed to supplement the former. Both the indices are evaluated in an efficient manner using a non-iterative compensation approach to simulate the effect of contingency. Only line outage contingencies are considered in this paper. Mathematical modeling for RSI and VSI calculation using compensation technique is given in Section 2.

2. CONTINGENCY ANALYSIS

Adequacy assessment which is evaluated by considering only transmission lines outages are obviously optimistic. This is due to the fact that the contribution to the adequacy indices from generator and combinations of generator and transmission line outages is very significant. These adequacy indices do not necessarily include the system dynamics or the ability of the system to respond to transient disturbances. They simply measure the ability of the system to adequately meet its requirements in a specified set of probabilistic states. In this study, the independent outages of generating units up to the second contingency level and the independent outages from the combination of transmission lines and

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generating units up to the second contingency level are also considered in addition to second level independent outages of transmission lines. The number of possible contingencies, however, increases tremendously when these outages are considered in the adequacy and security evaluation methods.

3. PERFORMANCE INDICES FOR CONTINGENCY SELECTION AND RANKING

The usual approach to contingency selection is to define a scalar function called the Performance Index (PI) which can be used to measure the severity of one or more components outages. The change in the PI resulting from outages can then be used to rank the contingencies in the order of their severity. The traditional approach [6-18] for contingency selection is to test sequentially all contingencies to evaluate system performance or reliability levels. This procedure simulates failures of one or more generating units and transmission lines and investigates their effects on line power flows. Equation (1) presents PI which measures system stress in terms of line overloads [6]

$$PI = \sum_{\ell=1}^{NL} \omega_\ell \left(\frac{P_\ell}{P_\ell^{lim}}\right)^{2n} \quad (1)$$

$where,$
$NL = number\ of\ lines$
$\omega_\ell = weighting\ factor\ of\ line\ \ell$
$P_\ell = active\ power\ flow\ in\ line\ \ell$
$P_\ell^{max} = maximum\ power\ limit\ of\ line\ \ell$
$n = an\ integer$

The performance index PI contains all line flows normalized by their limits. These normalized flows are raised to an even power (by setting $n = 1, 2, \ldots$); thus, the use of the absolute magnitude of the flows is avoided. Following a contingency, any line which is overloaded will make a normalized flow greater than unity, whereas a line whose flow is below its prescribed limit will make normalized flow less than unity. Squaring the normalized flows further increases the contributions due to overloads; but it decreases the contributions from non-overloaded lines. The ω can be regarded as tuning parameter and may be selected on the basis of experience with the system and on the relative importance put on various limit violations. The PI index has a relatively small value when all line flows are within their limits and a high value when there are line overloads. It therefore provides a good measure of the severity of line overloads for a given state in a power system.

Another new performance index called maximum flow performance index (PI_{MF}) has been developed to measure the system reliability level and can be defined as in equation

$$PI_{MF} = \sum_{\ell=1}^{NO} \omega_\ell \left(\frac{P_\ell^{max}}{P_\ell^{lim}}\right)^{2n} \quad P_\ell^{max} > P_\ell^{lim} \quad (2)$$

$where,$
$NO = number\ of\ overloaded\ lines$
$P_\ell^{lim} = max.possible\ power\ flow\ limit\ in\ line\ \ell$

4. LOAD FLOW METHODS FOR CONTINGENCY ANALYSIS

Load flow methods are usually performed in contingency analysis. There are several methods available for ac and dc load flow calculations for contingency evaluation of power systems [19-21]. The use of ac load flow method for contingency analysis is characterized by excellent accuracy but otherwise excessively demanding of computational time. Most possible contingencies do not create system problems and therefore it is not necessary to solve all possible contingencies by actual ac load flow analysis. An approximate method can be used to determine a list of contingencies which create system problems and a detailed investigation of these contingencies (to correct any masking effect) can be conducted in further studies. One of the most widely used approaches to reduce the computational time when conducting a series of contingency assessments is to rank the outage contingencies using fast techniques and then investigate these ranked contingencies using ac load flow method. As contingency analysis is only a tool for detecting possible overloading cases, more efficient and speedy methods are paramount considerations. Therefore, using dc rather than ac will be considered for its saving in computational time and acceptable accuracy.

5. NETWORK SENSITIVITY FACTORS

As mentioned before, to calculate the variation in the PI for certain contingency, the new flows in the lines are required. In order to reduce the load flow computation time, the flows are obtained using the network sensitivity factors instead of repeating the dc load flow. These factors are defined as:

a) Generation outage distribution factor (GODF).
b) Line outage distribution factor (LODF)

The GODF represents the change in flow of line l for unit change in generation at bus i and has the following scalar definition as in Equation [3]:

$$GODF_{\ell i} = \Delta P_\ell / \Delta P_i \quad (3)$$

$where,$
$\Delta P_\ell = change\ in\ active\ power\ flow\ in\ line\ \ell$
$\Delta P_i = change\ in\ active\ power\ generated\ at\ bus\ i$

The GODF is a linear estimation of the variation in the flow with a change in generation at a bus. Therefore, the effect of simultaneous changes on several generation buses can be calculated using superposition techniques [22]. The LODF is used in a similar manner, only they apply for testing overloads when a transmission line is lost due to an outage, and it represents the change in active power flow through line ℓ after the loss of line k and has the following definition as in Equation (4):

$$LODF_{\ell k} = \Delta P_\ell / P_k \tag{4}$$

$where,$
$\Delta P_\ell = change\ in\ active\ power\ flow\ in\ line\ \ell$
$in\ case\ of\ an\ outage\ in\ line\ k.$
$P_k = \ active\ power\ in\ line\ k\ before\ the\ outage.$

The LODF is also a linear estimation of the variation in active power flow through line ℓ after the loss of line k. Therefore, the effect of simultaneous changes on several lines can be calculated using superposition techniques [22]. By recalculating the GODF and LODF, a very fast procedure can be set up to obtain the new flows in the lines. Using Eq. (4), it can be found that

$$\Delta P_\ell = GODF_{\ell i} \cdot \Delta P_i \tag{5}$$

For a complete generation failure at bus i,

$$\Delta P_i = P_i$$

$$\Delta P_\ell = P_{\ell_{new}} - P_{\ell_{base}}$$

$where,$
$P_{\ell_{new}} = new\ calculated\ flow\ when$
$an\ outage\ occurs.$
$P_{\ell_{base}} = \ the\ base\ case\ flow\ in\ the\ line.$

The new flow in each line ℓ after a complete outage at generator i can be calculated by using the following equation

$$P_{\ell_{new}} = P_{\ell_{base}} + GODF_{\ell i} \cdot P_{\ell_{base}} \tag{6}$$

Also, the new flow in line l after any line contingency is given by

$$P_{\ell_{new}} = P_{\ell_{base}} + LODF_{\ell k} \cdot P_{k_{base}} \tag{7}$$

$where,$
$P_{k_{base}} = the\ base\ case\ flow\ at\ line\ k\ (the\ contingent\ line).$

In general, for multiple contingencies, superposition can be applied to calculate the new flow in any line when one or more generators are on outage as follows:

$$P_{\ell_{new}} = P_{\ell_{base}} + \sum_k GODF_{\ell i} \cdot P_{i_{base}} \tag{8}$$

Also, for one or more lines are on outage, the new flow in each line can be calculated as follows

$$P_{\ell_{new}} = P_{\ell_{base}} + \sum_k LODF_{\ell k} \cdot P_{k_{base}} \tag{9}$$

6. THE PROPOSED CONTINGENCY RANKING TECHNIQUES

A fast technique has been developed for selection and ranking of all credible contingency cases for system under study. This technique (steps are shown in Figure 1) is mainly based on performing a base case of ac load flow. The results of the base case are used to calculate the *GODF* and the *LODF* coefficients. Based upon the obtained results, the proposed technique can be outlined in the following main steps:

Step 1: With the help of the base case load flow calculations and for a given level of demand, the coefficients $GODF_{\ell i}$ and $LDOF_{\ell k}$ are determined for each line l and for each single contingency caused either by the loss of a unit i or by the loss of a line k (in fact, the coefficients $LDOF_{\ell k}$ are calculated only for the lines k where outages will cause overloads in the dc approximation).

Step 2: Using the coefficients calculated in step 1, it is then possible to calculate the active power flows through the lines when demand varies and in several cases of outages caused by the loss of one or more generation units or transmission lines. In the case of loss of two lines m and n, for instance, the active power flow through line ℓ will be written as (superposition technique):

$$P_\ell = P_\ell^0 + LODF_{\ell m} P_{12-21_{new}} \cdot P_m^0 + LODF_{\ell n} \cdot P_n^0 \tag{10}$$

where P_ℓ^0, P_m^0, P_n^0 are respectively, the active power flows through the lines ℓ, m, and n, when all the system components are available (base case). The power flows P_ℓ^0 are previously calculated with the help of an ac load-flow calculation. For each contingency considered, it is then possible to calculate the value of the performance index (PI) and to classify the contingencies in decreasing PI order.

The proposed technique, described above, consists of three major parts. The first part uses an ac load flow model to obtain the base load flow ($ACONTIN$). The second part constructs a dc load flow model ($DCONTIN$) and performs a screening to the network to obtain the new flow using both the $LODF$ and the $GODF$ flow due to the outage of a line and/or a generator. This is followed by ranking the contingencies according to the change in the performance index. The contingency ranking list is then tested using an ac load flow method $(ACONTIN)$. The process is terminated when the ac load flow indicates no masking of the ranked contingencies. The severe contingencies are indicated at the last step of the process.

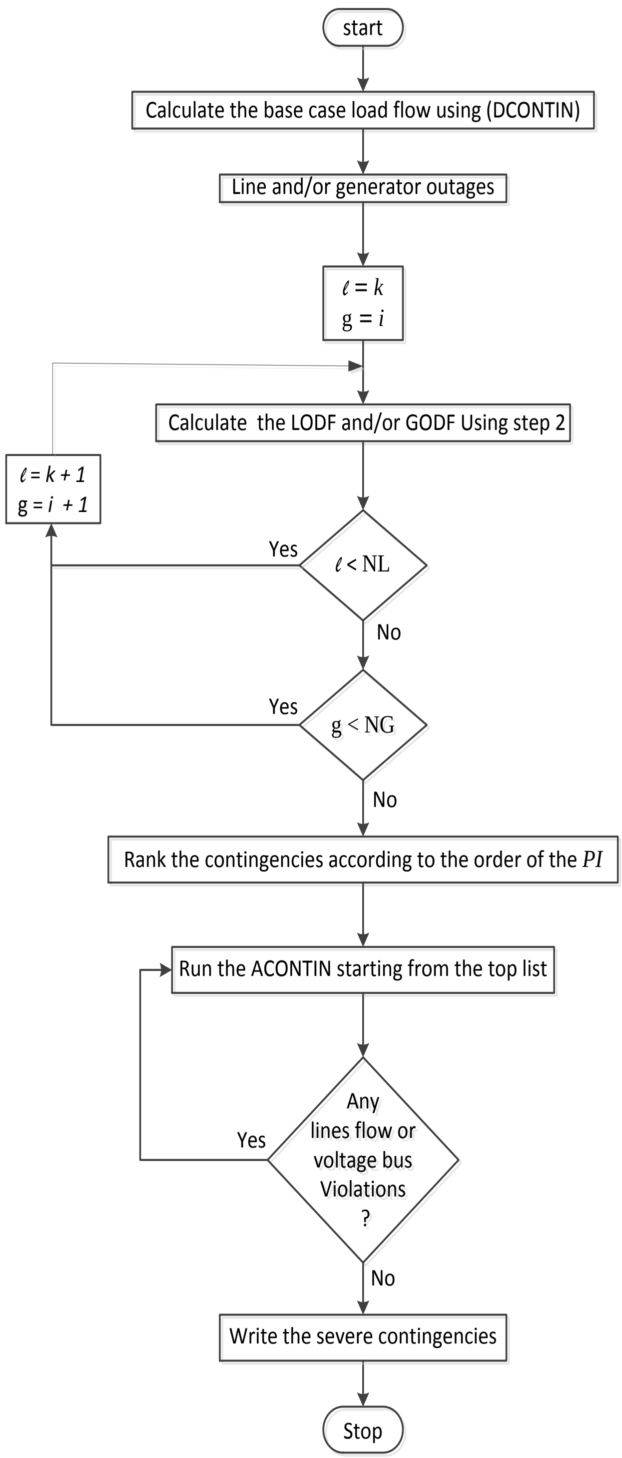

Figure 1. Schematic diagram of SEC (COA) system

7. STUDIED SYSTEM

Adequacy assessment has been conducted in this study for the Saudi Electric Company (*SEC*) power system of the central region. The single line diagram of *SEC* system is shown in Figure (2). The data of this system is shown in Appendix A (Tables A1 & A2). In this study, it has been assumed that contingencies are ranked from the set which consists of independent line outages up to the double-contingency level. Contingencies beyond the double-contingency level were not considered for ranking purposes (see Ref. [18]).

7.1 Calculating line flows for single contingency event

The results shown in Table (1) have been obtained by using both ac load flow and dc load flow with an increase of 15% in peak load of 1991. Using these data, new flows

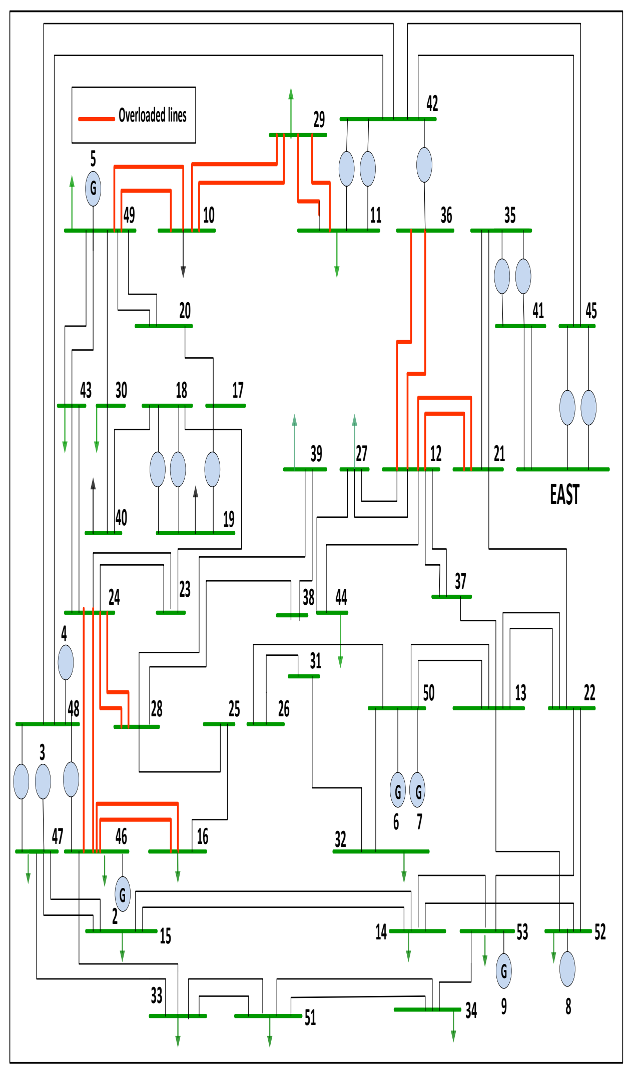

Figure. 2 Flowchart of the proposed algorithm

for the lines which will be overloaded under any single line outage can be evaluated, for example,

$$P_{12-21_{new}} = P_{12-21_{base}} + LODF_{42-45,12-21} \cdot P_{42-45_{base}}$$

$$(line\ 42-45\ is\ on\ outage)$$

$$= -162 + [(0.713) \cdot (-440)] = -475\ MW$$

Also, line flows under generation outage can be calculated by using Equation (6), yields

$$P_{11-42_{new}} = P_{11-42_{base}} + GODF_{11-42,2} \cdot P_{2_{base}}$$

$$(generator\ 2\ is\ on\ outage)$$

$$= -258 + [(-0.317) \cdot (300)] = -353\ MW$$

7.2 Calculating line flow for multi-contingency case

Using the data presented in Table (1), and following the same steps mentioned in the preceding section, the new flows of lines that will be overloaded under more than one line being on outages can be evaluated as:

$$P_{36-42_{new}} = P_{36-42_{base}} + LODF_{20-49,36-42} \cdot P_{20-49_{base}}$$

$$+LODF_{21-35,36-42} \cdot P_{21-35_{base}}$$

$$(lines\ 20-49\ and\ 21-35\ are\ on\ outages)$$

$$= -135 + [(0.01) \cdot (-0.317) + (0.66) \cdot (-278.1)]$$

$$= -319\ MW$$

Table (2) shows the flows in the above calculated lines under various contingency events using ac load flow, dc load flow and the proposed technique. It is noticed from the table that in case of generator contingency, only generator no. 5 will cause an overload at line 11-29 and all the other generators will only cause heavy loading on lines.

7.3 Generators and lines contingency cases

In case of lines contingencies, ranking for overload performance indices (with n=1) have been performed using ac and dc load flows methods. Table (3) lists the ranking for the single contingencies overloaded lines under each contingency case by using the proposed method. The overloaded lines for each contingency are shown in the table. In Table (4), the ranking has been done by repeating the conventional dc load flow method. Comparing the two tables, it can be noticed that line 1-45 is ranked as the first contingency, using the proposed method, rather than line 42-45, which is ranked first using the dc load flow method. In the dc load flow method, line 42-45 contributes the greatest amount of power imported from SEC east to SEC central. Also, it is noticed that line 1-41, which is key to importing power from SEC east was 13th in the priority list using the proposed method, while it was 16th in the priority list of the dc load flow method. A comparison between the results is exhibited in Table (2) and it clearly show that the proposed load flow method yields acceptable results. So, performing the proposed method to the SEC system, Also show the overloaded lines in SEC network under the severe single line or generator contingency. Tables 3 and 4 show that beyond the tenth ranked contingency, there is no over loaded lines (since PI<1). Consequently, the first ten contingencies are those which require detailed ac load flow analysis to correct any masking effect. It may be noticed that there are some differences in results obtained in the proposed method and the dc approximation. These results are however satisfactory since the maximum flow difference with respect to the exact solution is at the most 4.36%, and moreover, they are obtained much more rapidly than in the dc approximation.

Another significant contribution of this work to contingency selection and ranking approaches can be shown by using the maximum flow performance index (PI_{MF}) expressed by Eq. (2). An increment of the future peak loads has been suggested and the PI_{MF} is evaluated as seen in Table (5). From the table, it is clear that the maximum flow performance index and the number of the over loaded lines increase with load increase. Since the increase in the number of over loaded lines becomes smaller for large load increments, so, it does not give a convincing indication about the system state; on the other hand, the maximum flow performance index (PI_{MF}) will increase with load increase and hence can give good measure for system state.

8. CONCLUSIONS

In this work, an efficient and reliable technique has been proposed for the contingency ranking of generator and line outages causing over loading problems. The developed method proved its practicality and capability when applied to a large power system such as the SEC central system. Also, proved to be a competitive with the exact method (the ac load flow method) regarding its efficiency and precision. The method then could be used in applications such as composite power system reliability and security evaluation being able to handle both generation and transmission lines in the analysis.

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Appendix A - SEC-central region system data

Table A1- power plants data

bus no.	no. of units	voltage (kV)	max pwr (MW)	max reac pwr (Mvar lag)	max reac pwr (Mvar lead)
1	SEC East swing bus				
2	10	13.8	300	260	-260
3	10	13.8	300	260	-260
4	2	13.8	175	200	-200
5	12	13.8	500	500	-260
6	4	13.8	91	61	-8.4
7	7	13.8	216	300	-200
8	8	13.8	300	500	-112
9	8	13.8	300	500	-500

Table A2- Busses load data

bus no.	voltage (kV)	pwr (MW)	reac pwr (Mvar)	bus No.	voltage (kV)	pwr (MW)	reac pwr (Mvar)
10	132	164.8	79.8	32	132	20.9	10.0
11	132	91.4	56.0	33	132	31.0	31.0
12	132	179.0	86.6	34	132	7.6	3.7
14	132	102.8	49.8	35	132	14.3	2.2
15	132	108.6	52.6	37	132	4.8	2.3
16	132	171.4	83.0	38	132	12.4	6.0
19	132	175.2	84.5	39	132	21.9	10.6
20	132	39.0	18.9	40	132	13.3	6.4
21	132	137.0	66.3	43	132	4.8	2.3
22	132	49.5	00.0	44	132	10.5	5.0
23	132	43.8	21.2	46	132	51.3	0.0
25	132	153.3	47.2	47	132	20.0	0.0
27	132	160.9	77.9	49	132	74.3	17.0
28	132	160.9	77.9	50	132	143.8	69.6
29	132	20.0	9.7	51	132	86.0	73.0
30	132	3.8	1.8	52	132	107.6	9.7
31	132	136.2	65.9	53	132	30.5	0.0

Table (2) Comparison of line flows of three different methods

Lines i-k	Gen. or line on outage	ac lf MW	dc lf MW	Error (%)	Developed (MW)	Error (%)
12–21	42–45	-492	-487	1.13	-476	3.38
21–35	1–41	-746	-737	1.28	-714	4.36
11–42	2	-356	-354	0.64	-353	0.93
11–29	5 20–49	398	396	0.52	396	0.56
36–42	21–45 11–29	-322	-318	1.04	-319	0.68
42–45	16–25	-459	-454	1.10	-454	1.07

Table (1) Load flows of lines in MW

Lines		ac LF			lines		ac LF		
i	k	from i	from k	dc LF	i	k	from i	from k	dc LF
1	41	284	-287	294	18	40	-97	97	-99
1	45	437	-337	459	20	49	-119	119	-121
2	46	300	-300	300	21	22	-45	45	-42
3	47	300	-300	-300	21	35	-274	271	-278
4	48	175	-175	175	22	52	-52	52	-51
5	49	500	-500	500	22	53	-49	49	-48
6	50	91	-91	91	23	24	-78	78	-76
7	50	216	-216	216	24	28	275	-275	275
8	52	300	-300	300	24	43	-117	117	-118
9	53	300	-300	300	24	46	-235	234	-233
10	29	-131	131	-138	25	28	-52	52	-51
10	49	-58	58	-51	26	31	82	-82	81
11	29	154	-145	161	26	50	-81	81	-81
11	42	-258	258	-267	27	44	-37	37	38
12	21	-162	162	-163	28	38	17	-17	17
12	27	147	-147	147	28	39	23	-23	23
12	36	-133	132	-135	30	40	112	-112	115
12	37	-107	107	-105	30	49	-116	116	-119
12	44	49	-49	50	31	32	-75	75	-76
13	22	1	-1	0	32	50	98	-98	100
13	37	112	-113	111	33	46	37	-37	28
13	50	37	-37	39	33	47	-76	76	-72
13	52	-77	77	-77	33	51	4	-4	8
13	53	-72	72	-73	34	51	44	-44	44
14	15	-27	27	-26	34	53	-52	52	-53
14	52	-48	48	-49	35	41	-287	287	-249
14	53	-43	43	-44	36	42	-132	132	-135
15	47	-152	151	-150	38	39	2	-2	2
16	25	124	-125	126	42	45	-440	437	-459
16	46	-321	320	-323	42	48	51	-51	57
17	19	76	-76	76	43	49	-122	122	-123
17	20	-75	75	-76	46	48	-276	276	-287
18	19	126	-126	125	47	48	51	-51	55
18	23	-28	28	-26	51	53	-51	50	-47

Table (3): Lines contingencies ranking based on their severity measured by the size of line PI (proposed ac load flow method to correct masking effect)

Cont.	Contingent Lines (i-k)	PI	Over-loaded Lines (i-k)			No. of Over-loaded Lines
1	1–45	4.46	12–21	21–35		2
2	42–45	4.44	12–21	21–35		2
3	16–46	3.95	24–28	24–46	25–28	3
4	11–42	2.70	10–49	24–46	45–48	3
5	24–28	2.63	18–25	16–46		2
6	28–19	2.62	17–19	17–20		2
7	24–46	1.63	16–25	16–45		2
8	11–29	1.42	24–46	46–48		2
9	46–48	1.37	10–29	11–29		2
10	10–29	1.29	24–46	46–48		2
11	20–49	0.76				0
12	16–25	0.69				0
13	1–41	0.60				0
14	35–41	0.60				0
15	36–42	0.58				0
16	12–36	0.58				0
17	21–35	0.56				0

Table (4). Lines contingencies ranking based on their severity measured by the size of line F (load flow method)

Cont.	Contingent Lines (i-k)	PI	Over-loaded Lines (i-k)			No. of Over-loaded Lines
1	42–45	4.33	12–21	21–35		2
2	1–45	4.33	12–21	21–35		2
3	16–46	3.95	24–28	24–46	25–28	3
4	11–42	2.70	10–49	24–46	46–48	3
5	18–19	2.62	17–19	17–20		2
6	24–28	2.61	16–25	16–46		2
7	24–46	1.59	16–25	16–46		2
8	11–29	1.44	24–46	46–48		2
9	46–48	1.41	10–29	11–29		2
10	10–29	1.31	24–46	46–48		2
11	20–49	0.76				0
12	16–25	0.68				0
13	36–42	0.62				0
14	12–36	0.62				0
15	35–41	0.60				0
16	1–41	0.60				0
17	21–35	0.56				0

Table (5). Effects of load increment on the number of over loaded lines and the PI_{MF}

Load increment (%)	No. of over loaded lines	PI_{MF}
0	8	7.693
5	10	10.301
10	14	14.490
20	16	18.420
30	22	34.004
40	33	51.160
50	36	67.230
60	39	85.880
70	41	106.550