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VOLTAGE STABILITY STUDY FOR 220 Kv. MID DELTA ZONE NETWORK

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دراسه استقرار الجهد لشبكه وسط الدلتا الموحده ٢٢٠ ك.ف

تتعرض الشبكات الكهربائيه لأعطال متعدده تؤثر على درجه الموثوقيه والعول لإستمرار تدفق التيار. وحيث أن تعرض الشبكات الى إضمحلال الجهد أصبح الآن حدثا يودى فى الغالب الى الانطفاء الكلى للشبكات الموحده بصوره أسرع من اضمحلال ترددها فلذا وجب دراسه العوامل التى تودى الى إضمحلال جهد الشبكات الكهربيه فى حالات التشغيل المختلفه..

البحث يدرس طريقه لتحديد العوامل المؤثره على جهد الشبكه الموحده(٢٢٠ ك.ف) لمنطقه وسط الدلتا بجمهوريه مصر العربيه وذلك بإعداد البرامج الازمه لتحديد القضبان العموميه بالمحطات الرئيسيه المعرضه لاضمحلال الجهد واستنباط المعادلات الرياضيه الخاصه بذلك. يمكّن هذا البرنامج القائمين على تصميم وتشغيل الشبكات من تحديد أماكن ضعف الجهد بالمحطات فى ظروف التشغيل المختلفه لإمكان تجنب عدم إستقرار الشبكه الناتج عن إضمحلال الجهد ووضع السياسات التشغيليه المأمونه لتشغيل الشبكات.

ABSTRACT

With the increased loading and exploitation of the power transmission system, the problem of voltage stability and voltage collapse attracts more and more attention. A voltage collapse can take place in systems or subsystems, and can appear quite abruptly. Continuous monitoring of the system state is required for the detection of vulnerable system states due to voltage instability. This paper determines the weak areas of Mid Delta zone of the Egyptian power system using the concept of Glavitch's indicator L for estimating the system state subject to the various causes of voltage stability problem.

1. INTRODUCTION

The voltage collapse problem may be simply explained by the inability of the power system to supply the reactive power required or by an excessive absorption of reactive power by the system itself. A voltage collapse can take place in a system or a subsystem due to the following causes [4] :-

1) sudden increase in load
2) sudden loss of generation
3) loss of transmission lines
4) loss of voltage control.

There are static and dynamic aspects involved in voltage stability [2,4]. Static considerations relate voltage instability to the problems encountered when the system reaches a loading level beyond which a load flow solution no longer exists. While dynamic considerations relate to the modeling of real system elements (such as automatic generation control of the unit, exciter, tap changer of transformers, loads ..etc.).

The predication of voltage collapse under various contingencies, help to identify the critical location in the system where countermeasures can be applied. Due to the nature of this voltage problem which can appear quite abruptly, the methods which monitor the system state to predict the voltage instability must be fast and accurate. The aim of any method used for evaluating the voltage stability problem are in two points [2] :-

1) determine the critical loading condition (stability limit).
2) devise a set of indicators, to check how far a given operating condition is from the stability limit.

This paper presents the method devised to compute the indicator L and the implementation of this method on the Mid Delta Zone of the Egyptian power system to identify its weak area at increased load and transmission line outage contingencies.

2. MATHEMATICAL MODEL

This method is aimed for the detection of voltage instabilities using an indicator L. This indicator uses information of normal load flow (static consideration).

The technique followed in this method is characterized by the development of an analytical tool to assess the voltage stability of a two bus model. The definition of the bus indicators for such model is extended to evaluate the voltage stability of a multi-bus system [1].

2.1 Two bus system model

Figure(1) shows a two bus model, node 1 is a generator node, while node 2 is assumed to supply the load whose voltage behavior is of interest. The node voltage matrix equation for n-node grid can be written as :-

$$[I] = [Y]\,[V] \qquad (1)$$

where : -

[I] is node current vector
[Y] is admittance bus matrix
[V] is node voltage vector

The properties of node 2 can be described in terms of the admittance matrix of the system as :-

$$\overline{Y}_{22}.\overline{V}_2+\overline{Y}_{21}.\overline{V}_1=\overline{I}_2=\frac{\overline{S}_2^{*}}{\overline{V}_2^{*}} \qquad (2)$$

where :

$\overline{S}_2$ is the load complex power = $\overline{V}_2.\overline{I}_2^{*}$

so, equation (2) can be written as :

$$1+\frac{\bar{V}_0}{\bar{V}_2}=\frac{\vec{S}_2}{\bar{Y}_{22}.V^2_2}$$

where :

$$\bar{V}_0=\frac{\bar{Y}_{21}}{\bar{Y}_{22}}.\bar{V}_1$$

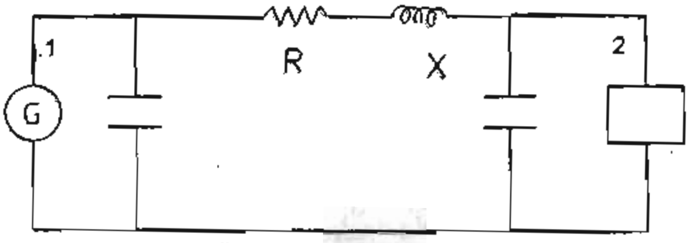

Fig.(1) The two buses model

This relation can be used to define an indicator (L) as follow :-

$$L=\left|1+\frac{\bar{V}_0}{\bar{V}_2}\right|=\left|\frac{\vec{S}_2}{\bar{Y}_{22}.V^2_2}\right| \tag{3}$$

Since at no-load condition $\bar{S}_2$ equal zero, and at stability limit V_2 is given by :-

$$V^2_2=\frac{S^2_2}{Y_{22}} \tag{4}$$

Then from equation (3) this indicator equals zero for no load condition, and equal one at stability limit condition.

2.2 Generalization for n nodes

In multi-bus system, there are two categories of nodes to be distinguished in order to evaluate the indicator (L). One is the load node which is characterized by the behavior of the PQ-node and the other comprises the generator nodes which may be given by PV-nodes or by a slack node.
Assuming a linear transmission system, a hybrid matrix (H) can be used to represent the multi-node system as follows [1] :-

$$\begin{vmatrix}V_L\\ I_G\end{vmatrix}=|H|\begin{vmatrix}I_L\\ V_G\end{vmatrix}=\begin{vmatrix}Z_{LL} & F_{LG}\\ K_{GL} & Y_{GG}\end{vmatrix}\begin{vmatrix}I_L\\ V_G\end{vmatrix} \tag{5}$$

where :-

V_L, I_L	Vector of voltage and current at load nodes.
V_G, I_G	Vector of voltage and current at generator nodes
Z_{LL}, F_{LG} K_{GL}, Y_{GG}	Sub matrices of the H-matrix

The H-matrix is generated from the Y-matrix by a partial inversion. For any PQ-node j, ($j \in N_L$) the equation of V_j can be written as :-

$$\bar{V}_j=\sum_{i\in\alpha_L}\bar{Z}_{ji}.\bar{I}_i+\sum_{i\in\alpha_G}\bar{F}_{ji}.\bar{V}_i \tag{6}$$

where :-

N_L, N_G the set of load and generator nodes respectively.

Multiplying eq., (6) by $\overline{V}_j^*$ then,

$$V_j^2 + \overline{V}_{0j} \cdot \overline{V}_j^* = \frac{\overline{S}_j^{+*}}{\overline{Y}_{jj}^+}$$

where :-

$$\overline{V}_{0j} = -\sum_{i \in N_G} \overline{F}_{ji} \cdot \overline{V}_i$$

$$\overline{Y}_{jj}^+ = \frac{1}{\overline{Z}_{jj}}$$

$$\overline{S}_j^+ = \overline{S}_j + \overline{S}_j^{corr}$$

$\overline{S}_j$ = the power of the node j

$\overline{S}_j^{corr}$ = the effect loads of the other nodes on the j-node

$$\overline{S}_j^{corr} = \left(\sum_{i \neq j}^{i \in N_L} \frac{\overline{Z}_{ji}^*}{\overline{Z}_{jj}^*} \cdot \frac{\overline{S}_i}{\overline{V}_i} \right) \cdot \overline{V}_j$$

A local indicator L for each node j can be given using equation (3) as :

$$L_j = \left| 1 + \frac{\overline{V}_{0j}}{\overline{V}_j} \right| = \left| 1 - \frac{\sum_{i \in N_G} \overline{F}_{ji} \cdot \overline{V}_i}{\overline{V}_j} \right| \qquad (8)$$

For stable situation the condition $L_j < 1$ must not be violated for any of nodes j. Hence a global indicator L describing the stability of the complete subsystem is given by :-

$$L = \mathrm{MAX}_{j \in N_L} \left| 1 - \frac{\sum_{i \in N_G} \overline{F}_{ji} \cdot \overline{V}_i}{\overline{V}_j} \right| \qquad (9)$$

Thus the important outcome of the presented theory is L < 1 for voltage stability to be guaranteed. This indicator L is a quantitative measure for the estimation of the distance of the actual state of the system from the stability limit. The actual L_j permits the determination of those nodes from which a collapse may originate.

3. THE DEVELOPED PROGRAM

The program is written in FORTRAN 77 using the stated algorithm to evaluate the system voltage stability conditions. The developed program has the following steps :-

1) Load flow by Newton Raphson technique for solving the following cases [5,6] :-
   i) The system configuration and load recorded on 25 January 1994 for the maximum day, maximum night and minimum day periods are taken as basic system conditions.
   ii) Contingency cases such as :
      a) change in certain load bus
      b) line outage
2) After solving the load flow problem, procedure of calculating the voltage stability indices begins as follows :-
   i) rearrange the bus numbers beginning with load buses followed by generation buses.
   ii) modify the Y-matrix to coincide with the new arrangement.
   iii) calculate the H-matrix from the modified Y-matrix by partial inversion method .
   iv) calculate the individual bus indicators L_j and then the global system indicator L.
   v) based on the individual bus indicators, weak node in the network is identified as follows :-
      a) the experience has shown that a threshold of 0.20 can be considered as the critical value for the indicator L [4,7].
      b) if the computed indicator of any load node exceeds this critical value, then this node is considered as a weak node .

4. A SIMULATION STUDY

Initially, the developed program has been tested using the two bus model, given in Fig (1). Also the definition of the bus indicators of this model is extended to evaluate the voltage stability of the Mid Delta Zone 220 KV network as a multi-bus system. The Mid Delta network consists of 15-220 KV buses of which 5-generating buses and 34-overhead transmission lines as shown in Fig.(2). The data of the Mid Delta Zone network is given in reference [3] . The network configuration and load recorded on 25 January 1994 during the periods of maximum evening, maximum day and minimum day are taken as base case for the study. Tables (1-a,b & c) give the network load and generation data at these periods.

5. TEST RESULTS OF TWO-BUS MODEL

The load at node 2 has been increased in equal steps up to the stability limit value of the node, and the corresponding indicator L of each load is found. Figure (3) illustrates bus 2 voltage and its indicator L at various load conditions. The bus 2 load is taken as p.u. of the stability limit load value, with constant power factor (0.8 lag). The figure shows that the indicator L equals one at stability limit load of bus (2) and equals zero for no load conditions, This result agrees with the theoretical results in literature [4]. Also, it can be seen that the value of the indicator varies between zero and one within which the voltage stability degree of the system can be measured. Fig (4) shows the relationship between the active and reactive power of node 2 for a set of L values. The value of L varies from 0.2 to 1.0 with a step = 0.2 . It can be seen that for each value of L the P-Q characteristics is in elliptic form. The two diagonals of the elliptic are being increased with increasing the indicator value, this expresses the degree of voltage instability.

6. TEST RESULTS OF 220 Kv. MID DELTA ZONE NETWORK

The developed program is used to identify the weak areas in the 220 kv Mid Delta zone network from voltage stability point of view .The following types of contingencies have been studied for this network :-

i) The load at each P-Q bus is changed in steps up to the steady state stability limit value of this bus.
ii) The effect of the outage of all double lines one at a time.
iii) The effect of the outage of all single lines one at a time.

The state of the network is monitored and weak areas in the network for each type of contingencies are identified.

6.1 EFFECT OF INCREASING THE LOAD ON A BUS

In this case the maximum evening load on 25/1/1994 is selected as a base load. Table (1.a) illustrates the system data of this period. The effect of increasing the load at each bus on the voltage stability has been investigated. In this case the load of a single bus is increased in steps to its stability load limit without changing its power factor and keeping the loads of other buses constant. Thus, the voltage indicator of all buses is obtained for each load change of the bus under consideration.
From the simulation study numerous results are obtained and summarized in table (2). All P-Q buses had been tested , but only three nodes are selected as an example for illustrating the results. These tested nodes are 4, 7 and 14.

Figure (5-a) shows the voltage and voltage indicator profile of node 4 with increasing its load. The stability voltage indicator of node 4 reaches the critical value at a load 545 MW and the voltage is equal to 0.93 pu.
Figure (5-b) illustrates the trend of voltage indicators of the nodes which are not having a significant effect by increasing the load of node 4 . It can be seen from the figure that nodes 8,14,15 and 7 are reaching in order the critical voltage indicator limit at a large load value of node 4. The values of these loads are 800,820,925 and 1160 MW respectively as given in Table(2). Also, figure (5-b) shows that nodes 3 and 2 are not reaching the critical limit of the voltage indicator, although the load of node 4 reaches the stability limit.

From figure (5-c) and table (2) it can be seen that, nodes 12,11,13,4,5,9 and 10 are forming a group of nodes, reaching the critical limit value of voltage indicator, at lower load value of node 4, compared to the group stated in figure (5-b). These nodes reach the critical limit when the load at node 4 is equal to 390,400,435,485,545,550,560 and 580 MW respectively. Thus, nodes 12,11,13 and 6 reach the critical limit of voltage indicator before node 4 itself. This means that, increasing of load at node 4 has a stronger effect on substations 12,11,13 and 6 in order. These nodes forming the weakest voltage area from node 4 load point of view.
The study shows that, to maintain a stable voltage within the network, the load of node 4 should be kept less than 390 MW instead of 545 MW.
Figure (6-a) and (6-b) illustrate the voltage indicator profile with increasing the load of node 7. From figure (6) and table (2) the following can be concluded :-

- The voltage indicator of node 7 reaches the critical limit at 440 MW.
- Nodes 13 and 5 voltage indicator reach the critical limit at load 620 and 760 MW respectively.
- The voltage indicator of nodes 4,14,15,3 and 2 do not reach the limit value as a consequence of increasing the load of node 7 to its stability limit. These nodes form the stable voltage area from node 7 load point of view as shown in Figure (6-a).
- Figure (6-b) shows that the affected nodes as a consequence of increasing the load of node 7 are 8,7,11,9,12,10 and 6 in descended order. Table (2) shows that the voltage indicator of node 8 reaches the critical limit before node 7. As a result, the operator should limit the load of node 7 at a value less than 390 MW instead 440 MW, to ensure the voltage stability of the network.

The trajectories of stability voltage indicator of all buses at different load of substation 14 are shown in figures (7-a) and (7-b). The voltage indicator of node 14 reaches the critical limit value at load 420 MW as given in table (2). In figure (7-b) the voltage indicator of nodes 7,8,3 and 2 are not affected by increasing the load of node 14 to the stability limit load value. While nodes 12,11,6,5,9,10 and 4 are reaching the

critical limit value of the voltage indicator at load 693,720,785,880,890 and 1000 MW as stated in table (2). These nodes can be considered as stable voltage nodes with respect to node 14 load.
Figure (7-b) shows the voltage indicator of the nodes that has been affected strongly by increasing the load of node 14. It can be seen that, the behavior of the voltage indicator profile of node 13,14 and 15 is mostly the same one. The voltage indicators of these nodes reach to the critical limit value at load 365,420 and 460 MW respectively as shown in the figure and table (2). These nodes are representing a weak voltage area with respect to node 14 load. Also, the load limit of node 14 should be 365 MW instead of 420 MW.

Table(2) The summery results of increasing node load case

Node under study			The load of node under study in MW at which the voltage indicator of other nodes reach to the critical value (L =0.2)														
Node No	Base load	P.F lag	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1																	
2																	
3																	
4	128	0.80	—	—	—	545	550	485	1160	800	560	580	400	390	435	820	925
5	156	0.80	—	—	—	645	555	490	1050	770	555	580	410	400	445	800	880
6	120	0.82	—	—	—	620	550	320	640	460	350	375	330	335	420	735	790
7	81	0.82	—	—	—	—	760	580	440	390	480	540	475	485	620	—	—
8	178	0.78	—	—	—	—	840	520	515	390	440	490	425	445	715	—	—
9	87	0.83	—	—	—	660	590	345	540	375	285	310	290	260	472	760	—
10	102	0.95	—	—	—	705	615	360	590	425	320	300	255	275	508	—	—
11	117	0.80	—	—	—	—	485	315	500	385	300	285	215	225	417	—	—
12	84	0.76	—	—	—	640	590	415	660	485	395	355	230	195	480	—	—
13	340	0.99	—	—	—	1000	945	860	—	—	930	960	760	770	500	670	750
14	175	0.91	—	—	—	950	880	785	—	—	890	920	720	693	365	420	460
15	324	0.92	—	—	—	—	—	840	—	—	—	—	775	765	490	540	540

6.2 EFFECT OF LINE OUTAGES

In this case the effect of the outages of all double lines one at a time and single line one at a time on the voltage stability during the three periods; maximum evening, maximum day and minimum day have been investigated. Tables (3 - 7) illustrate the double line outage cases which are causing voltage instability. In these tables the weak node is marked with (*). From these tables the following can be illustrated :-

a) during maximum evening :-
- when the double lines between bus 1 and bus 7 are taken out of service ,the power flow did not converge, indicating voltage instability (voltage collapse).
- when the two lines between bus 5 and 6 are taken out of service, the weak nodes are 6,8,9,10,11,12 as shown in table (3).
- when the two lines between bus 7 and 8 are taken out of service, the weak nodes are 5,6,8,9,10,11,12 as given in Table (4).

b) during maximum day :-
- when the double lines between bus 1 and 7 are taken out of service, the weak nodes are 6,7,8,9,10,11,12 as given in Table (5).

- when the two line between bus 7 and 8 are taken out of service, the weak nodes are 6,8,9,10,11,12 as illustrated in Table (6)..

c) during minimum day :-

- when the double lines between bus 1 and 7 are taken out of service, the weak nodes are 7,8 as shown in Table (7).

So, it can be concluded that , substation 7 is the weakest location in the network from the double line switching off, point of view. Consequently, the operator should re-configure the network before switching off or giving a permit to work for maintenance of any line in this substation.

In the case of single line outage the study shows that, there is no voltage instability recorded, due to the outage of any single line in the network, for all three load periods.

7. CONCLUSIONS

Extensive contingencies Investigation have been carried out to develop a view on the voltage instability problem on Mid Delta Zone network. Based on this study, a number of general conclusions can be drawn as follows:-

- The developed program is a useful tool to identify the weak voltage nodes and the load limit of each node so, the operator can ensure a stable voltage level within the network.
- Maintenance and dispatcher engineers should give much attention to the network, when there is planning for any line outage in substation 7 .
- The developed program can be used to obtain the guide lines for the operation and maintenance strategy.
- The concept of identifying the weak area in a system by the developed program is very useful to which this area can be analyzed in more detail, rather than all system, this concept saves time and simple in analysis.
- In case of load change, results show that the margin of a voltage instability for the realistic system is large in operation mode. But in planning mode with the same configuration of this network, this problem must be taken into account.

8. REFERENCE

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Table (1.a) System data at maximum evening period

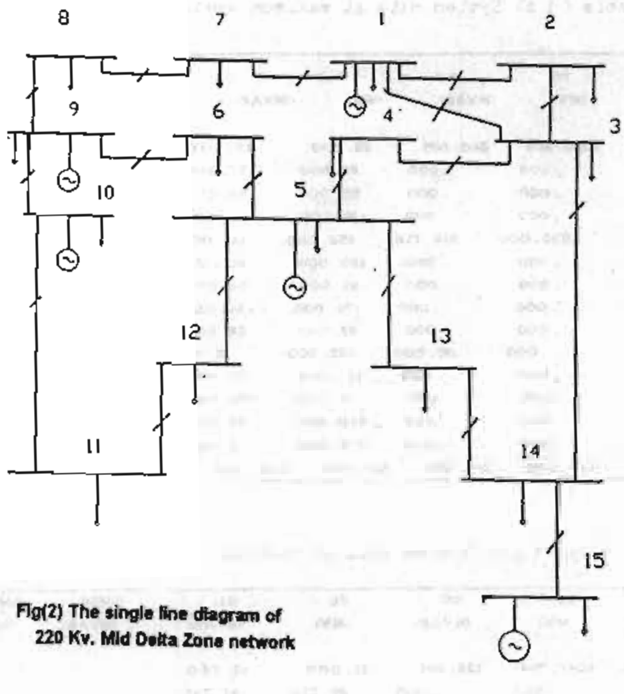
BUS NO	BUS TYPE	PG (MW)	QG (MVAR)	PL (MW)	QL (MVAR)	QMIN (MVAR)	QMAX
1	SLACK	1096.393	246.105	28.000	17.000		
2	PQ	.000	.000	83.000	57.000		
3	PQ	.000	.000	55.000	36.000		
4	PQ	.000	.000	128.000	94.000		
5	PV	550.000	314.716	156.000	111.000	.000	350.000
6	PQ	.000	.000	120.000	82.000		
7	PQ	.000	.000	81.000	56.000		
8	PQ	.000	.000	178.000	139.000		
9	PQ	.000	.000	87.000	58.000		
10	PV	.000	60.000	102.000	5.000	.000	60.000
11	PQ	.000	.000	117.000	87.000		
12	PQ	.000	.000	84.000	-70.000		
13	PQ	.000	.000	340.000	31.000		
14	PQ	.000	.000	175.000	76.000		
15	PV	440.000	215.405	324.000	140.000	.000	350.000

Table (1.b) System data at maximum day period

BUS NO	BUS TYPE	PG (MW)	QG (MVAR)	PL (MW)	QL (MVAR)	QMIN (MVAR)	QMAX (MVAR)
1	SLACK	1049.784	138.292	21.000	12.750		
2	PQ	.000	.000	62.250	42.750		
3	PQ	.000	.000	41.250	27.000		
4	PQ	.000	.000	96.000	70.500		
5	PV	412.500	176.222	117.000	83.250	.000	350.000
6	PQ	.000	.000	90.000	61.500		
7	PQ	.000	.000	60.750	42.000		
8	PQ	.000	.000	133.500	104.250		
9	PQ	.000	.000	65.250	43.500		
10	PV	.000	60.000	76.500	3.750	.000	60.000
11	PQ	.000	.000	87.750	65.250		
12	PQ	.000	.000	63.000	-52.500		
13	PQ	.000	.000	255.000	23.250		
14	PQ	.000	.000	131.250	57.000		
15	PV	105.000	202.609	243.000	105.000	.000	350.000

Table (1.c) System data at minimum day period

BUS NO	BUS TYPE	PG (MW)	QG (MVAR)	PL (MW)	QL (MVAR)	QMIN (MVAR)	QMAX (MVA
1	SLACK	895.849	76.961	16.800	10.200		
2	PQ	.000	.000	49.800	34.200		
3	PQ	.000	.000	33.000	21.600		
4	PQ	.000	.000	76.800	56.400		
5	PV	330.000	88.920	93.600	66.600	.000	350.0
6	PQ	.000	.000	72.000	49.200		
7	PQ	.000	.000	48.600	33.600		
8	PQ	.000	.000	106.800	83.400		
9	PQ	.000	.000	52.200	34.800		
10	PV	.000	60.000	61.200	3.000	.000	60.0
11	PQ	.000	.000	70.200	52.200		
12	PQ	.000	.000	50.400	-42.000		
13	PQ	.000	.000	204.000	18.600		
14	PQ	.000	.000	105.000	45.600		
15	PV	84.000	152.651	194.400	84.000	.000	350.000



Fig(2) The single line diagram of 220 Kv. Mid Delta Zone network

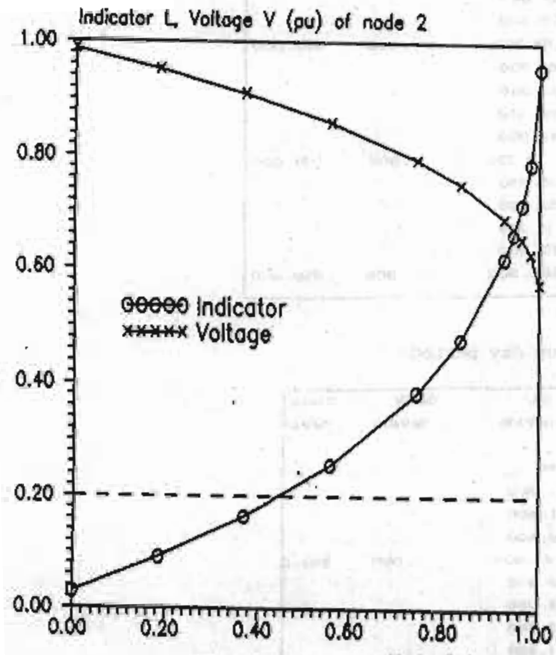


Fig (3) The relation between the , the load of node 2 with it's voltage and the stability voltage indicator(L).

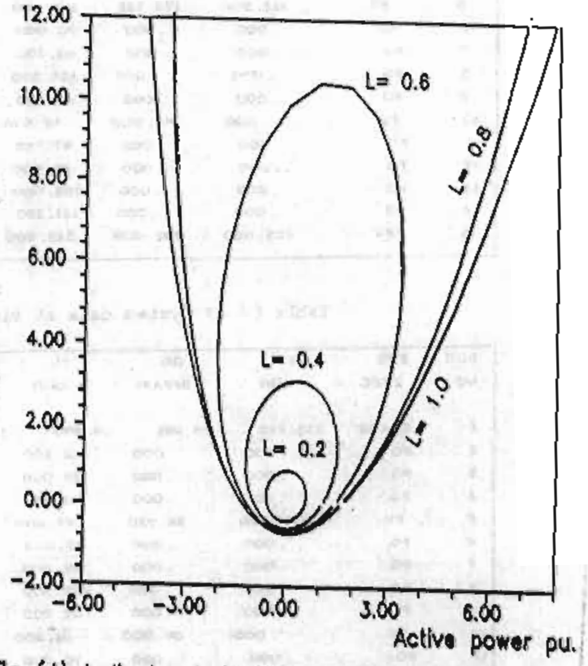


Fig (4) Indicator L in the complex S_2 -plane

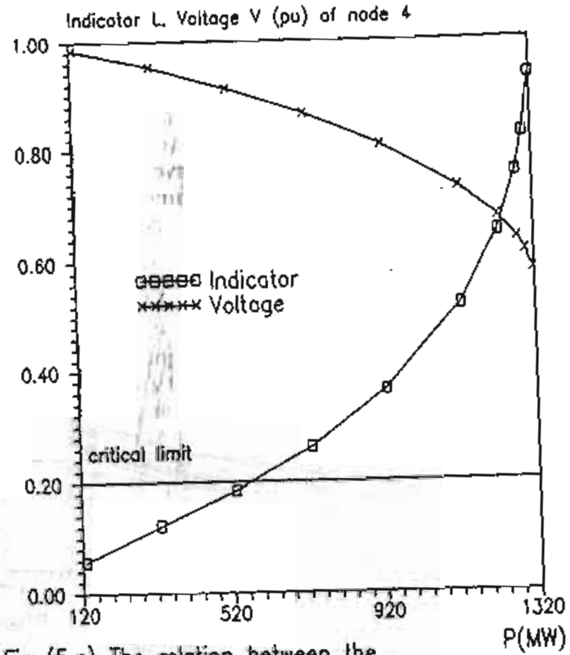


Fig (5.a) The relation between the the load of node 4 with it's voltage and the voltage indicator(L).

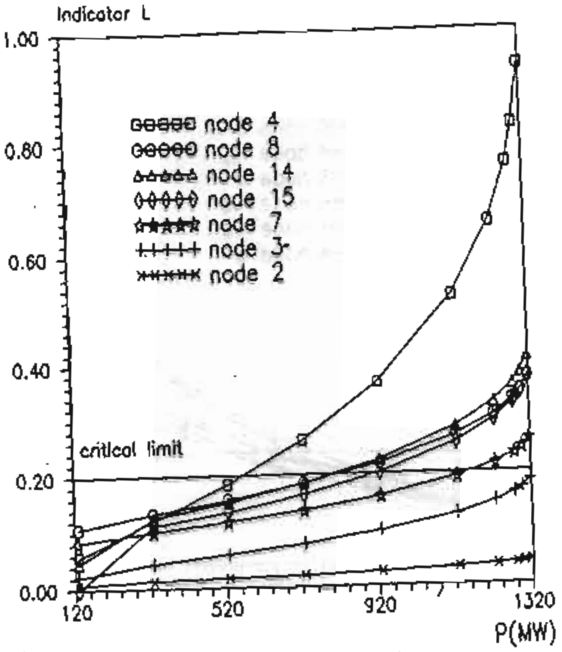


Fig (5.b) Voltage indicator of stable nodes with increasing the load of node 4.

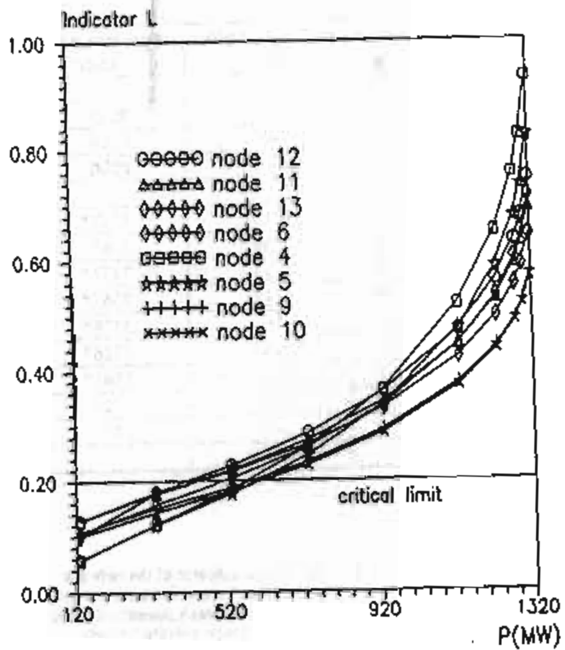


Fig (5.c) Voltage indicator of nodes affected by inreasing the load of node 4.

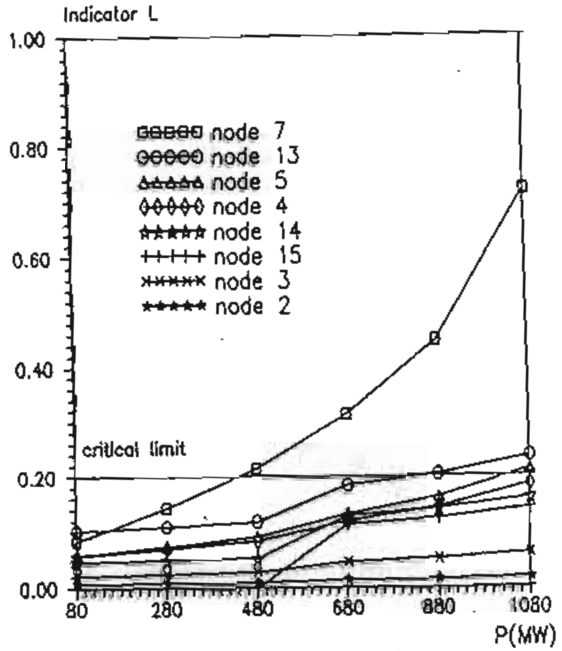


Fig (6.a) Voltage indicator of stable nodes with increasing the load of node 7.

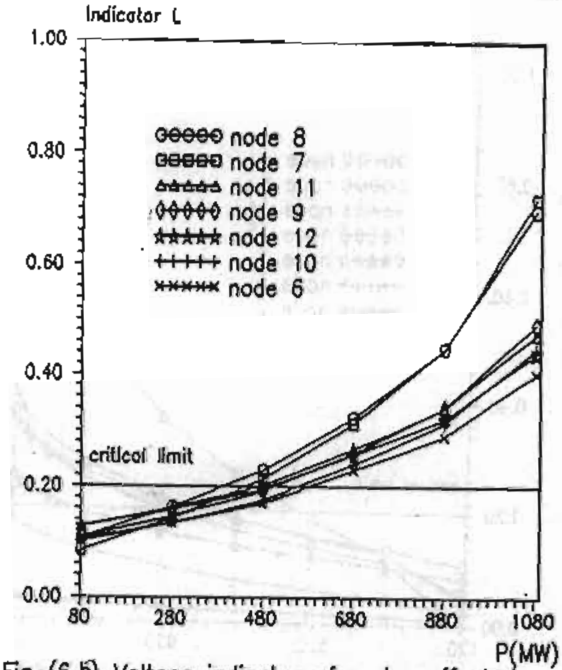


Fig (6.b) Voltage indicator of nodes affected by inreasing the load of node 7.

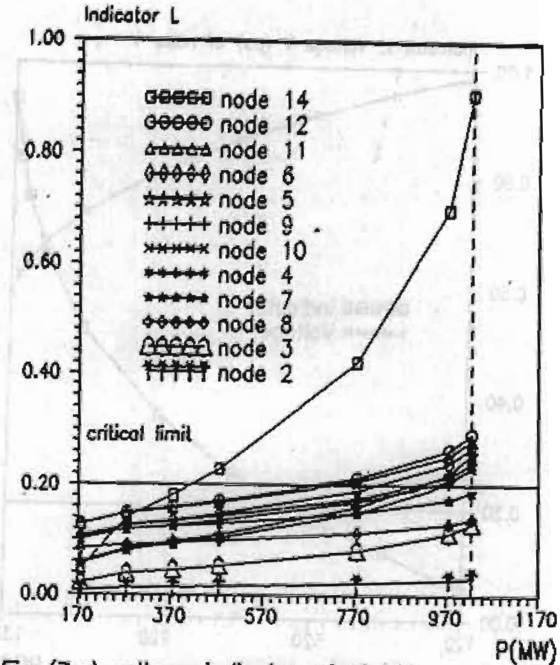


Fig (7.a) voltage indicator of stable nodes with increasing the load. of node 14.

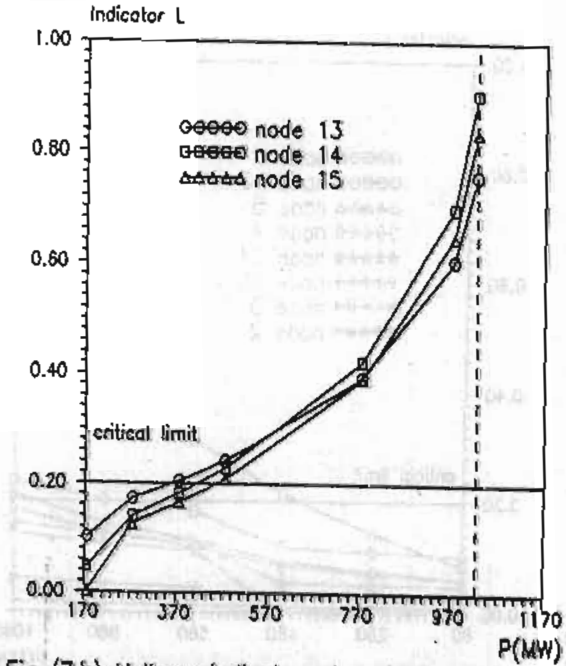


Fig (7 b) Voltage indicator of nodes affected by increasing the load of node 14.

Node No.	Indicator before outage	Indicator after outage
1		
2	.0049	.0049
3	.0107	.0106
4	.0090	.0090
5		
6	.0953	.3787*
7	.0936	.1768
8	.1223	.2431*
9	.1317	.3367*
10	.1462	.3378*
11	.1567	.3226*
12	.1367	.2641*
13	.1034	.1034
14	.0435	.0435
15		

Table (3) The voltage indicator of the network substations before and after the outage of tie lines between substation 5 and 6 during maximum evening periods.

Node No.	Indicator before outage	Indicator after outage
1		
2	.0049	.0141
3	.0107	.0512
4	.0090	.1874
5		.2197*
6	.0953	.4973*
7	.0936	.0236
8	.1223	.8122*
9	.1317	.6508*
10	.1462	.6541*
11	.1567	.6411*
12	.1367	.5585*
13	.1034	.2128*
14	.0435	.0798
15		

Table (4) The voltage indicator of the network substations before and after the outage of tie lines between substation 7 and 8 during maximum evening periods.

Node No.	Indicator before outage	Indicator after outage
1		
2	.0036	.0100
3	.0080	.0358
4	.0068	.1253
5		.1431
6	.0684	.3086*
7	.0671	.5179*
8	.0873	.5044*
9	.0940	.3994*
10	.1044	.3994*
11	.1121	.3892*
12	.0987	.3452*
13	.0761	.1461
14	.0322	.0565
15		

Table (5) The voltage indicator of the network substations before and after the outage of tie lines between substation 1 and 7 during maximum day periods.

Node No.	Indicator before outage	Indicator after outage
1		
2	.0036	.0088
3	.0080	.0304
4	.0068	.0997
5		.1140
6	.0684	.2382*
7	.0671	.0175
8	.0873	.3587*
9	.0940	.3018*
10	.1044	.3062*
11	.1121	.3031*
12	.0987	.2725*
13	.0761	.1313
14	.0322	.0515
15		

Table (6) The voltage indicator of the network substations before and after the outage of tie lines between substation 7 and 8 during maximum day periods.

Node No.	Indicator before outage	Indicator after outage
1		
2	.0029	.0029
3	.0063	.0063
4	.0054	.0054
5		
6	.0531	.1049
7	.0521	.2267*
8	.0675	.2191*
9	.0727	.1593
10	.0809	.1600
11	.0870	.1549
12	.0771	.1297
13	.0602	.0602
14	.0255	.0256
15		

Table (7) The voltage indicator of the network substations before and after the outage of tie lines between substation 1 and 7 during minimum day periods.