Reliability & Sensitivity Analysis of IKR Regional power Network.

Dr. Asso Raouf Majeed, IEEE member
Electrical Engineering Department , Sulaimani University,
Sulaimania / Iraq
(e-mail: drassomajeed@hotmail.com).

***Abstract*-- This paper presents a developed algorithm for reliability sensitivity analysis of engineering networks. . Reliability Modeling is proposed for the Iraqi Kurdistan Regional Power Network (IKRPN) using Symbolic Reliability function of the model. The written Pascal code for the developed algorithm finds efficiently path sets and cut sets of the model. Reliability and Unreliability indices are found. The sensitivity of these indices are found with respect to the variation of the network's elements reliabilities**

***Index Terms*—Reliability, Symbolic reliability function, Boolean algebra, Sensitivity, path sets , cut sets, power network.**

I. INTRODUCTION

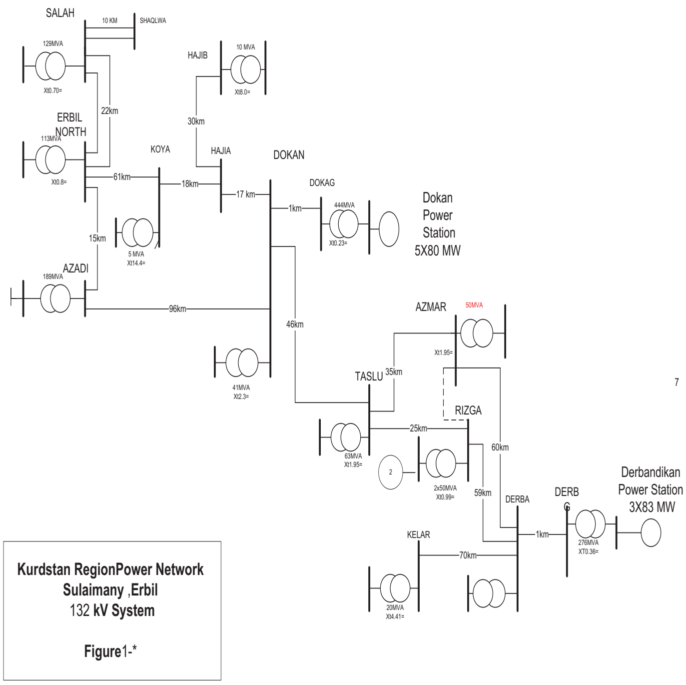
THE electric power system of the three Governorates in the Iraqi – Kurdistan region is a part of the Iraqi National Grid. The huge destruction in the overall Iraqi power system because of successive wars resulted to sectionalize the grid to many regional networks. Some times these regions are operated separately. [1][2]

IKRPN Fig. (1) consists of two hydro power plants , namely Dokan plant with installed capacity plant of (5 x 80) MW and Derbendikhan with installed capacity of (3 x 83) MW as well as three small 29 MW diesel power plants each is located in governorate center to supply emergency and essential loads. Recently a new Gas turbine power plant is connected with system with a capacity of 4x125 MW.

The transmission system of the region is of 132 KV voltage. The grids of the three governorates are connected with Kirkuk by two lines and Mousl with also two lines. The dispatch control center of the North region where located in TAZA (near Kirkuk) is used to operate and control the regional power system with the coordination of the regional control center in Erbil. [3].

Many studies were performed to investigate the reliability and availability of this regional network [3][4][5][6].

In this paper we present a study of the reliability and sensitivity of the overall network due to the variation of the reliabilities of main power plants and transmission links.



II. SYMBOLIC RELIABILITY FUNCTIONS USING BOOLEAN ALGEBRA AND SENSITIVITY ANALYSIS

Many algorithms were developed for studying and investigating sensitivity of reliability of different probabilistic models [6][7][8] [9].

In this paper we present an algorithm for finding the symbolic reliability function which was proposed by Dotson [9] then modified and implemented by Yoo Y. and Narsingh Deo [10] using Fortran 77. In this paper this algorithm is improved and integrated with sensitivity algorithm then implemented using Pascal Language. The written code is used for the reliability study of IKRPN.

A: Network Representation:

In this method the network is represented by reliability block diagram RBD. All the parallel links between any node pairs must be replaced by an equivalent block with reliability that is equal to the union of the parallel links. The vertices are numbered from 1 to n, and edges from 1 to m. Two terminal vertices, source and sink, are denoted as s and t respectively. The terminal pair reliability is denoted as R. A network can be represented by its adjacent matrix G=[gii] such that gij=1 if there exists edge (i,j) and 0 , otherwise.

B: Mathematical Background:

An elementary event E is defined as a particular realization of the network, i.e it is the specification of the success or failure of each edge. It is coded as a vector E{ei} of size m. Where m is the number of links or components in the system.

ei= 1 , if the edge i succeeds and -1, if the edge i fails. An event which is elementary is an event. Any two events which differ exactly in one position can be combined into one event. For example, event [1 1 1 1 -1] and [1 1 1 1 1] are combined into one event [1 1 1 1 0]. An event of [1 -1 1 1] may be rewritten as a set notation form { 1 $\bar{2}$ 3 4}, where complement 2 implies that the second element of the event is -1.

The probability of success or failure events is calculated using:

$$P\{e_i\} = \Pi_{i=1}^{m} P\{e_i\} \tag{1}$$

where:

$$P\{e_i\} \begin{cases} = r_i & \text{, if } e_i=1 \\ = 1- r_i & \text{, if } e_i=-1 \\ =1 & \text{, otherwise} \end{cases} \tag{2}$$

Terminal – pair reliability R is the sum of the probability of each event in the set S.

$$R = \sum_{i-1}^{ns} P\{Si\} \tag{3}$$

where ns is the number of success events and Si is the ith event.

R can be obtained from terminal-pair unreliability $\bar{R}$

Where:

$$\ddot{R} = 1 - R = \sum_{i-1}^{nf} P\{Fi\} \tag{4}$$

Where P{Fi} is the probability of the failure event, and nf is the number of failure events.

The sensitivity of the system reliability with respect to the component reliability is performed by obtaining the partial derivatives with respect to its component reliability. The sensitivity index is normally called reliability importance and given by [10]:

$$IMPi(sys) = \frac{\partial P(System = success)}{\partial pi} \tag{5}$$

Where:

IMPi(sys) : is the reliability importance index w.r.t component i

$\frac{\partial P}{\partial pi}$: partial derivative of probability function w.r.t component i.

A vector of m dimension is defined to store the calculated partial derivatives of every success event with respect to each component. The overall result is reached by summation of the calculated IMP in each iteration as given below:

$$\text{Partial derivative of success event} = \frac{\partial S_k}{\partial pi} \tag{6}$$

Where:

K: order number of the success event and I indicate the associated component.

All the partial derivatives are then given in the following matrix:

$$\begin{bmatrix} \frac{\partial S1}{\partial p1} & \frac{\partial S1}{\partial p2} & - & - & - & \frac{\partial S1}{\partial pm} \\ - & - & - & - & - & - \\ \frac{\partial Sj}{\partial p1} & \frac{\partial Sj}{\partial p2} & - & - & - & \frac{\partial Sj}{\partial pm} \\ - & - & - & - & - & - \\ \frac{\partial Sns}{\partial p1} & \frac{\partial Sns}{\partial p2} & - & - & - & \frac{\partial Sns}{\partial pm} \end{bmatrix} \tag{7}$$

$$IMP1 = \sum_{i-1}^{ns} \frac{\partial Sk}{\partial p1}$$

$$IMP2 = \sum_{i-1}^{ns} \frac{\partial Sk}{\partial p2} \tag{8}$$

.------

$$IMPm = \sum_{i-1}^{ns} \frac{\partial Sk}{\partial pm}$$

C: Algorithm and Flowchart:

For this purpose the following assumptions are made:

1- The vertices (nodes) can not fail.
2- The edge failures are mutually statistically independent.

The main steps of the algorithm are given below:

1- Finding and enumerating the disjoint success events.
2- Finding and enumerating the disjoint failure events.
3- Evaluating the exact network reliability and unreliability.
4- If the number of the disjoints terms exceeds the specified capacity of the “ elementary events 2-dimensional array”, the program run can be terminated and the reliability indices can be

evaluated using upper and lower bounds.

5- Enumeration of all minimal paths.
6- Enumeration of all minimal cuts.
7- Evaluation of sensitivity of the system reliability with respect to the network units. Fig.(2) shows the flowchart of the implemented program

.

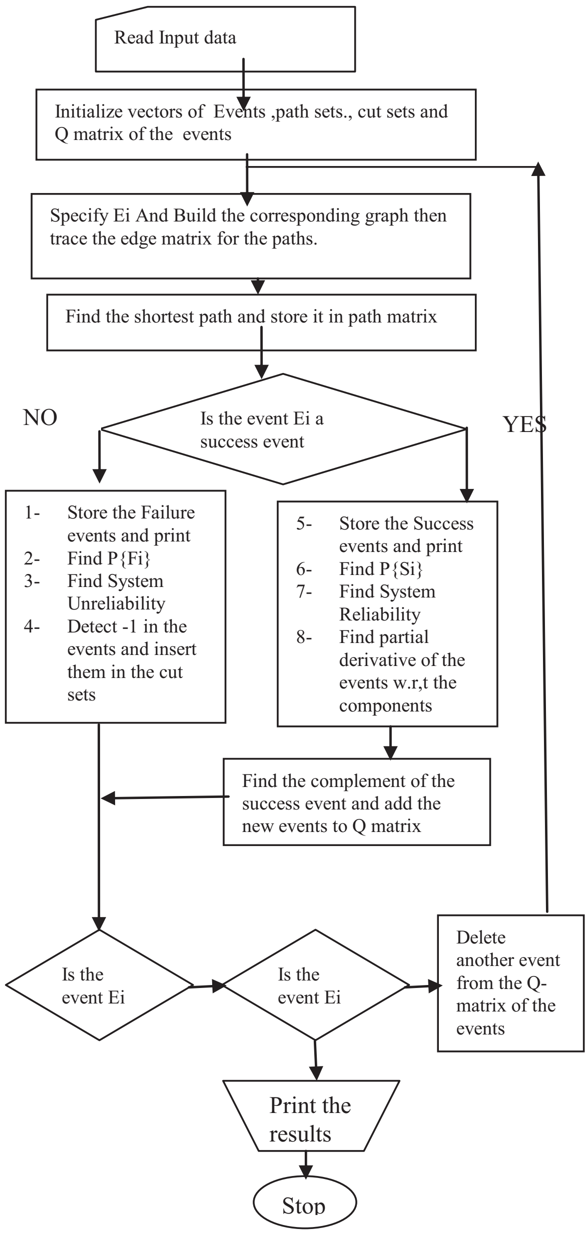


Fig. (2). shows the flowchart of the written program.

III. CASE STUDY

THE SINGLE LINE DIAGRAM OF IKRPN IS SHOWN IN FIG. (1). THE SYSTEM IS MODELED AS DIRECTED GRAPH CONSISTING SETS OF nodes and branches as given in tables (1) & (2). Branches of bi-directions are represented by lines of two arrows from both sides and the uni-direction lines has only one arrow with direction depending on the power flow signal. Fig. (3) gives the graph model showing the connectivity of the power network starting from the power sources (Hydro power plants and the power flow of the tie lines between the IKRPN and the other areas of the Iraqi national grid.

In order to find the reliability sensitivity index of the system with respect to the changes in the branch reliabilities, it is required to detect all the minimal path sets between the different power sources to the selected output node, as given in table(3). In the first row the required output nodes, which represent a substation in the system are given.

In order to find the overall system reliability all the success events are found as explained in the algorithm.

Table (4) gives numbers of the success, failure events, upper and lower bounds of the system reliability for each considered output node (substation).

Table (5) gives the results of evaluation of the sensitivity index that calculated using equation (8) considering Rezgare substation as output node. The variation of IMP are given for different component reliabilities.

Fig.s(6-a) and (6-b) show the impact of each component that makes un element of the pathsets for the most important two nodes Rezgare and north Erbil (which supplies a large portion of Sulaimani and Erbil cities with electrical power) .

TABLE I. NODE NUMBERING AND CODING

Node No.	Name	Node No.	Name
1	Water Reservoir	10	Cham
2	Dukan HP	11	N. Erbil
3	DbK HP	12	Azadi
4	Dukan SS	13	Klar
5	DbK SS	14	Krk400
6	Taslja	15	Mosl
7	Azmr		
8	Razgare		
9	Sul DP		

TABLE II. BRANCH NUMBERING AND CODING

Branch No.	Code no.	Branch No.	Code no.
1	1-2	12	6-7
2	1-3	13	6-8
3	2-4	14	7-6
4	3-5	15	8-6
5	4-6	16	8-7
6	4-11	17	11-12
7	4-12	18	14-10
8	5-7	19	6-10
9	7-8	20	14-10
10	5-13	21	12-6
11	14-13		

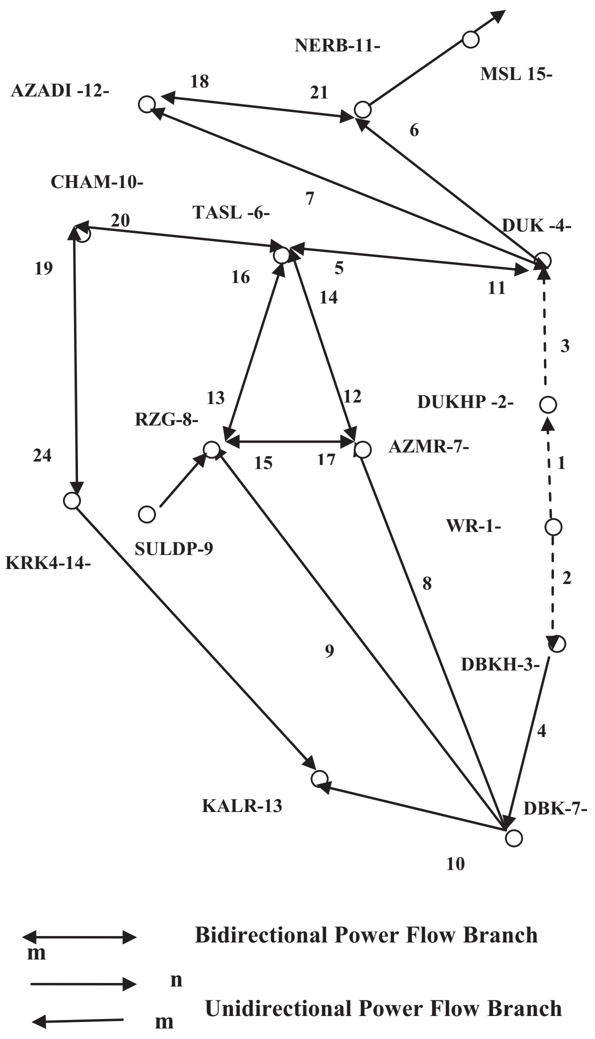


Fig.(3). Reliability Network Model

TABLE III. SYSTEM RELIABILTY FOR DIFFERENT BRANCH RELIABILITIESW R T REZGARE AS OUTPUT NODE

Branch Reliability	System Reliability
0.99	0.9994011789
0.95	0.9852336203
0.9	0.9426642138
0.87	0.9054119486
0.85	0.8763850345
0.8	0.7919173632
0.75	0.6954860687
0.7	0.5933575522

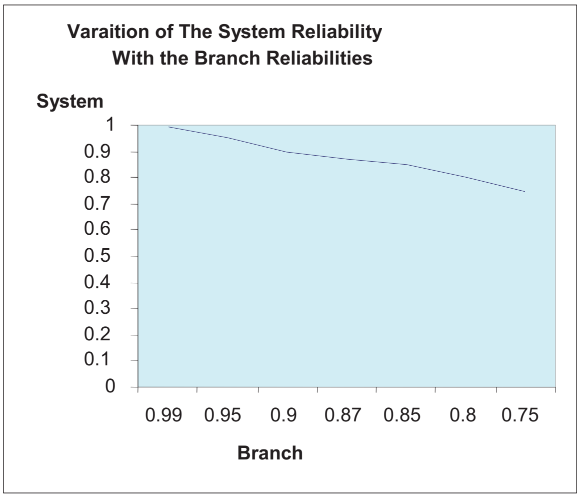


Fig. (4) Effect of variation of the branch reliabilities on the system reliability w r t Rezgare node

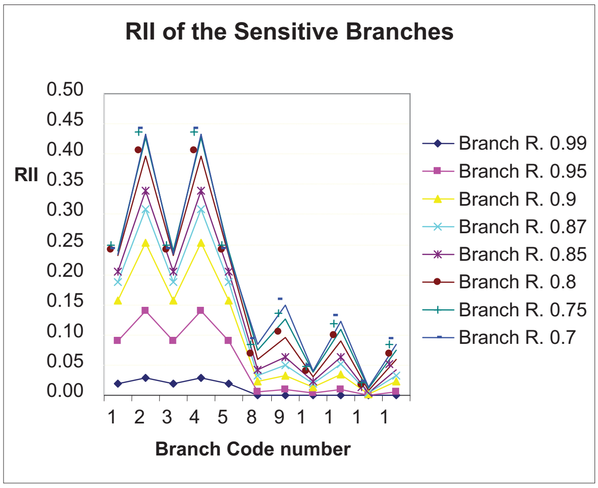


Fig. (5) Reliability importance index variation for the different branches due the change in the branch rel. considering Rezgare as output node.

TABLE IV. IMP FOR THE SYSTEM DUE TO DIFFERENT COMPONENT RELIABILITIES CONSIDERING REZGRE AS OUTPUT NODE

Comp. Reliability	0.99	0.95	0.9	0.87
System Reliability	0.99940118	0.98523362	0.942664213	0.90541194
Rel. Import. Index of the comp.	0.01959709	0.08968300	0.157943682	0.18851602
	0.02959118	0.13898770	0.252794682	0.30772369
	0.01959709	0.08968300	0.157943682	0.18851602
	0.02959118	0.13898770	0.252794682	0.30772369
	0.01959709	0.08968300	0.157943682	0.18851602
	0.00029198	0.00649646	0.022065372	0.03349302
	0.00039287	0.00905842	0.032140962	0.05008505
	0.0001921	0.00406260	0.0129973	0.01905795
	0.0004831	0.01046718	0.03453127	0.05159830
	0.0000028	0.00029042	0.00177803	0.00330636
	0.0002919	0.00649646	0.02206537	0.03349302

TABLE FOURE (CONTINUED)

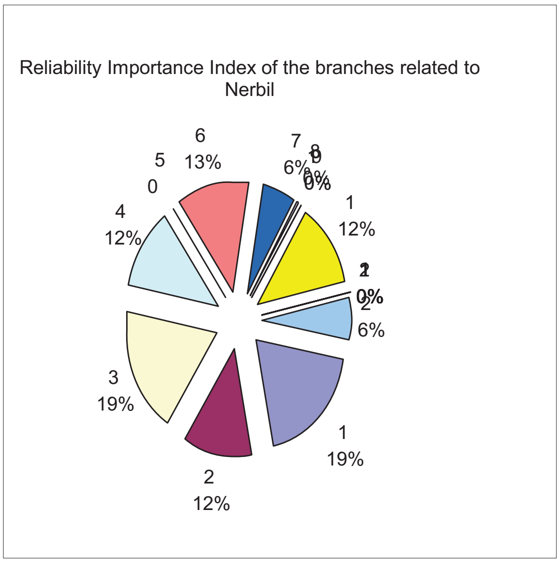
Comp. Reliability	0.85	0.8	0.75	0.7
System Reliability	0.876385034	0.791917363	0.695486068	0.593357552
Rel. Import. Index of the comp.	0.204677326	0.231112704	0.239570617	0.233144646
	0.338615279	0.395976704	0.426338195	0.432623646
	0.204677326	0.231112704	0.239570617	0.233144646
	0.338615279	0.395976704	0.426338195	0.432623646
	0.204677326	0.231112704	0.239570617	0.233144646
	0.041351358	0.060063744	0.075187683	0.084978936
	0.062939556	0.095657984	0.125587463	0.149360526
	0.023001389	0.031588352	0.037387847	0.039911823
	0.063079868	0.089554944	0.109794616	0.121714236
	0.004532156	0.007995392	0.011432647	0.014197113
	0.041351358	0.060063744	0.075187683	0.084978936

TABLE V. RELIABILITY OF SELECTED OUTPUT NODES IF ALL BRANCHES 'RELIABILITY IS 0.99

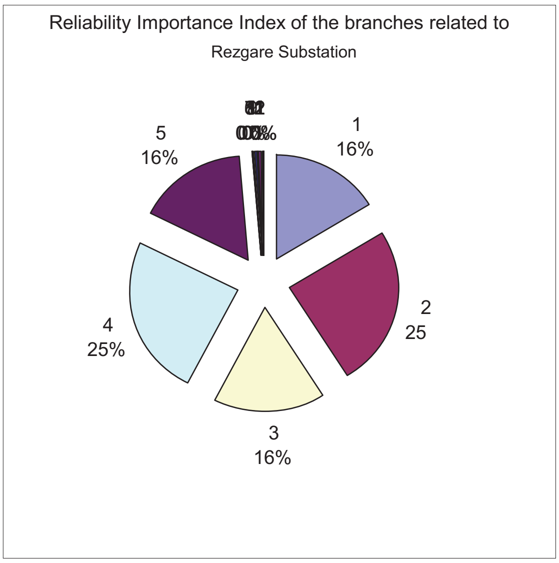
Branch Rel.	*pi=0.99*					
Name of output node		*Rezgare*	*Azmr*	*tasloja*	*NErbil*	*Azadi*
no. of paths		*5*	*5*	*5*	*8*	*8*
no. of success events		*14*	*14*	*16*	*18*	*18*
no. of failure events		*14*	*14*	*12*	*20*	*20*
Reliability	*upper bound*	*0.999401255*	*0.999401255*	*0.999403186*	*0.999206339*	*0.999206339*
	lower bound	*0.999401179*	*0.999401179*	*0.999403071*	*0.999206132*	*0.999206132*

TABLE VI. LIST OF THE PATHS FOR SOME SELECTED BUSBAR NODES

	Path number	Name of output node				
		Rezgare	Azmr	tasloja	NErbil	Azadi
Path Sets	p1	2 4 9	2 4 8	1 3 5	1 3 6	1 3 7
	p2	1 3 5 13	1 3 5 12	2 4 8 14	2 4 6 8 11 14	2 4 7 8 11 14
	p3	1 3 5 12 15	1 3 5 13 17	2 4 9 16	1 3 7 21	1 3 6 20
	p4	2 4 8 15	2 4 9 17	2 4 9 14 17	2 4 7 8 11 14 21	2 4 6 8 11 14 20
	p5	2 4 8 13 14	2 4 9 12 16	2 4 8 15 16	2 4 6 9 11 16	2 4 7 9 11 16
	p6				2 4 7 9 11 16 21	2 4 6 9 11 16 20
	p7				2 4 6 9 11 14 17	2 4 7 9 11 14 17
	p8				2 4 6 8 11 15 16	4 7 8 11 15 16



a: (North Erbile Node)



B: (Rezgare Substation Node)

FIG. (6) Reliability Importance Index of branches with respect to a: NErbil and b: Razgre

IV. DISSCSSION AND CONCLUSION

The outcomes of this study are the following points.

1. The System Reliability decreases with the decrease of branches reliabilities , as given in table two and shown in fig. (4)
2. Reliability Importance Index (RII) of all the network branches are shown in fig. (5) , we observe how the sensitivity of the branch are less for low availabilities branches. i.e the effectiveness of the failures of a branch will be very higher if the system has poor reliabilities.
3. Some elements (for example node 2, node 4) are more sensitive, therefore attentions must be paid for those elements.
4. Table V gives information about number of success and failure events detected by the method that implemented here. Reliabilities were calculated between two upper and lower bounds.
5. Fig.(6) gives the impact of the different branches on NErbil and Razgree respectively. It is concluded that the higher percentages are of more importance with respect to that output node.

V. REFERENCES

[1] A. R Majeed, "Power System Analysis For Kurdistan Region of Iraq", Technical Report, Sulaimani Electricity Authority. 1998.

[2] Electricity Network Development Plan Sulaimany Governorate, UNDP-ENRP, Distribution Sector Revision 1- February 2002.

[3] Majeed A. R,& Ezat G., "Reliability Modeling And Evaluation Of Sulaimani-Erbil Power System", June, 2006, Montréal, Canada, IEEE ,1-4244-0493-2/06/$20 © 2006.

[4] Hussien J. & A. R Majeed , "Reliability Study of Regional power Network communication", IEEE PES TRANSMISSION AND DISTRIBUTION CONFERENCE, Venezuela, Caracas 2006 PT3-008, August 15-18 , 2006,

[5] Majeed, A. R. &Sadeq N."Availability And Reliability Evaluation of Dokan Hydro Power Station ", IEEE PES TRANSMISSION AND DISTRIBUTION CONFERENCE, OP2-008, August 15-18 , 2006, Caracas , Venezuela, 2006

[6] A. Gandini “Importance and Sensitivity Analysis in Assessing Systems Reliability”, IEEE Trans. On Reliability, Vol. 39, no. 1, 1990 April.

[7] Boudewijn R. and Adrianus M. “ Sensitivity & Uncertainty Analysis of Markov-Reward Models”, IEEE Trans. On Reliability , Vol. 44, No. 1, 1995 March,

[8] Liudong Xing and Joanne Bechta ,” Analysis of Generalized Phase-Mission System Reliability, Performance, and Sensitivity”, IEEE Trans. On Reliability, Vol. 51, No. 2, June 2002.

[9] Dotson W, Gobien. J., "A new analysis technique for probabilistic graphs", IEEE Transactions Circuits & Systems, Vol. 26, pp 855-865, 1979.

[10] Y. B. Yoo, Narsingh Deo,”A Comparison of algorithms for terminal-pair reliability”, IEEE Trans.