AN IMPROVED RELIABILITY ASSESSMENT TECHNIQUE FOR A COMPOSITE POWER SYSTEM

A. Moussa*, M. El-Gammal*, E. Abdallah* and N. Aziz**

* Department of Electrical Engineering, Alexandria University, Egypt
** Informatics Institute, Mobark City for Scientific Research, Alexandria, Egypt

ABSTRACT

A major difficulty in the reliability evaluation of large composite generation and transmission power system is the computational time required to perform the required analysis. This paper presents a new method based on a graph partitioning technique for composite system reliability evaluation. The main advantage of this method is that its simplicity and its execution time are very small compared to other well known developed methods. An algorithm is developed for computer implementation for the assessing of failure probability at any bus in a composite power system. The developed method is tested on IEEE-Roy Billinton Test System (RBTS) to check its validity.

Keywords: Power system reliability , Composite system reliability, Network tearing

INTRODUCTION

The problem of assessing the ability of the composite generation and transmission system to satisfy the load and energy requirements at major load points is designated as HLII assessment [1]. It can be seen from bibliographies on power system reliability evaluation [2-6] that there is a much smaller body of literatures available in the HLII area and the initiation of this activity came several decades after significant development in HLI evaluation [1].

Adequacy assessment at the HLII is a complex task and there is no single accepted procedure. A wide range of techniques have been proposed for reliability evaluation in HLII; many of them are basically varied in fundamental approaches to the problem [1]. Reference 7 illustrates some of the fundamental differences between two methods. The first utilizes Monte Carlo approach and is used by ENEL in Italy in its planning practice. The second approach is developed at the University of Saskatchewan and uses a contingency evaluation procedure. These two methods are representative of other evaluation methods found in Europe and North America respectively. Power-system reliability evaluation techniques can be generally categorized as being either analytic or simulation. Analytic techniques represent the system by analytical models and evaluate the indices from these models using mathematical solutions. Monte Carlo simulation methods estimate the indices by simulating the actual process and random behavior of the system.

This paper introduces an effective approach to be used in bulk power system reliability assessment. This method is based on the graph partitioning technique presented by the authors in Reference 8 taking the following constraints into consideration:-

- Amount of available system generation and its reliability.
- Maximum transmission lines capacity.
- Maximum available load to be connected at each bus.

The validation and efficiency of the proposed technique are realized through application to the IEEE-RBTS bus power system model [9].

BASIS OF THE PROPOSED METHOD

The developed method can be divided into three main parts as follows:-

1. Load modelling and generation reliability evaluation.
2. Tearing the whole network into trees and tearing elements.
3. Calculating load point reliability.

Load Modelling and Generation Reliability Evaluation

The aim of this part is to calculate the reliability of generating station at each bus. This is carried out under the following assumptions:-

1. The load at each bus is considered to be fixed and equal to its maximum value.
2. Transmission line losses are negligible .
3. The total system load is shared between generating stations as proportional to the installed generation capacity at each bus.
4. The forced outage rate of each generator in a generating station is considered to be an independent event.

Therefore, the calculation steps will be as follows:-

- Step 1: Calculate the total system load by summing up the maximum loads in the system.
- Step 2: Sum up all generator unit ratings at each bus to find the total installed capacity at each bus and the whole system installed capacity.
- Step 3: Calculate the amount of generation which must be supplied by each generating station as a ratio of total system load. This ratio equals this bus installed generation capacity to the total system installed capacity.
- Step 4: Calculate the probability of each generating station to supply its share of the system load.
- Step 5: For each bus having installed generation capacity, add a virtual transmission line connecting the bus to a virtual bus of zero failure probability, called the source bus and has the code number "0". The availability of this line is equal to the generating station probability to supply its portion of the system load.

Tearing the Whole Network into Trees and Tearing Elements

In this part, the network [G] is torn into "a" subnetworks $[G_1, G_2, G_3, \ldots\ldots G_a]$ called trees and "b" separate elements called tearing elements $[t_1, t_2, \ldots\ldots t_b]$. The tearing process follows an efficient graph partitioning technique developed in Reference 8. It can be summarized as follows:

1. Present the network in its stochastic form including the added virtual transmission lines.
2. From the stochastic network construct the bus incidence matrix for the power system.
3. Process in the bus incidence matrix to divide the whole networks into trees. Each tree must satisfy the following conditions:-
   i) A tree must contain a virtual transmission line which means that the first node in each tree must be the source node. The tree is not allowed to have more than one virtual transmission line.
   ii) Trees are not allowed to have any nodes in common other than the source node number "0".
   iii) Trees are not allowed to have any elements in common.
   iv) The elements in every tree are connected head-to-tail.
   v) A tree must not contain any closed loop.

   After the construction of all possible trees, the remaining elements are called the tearing elements.

Calculating Load Point Reliability

In this part the initial values of load points reliabilities are calculated in each tree. The tearing elements are then added in steps and at each step the load point reliabilities are updated. The following assumptions are made:-

(a) Every line has a maximum transmission capacity. It can not supply higher loads.
(b) There is only one direction for the power flow in each transmission line.

This part can be achieved in the following steps:-

(i) In the initial calculation part the bus reliabilities of each tree are calculated.

(ii) In the repetitive calculation part, the tearing elements are added sequentially. Priority is given to a tearing element to enhance the insufficient supply of certain bus load demand. This is divided in a number of passes in each of which all buses connected loads are fed.

THE ALGORITHM STRUCTURE

An algorithm based on the method described in the previous section is developed for computer implementation. This algorithm is divided into the following modules: -

1. Data-input module.
2. Generation reliability module.
3. Tearing module.
4. Initial calculation module.
5. Repetitive calculation module.

Data-Input Module

Power system configuration can be presented in a text file. The computer program reads the data from this input file and saves them in records as follows:-

i- Line data is saved in line records which contain the following fields : its number ,its two terminal nodes ,its transmission capacity ,its outage rate and repair time.

ii- Generator data is saved in generator records which contain the following fields: its number ,its capacity, its location and its forced outage rate (FOR).

iii- Bus data is saved in bus records which contains the following fields: its number, its installed generation and its load.

A flowchart of this module is shown in Figure 1.

Generation Reliability Module

In this module the reliability of the installed generation capacity at each bus is calculated. The procedure is as follows:-

(1) Calculate total system load demand as

$$T_{load} = \sum_{i=1}^{n} L_i \qquad (1)$$

Where L_i is the load demand at bus number "i" in MW & n is the total number of the buses in the network.

(2) Calculate the installed generation capacity at each bus

$$G_i = \sum_{j=1}^{m_i} g_j \ \forall\ i = 1,2,\ldots..n \qquad (2)$$

Where m_i is the number of generating units installed at bus # i

(3)Calculate total system installed generation capacity T_{gen},where

$$T_{gen} = \sum_{i=1}^{n} G_i \qquad (3)$$

(4) Calculate the amount of generation "GS_i" that each bus in the network will share to feed system loads according to the assumptions mentioned earlier.

$$GS_i = \frac{G_i}{T_{gen}} * T_{load} \qquad (4)$$

(5) For each bus # i having connected generating units, calculate the probability that these units can supply an amount $\geq GS_i$. This probability can be calculated as follows:-

- Assume that every generator unit has two states, up and down. The probability of any unit to be down is equal to its forced outage rate "FOR". The total number of states for all possible combinations of generator units installed at this bus is K_i

$$K_i = 2^{m_i} \qquad (5)$$

- Convert the decimal number of each state (from 0 to K_i-1) to a binary number consisting of number of bits equal to "m_i". Each bit represents the state of a generator unit at this bus (1 means up and 0 means down).
- For each state j multiply each bit of its equivalent binary number by the capacity of the generator unit it represents and add these products to calculate the generation available capacity "$GA_i^{state=j}$" at this state. If $GA_i^{state=j} \geq GS_i$ then calculate the probability of this state by multiplying "FOR" or "1-FOR" of the first generator if its bit is 0 or 1 respectively by the "FOR" or "1-FOR" of the second generator if its bit is 0 or 1 ,respectively and so on.
- The probability that this generating station can generate its shasre GS_i or more is obtained by adding all the state probabilities in which $GA_i^{state=j} \geq GS_i$.

- A virtual transmission line is added between bus no. "i" and the virtual bus number "0" (the source bus) and is given the code number e+v+1 where e is the total number of lines in the system and v is the total number of the previously added virtual lines. The availability of this virtual line is equal to the probability that this generating station at bus i can generate its share GS_i or more. The flowchart of Figure 2 illustrates this module.

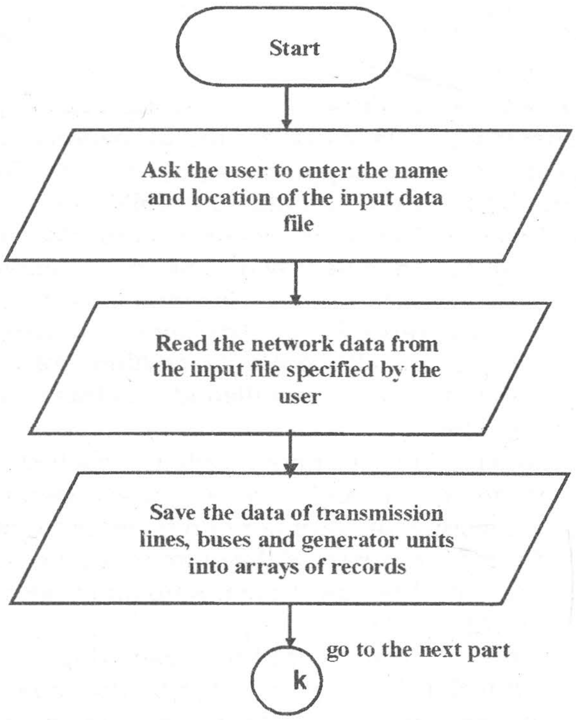

Figure 1 Flowchart of the data-input module

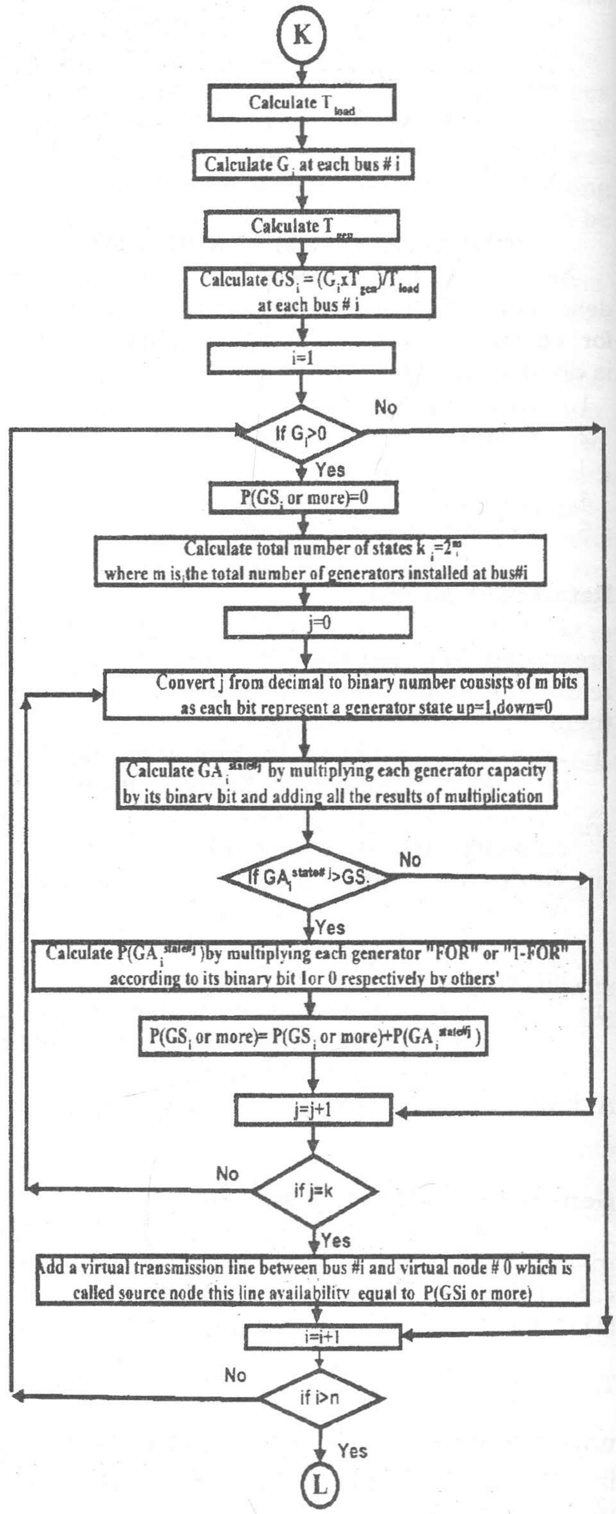

Figure 2 A flowchart of generation reliability module

Tearing Module

The aim of this module is to tear the whole network into "a" trees and "b" tearing lines. The main steps are as follows:,

- Construct the bus incidence matrix (A matrix) for the system stochastic network after adding the virtual lines. The dimension of this matrix will be z * (n+1) where z=e+v is the total number of lines after adding the virtual lines. The elements of the A matrix are as follows:-

  a_{ij} = 1 if the i^{th} element is incident to the j^{th} node & 0 otherwise .
- Process in the A matrix to construct the trees. The tree must satisfy the conditions mentioned earlier. A tree # i is constructed as follows:

1. Consider the general A matrix shown in Figure 3. As any tree must contain a virtual line, the last rows of the A matrix from "row#z" to "row#e+1" until a row (#z-1 for example) is found such that the line it represents does not belong to any previous tree. This line will be the first line in the tree and it will take the order #1 in this tree.
2. This row is scanned until the other end of the line (at column #"c") is found. The element which this row represents (element #"z-1") is marked to belong to tree # i and node "c" is also marked to belong to tree # i.
3. Column #"c" is then scanned until another entry of "1" is found (at row #"a").
4. Row #a is now scanned to find the other end of the line it represents (at column # "f"). This element ,i.e, element # "a" is marked to belong to tree # i if and only if:-
   i) Node "f" is not an end of a virtual line, and
   ii) Node # "f" does not belong to a previous tree.

   If the previous two conditions are satisfied then node #"f" is marked to belong to tree #i.
5. Steps 3 and 4 are repeated until a stopping criterion is satisfied. This ends the construction of tree # i. The stopping criterion used in this module is stopping criterion #2 of Reference 8 to assure that the tree contains a maximum number of lines.
6. Steps from 1 to 5 are repeated for each tree until there is no more available trees. The remaining elements are the tearing lines.

The flow chart which represents the tearing module is shown in Figure 4.

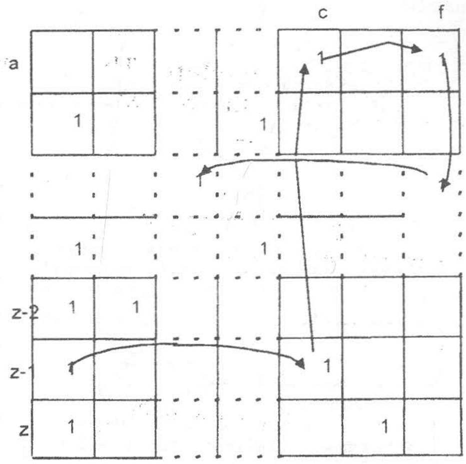

Figure 3 Construction of any tree from the A matrix

Initial Calculation Module

The aim of this module is to calculate load point reliabilities at all buses of each tree. Two factors must be taken into consideration. The first is that the power flow in each line has only one direction ,the second is that the power flow in each line must not exceed its maximum capacity. The steps of the module are as follows:

(i) Calculate the availabilities of system lines. The availability constant "A_i" of a line #i having an outage rate λ_i per year and mean outage duration r_i hours is calculated as follows:-

$$A_i=\mu_i/(\lambda_i+\mu_i) \qquad (6)$$

where μ_i=8760/r_i is the repair rate per year.

(ii) Save the maximum transmission capacity of each line into a vector consisting of "e" rows. This vector will be called the capacity vector C.

(iii) Construct a vector consisting of "n" rows to save system buses reliabilities which are updated at each step. This vector will be called the reliability vector R.

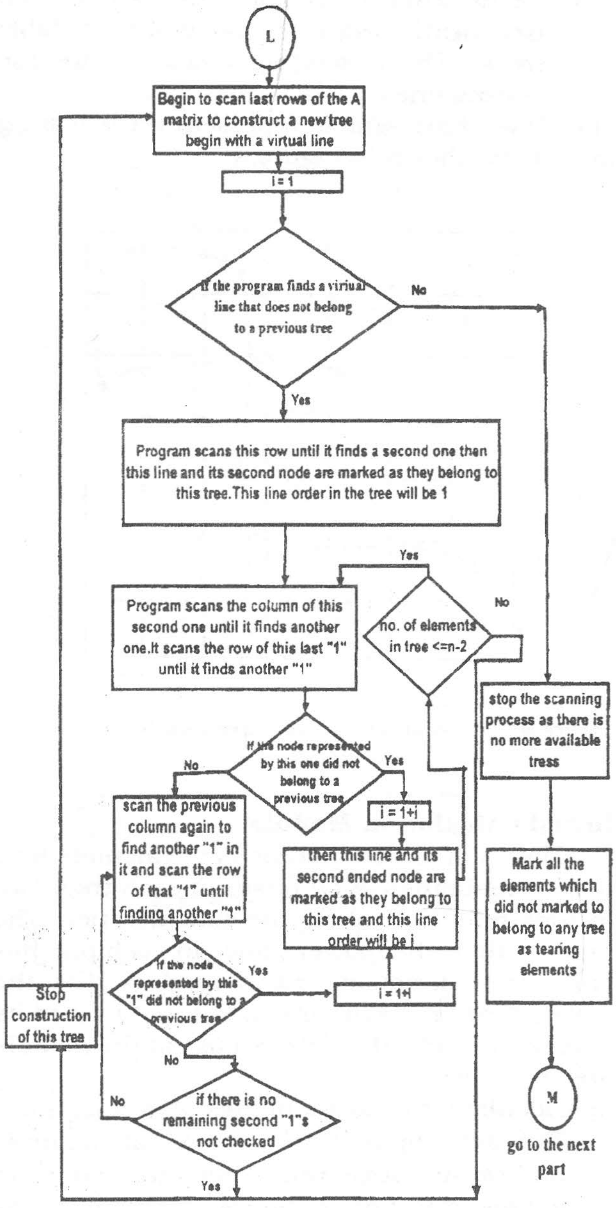

Figure 4 The flowchart of tearing module

Initially R(1)=R(2)=................ = R(n-1) =R(n)=0.

(iv) Construct a vector consisting of "n" rows to save temporary reliabilities of system buses. Each entry represents the reliability of a bus whose available transmission capacity at a certain step is not enough to feed its total load which means that only a part of the load equal to the transmission capacity will be fed. This vector will be called the temporary reliability vector Rt. Initially Rt(1)=Rt(2)=.........=Rt(e)=0.

(v) Consider any tree as shown in Figure 5. Each node in this tree has its own order. The source node order is "0" and node #a order is "1" and so on. The load connected to a node whose order is "x" is $L(or_x)$. Likewise, each line has its order "or_x", availability $A(or_x)$ and capacity $C(or_x)$.

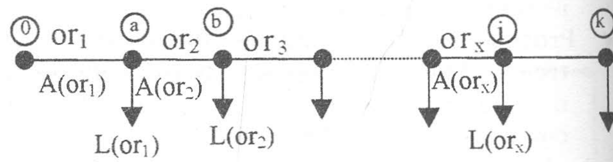

Figure 5 Processing of initial calculation module

(vi) For any node # "i" of order "x" >1 in a tree and whose load is L_i; there are three possibilities:-

1. If each transmission line preceding this node has a capacity higher than the load at node #i,,i.e., min $\{C(or_2), C(or_3), \ldots, C(or_x)\} \geq L_i$, then node "i" reliability at this step is calculated as follows:-

$$R^1(i)= A(or_1)xA(or_2)x\ldots\ldots A(or_x) \qquad (7)$$

The capacity of all these lines are decreased by an amount equal to L_i i.e., $C(or_2)=C(or_2)-L_i$, $C(or_3)=C(or_3)-L_i$ ...., $C(or_x)=C(or_x)-L_i$. The load at bus #i in this pass will be set to zero as it is now fully fed ,i.e., $L_i=0$.

2. If any of the transmission lines preceding this node has a capacity smaller than the load at node # i, i.e., min $\{C(or_2), C(or_3), \ldots, C(or_x)\} < L_i$,the load is partially fed by an amount equal to the minimum transmission capacity available. A temporary reliability value for this node is calculated as follows:

$$Rt^1(i)= A(or_1)xA(or_2)x\ldots\ldots A(or_x) \qquad (8)$$

The bus reliability will be still equal to zero R(i)=0. The reliability of all subsequent nodes will equal to zero. The process in this tree will be ended. The load at this bus and the capacity of all lines preceding this bus are decreased by an amount equal to $\min\{C(or_2), C(or_3), \ldots\ldots\ldots, C(or_x)\}$.

3. If any of the transmission line preceding this node, i.e., of order x or less has a zero capacity then the reliability of this node will remain zero, i.e., $R(i)=0$ and the reliability of all subsequent nodes will also equal to zero, i.e, $R(i+1)=R(i+2)\ldots=0$. The process in this tree will be ended.

Repetitive Calculation Module

In this module the tearing lines are added one at a time and after each the reliability vector of all system buses is updated. The addition of the tearing lines will be carried out in number of passes. In the first pass only the tearing lines whose addition results in feeding all the loads are added. In the second pass each load is fed again by another path constructed by adding the remaining tearing lines. Subsequent passes are carried out until all tearing lines are added. The procedure in any pass #i is as follows:-

1. At the beginning of each pass, say at step # s+1, scan the temporary reliability vector, if there is a bus #i -in tree #a- has a nonzero temporary reliability, i.e., $Rt^s(i) \neq 0$, then first add a tearing line "t" as shown in Figure 6 satisfying the following conditions:-

(i) Its second end is node #i; or, if there is not any, a node previous to it in the same tree, i.e. tree #a.

(ii) Its first end "j" is a second end of a line of order "x" in another tree, say, tree #b. The tearing lines which has less order has to be added first, i.e., try x=1, then x=2 and so on.

(iii) Its first end node load and all preceding node loads in tree #b are equal to zero, i.e., they are fully fed before.

(iv) The capacity of any line which has order "x" or less in tree #b must be higher than zero.

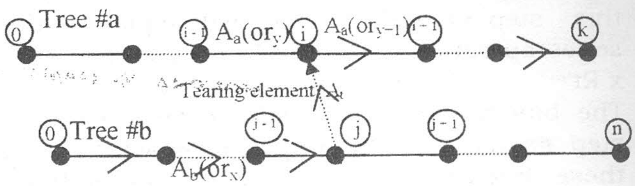

Figure 6 Processing of repetitive calculation module

After adding each tearing line there are two possibilities:-

(i) If the added tearing line and each transmission line preceding its first node "j" in tree #b, has a capacity higher than the remaining load at node #i which is L'_i, i.e., $\min\{C_b(or_2), C_b(or_3), \ldots\ldots\ldots, C_b(or_x), C(or_t)\} \geq L'_i$ then node "i" reliability at this step is calculated as follows:-

Let $$R'^{s+1}(i) = A_b(or_1) x A_b(or_2) x \ldots\ldots x A_b(or_x) x A_t \qquad (9)$$

where $A_b(or_x)$ is the availability of the line whose order is "x" in tree #b and A_t is the availability of the tearing line. The reliability of bus # i at this step will then be the parallel equivalent of the series equivalent of { Rt^s and R'^{s+1} } and its reliability in the previous step R^s, i.e.,

$$R^{s+1} = 1 - [\,(1 - R'^{s+1} \times Rt^s) * (1 - R^s)\,]$$

The capacities of all these lines are decreased by an amount equal to L'_i. The load at bus #i in this pass will be equal to zero as it is now fully fed, i.e., $L_i=0$.

The reliability of the nodes after node #i in tree #a and their loads was not fed in this pass will be updated in order, as there is enough transmission capacity until a temporary reliability value is calculated for a node which mean that there is not enough transmission capacity.

(ii) If the added tearing line or any transmission line before its first node "j" in tree #b has a capacity less than the remaining load at node #i, the load is fed by the minimum transmission capacity available. The temporary reliability value for this node is calculated as follows:-

Let $$Rt'^{s+1}(i) = A_b(or_1) x A_b(or_2) x \ldots\ldots\ldots A_b(or_x) x A_t \qquad (10)$$

The temporary reliability value for this node at this step is updated and will equal to the series operation of Rt^s and Rt'^{s+1} ,i.e., $Rt^{s+1}=Rt^s \times Rt'^{s+1}$

The bus reliability will still have its value at step #s ,i.e., $R^{s+1}(i)=R^s(i)$. The capacities of all these lines are decreased by an amount equal to $\min\{C_b(or_2),C_b(or_3),....,C_b(or_x),C_t\}$

The load at this bus is likewise decreased by the amount it is fed, i.e., $L''_i=L'_i-\min\{C_b(or_2),C_b(or_3),........,C_b(or_x),C_t\}$

(2)After adding the tearing lines in the just described way until all loads which are fed partially are completely fed. Add a tearing line which is connected between a node #i in any tree #a who is completely unfed in this pass (if it is the first pass then its reliability is still equal to zero) and a second node #j in any tree #b. This line must satisfy the previously mentioned conditions in (1). After adding each tearing line there are two cases:-

First case

$\min\{C_b(or_2),C_b(or_3),.....,C_b(or_x),C(or_t)\}\geq L_i$ So,

$$\text{let } R'^{s+1}(i)=A_b(or_1)xA_b(or_2)x......xA_b(or_x)xA_t \quad (11)$$

The reliability of bus #i at this step will be the parallel equivalent of $R^s(i)$ and $R'^{s+1}(i)$, i.e.,

$$R^{s+1}(i)=1-[(1-R'^{s+1}(i))x(1-R^s(i))] \quad (12)$$

The capacity of all these lines is decreased by an amount equal to L_i. The load at bus #i in this pass will be equal to zero as it is now fed in this pass. The reliability of the nodes subsequent node #i in tree #a whose their loads were not fed yet in this pass will be updated in order as there is enough transmission capacity until a temporary reliability value is calculated for a node which mean that there is not enough transmission capacity.

Second case

$\min\{C_b(or_2),C_b(or_3),...,C_b(or_x),C(or_t)\}< L_i$ In this case the load is fed by the minimum transmission capacity available. The temporary reliability value for this bus is calculated ,

$$Rt^{s+1}(i)=A_b(or_1)xA_b(or_2)x.......A_b(or_x)xA_t \quad (13)$$

The bus reliability will still have its value at previous step. The load at bus #i and the capacity of all these lines are decreased by $\min\{C_b(or_2),C_b(or_3),....,C_b(or_x),C_t\}$. (3)After all the loads are equal to zero which means that they are all completely fed, this will be the end of this pass number i. If there is remaining tearing lines then another pass will begin by restoring all the loads to their original value and the previous two parts are repeated.

APPLICATION

The proposed technique is tested by applying it to IEEE-RBTS. The single line diagram of the test system is shown in Figure 7. All the data needed to calculate its buses reliability are given in Reference 9. The obtained results are compared with those obtained in Reference 10 to check the accuracy of the developed method. Reference 10 solves the IEEE-RBTS system once with the "Network Flow Approach" and once with the "AC load flow approach". It calculates failure probability at each node which is equal to [1-load point reliability]. Tables 1 and 2 compare the results obtained by the developed method with those of Reference 10

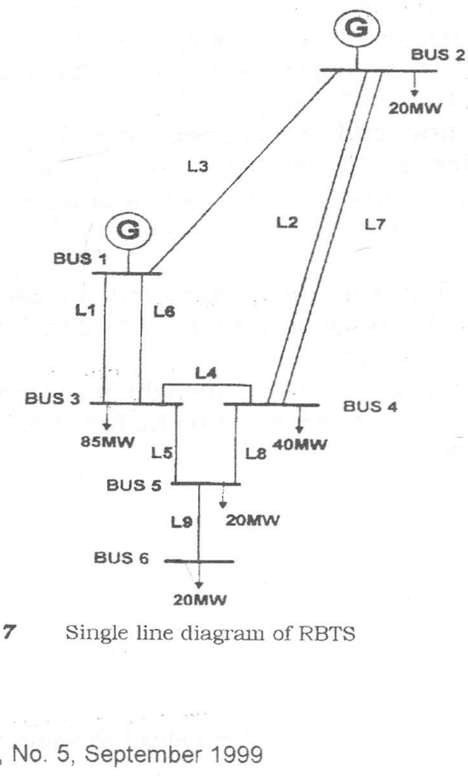

Figure 7 Single line diagram of RBTS

Table 1 Comparison between the developed method and network flow approach

Bus #	Bus reliability		Absolute difference	Error %
	Developed Method	Network flow approach		
1	0.9404295	N/A	----------	--------
2	0.9986	0.9916633	0.006937	0.7%
3	0.99235	0.9916633	0.000687	0.07%
4	0.999278	0.99161	0.007668	0.77%
5	0.9981	0.99162	0.00659	0.66%
6	0.99297	0.99048	0.00249	0.25%

It can be seen that the maximum error in Table 1 is 0.77% and the maximum error in Table 2 is 0.59% which are acceptable. If line #2 is not permitted to be over loaded, the error will be larger as node #6 reliability in the developed method will be 0.87737. It can be said that the proposed method in this case gives a pessimistic value for the reliability of this bus which is only connected to the remaining network by one line.

Table 2 Comparison between the developed method and AC load flow approach

Bus #	Bus reliability		Absolute difference	rror %
	Developed Method	AC load flow approach		
1	0.94042955	N/A	----------	-------
2	0.9986	0.99377	0.00483	0.49%
3	0.99235	0.99126	0.00109	0.11%
4	0.999278	0.99366	0.005618	0.56%
5	0.9981	0.99979	0.00169	0.17%
6	0.99297	0.998839	0.00592	0.59%

CONCLUSION

In this paper, an efficient algorithm is developed based on the tearing process to calculate the buses reliability of a composite power system. The proposed method is applied to the IEEE-RBTS and it is proved that this method is a powerful and accurate method which has the following advantages:-

1. The solution steps do not include any complex calculations.
2. It does not include any load flow iterations which are time consuming and subject to divergence in some contingencies.
3. The CPU time for any program based on this algorithm will certainly be very small compared to Monte Carlo simulation methods or contingency enumeration methods .

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طريقة مطورة لتقدير إعتمادية منظومة القوة الكهربية المركبة

عبد المنعم موسى*، محمود الجمال*، إمتثال نجم* و نادر عزيز**
* قسم الهندسة الكهربية كلية الهندسة جامعة الإسكندرية
**معهد المعلوماتية - مدينة مبارك للبحث العلمى

ملخص البحث

من أكبر الصعوبات التى تواجه حساب اعتمادية شبكة القوى الكهربية المركبة (توليد+نقل) هو وقت الحساب المستهلك فى عمل تحليل للشبكة. يقدم هذا البحث طريقة مبتكرة لتقدير إعتمادية منظومة القوة الكهربية المركبة بإستخدام تقنية تجزئة الشبكة. ومن أهم مميزات هذه الطريقة بساطتها وقلة الوقت المستخدم فى تحليل منظومة القوة الكهربية بدرجة كبيرة مقارنة بالطرق التقليدية الأخرى. ويقدم البحث خوارزم مبنى على أساس هذه الطريقة لتسهيل إستخدامها على الحاسب الآلى وذللك لحساب إحتمال فشل أى قضيب فى الشبكة المركبة. وقدم تم إختبار هذه الطريقة بتطبيقها على شبكة الإختبار القياسية (IEEE-Roy billinton) للتأكد من صحة هذه الطريقة.