A new method to calculate bus failure frequency of composite power systems based on graph partitioning technique

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This paper is a direct continuation of the work in which a reliability assessment of a composite power system based on graph partitioning technique was developed. The technique is expanded to calculate bus failure frequency of composite power systems. The proposed algorithm is more efficient and accurate than others and it is tested on IEEE-Roy Billinton Test System (RBTS).

يعتبر حساب تردد حدوث عدم وجود قدرة كافية عند أحد قضبان شبكة القوى الكهربية المركبة (توليد+نقل) عامل مهم لا يقل أهمية عن حساب الاعتمادية. يقدم هذا البحث طريقة مبتكرة لحساب تردد الفشل لمنظومة القوى الكهربية المركبة باستخدام تقنية تجزئة الشبكة. يعتبر هذا البحث امتداد لبحث سابق قدم طريقة لتقدير إعتمادية منظومة القوى الكهربية المركبة. ومن أهم مميزات الطريقة بساطتها وقلة الوقت المستخدم فى تحليل منظومة القوى الكهربية بدرجة كبيرة مقارنة بالطرق التقليدية الأخرى. ويقدم البحث خوارزم مبنى على أساس هذه الطريقة لتسهيل استخدامها على الحاسب الآلى وذلك لحساب تردد فشل أى قضيب فى الشبكة المركبة. وقدم تم اختيار هذه الطريقة بتطبيقها على شبكة الاختبار القياسية (IEEE-Roy billinton) للتأكد من صحة هذه الطريقة وتم الحصول على نتائج جيدة.

Keywords: Power system reliability, Composite power system, Failure frequency, Network tearing.

1. Introduction

Calculation of the frequency of occurrence of an insufficient capacity condition at certain bus is as important index as bus reliability index.

This paper introduces an effective approach to be used in calculating failure frequency of any bus in composite power system reliability assessment. This method is an expansion of the method represented in [1]. The developed method is based on the graph partitioning technique [2] taking into consideration, the amount of available system generation and its reliability, maximum transmission lines capacity and 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 [3].

2. Basis of the proposed method

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

1) Calculation of generation failure frequency.
2) Tearing the whole network into trees and tearing elements.
3) Calculating bus failure frequency.

2.1. Calculation of generation failure frequency

In this part each generator is represented by two-state model as shown in fig. 1, and the forced outage rate (FOR) of each generator is considered to be an independent event.

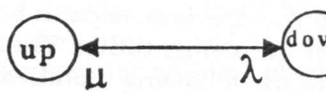

Fig. 1. Two-state model of generating units.

The load at each bus is assumed to be fixed and equal to its maximum value and the transmission line losses are negligible.

Also the total system load is assumed to be shared between generating stations as proportional to the installed generation capacity at each bus.

2.2. Tearing the whole network into trees and tearing elements

The network [N] under study is torn into "a" subnetworks $[N_1, N_2, N_3, \ldots\ldots N_a]$ 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 [2].

2.3. Calculating bus failure frequency

In this part the initial values of bus failure frequency are calculated in each tree. The tearing elements are then added in steps and at each step the buses failure frequency 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 buses failure frequency and failure rate 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.

3. 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 failure frequency module.
3-Tearing module.
4-Initial calculation module.
5-Repetitive calculation module.

3.1. 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 [1].

3.2. Generation failure frequency module

In this module failure frequency 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 and 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 in section (2.1).

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

(5) For each bus # i having connected generating units, calculate the failure frequency of the generating station at this bus to supply an amount $\geq GS_i$. This value 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,

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

- The total rate of departure at any state "i" of generators combinations "$\lambda_{state\# \ i}$" is calculated as follows,

$$\lambda^{state\#i} = \sum_{j=1}^{n} \lambda_j + \sum_{j=1}^{m} \mu_j , \qquad (6)$$

where n is the number of generators in the up state and m is the number of generators in the down state in state # i of generators combinations in a bus with generating station have m+n generators installed, λ is the generator outage rate and μ is its repair rate.

- 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 P_i 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.
- Calculate the failure frequency of this state f_i [4]:

$$f_i = P_i * \lambda^{state\#i} . \qquad (7)$$

- The probability $P(GS_i)$ and failure frequency $f(GS_i)$ that this generating station can generate its share GS_i or more are obtained by adding all the state probabilities and failure frequency respectively in which

$$GA_i^{state\#j} \geq GS_i .$$

- The equivalent outage rate of this generating station to supply its share of the system load is calculated as follows:-

$$\lambda(GS_i) = f(GS_i) \;/\; P(GS_i). \qquad (8)$$

- 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 ,frequency failure and outage rate of this virtual line are equal to $P(GS_i)$, $f(GS_i)$ and $\lambda(GS_i)$, respectively.

3.3. Tearing module

The aim of this module is to tear the whole network into "a" trees and "b" tearing lines [1].

3.4. Initial calculation module

The aim of this module is to calculate failure frequency 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 availability 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:

$$A_i = \mu_i \;/\; (\lambda_i + \mu_i), \qquad (9)$$

where $\mu_i = 8760/r_i$ 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 that are updated at each step. This vector will be called the reliability vector R. 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 that 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) Construct a vector consisting of "n" rows to save system buses failure frequency which are updated at each step. This vector will be called failure frequency vector f. Initially f(1)=f(2)=..........=f(n-1)=f(n)=0.

(vi) Construct a vector consisting of "n" rows to save temporary failure frequency of system buses. This vector will be called the temporary failure frequency vector ft. Initially ft(1)=ft(2)=.........=ft(e)=0.

(vii) Consider any tree as shown in fig. 2. 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", avaliability $A(or_x)$, capacity $C(or_x)$ and outage rate $\lambda(or_x)$.

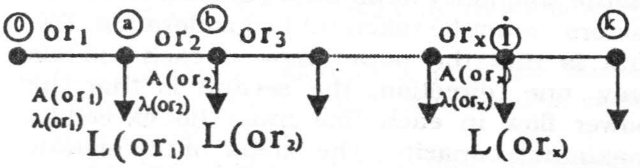

Fig. 2. Processing of initial calculation module.

(viii) 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., $\min\{C(or_2), C(or_3), \ldots\ldots, C(or_x)\} \geq L_i$, then node "i" reliability at this step is calculated as follows:

$$R^1(i) = A(or_1) x A(or_2) x \ldots A(or_x). \quad (10)$$

The equivalent failure rate of this node[5]:

$$\lambda^1_{eq}(i) = \sum_{j=1}^{x} \lambda(or_j). \quad (11)$$

The failure frequency of this bus is calculated as follows:

$$f^1(i) = R^1(i) * \lambda^1_{eq}(i). \quad (12)$$

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:

$$Rt^1(i) = A(or_1) x A(or_2) x \ldots A(or_x). \quad (13)$$

The temporary equivalent failure rate of this node

$$\lambda t^1_{eq}(i) = \sum_{j=1}^{x} \lambda(or_j). \quad (14)$$

The temporary failure frequency of this bus is calculated as follows:

$$ft^1(i) = Rt^1(i) * \lambda t^1_{eq}(i). \quad (15)$$

The bus reliability and failure frequency 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 $\min\{C(or_2), C(or_3), \ldots\ldots, C(or_x)\}$.

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

3.5. 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 fig. 3. 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 have less order have 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.

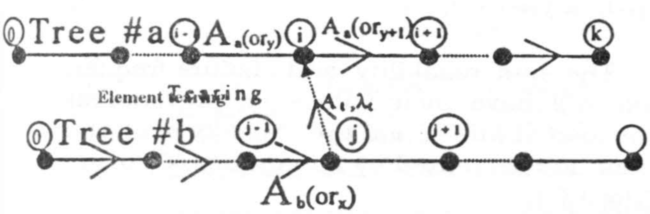

Fig. 3. Processing of repetitive calculation module.

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., $\min\{C_b(or_2),C_b(or_3),\ldots,C_b(or_x),C(or_t)\} \geq L'_i$.

The procedure to calculate node "i" failure frequency at this step is calculated as follows:

•Let $R'^{s+1}(i) = A_b(or_1) x A_b(or_2) x \ldots x A_b(or_x) x A_t$, (16)

where $A_b(or_x)$ is the availability of the line whose order is "x" in tree #b & A_t is the availability of the tearing line.

•Node "i" failure frequency at this step is calculated as follows:

Let $\lambda'^{s+1}(i) = \lambda_b(or_1)+\lambda_b(or_2)+\ldots+\lambda_b(or_x)+\lambda_t$, (17)

where $\lambda_b(or_x)$ is the outage rate of the line whose order is "x" in tree #b & λ_t is the outage rate of the tearing line.

•The series equivalent of λ'^{s+1} & λt^s is calculated as follows:

$$\lambda''^{s+1} = \lambda'^{s+1} + \lambda t^s. \quad (18)$$

• The series equivalent of $R''^{s+1}(i)$ & Rt^s is calculated as follows:

$$R''^{s+1}(i) = R'^{s+1}(i) * Rt^s , \quad (19)$$

• Let $f'^{s+1}(i) = \lambda''^{s+1} * R''^{s+1}(i)$. (20)

• Hence, the failure frequency of bus # i at this step (s+1) will then be the parallel equivalent of $[f^s(i)$ & $f'^{s+1}(i)]$ which is calculated as follows [5]:

$$f^{s+1} = [f^s(i)*(1 - R''^{s+1}(i)] + [f'^{s+1}(i)*(1 - R^s(i)]. \quad (21)$$

The capacities of all the lines belonging to tree #b and their order from 2 to x and that of the tearing line 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 failure frequency 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 means 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 failure frequency for this node is calculated as follows:

•Let $Rt'^{s+1}(i) = A_b(or_1) x A_b(or_2) x \ldots A_b(or_x) x A_t$. (22)

• The temporary reliability value for this node at this step is updated and will equal to the 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 fig. 3. 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 have less order have 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.

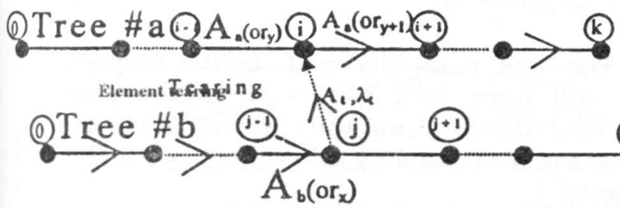

Fig. 3. Processing of repetitive calculation module.

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., $\min\{C_b(or_2),C_b(or_3),\ldots,C_b(or_x),C(or_t)\} \geq L'_i$.

The procedure to calculate node "i" failure frequency at this step is calculated as follows:

•Let $R'^{s+1}(i) = A_b(or_1)xA_b(or_2)x\ldots xA_b(or_x)xA_t$, (16)

where $A_b(or_x)$ is the availability of the line whose order is "x" in tree #b & A_t is the availability of the tearing line.

•Node "i" failure frequency at this step is calculated as follows:

Let $\lambda'^{s+1}(i) = \lambda_b(or_1)+\lambda_b(or_2)+\ldots+\lambda_b(or_x)+\lambda_t$, (17)

where $\lambda_b(or_x)$ is the outage rate of the line whose order is "x" in tree #b & λ_t is the outage rate of the tearing line.

•The series equivalent of λ'^{s+1} & λt^s is calculated as follows:

$$\lambda''^{s+1}=\lambda'^{s+1} + \lambda t^s. \quad (18)$$

• The series equivalent of $R''^{s+1}(i)$ & Rt^s is calculated as follows:

$$R''^{s+1}(i)=R'^{s+1}(i) * Rt^s , \quad (19)$$

• Let $f'^{s+1}(i)= \lambda''^{s+1} * R''^{s+1}(i)$. (20)

• Hence, the failure frequency of bus # i at this step (s+1) will then be the parallel equivalent of $[f^s(i)$ & $f'^{s+1}(i)]$ which is calculated as follows [5]:

$$f^{s+1}= [f^s(i)*(1- R''^{s+1}(i)] + [f'^{s+1}(i)*(1- R^s(i)]. \quad (21)$$

The capacities of all the lines belonging to tree #b and their order from 2 to x and that of the tearing line 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 failure frequency 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 means 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 failure frequency for this node is calculated as follows:

•Let $Rt'^{s+1}(i) = A_b(or_1)xA_b(or_2)x\ldots A_b(or_x)xA_t$. (22)

• 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., $Rt^{s+1}=Rt^s \times Rt'^{s+1}$

- Let $\lambda'^{s+1}(i)=\lambda_b(or_1)+\lambda_b(or_2)+\ldots+\lambda_b(or_x)+\lambda_t$. (23)

- The temporary outage rate for this node at this step is updated and will equal to the series operation of λt^s and $\lambda t'^{s+1}$, i.e.,

$$\lambda t^{s+1}=\lambda t^s + \lambda t'^{s+1} . \qquad (24)$$

- The temporary frequency failure for this node at this step is calculated as follows:

$$f\, t^{s+1}(i)= \lambda t^{s+1} * Rt^{s+1}(i) . \qquad (25)$$

The bus reliability and failure frequency will still have their values at step #s ,i.e., $R^{s+1}(i)=R^s(i)$ & $f^{s+1}(i)=f^s(i)$.

The capacities of all these lines are decreased by an amount equal to min $\{C_b(or_2), C_b(or_3), \ldots, C_b(or_x), C_t\}$

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

(2) After adding the tearing lines in the just described way until all loads which are fed partially are completely fed, add a tearing lines which is connected between a node #i in any tree #a which 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:

(i) First case, min $\{C_b(or_2), C_b(or_3), \ldots, C_b(or_x), C(or_t)\} \geq L_i$

- Let $R'^{s+1}(i) =A_b(or_1)xA_b(or_2)x\ldots xA_b(or_x)xA_t$. (26)

Let $\lambda'^{s+1}(i) =\lambda_b(or_1)+\lambda_b(or_2)+\ldots+\lambda_b(or_x)+\lambda_t$. (27)

Let $f'^{s+1}(i)= \lambda'^{s+1} * R'^{s+1}(i)$. (28)

- Hence, the failure frequency of bus # i at this step (s+1) will then be the parallel equivalent of $[f^s(i)$ and $f'^{s+1}(i)]$ which is calculated as follows[5]:

$$f^{s+1} = [f^s(i)*(1- R'^{s+1}(i))] + [f'^{s+1}(i)*(1- R^s(i))]. \qquad (29)$$

The capacities of all the lines belonging to tree #b and their order from 2 to x and that of the tearing line 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 fed in this pass. The reliabilities and failure frequencies of the nodes subsequent to 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 means that there is not enough transmission capacity.

(ii) Second case, min$\{C_b(or_2), C_b(or_3), \ldots, C_b(or_x), C(or_t)\} < L_i$

In this case the load is fed by the minimum transmission capacity available. The temporary reliability and temporary outage rate for this bus are calculated as follows:

$$Rt^{s+1}(i)=A_b(or_1)xA_b(or_2)x\ldots A_b(or_x)xA_t. \qquad (30)$$

$$\lambda t^{s+1}(i)=\lambda_b(or_1)+\lambda_b(or_2)+\ldots.\lambda_b(or_x)+\lambda_t. \qquad (31)$$

The temporary frequency failure for this node at this step is calculated as follows:

$$f\, t^{s+1}(i)= \lambda t^{s+1} * Rt^{s+1}(i) . \qquad (32)$$

The bus reliability and failure frequency will still have their values at previous step. The load at bus #i and the capacity of all these lines are decreased by min$\{C_b(or_2), C_b(or_3), \ldots, C_b(or_x),C_t\}$.

(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.

4. Application

The proposed technique is tested by applying it to the IEEE-RBTS. The single line diagram of the test system is shown in fig.4. All the data needed to calculate its buses failure frequency are given in [6]. After applying generation failure frequency module the system new configuration will be as shown in fig. 5. The obtained data for the two added virtual lines are given in table 1. The output results of the tearing module is shown in fig. 6.

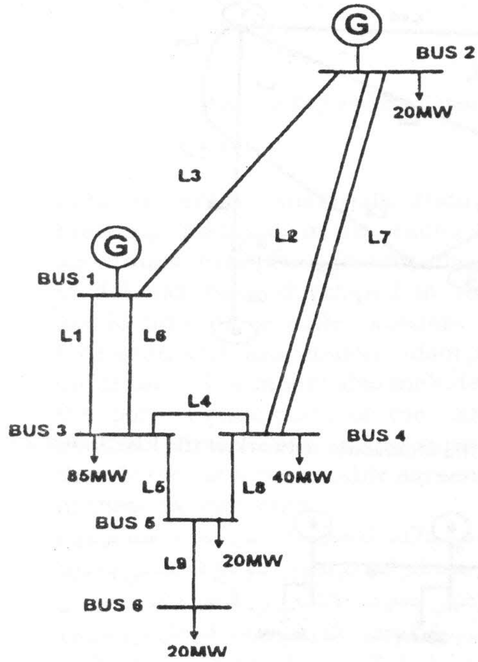

Fig. 4. Single line diagram of RBTS.

Table 1
The obtained data for the added virtual lines

Virtual line #	Its availability	Its failure rate	Its failure frequency
10	0.940429	29.40316	27.6516
11	0.978675	29.429586	28.802

The obtained results are compared with that obtained in [3] to check the accuracy of the developed method. Ref. [3] solves the IEEE-RBTS system once with the "Network Flow Approach" and once with the "AC load flow approach". It calculates failure frequency of each load bus. Table 2. compares the results obtained by the developed method with those of [3].

It can be seen that the results have a slight difference in some buses which are buses # 2,4 and 5. The obtained failure frequency is higher in buses # 3 and 6. [3] itself when using two different methods obtained different results. The difference in results is due to the assumptions assumed in each method procedures. The developed method gives pessimistic results since all the buses are assumed to have their maximum load at the same time. The developed method contains no iterations, it only contains simple algebraic operations. The execution time of the developed software package program, using Intel 486 machine and compiler of the Pascal language, does not take more than 0.1 of the second in comparison with other analytical methods which requires the execution of load flow programs hundreds of time to solve the composite system reliability problem and the execution time on the same machine may take several hours.

Table 2
Comparative results between the developed method and other methods

Bus #	Bus failure frequency		
	Developed method	Network flow approach	AC load flow approach
2	2.52633	3.6419752	2.6840122
3	10.43242	3.7288585	4.2465763
4	1.82512	3.7290108	2.8416128
5	3.13957	3.7314045	0.2929301
6	11.74721	4.8542213	1.1587838

5. Conclusions

This paper introduces an effective approach to be used in calculating failure frequency of any bus in composite power system reliability assessment. This method is an expansion of the method represented in [1]. The developed method is based on the graph partitioning technique presented by the authors in [2].

The developed method has the following merits over other ones:

(1) The solution steps do not include any complex calculations, it contains only simple algebraic operations.

(2) It does not include any load flow iterations that 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.

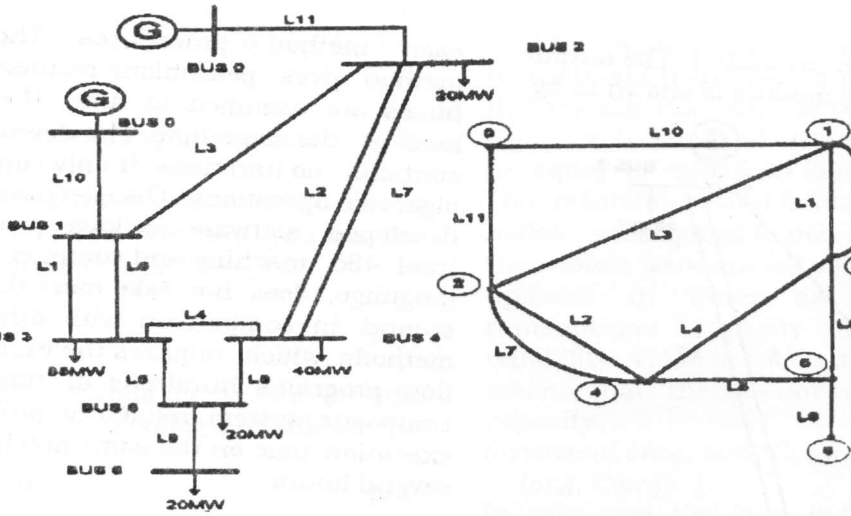

Fig. 5. a) Single line diagram of the RBTS after adding the virtual lines. b) The stochastic network of the RBTS after adding the virtual lines.

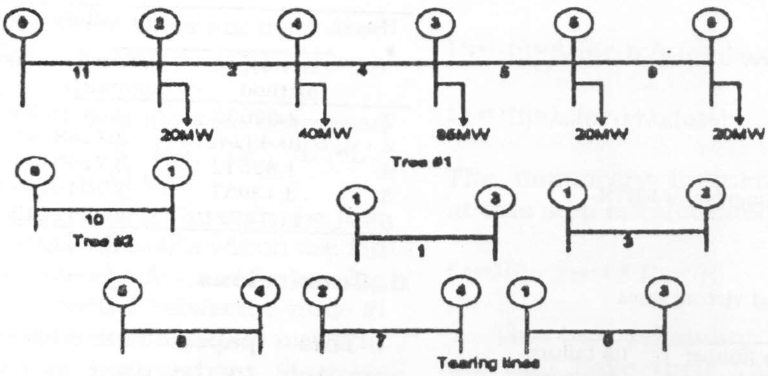

Fig. 6. Results of the tearing process on the modified RBTS system.

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