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ORIGINAL ARTICLE

Composite power system reliability evaluation using modified minimal cut set approach

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Minimal cut set;
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Abstract The composite power system reliability analysis is generally based on minimal path or cut enumeration, tracing of power flow paths from which the related reliability indices are calculated. The minimal cut set is a popular method in the reliability analysis for simple and complex configurations. Average availability of power supply at the consumer end is one of the reliability assessment parameter. This paper is concerned about the evaluation of this reliability index. A step by step procedure for a modified minimal cut set method is explained in this paper using IEEE 6 bus, 14 bus and Single area IEEE RTS 96 system. The proposed algorithm is easy to program and can be applicable to any system. The proposed algorithm is validated with the Classical Node Elimination method, Step by Step algorithm using Conditional Probability and Monte Carlo Simulation method. The proposed technique is tested with a practical example taken from Roy Billinton paper (Reliability evaluation in distribution and transmission systems).

1. Introduction

The role of the modern power system is to satisfy the load as economically as possible, and with some reasonable level of continuity and quality. There are several methods available for the calculation of average power availability, which is one of the important reliability indices [1–8]. Some of the popular methods used are Minimal cut set, Series- Parallel, Star-Delta, Tracing of Power flow paths, Node Elimination method and step by step algorithm using conditional probability. The modified minimal cut-set approach is proposed in this paper is an improvement over the method reported in [9]. In [9], all the branches included in each cut set of order 1 and also are assumed to be in parallel. Assuming that the sending end of each branch in the cut set has the same probability of availabilities and which is not correct. In the proposed method has this assumption is not used. The procedure adapted is explained in the following sections. The initial step in the cut-set method is to figure out the minimal cut-sets of the system. The identification of minimal cuts becomes more difficult in large complex systems. Some algorithms like Node Elimination method are developed further to reduce this effort for identification.

One of the objectives used for the evaluation of composite power system reliability is power availability at load buses [10–13]. Some assumptions made in the proposed algorithm are given below.

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- The failure and repair rates during the operating life of the component are assumed to be constant and the probability distribution of the failure and repair states of the component are exponentially distributed.
- Each Component repair and failure state is independent of the states of other components.

A system is said to be connected if there exists a path between the source and the sink. The removal of the cut set results in the separation of the system into two independent subsystems. One contains all inputs and other system contains all node points. A cut set is a set of components whose failure will cause system failure [14–20]. More details of the cut set are available in Appendix A with example. The proposed algorithm discussed in this paper has the following advantages.

- It is very efficient and easy to program.
- The proposed algorithm is applicable to any number of bus systems.
- It takes less computation time compared to other methods.

In literature several methods are available for the calculation of network reliability. Monte Carlo simulation technique has been used by many authors for the estimation of reliability indices including power availability [21–23]. This method is very popular but takes large computational time. However, it is widely used for comparison testing of the new methods. The results obtained by the proposed method are validated by Monte Carlo Simulation and also by Classical Node Elimination method discussed in [24–30]. The steps for the methodology used in the proposed method are discussed in the following sections.

The paper is organized as follows. Section 2 discusses the proposed technique and Section 3 deals with the results and Section 4 describes the results obtained.

2. Evaluation technique

The technique is used to find the average power availability at the consumer end in a composite power system and is based on the minimal cut sets.

The steps involved in the proposed algorithm are

1. Draw the graph of the network.
2. Generators are connected to the network node through a branch towards that node.
3. Loads are directly connected to the bus called the load node.
4. All branches are represented by the reliability parameters failure and repair rates (λ & μ).
5. Choose a particular load node.
6. Obtain the cut set which isolates this node.
7. For those cut branches which are incident in this node assume the probability of availability of power at the node at the other end of the branch.
8. Based on these probabilities (P), compute the probability of average power availability $\left(\sum P \times \left(\frac{\mu}{\lambda+\mu}\right)\right)$ at the chosen load node.
9. Find the cut set which isolates all these above nodes identified in step7.
10. Repeat steps 7 and 8 to find the power availabilities at these nodes assuming the probabilities at the other end of the branches in the cut set.
11. Using these probabilities evaluate the probability of power availabilities at these cut nodes.
12. Repeat this exercise until all the nodes are covered including all generator nodes.
13. Using these probabilities works backwards to compute the probability of power availability at the chosen load node.
14. Repeat this exercise for all the load nodes.
15. Obtain the system overall average power availability from step 14.

The proposed algorithm is tested with the practical example taken from the Roy Billinton paper. The configuration of the example is shown in the Fig. 1. The system is connected to generators at the buses 1, 7 and 8 through interconnecting transformers. The failure and repair rates are assumed to be identical for all components throughout the system. This is only for convenience. If different failure and repair rates are specified for each component like generator, transformer, line, etc. the same can be used. There will be no change in the procedure steps 1 to 15 indicated above.

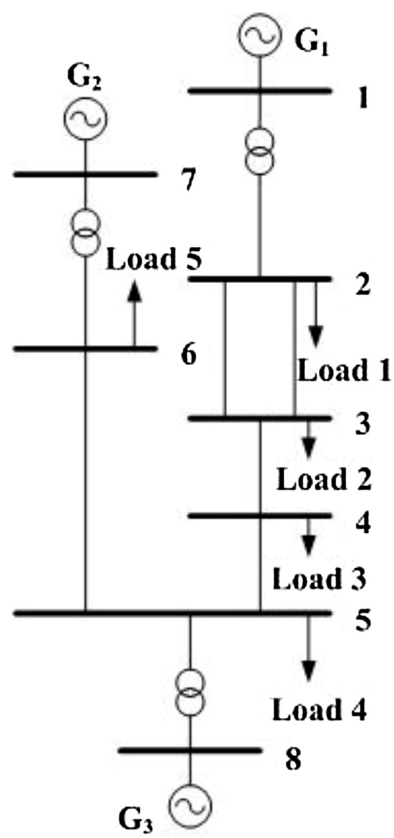

Fig. 1 Practical example.

Table 1 Average power availability in practical example.

S. no.	Load no.	Proposed method	Node elimination method	Monte Carlo Method	Step by step algorithm using conditional probability
1	Load 1	0.994	0.999	0.989	0.999
2	Load 2	0.984	0.985	0.974	0.992
3	Load 3	0.985	0.995	0.956	0.995
4	Load 4	0.991	0.998	0.985	0.998
5	Load 5	0.988	0.998	0.965	0.998

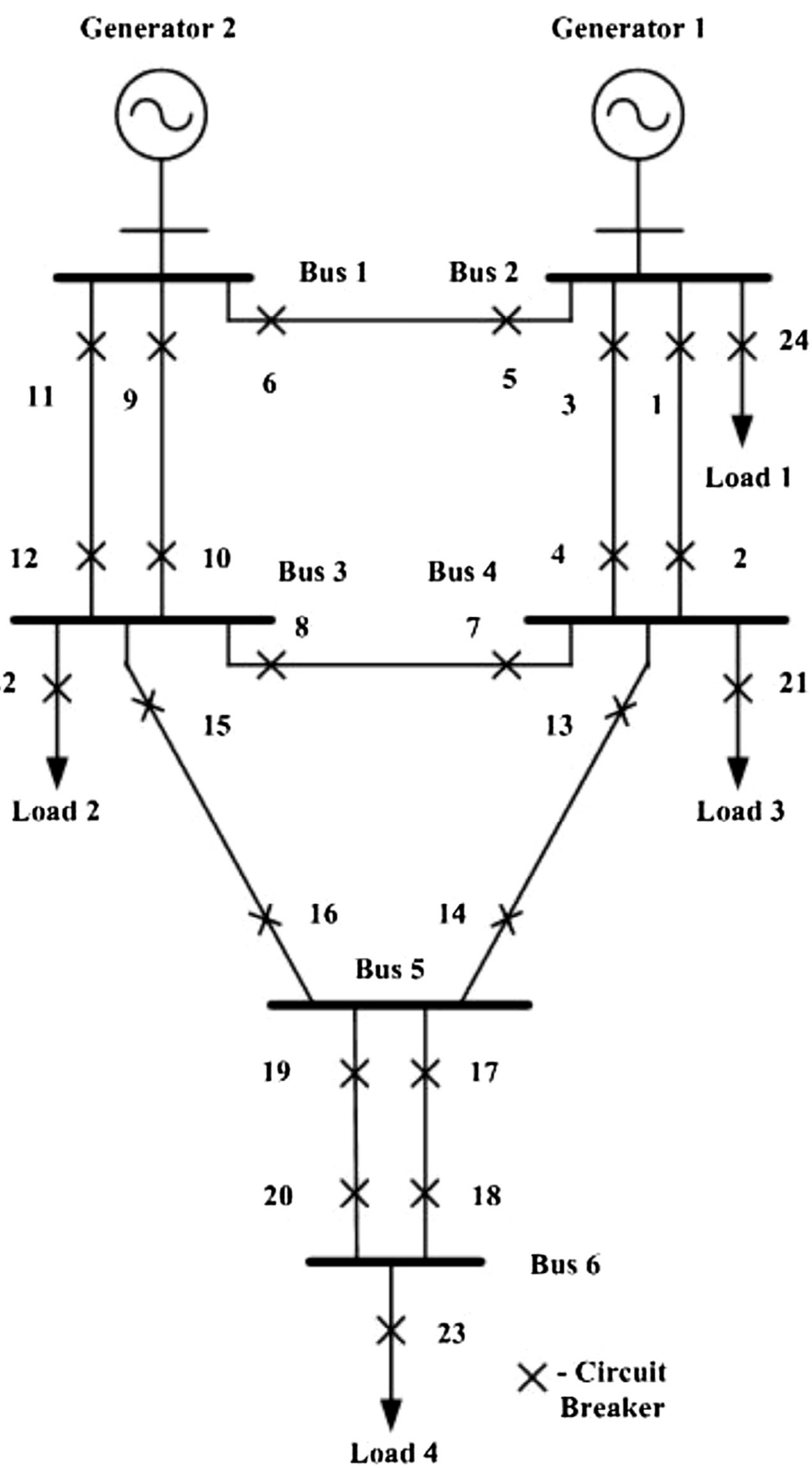

Fig. 2 IEEE 6 bus reliability test system.

3. Results and discussion

The algorithm presented in the previous section has been applied to practical example. In this practical example all components are assumed to have identical reliability data ($\lambda = 0.1$, $\mu = 10$). The results are shown in Table 1. The proposed methodology is validated by the Monte Carlo Simulation

Table 2 Average power availability in IEEE 6 bus system.

S. no.	Load no.	Proposed method	Node elimination method	Monte Carlo method	Step by step algorithm using conditional probability
1	Load 1	0.994	0.994	0.92737	0.990
2	Load 2	0.984	0.967	0.89847	0.978
3	Load 3	0.935	0.939	0.90790	0.946
4	Load 4	0.883	0.884	0.85934	0.887

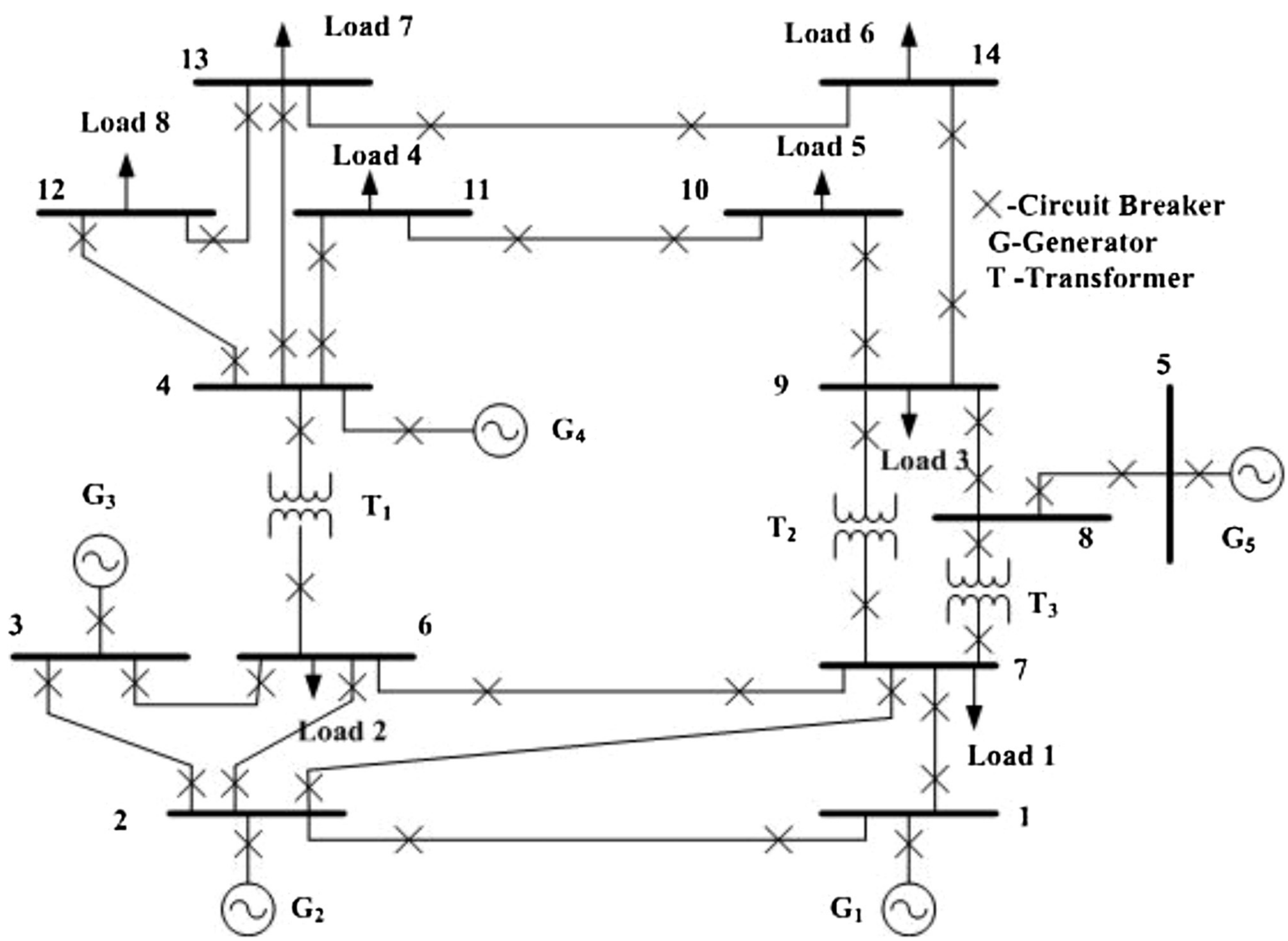

Fig. 3 IEEE 14 bus reliability test system.

Table 3 Average power availability at different loads in IEEE 14 bus system.

S. no.	Load no.	Proposed method	Node elimination method	Step by step algorithm using conditional probability
1	Load 1	0.956	0.967	0.957
2	Load 2	0.955	0.967	0.957
3	Load 3	0.967	0.967	0.966
4	Load 4	0.929	0.938	0.928
5	Load 5	0.911	0.914	0.914
6	Load 6	0.911	0.917	0.917
7	Load 7	0.942	0.951	0.944
8	Load 8	0.933	0.939	0.939

method [23], Node Elimination method [24] and Step by step algorithm using Conditional Probability [28].

The algorithm developed in this paper is also applied on IEEE suggested power system network to validate the results. The IEEE 6 Bus system is shown in Fig. 2. The reliability data of the system is given in the Appendix A. The power availability at the load buses are given in Table 2.

To show the efficiency of the proposed method for reliability analysis of large systems, the IEEE 14 bus system and IEEE RTS 96 system are used. The IEEE 14 bus system is shown in Fig. 3. The reliability data of the IEEE 14 bus system is given in Appendix A. The results obtained for the IEEE 14 bus system are shown in Table 3.

The proposed methodology is also applied and tested on IEEE single area RTS-96 system shown in Fig. 4. The reliability data for IEEE single area RTS-96 System is taken from [18]. The average power availability at the load buses for the system is shown in Table 4. The results show the effectiveness

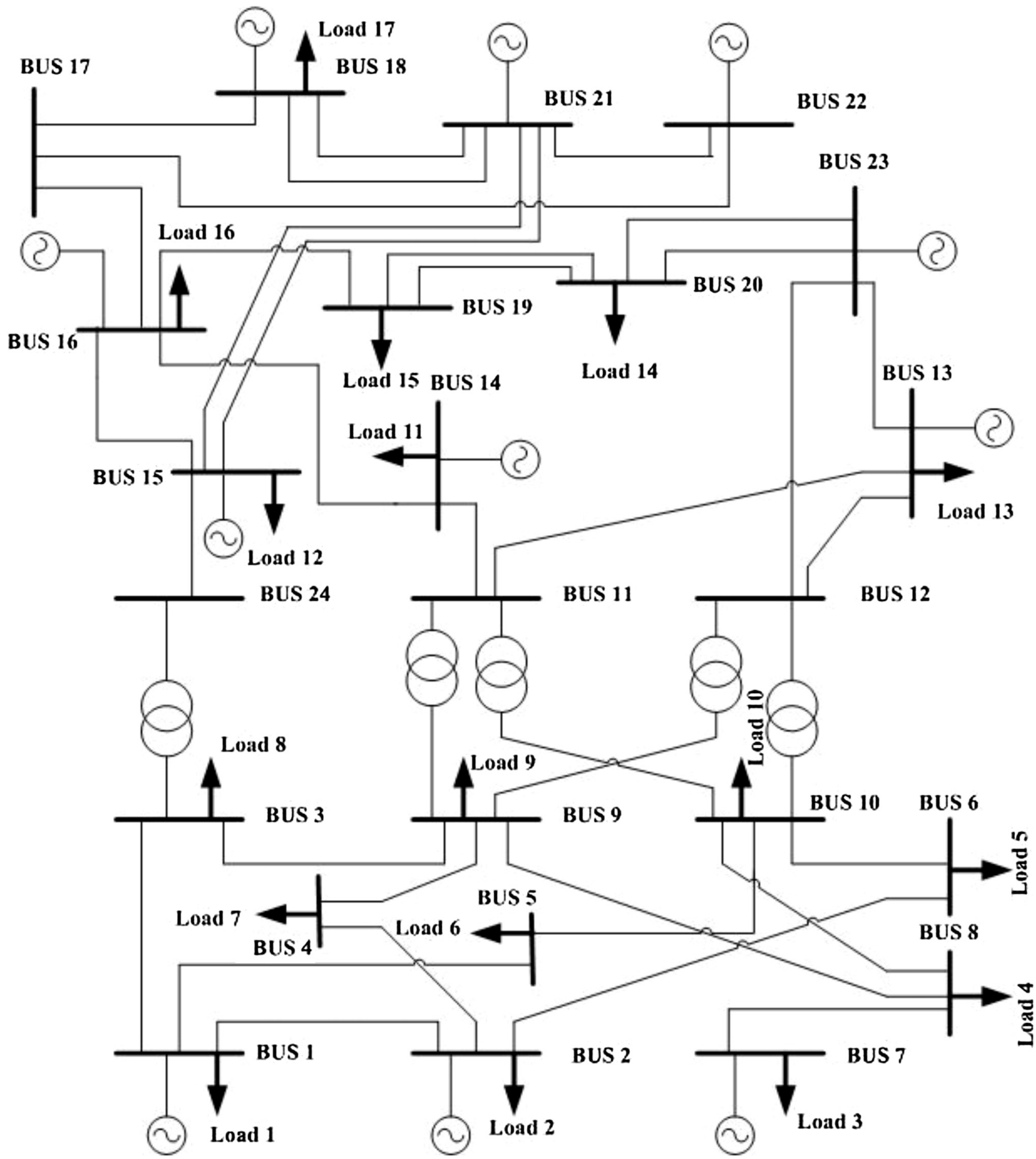

Fig. 4 IEEE single area RTS-96 system.

Table 4 Average power availability at different loads in IEEE single area RTS-96 system.

S. no.	Load no.	Proposed method	Node elimination method	Step by step algorithm using conditional probability
1	Load 1	0.881	0.885	0.885
2	Load 2	0.822	0.819	0.829
3	Load 3	0.555	0.558	0.555
4	Load 4	0.852	0.846	0.852
5	Load 5	0.812	0.812	0.812
6	Load 6	0.813	0.812	0.813
7	Load 7	0.815	0.812	0.813
8	Load 8	0.833	0.836	0.833
9	Load 9	0.855	0.859	0.859
10	Load 10	0.854	0.857	0.854
11	Load 11	0.811	0.818	0.811
12	Load 12	0.836	0.832	0.836
13	Load 13	0.844	0.845	0.844
14	Load 14	0.786	0.788	0.788
15	Load 15	0.764	0.763	0.764
16	Load 16	0.862	0.868	0.864
17	Load 17	0.800	0.808	0.800

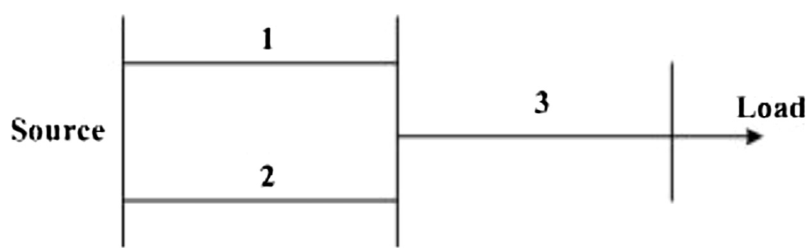

Fig. 5 Simple system to illustrate the cut-set concept.

Table 5 Cut sets.

Cut set	Components in cut
1	3
2	1, 2
3	1, 3
4	1, 2, 3
5	2, 3

Table 6 Minimal cut-sets.

Cut set	Components in cut
1	3
2	1, 2

of the proposed methodology and also its applicability to larger systems is also achieved. The methodology is tested with standard RTS 96 system.

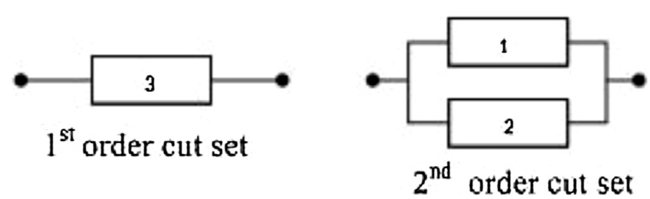

Fig. 6 Minimal cut sets for example system.

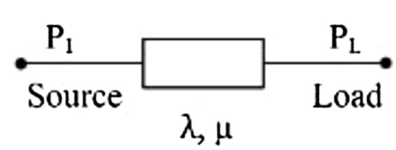

Fig. 7 Cut set branch.

4. Conclusion

In this paper the reliability analysis is achieved by a new step by step algorithm using modified minimal cut set approach. The proposed algorithm is tested with one practical example, IEEE 6, 14 and IEEE RTS 96 systems. The results show the effectiveness and applicability of the proposed method for large power system. The algorithm is programmed in MAT LAB and is applicable to any system. The methodology developed is validated by the Node Elimination method, Step by step algorithm using Conditional Probability and Monte Carlo Simulation method. The proposed method is useful for the reliability analysis in the planning of power systems.

Appendix A

The general approach is given in the following example where the cut sets for load in Fig. 5 are shown in Table 5.

The definition of a minimal cut-set as a cut set in which there is no subset of components whose failure alone will cause the system to fail, implies that a normal cut set corresponds to more component failure than are required to cause system failure. The minimal cut-sets for the load in the given example are shown in Table 6. The order of the cut sets are shown in Fig. 6.

The concept of conditional probability is explained with the example given in Fig. 5. In this system the generator is connected at the right side. The load bus is 3. The second order cut set is supplied by two paths and having sending end power availability of P_1. The equivalent system is shown in Fig. 7. λ, μ are the overall equivalent failure and repair rates of branches 1 and 2 in parallel and in series with branch 3.

Considering the probability of power availability at the source end, the equivalent failure, repair rates between source and load are given by

$$\lambda' = \frac{\lambda}{P_1} \tag{1}$$

$$\frac{1}{\mu'} = (1 - P_1)\frac{1}{\lambda} + \frac{P_1}{\mu}$$

$$\mu' = \frac{\lambda \times \mu}{(1 - P_1)\mu + P_1\lambda} \tag{2}$$

The net power availability at the receiving end is given by

$$\text{Power availability} = \frac{\mu'}{\mu' + \lambda'} \tag{3}$$

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