RELIABILITY ASSESSMENT OF DISTRIBUTION SYSTEMS WITH DISTRIBUTED GENERATION BASED ON BAYESIAN NETWORKS

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Abstract:

Reliability assessment is of primary importance in designing and planning distribution systems that operate in an economical manner with minimal interruption of customer loads. Distributed generation (DG) units are subject to failures as all other generation units, the random behavior of these units must be taken into account in the analysis. In this paper, a new method based on Bayesian Networks is introduced for reliability analysis of distribution systems with distributed generation. The method permits not only computing the reliability indices of a distribution system but also presenting the effect of each component or some components on the system reliability. Thus the shortcomings of traditional reliability assessment methods are overcome. The impacts of DG units, their location, DG unit capacity in each location and their availability, on distribution system reliability are investigated using a study case of distribution including distributed generation.

1 Introduction

At present, the deregulated electric power utilities are being restructured and operated as distinct generation, transmission and distribution companies and the responsibility of maintaining reliability of the overall power system is shared by all involved companies instead of by a single electric utility [1]. Distributed generation (DG) is expected to play an increasing role in emerging power systems because they use different types of resources and technologies to serve energy to power systems. DG is expected to improve the system reliability as its backup generation. Since DG units are subject to failures as all other generation units, the random behavior of these units must be taken into account in the analysis [2].

The main goal of power system reliability assessment is to provide qualitative analysis and indices in power supply reliability for the operation and planning system. After the qualitative analysis, it is very necessary to find out weak system components. At present, there are only two approaches, analytical approach and Monte-Carlo Simulation approach, used to calculate the reliability indices. However, both of them cannot find weak system components. Bayesian network (BN) is one of the most effective theoretical models for uncertainty knowledge expression and inference. Based on probability theory, it can make causal inference, diagnosis inference and explaining inference. Given one or several variables values, all the other variable conditional probabilities can be obtained. Therefore, we can make any kinds of hypothesis analysis in the view of the whole system and sequentially can

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identify system bottlenecks. Reference [3] discusses the properties of the modeling framework that make BN particularly well suit for reliability applications. Reference [4] proposes a novel BN-based reliability modeling/analysis approach to handle the ever-increasing complexity of systems, and perform various analyses such as reliability index computation, and sensitivity analysis. Reference [5] presents a continuous-time Bayesian network (CTBN) framework for dynamic systems reliability modeling and analysis. References [6] discuss BN models of generic multi-states reliability systems and its inference techniques. Reference [7] is the first paper to apply BN in reliability evaluation of interconnected power systems. References [8-11] make some study on applying BN to reliability evaluation of power stations or distribution systems. Most of power system reliability parameters and network structures come from References [12, 13]. References [14-15] presented Bayesian Network time-sequence simulation inference algorithm for reliability assessment of power systems. References [16] studied the convergence criterion for distribution systems reliability assessment based on Bayesian Network sequential simulation.

In the process of applying Bayesian networks to reliability assessment of power system, all the above references [9-16] do not consider the impact of DG units upon the power systems. References [17] consider the DG and Micro grids, but it used Monte Carlo Simulation method to evaluate distribution system reliability. In this paper, reliability assessment of distribution systems including distributed generation based on Bayesian Networks is presented. A sensitivity analysis is performed to examine the impact of DG units, their location, their availability, and their number on reliability indices.

2 The establishment of the Bayesian network

2.1 The reliability test system

By comparing the computing results of the traditional analysis approach and the Bayesian networks method, the correctness of the Bayesian networks method for reliability assessment can be vindicated. The example system has come from a reliability test system (RBTS) [12], it is shown in Fig. 1. The failure rate (λ) and outage time (r) of distributed generation are 5 f/yr and 50 hr respectively [2], breakers 6,7 and 8 are assumed to be 80% reliable with no alternative supply to main feeder 4[13],the other failure element parameters derived from reference [12].

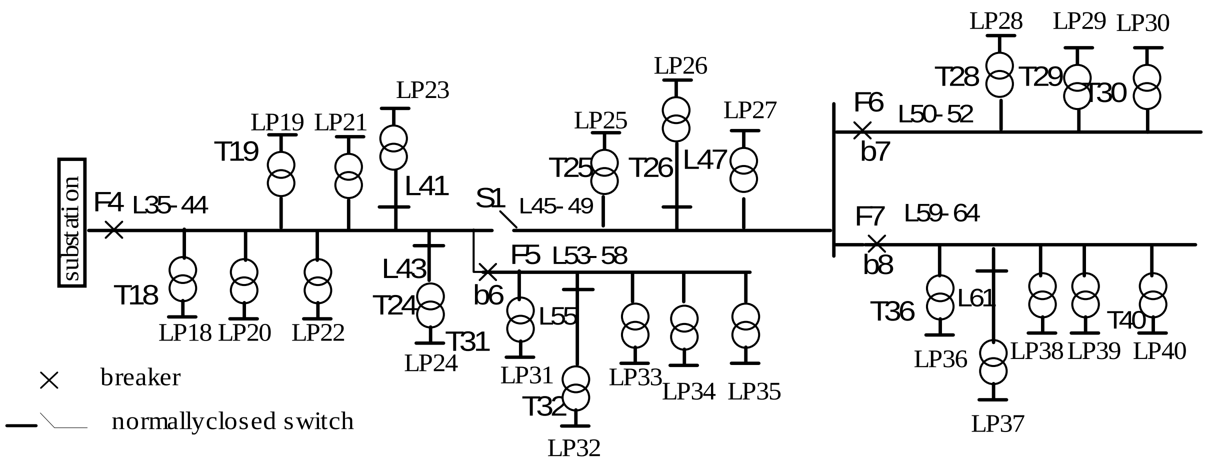

Figure 1. Complete Single line diagram of RBTS.

The approaches to Build Bayesian network are: first, represent the distribution system topology by using a dynamic chain form. Then, find all kinds of fault models by using a chain form searching technology. Last, build the corresponding Bayesian network by utilizing a node model [9]. Fig. 2 is the Bayesian network derived from Fig. 1.

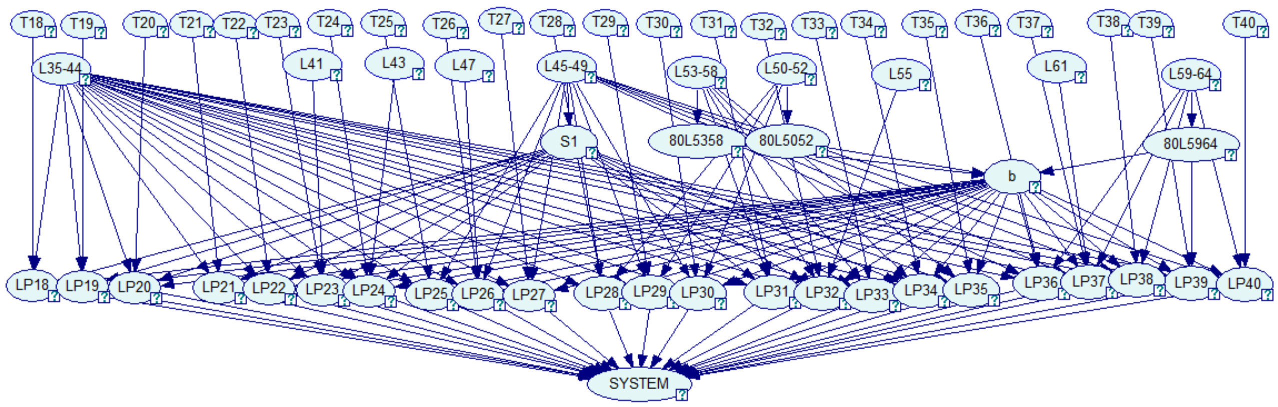

Figure 2. The Bayesian network of Figure 1.

Based on the element data and the configuration of the general feeder [18], a set of traditional analysis formulas for calculating the basic load-point indices of load-point failure rate λ_s , average outage duration r_s and average annual outage time U_s for load point s of a general feeder is as follows:

$$\lambda_s = \sum_{i \in s} (\lambda_i' + \lambda_i'') \tag{1}$$

$$U_s = \sum_{i \in s} (\lambda_i' r_i' + \lambda_i'' r_i'') \tag{2}$$

Table 1 shows a representative sample of the load-point reliability indices, the indices are equal to the calculation results of literature [13]. The average service availability index (ASAI) of the system can be calculated using the following formula:

$$ASAI = \frac{8760 \sum_i N_i - \sum_i N_i U_i}{8760 \sum_i N_i} \tag{3}$$

$$r_s = \frac{U_S}{\lambda_S} \tag{4}$$

Where λ_i' = failure rate of the failed component i (occ/year);

λ_i'' = the maintenance outage rate of the component i (occ/year);

r_i' = repair time of the failed component i (h);

r'' = maintenance outage time of the component i (h).

Here, N_i is the number of a customer in the load point i, U_i is the average annual outage time at the load point i.

The calculated result is 0.99817, which is equal in value by the Bayesian networks computational inference. It indicates that the Bayesian networks method can be used for reliability assessment of a power distribution system.

Table 1. Load-point indices

Load point (i)	Failure rate (occ/year)	Outage duration (h)	Unavailability (h/year)
1	0.3303	2.4716	0.8163
10	0.3595	2.2434	0.8065
20	3.4769	4.1915	14.5735
25	3.4769	5.0216	17.4595
35	3.6498	4.2298	15.438

2.2 Distribution system including distributed generation

The studied system was adapted from a reliability test system (RBTS) [12]. Add 4 distributed generations (DG) and change breakers of feeder F5-F7 into normally closed switches, the adapted system as shown in Fig. 3. The failure rate (λ) and outage time (r) of distributed generation are 5 f/yr and 50 hr respectively [2], the other failure element parameters derived from reference [12].

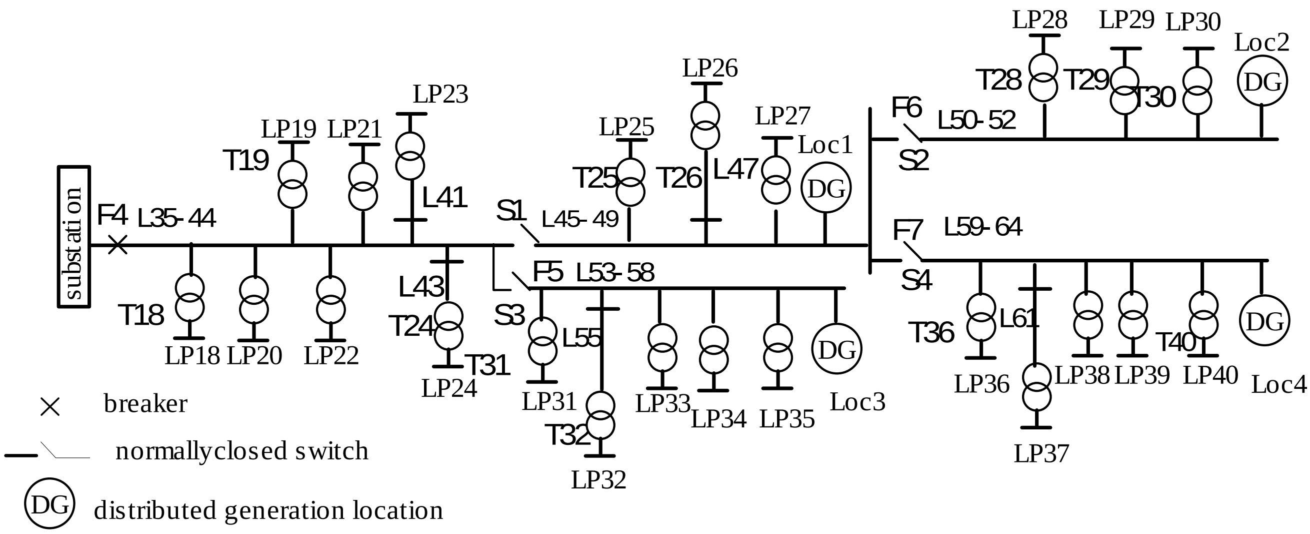

Figure 3. Complete Single Line Diagram of RBTS.

In this paper, DG units are on line mode. The capacities of DG1, DG2, DG3 and DG4 are greater or equal than the corresponding island zone1, zone2, zone3 and zone4 respectively [19]. The island zones and their loads capacities are shown in Fig. 4. If the DG rating is less than the loads on the island, then the zone loads should be partly cut down when the island is only supplied by zone DG units, that case is not considered in the paper. Fig. 5 is the Bayesian network derived from Fig. 3.

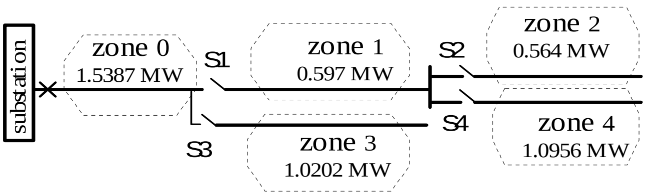

Figure 4. The island zones of the radial distribution network

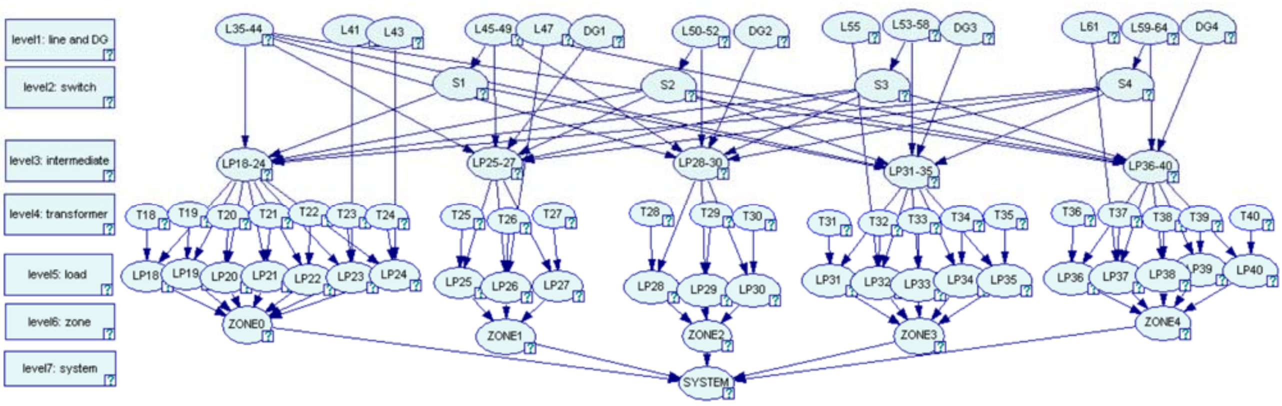

Figure 5. The Bayesian network of Figure 3.

3 The effect of DG units and each component on system indices

3.1 The effect of DG units on system indices

After building the Bayesian network, the index ASAI (Average Service Availability Index) can be calculated based on Bayesian network exact inference algorithm [20]. Based on index ASAI, the other indices, such as Average Service Unavailability Index (ASUI), System Average Interruption Duration Index (SAIDI), Energy Not Supplied Index (ENS) and Average Energy Not Supplied Index (AENS) can be computed, the computational formulas are as follows:

$$ASUI = 1 - ASAI \quad (5)$$

$$SAIDI = ASUI * 8760 \quad (6)$$

$$\text{ENS} = \sum(\text{the average load connected to load point} * \text{SAIDI}) \quad (7)$$

AENS=ENS/total number of customers served (8)

Suppose the DG units are equipped protection relays, the fault of the DG units will not affect the System Average Interruption Frequency Index (SAIFI). The distribution system indices with DG units and without DG units are shown in Fig. 6. The reliability of zone 0 is not influence by DG units, the reliability of the other zones and the entire system is strongly affected by DG units.

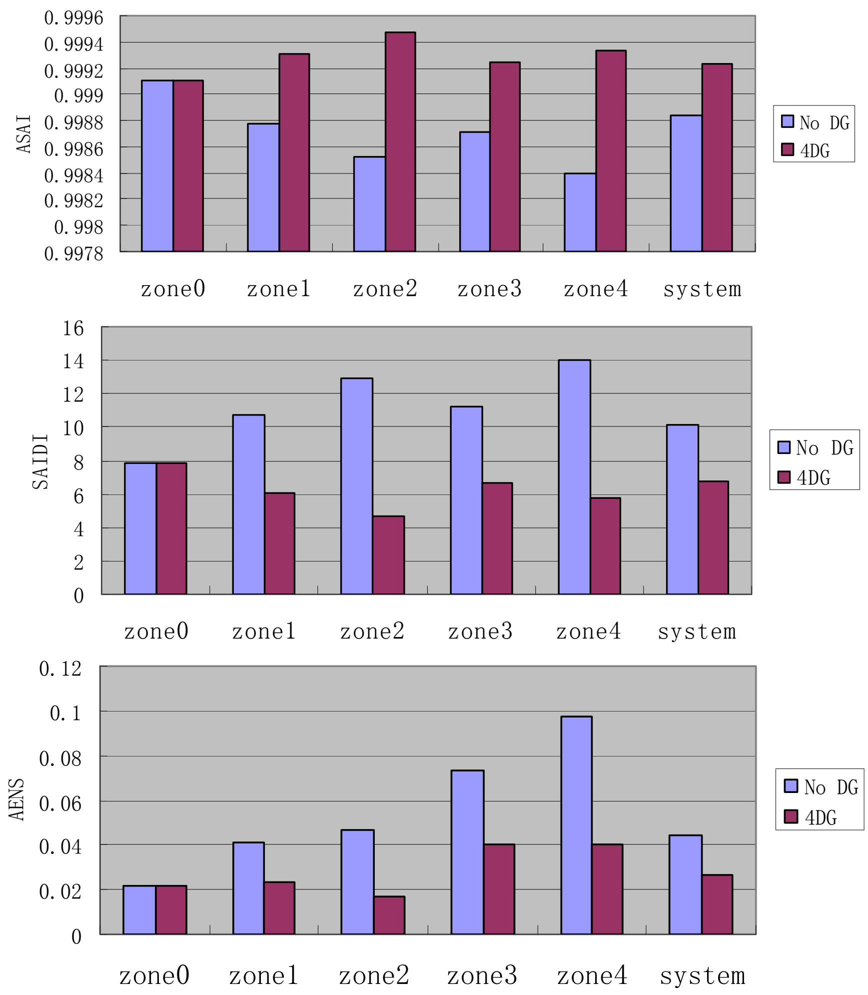

Figure 6. The indices.

3.2 The effect of each component on system index ASAI

Based on Bayesian network diagnosis inference, each posterior probability of components can be computed on the condition of system failure [21-22]. In Fig. 7, each failure probability of components is the condition of system failure or load point 40 failure. Thus, we can know that feeder line L35-44, L53-58, L45-49, L50-52, L59-64 and DG units in turn principally affect the entire system reliability, and the influence of the four DG units on the entire system is far larger than the influence of all transformers. These element availabilities should be increased to enhance the entire system reliability, i.e. by reducing these failure element rates (λ) or shortening their outage time (r). We can also know that the feeder line L59-64 is the main weak component of load point 40 supply.

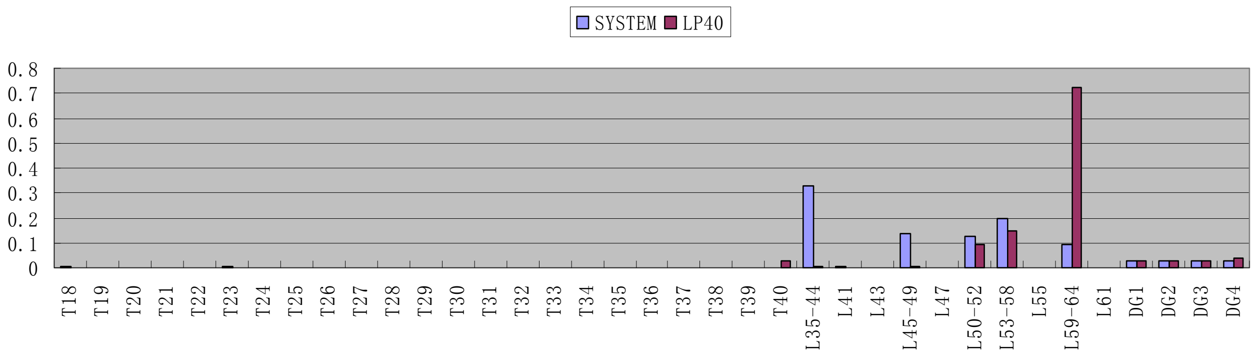

Figure 7. Components failure probabilities on the condition of system or load point 40.

In the results presented in the previous cases, it was assumed that the failure rate of the all DG units is 5. It is important to perform sensitivity studies and to consider the impacts on system indices of DG unit availabilities. This is illustrated in this case by varying the availabilities of DG units and by determining their effects on system indices. Table 2 shows the DG units failure probabilities on the condition of system failure in different failure rates. The results clearly demonstrate the reliability enhancement of the system index ASAI when the availabilities associated with DG units are increased; the influence of DG2 and DG4 units on the entire system is larger than DG1 and DG3; the influence of DG4 unit on the entire system is greatest among the four DG units.

Table 2. DG unit failure probabilities on the condition of system failure

λ (f/yr Failure rate)	DG1	DG2	DG3	DG4
5	0.029005	0.029435	0.029052	0.029447
15	0.087037	0.0881325	0.087055	0.0881649
25	0.144902	0.146604	0.14493	0.146653

3.3 The impact of locations and capacities of DG on system indices

The impacts on system indices of locations and capacities of DG units are illustrated in this case [23-24]. Fig. 8 shows the effects on system index ASAI so that each column pattern is associated with a different location and different capacity. Results show that index is strongly sensitive to the location of DG units. Consequently, the location of DG units in a distribution system is very important and the best location for the certain capacity of DG units can be chosen from the results. According to Fig. 8, we can see that location2 and location4 are important when the capacity of DG units is larger than 1.8 MW; the system reliability is very susceptible to the capacity of DG units at location4.

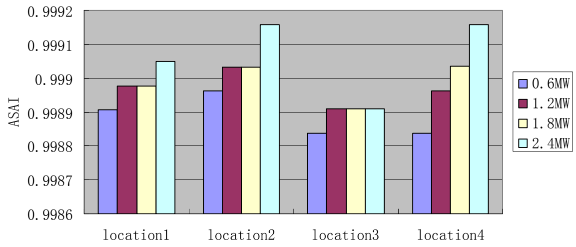

Figure 8. The impacts on system indices of locations and capacities of DG units.

4 Conclusion

By Bayesian network diagnostic inference, the effect on system reliability of each component can be clearly presented. Thus, provide the instructive concrete information for real engineering decision-making such as, improving system reliability, identifying weak components and making check and repair plan, etc.

This paper proposed a novel approach to study the DG impacts on distribution system reliability. The method assumes DG units on line and considers availability and unavailability of DG units. The results show that indices are too sensitive to location, capacity and availability of DG units. Hence, the capacity of DG unit for the best location in a distribution system can be obtained using the proposed method.

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