AN APPROACH FOR RELIABILITY ASSESSMENT OF DISTRIBUTION NETWORKS WITH DG

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ABSTRACT

Distributed Generation (DG) is predicted to play an increasing role in the electric power system in the near future. Based on the theory of Bayesian network, this paper discusses backup generation to radial model and the use of DG for improving the supply reliability in distribution systems. Reliability calculation results of an example feeder under different DG sizes are presented in the paper. From the compared results, it is obvious that DG installation can improve reliability indices and reduce the interruption cost considerably.

INTRODUCTION

As electricity demand is expected to grow at an annual rate of 1.4% (a relatively lower rate) between now and 2020 in the developing countries [1], Distributed Generation (DG) is predicted to play an increasing role in the electric power system in the near future. DG is the generation connected to the distribution network at MV (30-1kV) or LV（<1kV), which is of limited size (roughly 10 MW or less). DG technologies include conventional and no conventional energy technologies such as diesel engine driven generators, wind turbines, fuel cells, and micro turbines.

DG applications result in positive and negative side effects for both utility and customers. Positive impacts include voltage support, loss reduction, distribution capacity release, and improved utility system reliability [2]. In contrast, voltage controls problem, short circuit problem, unbalanced loads and impedances are the troublesome impacts of DG on power system [3].

With the widespread of DG, it is critical for utilities to minimize the negative impact and maximize the positive impact of DG. For this to be accomplished, models must be able to quantify the reliability impact of DG on distribution systems.

A Bayesian network technique is presented in this paper to study the DG impact on the distribution system reliability. This paper is arranged as follows: section 2 of this paper introduces the effect of DG on the reliability; section 3 investigates the proposed reliability assessment model; the method is then applied to a sample distribution system in section 4 and the results are compared for different DG sizes; section 5 summarizes this paper.

IMPACT OF DG ON SYSTEM RELIABILITY

Generally, there are 3 important applications of DG. The most common application of DG is for backup generation. DG unit remains offline during normal operation and is started to supply electricity to critical loads after an interruption occurs. The next most common application for DG is peak shaving. During the periods of high energy demand and/or high energy prices, on-site generators are started up and used to serve part of the on-site loads. Another application for DG that is gaining in popularity is referred to as net metering, where on-site generation can exceed site demand and result in power being fed back into the distribution system [4]. In this paper, we just study the DG for backup generation.

The impact of DG on the distribution system reliability depends on many factors, for example, the allocation and sizing of DG, the switch operation, etc. The location for DG placements is of key importance. The reliability indices are highly sensitive to location. It could be improved by properly allocating DG.

At the same time, the switch is also very important to the reliability. In the case that there are no switches connects on the main line and if any section on the main distribution line fails, it would result in power outage for all the distributor laterals. Without switches on the main line, installing a DG on the main distribution feeder will not improve the system reliability. Once switches are in place, the failed section can then be isolated and the rest of the loads can be supplied by both the substation and DG.

After an interruption occurs, the transfer switch shifts the downstream load from the utility to the DG unit. So the sizing of DG determines how much load could be transferred to the DG unit. If the DG size is higher than the load, the load block unavailability duration is only the time for isolating the fault and connecting the DG. Otherwise, the block unavailability duration will be the repair time of the failed component.

In this paper, it is assumed that DG installed at the end of the line. The Bayesian network model fully considers the impact of switches and DG on the reliability. Based on the model, the impact of different DG sizes on the reliability can be compared.

RELIABILITY ASSESSMENT MODEL

Tab.1 Variables Table

Symbol	Description	Unit
λ_i	average failure rate of L_i	f/yr
l_i	length of L_i	km
r_i	average failure repair time of L_i	h
st_D	switching time of section switches	h
st_{DG}	switching time of DG	h
r_D	value is $\max\{st_D, st_{DG}\}$	h
U_{DG}	probability of DG failure	%
r_{DG}	failure repair time of DG	h
t_{DG}	outage time associated with DG	h
P_j	load of LP_j	kW
n_A, n_B	customer number of load point A,B	cust.

BASIC THEORY

A distribution feeder consists of a set of series components, including lines, section switches, etc. A customer connected to any load point of such a system requires a set of components between load and supply points.

The failure rate, repair time and unavailability of load point LP_j are calculated as follows,

$$\lambda_j = \sum_{i\in I}\lambda_i l_i$$

$$U_j = \sum_{i\in I}\lambda_i l_i t_{ij}$$

$$r_j = U_j / \lambda_j$$

Where I is the set of the fault equipments which cause the interruption of the given load point j; t_{ij} is the interruption time of the given load point j due to the fault of equipment i.

Interruption in the system may cause the loss of power supply. The reliability index Expected Energy Not Served (EENS) is used to measure the loss of energy due to interruptions.

$$E_j = U_j P_j$$

The cost of power and energy not supplied is calculated by [5]

$$C_j = \sum_{i\in I}\lambda_i l_i \{a_j(t_{ij}) + b_j(t_{ij})t_{ij}\}P_j$$

Where $a_j(t_{ij})$, $b_j(t_{ij})$ are the costs per power and energy not supplied at load point LP_j, and the interruption time is t_{ij}.

BAYESIAN NETWORK SIMULATION

Bayesian network is consisted of directed acyclic graph and the conditional probability table [6]. For the given network, this paper divides the feeder into four levels (including the component level, switch level, load level and the feeder level), finds out the relationship and conditional probability table of each level node, and consequently establishes the Bayesian network model of the feeder system. Based on this model, the reliability indexes of the feeder system and each load can be obtained [7].

The nodes of each level and the relationship between each level will be described in the following.

The component level

This level mainly refers to the lines (L). The section switches, transformers and fuses are assumed to be 100% available in the analysis to illustrate the reliability model. The conditional probability is their prior probability.

$$P(L_i = 1) = 1 - \lambda_i l_i r_i / 8760$$

The switch level

This level design in Bayesian network is mainly used to consider the impact between a section switch and the back-up generation DG. As mentioned above, both the switches and DG are very important to the reliability.

In order to calculate the conditional probability of this level, suppose a feeder is divided into i sections through the section switch D_i. When line L_i fails, only opening the first section switch D_i downstream the fault, then closing the normally open switch to connect to DG, the load points behind line L_i can be restored with the premise that the transfer load capacity is equal to the DG unit capacity. So nodes $L_i D_i A$ are introduced in order to represent the relationship between the section switch D_i and the back-up generation DG. Then only the load points behind D_i are affected. The conditional probability is,

$$P(L_i D_i A = 1) = 1 - (\lambda_i l_i r_D + \lambda_D t_{DG})/8760$$

Where t_{DG} is equal to the switching time of DG (st_{DG}) if the DG can work successfully, or equal to the repair time (r_{DG}) if the DG fail to start. The average of this value can be evaluated as follows:

$$t_{DG} = (st_{DG} \mid \text{DG Success}) + (r_{DG} \mid \text{DG Unsuccess})$$
$$= st_{DG} \times (1 - U_{DG}) + r_{DG} \times U_{DG}$$

In the same way, after line L_i fails, only opening the first section switch D_{i-1} upstream the fault, the load points before line L_i can be restored. So nodes $L_i D_{i-1}$ are introduced in order to represent the relationship between the section switch D_i and the fault line. Then only the load points before D_i are affected. The conditional probability is,

$$P(L_i D_{i-1} = 1) = 1 - \lambda_i l_i st_D / 8760$$

The load level

The parent nodes of the load level nodes are those that affected the load points, including the related nodes of component level and switch level. The logic relationship is "or".

The feeder level

The feeder level model represents the relationship between the nodes of load level and feeder level. It is the "causal" relationship.

Calculation flow chart

The flow chart of the Bayesian network model and reliability calculation is shown in Fig. 1.

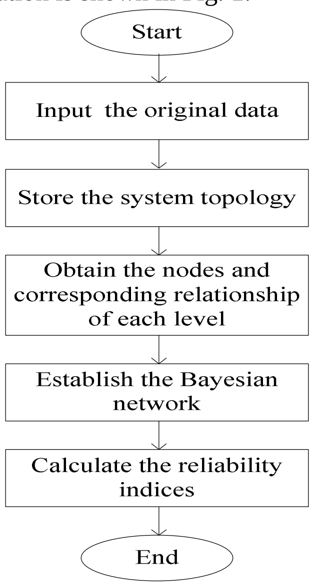

Fig. 1 Flow chart of reliability calculation

Step1: input the network parameters and components reliability parameters in the term of Multi-tuple;

Step2: store the system topology by Adjacency list;

Step3: the corresponding nodes and the relationship of each level obtained by Depth-First network search;

Step4: establish the Bayesian network by the Tree structure

Step5: calculate the reliability indices by the Variable Elimination method.

METHOD OF APPLICATION

In this section, the application of the proposed method to analyze the DG impact is investigated. A distribution test system is shown in Fig.2, which consists of 4 sections, 4 load points and one DG which is installed at the end of the feeder.

To demonstrate the reliability impact of DG on the distribution test system, four different DG sizes have been studied.

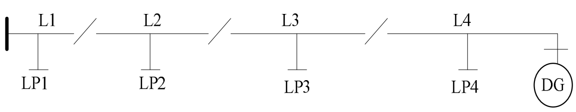

Fig. 2 Distribution test system

Basic data

Section switches, transfers and fuses are assumed to be 100% available. The switching time of section switches st_D = 1h. The probability of DG failure assumed to be 10%; the repair time is 16h. The section data are shown in Table 2.

Table 2 Section data

Section number	Failure rate (f/km•yr)	Length (km)	Repair time (h)	Load (kW)
L1	0.04	3	4	900
L2	0.04	2.5	4	200
L3	0.04	2	4	300
L4	0.04	2.5	4	100

The Bayesian network of this test system is illustrated in Fig. 3. Nodes of the switch level are variable depending on the DG size.

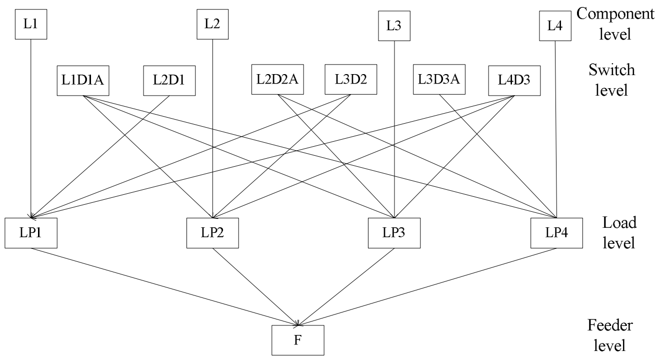

Fig. 3 Bayesian network of the test system

Different reliability indices

The impact of different DG sizes on SAIFI and SAIDI are shown in Fig.4-Fig.5. From the results, it is obvious that DG installation can improve reliability indices considerably.

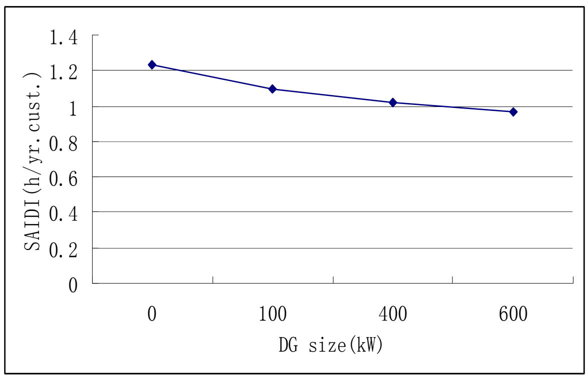

Fig. 4 Variation of SAIDI under different DG sizes

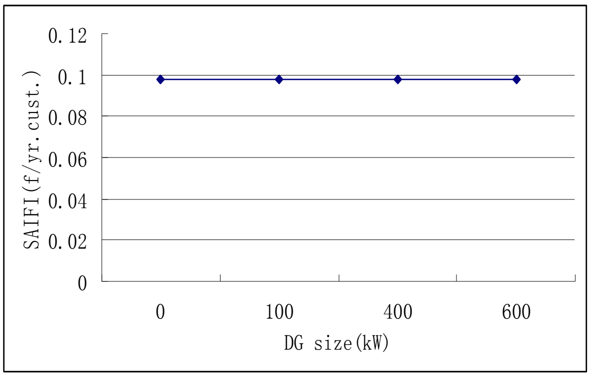

Fig. 5 Variation of SAIFI under different DG sizes

Different interruption costs

The results for the impact of DG size on EENS and interruption cost are shown in Fig.6-Fig.7. It is obvious that the larger the DG size, the lower EENS and interruption cost.

The interruption cost parameters used in the study: $a_j(t_{ij})$ =2yuan/kW, $b_j(t_{ij})$ =10yuan/kWh.

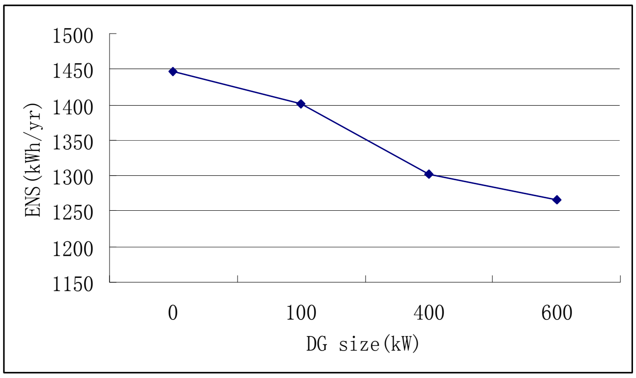

Fig. 6 Variation of ENS under different DG sizes

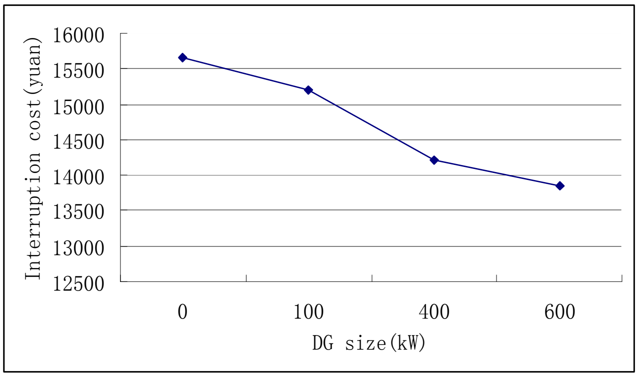

Fig. 7 Variation of interruption cost under different DG sizes

The results for improvement in reliability indices are tabulated in Table 3. The difference is more pronounced under higher level outages.

Table 3 Improvement in reliability indices

DG Size (end of the line)	SAIDI	CAIDI	ENS	Interruption Cost
100kW	11.2%	11.2%	3.1%	2.9%
400kW	17.3%	17.3%	10%	9.2%
600kW	21.9%	21.9%	12.6%	11.5%

CONCLUSION

Utilities can expect to see an increase in the amount of DG connected to their distribution systems. Although these sources of power can create many complications, they also have the ability to improve system reliability. Based on the theory of Bayesian network, this paper discusses backup generation to radial model and the use of DG for improving the supply reliability in distribution systems.

The method is then applied to a sample distribution feeder. The DG impacts on reliability indices and interruption cost are calculated with different DG sizes. The results showed that the larger DG size, the better the reliability and the lower interruption cost of the system.

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