EVALUATION OF DG CONTRIBUTION CONSIDERING NETWORK RELIABILITY

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ABSTRACT

This paper presents a new approach to evaluating distributed generation (DG) contribution to network security demand. Unlike the existing approaches which tend to be either oversimplified or too optimistic, the improved method for the first time takes into account the reliability level of the connecting network between the examined DG site and its corresponding load center. A worked example applying this methodology has been provided, in which the network structure and DG scenario is based on the case study given in the original P2/6 document. It is believed that by combining the availabilities of the generation site and the reliability of its connecting network, a more reasonable result in terms of DG security contribution could be obtained.

INTRODUCTION

The transition to a low carbon economy will see a substantial rise of renewables into in the energy mix, a considerable of which will be located at distribution levels. However, such a transition also leads to a number of technical, commercial as well as regulatory issues [1]. A typical example of these is the uncertainty and unreliability of the power received by end-users due to the involvement of a large amount of intermittent resources.

With relatively low penetrations and limited influences, the transmission and distribution network operators have simply chosen to neglect the contributions made by such dispersed resources [2]. Nevertheless, when the DG penetration reaches a threshold level in the foreseeable future, it will have a significant impact on the power system adequacy and security capacity. From the perspective of power system planning, what is of interest will be how much grid supply point (GSP) capacity can be replaced by the DGs connected below it without degrading the original network reliability [3]. For this reason, an approach that is able to evaluate and quantify the security contribution of DG appears to be timely and vital particularly in a low carbon future.

For almost four decades, the Engineering Recommendation (ER) has been regarded as one of the most important power system planning guidelines, and it must be complied with by all the Distribution Network Operators (DNOs) in Great Britain [4]. Revised by Energy Networks Association in 2006, the latest version—P2/6 provides DNOs with an approach to assessing security contribution by different categories of DG technology [4]. However, being rather deterministic and oversimplified, the method proposed by P2/6 has a few major shortcomings and needs to be updated accordingly [5].

One of the main drawbacks is that it overlooks the potential influence of distribution network characteristics. More specifically, it fails to take into account the exact configuration of the examined network, and it neglects the specific location of DG sites assuming that all the distributed resources are located next to the corresponding load centers [6-8]. Consequently, potential connecting network failures have been ignored. This is apparently far from the truth. The exact contribution from each DG is not only determined by the availability of the specific generation site itself, it is also subject to the reliability level of the connecting network in between the DG and its load center. Therefore, to achieve a more accurate and reasonable result, the availabilities of both aspects should be taken into consideration.

An improved methodology has been presented in this paper, which combines the DG contribution values stated in the P2/6 and the mathematical theories used for the reliability evaluation of power systems. Taking into account the characteristics of the connecting networks, it is believed that this improved method could provide more realistic and reasonable results in terms of DG security contribution.

ESTABLISHMENT OF AVAILABILITIES OF DG AND ITS CONNECTING NETOWRK

Availability of DG site

The availability of an exact DG site could be derived from its historical operating data. For different DG technologies, the availabilities are significantly different. For non-intermittent generations, such as landfill gas and Combined Heat and Power (CHP), the availability could be as high as 95%, whereas for intermittent generations like wind farm, the availability could merely be around 30% [6-8].

Accordingly, the contribution values provided in P2/6 have been adopted as DG site availabilities for this study.

Availability of connecting networks

The connecting network between each DG and its load center could have a variety of configurations. For instance, it could be a transformer only, a transmission line only, two transformers in parallel, or two transmission lines in parallel. Fig. 1 shows the situation when the connecting network is comprised of a transformer or a transmission line.

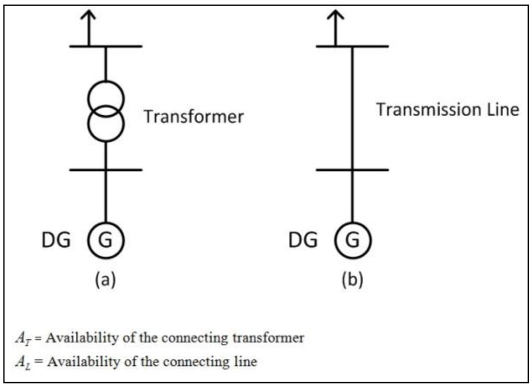

Figure 1. Connecting networks with one component

In this case, it is apparent that the availability of such connecting network is equivalent to the availability of the component itself, which could be derived from parameters like its annual failure rate and repair time. At the same time, it could be imagined that longer lines would lead to higher probabilities of failure [9].

As shown in Fig. 2, when the connecting components are located in parallel with each other, the total network availability could be calculated by:

$$A_p = A_1 + A_2 - A_1 A_2 \qquad (1)$$

Where:

A_p is the whole availability of the paralleled connecting network;

A_1 is the availability of component 1;

A_2 is the availability of component 2 in the connecting network.

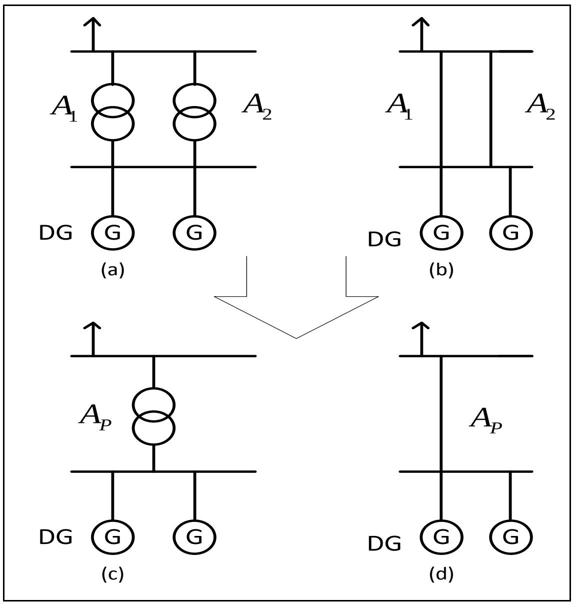

Figure 2. Paralleled connecting network

Similarly, the availability of a meshed connecting network could be derived by representing it with a combination of series- and parallel-connected components.

Remote generation equivalent model

As mentioned in the previous section, one of assumptions of P2/6 is that the examined DG is connected directly to its supplying customer. Consequently, it fails to take into account the situation of 'remote generation', which refers to a generation located far away from its demand certer [10]. With the rapidly increasing penetration of DGs into the distribution network, these renewable and dispersed generations tend to be distributed at different locations across the whole network. Therefore, in reality, the reliability of the medium in between the remote generation and its supplying demand could pose a major threat on the expected DG contribution value.

To tackle this problem, every remote generation, which is originally remote from the load center, is converted into an equivalent model, which is now adjacent to its customer. Fig. 3 illustrates the concept of this conversion. As shown in the figure, a remote generation G is originally connected with its demand through a long-distance connecting network; while in the case of its equivalent model, the new generation site–G', is right next to its supplying customers.

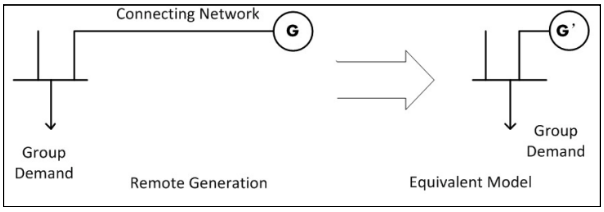

Figure 3. Equivalent model of remote generation

As a result of such conversion, the availability of the equivalent generation should be a reflection of not only the availability of the original remote DG, but also the reliability of the connecting network. The availability of the equivalent model is:

$$A_{G'} = A_G \cdot A_{CN} \qquad (2)$$

Where:

$A_{G'}$ is the availability of the equivalent DG model;

A_G is the availability of the original remote DG;

A_{CN} is the availability of the connecting network.

By transforming into equivalent models, the influence of connecting networks on DG contribution could be considered. As a result, the availabilities of all the remote DGs across the whole network could be more realistically evaluated.

MODEL BUILDING FOR A GROUP OF DGS

The main objective of the standard ER P2/6 is to quantify how much contribution each DG could make to the security capacity of the distribution network, under the circumstance of N-1 and N-2 outages [11]. In practice, a single GSP always has a number of DGs connected below it. From the perspective of system planning, what is of interest is the aggregate contribution that could be made to the system group demand.

The probability of all the DGs being able to provide the required contribution could be calculated by a recursive algorithm [12]. For two-state DG sites, the cumulative probability of a particular capacity outage state–S could be calculated as:

$$P(S) = (1-R)P'(S) + R \cdot P'(S-C) \quad (3)$$

Where:

C is the capacity of the added DG;

R is rate of forced outage of the added DG;

$P'(S)$ is cumulative probability of the capacity outage state of S MW before the new DG site is added;

$P(S)$ is the new cumulative probability after the site is added.

To include DG sites with derated states, the cumulative probability of state S capacity outage could be calculated as [12]:

$$P(S) = \sum_{i=1}^{n} p_i P'(S - C_i) \quad (4)$$

Where:

n is the number of states of the added DG site;

C_i is the capacity outage when the added DG is at state i;

P_i is the probability of existence of state i.

WORKED EXAMPLE

This section applies the approach proposed in this paper to the example used in the P2/6 document [11]. The structure of the network has been shown in Fig. 4 below.

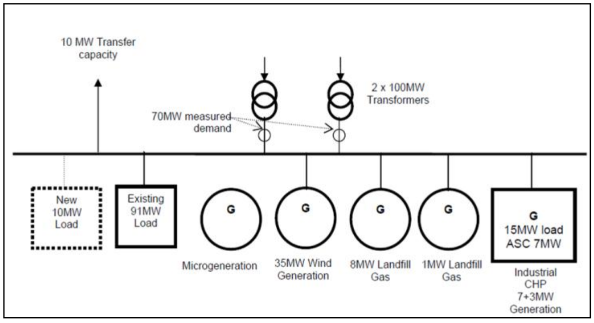

Figure 4. Structure of the analyzed network

Under the circumstance of N-1 outage, there would be merely one transformer supplying the demand group in the network, and the DGs connected are supposed to fill the power gap between the remaining transformer capacity and the security demand. According to P2/6, the 8MW landfill gas, the wind generation and the CHP embedded in the distribution system are regarded as the ones actually contribute to the capacity deficit in this example, and according to the method provided in P2/6, the expected security contribution of each is shown in Table I.

Table I
P2/6 security contribution of each DG

Plant type	Security contribution
Landfill Gas	6 MW
Wind farm	9.8 MW
CHP	6.9 MW

In this example, the landfill gas and the CHP are non-intermittent generations. For the landfill gas, it has 4 units, each of which has the capacity of 2 MW, and it is assumed that all the units are identical. The probability of each possible capacity state of the landfill gas could be calculated by:

$$P(s) = \frac{n!}{s!(n-s)!} \cdot p^s \cdot q^{n-s} \quad (5)$$

Where:

$P(S)$ is the probability of being at state S;

n is the number of units;

p and q are the availability and unavailability of each landfill gas unit respectively.

Table II shows the capacity states and the corresponding probabilities of the landfill gas, and the probability of it successfully generating at least 6 MW as required by P2/6 is:

$$p_{\geq 6MW} = p^4 + 4pq^3$$

Table II
Landfill gas capacity states and probabilities

Capacity available	Capacity unavailable	State probability
8 MW	0 MW	P^4
6 MW	2 MW	$4p^3q$
4 MW	4 MW	$6p^2q^2$
2 MW	6 MW	$4pq^3$
0 MW	8 MW	$(1-p)^4$

An availability of 95% has been assumed as the CHP site availability，and the probability of the wind farm generating as much power as shown in Table I is P_{WF}. Table III and Table IV show the CHP and wind farm situations respectively.

Table III
CHP capacity states and probabilities

Capacity available	State probability
$\geq$ 6.9 MW	95%
$\leq$ 6.9 MW	5%

Table IV
Wind farm capacity states and probabilities

Capacity available	State probability
≥ 9.8 MW	P_{WF}
≤ 9.8 MW	1-P_{WF}

For the situations that the DG is a remote generation, the probability of the DG capacity state should multiply the availability of the connecting network to get a combined probability representing the DG contribution. Table V shows the connecting network availability.

Table V
Connecting network availability

Connecting network state	Probability
Up	P_{CN}
Down	1-P_{CN}

According to the recursive algorithm (3), the cumulative probabilities of each capacity outage state of the CHP and wind farm are calculated firstly. Then, when the landfill gas units are added, the cumulative probability could be obtained referring to equation (4).

1) When only the CHP considered:

$$P(0) = P_{CHP} \cdot 1 + (1 - P_{CHP}) \cdot 1 = 1.0$$
$$P(6.9) = P_{CHP} \cdot 0 + (1 - P_{CHP}) \cdot 1 = 1 - P_{CHP}$$

2) When wind farm added:

$$P(0) = P_{WF} \cdot 1 + (1 - P_{WF}) \cdot 1 = 1.0$$
$$P(6.9) = P_{WF}(1 - P_{CHP}) + (1 - P_{WF}) \cdot 1$$
$$P(9.8) = P_{WF} \cdot 0 + (1 - P_{WF}) \cdot 1 = 1 - P_{WF}$$
$$P(16.7) = P_{WF} \cdot 0 + (1 - P_{WF})(1 - P_{CHP})$$

3) When landfill gas added:

$$P(22.7) = p^4 \cdot 0 + 4p^3q \cdot 0 + 6p^2q^2 \cdot 0 + 4pq^3(1 - P_{WF})(1 - P_{CHP}) + (1-p)^4(1 - P_{WF})(1 - P_{CHP})$$

As shown in Table I, under the circumstance of N-1, the three contributory DG sites could contribute a collective security contribution of 22.7 MW, which is according to P2/6. Now, with the reliability of the connecting networks and the remote generations taken into account, the updated probability of successfully providing the aggregate security contribution as required by P2/6 is:

$$P_{aggregate} = 1 - P(22.7)$$

CONCLUSIONS

This paper presents a new approach to calculating the network security contribution made by DGs. Compared with the original methodology proposed in the ER P2/6, the approach proposed in this paper for the first time takes into account the potential failure of distribution network circuits and thus the availability of DG connecting networks. By converting remote generations into equivalent models, the proposed approach also reflects the potential reliability risk particularly when DGs are far from main load centers. With these factors integrated, a more reasonable assessment of DG security contribution could be achieved, which would in turn help the network planners form a more realistic projection in the future system demand patterns.

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