IMPROVING DISTRIBUTION SYSTEM RELIABILITY BY MEANS OF DISTRIBUTED GENERATION

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ABSTRACT

This paper discusses the use of distributed generation (DG) for improving the supply reliability in distribution systems. The first part of the paper contains the results of a simple analytical study of the reliability for individual customers with distributed generation on-site. The difference between disconnector-type interfaces and breaker-type interface is emphasised. In the second part of the paper the reliability improvement for non-DG costumers is studied. General design recommendations are given based on the results.

INTRODUCTION

Distributed energy resources (DER), including distributed generation and storage have a number of well-published advantages [1][2]. One of the advantages is the ability of DER units to supply loads during a grid failure. The widely used battery-based UPS is an example of a distributed energy storage device aimed at improving supply reliability. Also, on-site generating units in large industrial installations are often used for this purpose.

DER allow for improved customer supply reliability for customers supplied from DER units. Calculations have been performed to quantify the improvement in reliability for the DER customer mainly resulting from the theoretical possibility of island operation. Failure of the DER unit during island operation will introduce additional interruptions. Results from an analytical reliability calculation of an example feeder are presented in the paper.

Such improvement for one specific customer does however not improve the reliability of the network as island operation of the DER with its local loads will not prevent interruption of supply to other customers. The reliability of the network can be improved if the DER unit is able to supply other loads as well. This requires additional control equipment, additional switchgear and most likely also communication equipment and load-shedding protocols. In this paper we will not address the technical issues involved with islanding, but quantify the improvements that can be obtained when island operation of DER with multiple customers is possible. Results from a Monte-Carlo simulation of an overhead-line feeder with DER island operation enabled are presented in this paper.

A number of general conclusions are drawn from the studies, including recommendations for the design of distribution networks such that optimal use is made of the DER units for improving network reliability.

ISOLATION AND RESTORATION

The presence of DER units does not change a number of the fundamental rules in the operation of distribution systems. We may assume that for the foreseeable future switching actions will take place by mechanical switching devices. Three different types of devices have to be distinguished based on their function: circuit breakers are the only devices that can interrupt a short-circuit current; disconnectors are the only devices that can provide safe isolation but they can interrupt a very small current only: load switches can interrupt a current up to the rated current. The prospect for network reliability improvement by DER units depends to a large extent on the presence of appropriate switching devices and the speed with which they can be switched. In short, one may state that circuit breakers reduce the number of interruptions whereas disconnectors can be used to reduce the duration of interruptions.

ANALYTICAL RELIABILITY CALCULATION (AND THE EFFECT OF CHOICE OF INTERFACE SWITCHGEAR)

A comparison has been made for the reliability between three cases: no-DER or DER without islanding capability; DER with disconnector-type interface; DER with breaker-type interface. The following component data have been used for a 20-km linear overhead feeder without side branches: 0.5 faults per km per year; 10 minutes automatic switching time; 5 hours manual fault-isolation time; 48 hours repair time; 20 hours expected time-to-failure of DER unit during island operation, 1 hour repair time of DER unit. In the study the DER is located from 0 to 100% of the line length to investigate the effect of location as well as interface switchgear type. See [3] for more details of the calculations.

The results of an analytical reliability calculation are shown in Figure 1 and Figure 2. The impact of failures during island operation on interruption frequency and unavailability is high. Note that the unavailability of the DER unit during island operation is only 5%. The unavailability of the supply is improved for all locations, but the difference between disconnector-type interface and breaker-type interface is small as automatic switching is assumed.

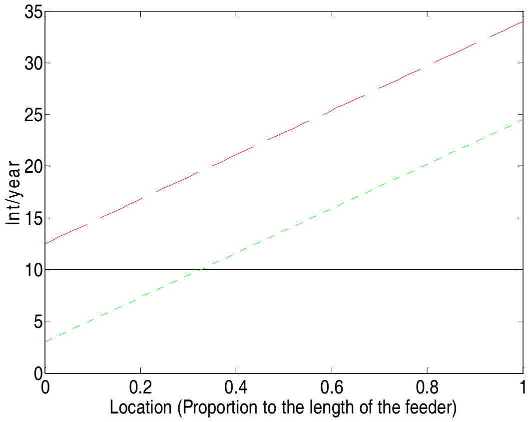

Figure 1 - Interruption frequency for customer supplied from DER unit; no islanding (solid line); disconnector-type (dashed); breaker-type (dotted).

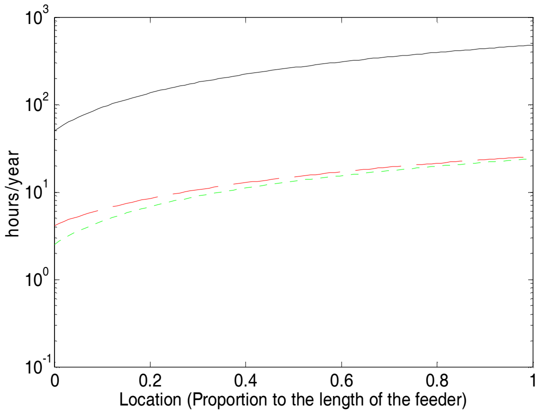

Figure 2 - Unavailability for customer supplied from DER unit; no islanding (solid line); disconnector-type (dashed line); breaker-type (dotted line). Note the logarithmic vertical scale.

The interruption frequency is up to three times higher for the disconnector-type interface as for the no-DER case and up to two times higher for the breaker-type interface. These solutions are only suitable when the customer interruption costs are most heavily influenced by unavailability and not interruption frequency.

For an industrial process customer the process unavailability has been calculated as a function of the DER unit reliability. The results are presented in Figure 3 and Figure 4. Figure 3 shows results for a process restart time of zero. In Figure 4 a process restart time equal to 10 hours is assumed. Note that the reference is to the restart time of the process supplied from the DER unit. The restart time of the DER unit is 10 minutes in both cases. Long process restart time is equivalent to a high cost per interruption. In that case a breaker-type interface is clearly advantageous assuming the DER unit reliability is sufficiently high.

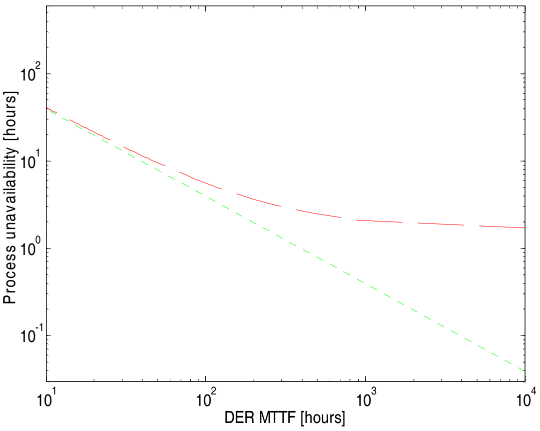

Figure 3 - Process unavailability, as a function of DER unit reliability for zero process-restart time: breaker-type interface (dotted) and disconnector-type interface (dashed).

For low reliability (small MTTF) of the DER unit, the difference in unavailability between disconnector-type interface and breaker-type interface is small since failures of the DER unit dominate. For high DER unit reliability the breaker-type interface results in significantly lower process unavailability than the disconnector-type interface.

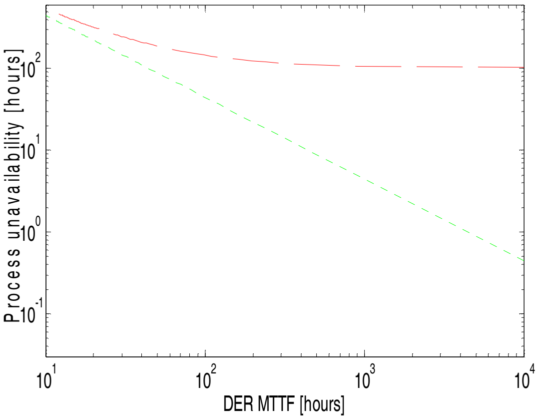

Figure 4 - Process unavailability, as a function of DER unit reliability for a 10-hour restart time: breaker-type (dotted) and disconnector-type interface (dashed).

PROBABILISTIC RELIABILITY CALCULATION FOR OVERHEAD LINE NETWORK

Simulations of distribution feeder reliability with DER have been conducted using a Monte-Carlo simulation approach [3][4]. The overhead-line feeder studied is shown in Figure 5. It consists of 10 line segments. The first 5 segments have a relatively low failure rate and isolation time. They represent short length segments in a suburban environment. Segments 6 through 8 represent longer feeder segments in a rural area, with the associated higher failure rate and isolation time. Segment 9 leads through a forest and segment 10 is a short segment supplying a small number of remote customers. The interruption frequency, unavailability and interruption costs have been calculated for loads connected to segments 5, 8 and 10.

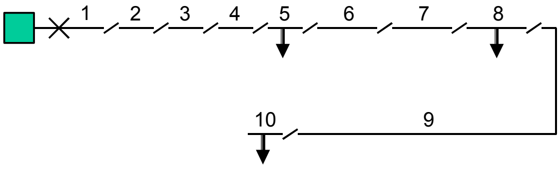

Figure 5 - Overhead-line feeder studied.

Five different scenarios have been studied with different levels of DER penetration:

- Scenario 2a: No DG
- Scenario 2b: DG at segment 10
- Scenario 2c: DG at segment 10, circuit breaker between segment 9 and 10
- Scenario 2d: DG at segment 8
- Scenario 2e: DG at segment 8, circuit breaker between segment 8 and 9

The estimated interruption frequency and unavailability are shown in Figure 6 and Figure 7. The five bars represent the five scenarios in sequence. Note that all values for the DG customers have been multiplied by a factor 10 to make them more visible. The interruption frequency for the non-DER loads increases marginally due to the presence of DER for most scenarios. However the unavailability decreases with DER units in place. The duration of interruptions is reduced because the DER unit forms a backup source during the repair of the faulted component. The increase in interruption frequency is due to failures of the DER unit during island operation.

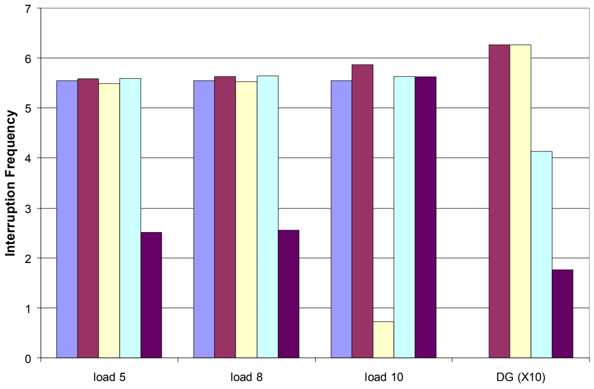

Figure 6 - Interruption frequency for five different scenarios. Note that the values for the DG load have been multiplied for a factor of 10 to increase visibility.

The interruption frequency for load 5 and load 8 reduces to half its original value in scenario 2e. This is not due to any DER but due to the presence of the circuit breaker between segments 8 and 9. Faults in segment 8 (about half of the total number of faults on the feeder) no longer lead to an interruption for this load.

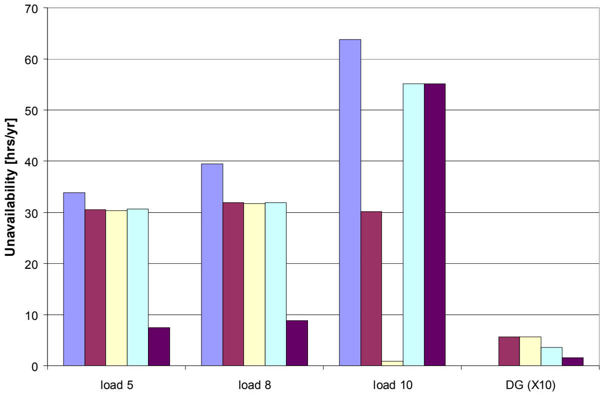

Figure 7 - Unavailability for five different scenarios. Note that the values for the DG load have been multiplied by a factor of 10 to increase visibility.

The reduction in unavailability is even more significant than the reduction in interruption frequency as the isolation is much higher for segment 9 than for the other segments. For scenario 2c the interruption frequency for load 10 is reduced significantly because the presence of the circuit breaker between segments 9 and 10 allows for fault-ride through for all load connected to segment 10. This gives a large reduction in both interruption frequency and unavailability.

The differences in interruption frequency and unavailability of the DER unit between the four DER-scenarios are directly related to the percentage of time during which the unit is in island operation. For scenarios 2b and 2c the DER unit is connected to the end of the feeder, where the unavailability is higher and hence the DG unit will be in an island more frequently and thus its own failures will be more evident in this mode of operation.

IMPACT OF DER UNIT RELIABILITY

The calculations for scenario 2e have been repeated for different values of the reliability of the DER unit. The failure rate of the DER unit has been varied between 1 failure per year and 80 failures per year, with its unavailability held constant at 80 hours per year. The resulting interruption frequency for the DER load is shown in Figure 8.

The DER load interruption frequency increases significantly for DER failure rates of 10 per year and higher. The load unavailability (not shown here) remains the same.

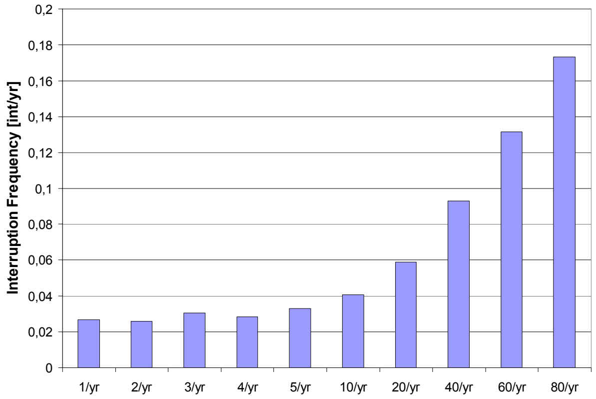

Figure 8 - Interruption frequency for the DER load, for different failure rate of the DER unit. The DER unit unavailability has been held constant at 80 hrs/yr.

EFFECT OF VARYING REPAIR AND ISOLATION TIME DISTRIBUTIONS

The use of Monte-Carlo simulation techniques makes it possible to study the influence of different distributions for repair and isolation time. In this study a combination of two Weibull distributions were used : one with a low expected value ; one with a high expected value. The ratio between the two contributions is varied while maintaining the same expected value for the total distribution. The results are shown in Figure 9: the number of interruptions lasting more than 3 or 4 hours shows a clear increase whereas the total number of interruptions (not shown here) is relatively unaffected.

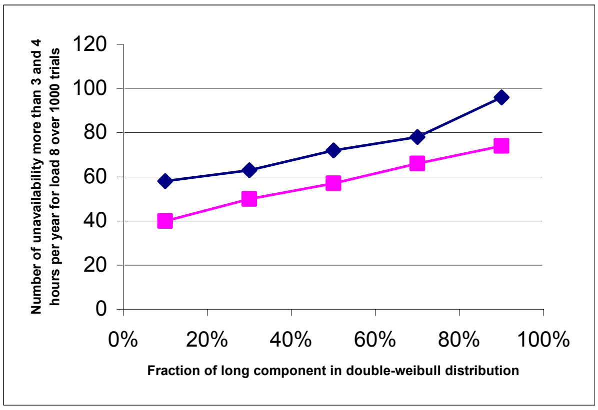

Figure 9 - Number of unavailability more than 3 (diamonds) and 4 (squares) hours per year for load 8 over 1000 trials for different values of long interruption components, with constant expected value.

DESIGN RECOMMENDATIONS

From the results presented in this paper and in other publications [3][4] a number of design recommendations are proposed:

- A DER unit with island-operation capability should be equipped with disconnector-type interface when interruption costs are mainly influenced by the unavailability (interrupted minutes per year).
- A DER unit with island-operation capbility should be equipped with breaker-type interface when interruption costs are mainly influenced by the interruption frequency (number of interruptions per year).
- When the reliability of the DER unit during island operation is low, the breaker-type interface gives similar interruptions costs as the disconnector-type interface.
- To reduce the unavailability of non-DER customers, disconnectors and circuit breakers have to be installed at appropropriate locations. Disconnectors reduce the unavailability; circuit breakers reduce the interruption frequency.
- A DER unit provides more equal reliability for customers along the feeder. The impact of a DER unit is most for customers closest to the DER unit and for a DER unit near the end of the feeder.

CONCLUSIONS

The relationship between reliability of supply for distribution customers and DER with island-operation capability has been presented. The choice of switchgear interface is determined by the reliability requirements of the load. By allowing island operation of the DER unit with other loads, the reliability of the distribution network can be improved. It is shown that the reliability of the DER unit during island operation has a large impact on the resulting reliability. The interruption length distributions for repair and restoration time impacts the number of interruptions longer than a certain duration.

REFERENCES

[1] H.L. Willis, W.G. Scott, *Distributed power generation - planning and evaluation*. Marcel Dekker, New York, 2000.
[2] N. Jenkins, R. Allan, P. Crossley, D. Kirschen, G. Strbac, *Embedded generation*. Institution of Electrical Engineers, London, 2000.
[3] M. H. J. Bollen, Y. Sun, G. W. Ault, J. R. McDonald, Methods for reliability assessment in future power distribution networks. *International Conference on Future Power Systems*, Amsterdam, Netherlands, 16-18 Nov 2005.
[4] Y. Sun, M. H. J. Bollen, G. W. Ault, Probabilistic Reliability Evaluation for Distribution Systems with DER and Microgrids. International *Conference on Probabilistic Methods Applied to Power Systems*, Stockholm, Sweden, June 11-15, 2006.

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