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Comparison of the effect of the distributed generators vs new distribution substation on the reliability of the power distribution grid

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Abstract

The Distributed Generators (DGs) offer great opportunity to modernize the electrical infrastructure and apply the concept of the smart grid. One of the many virtues of the DGs is the expected improvement in the reliability of the power distribution systems. Specifically, the DGs could be used during major outages and blackouts to provide service to customers in the healthy parts of the distribution grid. In addition, it helps to alleviate the congestion of the electrical network during peak hours, which contributes to improving the reliability indices in all. In this work, we model the impacts of the DGs on the reliability and compare the results with those obtained when building new distribution substation at the feeder. Parts of the simulation will include a partial economic comparison on the savings from each option.

Keywords: Distributed generators, power system reliability, smart grid, microgrid

1. Nomenclature

IEEE: Institute of Electrical and Electronics Engineering.

SAIDI: System Average Interruption Duration Index.

SAIFI: System Average Interruption Frequency Index.

CAIDI: Customer Average Interruption Duration Index.

EUE: Expected Un-served Energy.

ASAI: Average Service Availability Index.

DGs: Distributed Generators.

AR: Automatic Recloser.

AS: Automatic switch.

2. Introduction

Power system reliability is a key aspect in power distribution system planning, design, and operation. Around 90% of the interruption occurs in the area between the distribution substation and the customer's own meter, which show that the issue of the reliability of power distribution is considered a major one. Much of the attention has been attributed to this area in the recent years after the reliability of both generation and transmission systems occupied the interest from the early days of the electricity [1], [2].

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The traditional power distribution system is radial in nature, the power flows in one direction from the distribution substation to the load point. This radial system has low reliability, and those customers who are located at the end of the circuit, tend to be more prone to power outages than any other customers. Since there are no alternative sources to back up the traditional distribution systems, there is a high chance that a major fault on the feeder would affect a substantial number of customers in the radial configuration. The concept of reliability can be explained as two states or conditions: up and down. The "up state" means that the system is functioning well with no problems in operations due to outages or equipment failures; while the "down state" points out to a problem at some point in the system, mainly due to an interruption. What makes the problem worse is when failure of one equipment influences the failure of other equipment in the grid, which increases the chances of cascading outages [2]-[5].

The reliability of power distribution systems is promised to witness major benefits under the concept of the modernized electrical infrastructure, simply referred to as the smart grid. The distributed generators (DGs), although dated back to the late 1970's, are considered among those applications that attribute to the definition of smart grids. DGs are located near the load centers which reduce the losses, and provide the possibility of operating the unaffected parts of the distribution network during outages as microgrid, eventually improving the system's overall reliability indices. The main goal of this paper is to study whether the DGs are preferred over the traditional approach followed by a utility (which is building new distribution substations) in improving the reliability and operation of the distribution networks. The model used in this work is the IEEE 34 node test feeder, released in 2003 by the IEEE PES Distribution System Analysis Group [6]. The software used in our simulation and modeling is DISREL, an intelligent-based program that is developed by General Reliability Inc. for power transmission and distribution studies.

3. Literature Review

There have been good amounts of research to measure the potential benefits the DG. Reference [7] discusses the potential features of the smart grid and the impact of the interconnections of renewable energy sources (of 10 MW or less) as dispersed sources on the power distribution grid from a reliability point of view. It reviews the recent efforts that have been made to standardize the interconnection requirements for DG units. Reference [8] proposed a Markov model approach that measures the reliability of the power grid by incorporating both conventional and/or renewable distributed generation (DG) units. They assume that if the DG unit is a renewable base load unit, it will be operated in parallel with the utility supply and connected or disconnected based on grid's need. It also considers conventional DG units as backup and will be operated and connected to the grid during emergencies only. To evaluate the reliability of the distribution network including the DG, the output power of the incorporated DGs must supply the demand adequately during the interruptions. During the DG islanded mode, it is said that the DG may not be able to provide sufficient power to meet the demand quickly, which will result in a reduction of the reliability indices that are related to the islanded system. During the isolation, if the DG available capacity is greater than the demand, the DG will be able support the load. However, if the DG is unable to provide enough loads, then the DG will be disconnected, since power generated does not match load demand with losses, and might only be used to supply critical loads. Reference [8] concludes that the DG units operating at an islanded mode can enhance SAIDI, but at the same time could lead to an eventual increase in the interruption frequency (SAIFI). References [9], [10] demonstrate and discuss the process of the integration of the DG units into a microgrid, including a peer-to-peer and plug-and-play functionality. The tests considered critical conditions and recorded the timely response of the system in isolation mode and at autonomous reconnection to the grid. In addition, references [11]-[13] present valuable studies related to the interconnection and installation of DG units to the electrical systems. The studies show different kinds of DG units and the promising outcomes resulted from reconfiguration schemes that DGs help in achieving, while reference [14] illustrates the importance of the optimal placement of switching devices in the radial distribution systems.

4. Case Studies

4.1. Case study one: The reliability impact of adding a new source of supply to the radial feeder

One of the great advantages that make the DG more desirable is the cost of its installation. Although a high one at certain cases, based on the DG type, it could be taken care off by Independent Power Producers (IPPs), where these investors would receive incentives in the form of deferral credits for replacing distribution facility requirements [15]. In this paper, we model the reliability impacts of DG units on the test system, and try to make a comparison to those of the traditional option through modeling a new source of supply to the distribution system. DISREL can provide the system responses to the reconfiguration schemes with the DGs installed on it, and quantify each option it suggests by making comparisons on the outage costs for each case. Expected Unserved Energy (EUE) is calculated by the software based on the frequency, the duration, and the time the load was interrupted. Fig. 1 shows the modified IEEE 34-node feeder when the utility decides to construct a new source of supply (new distribution substation) to supply more customers, reduce the congestion on the lines and to improve the reliability indices. The proposed location of this substation is at node 890, the densest load in the test system. Table 1 shows the system indices after modeling the modified test system.

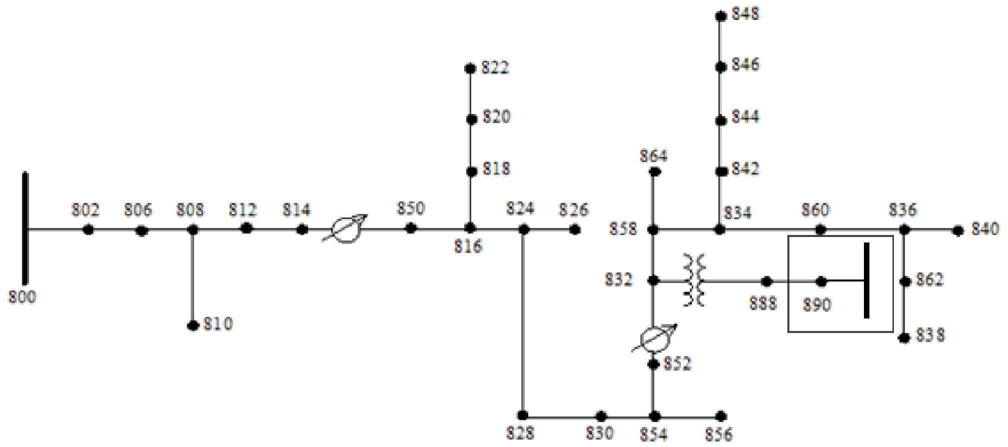

Fig. 1. Adding new source of supply to the IEEE 34 node test system.

Table 1. Results of different reconfiguration schemes for case study one

Case Description	SAIFI	SAIDI	CAIDI	ASAI	EUE (kW)	Outage Cost ($)
Base Case + New Source	5.35187	687.95905	128.54552	0.998691082	18,735	186,839.00
Add AR [832-888]	4.20221	504.3049	120.00947	0.999040544	13,761	137,123.00
Add AR [888-890]	4.30497	516.63666	120.00924	0.99901706	14,098	140,488.00
Add AR [834-860]	4.84965	626.57263	129.19943	0.998807907	17,063	170,170.00
Add AR [858-834]	4.87825	609.60144	124.96304	0.998840153	16,599	181,154.00
Add AR [832-858]	4.91459	601.53308	122.39732	0.998855531	16,379	163,363.00

Modeling of the modified system, shown in Fig. 1, has yielded the expected outcomes that would result from building a new source of supply, which is a significant improvement in the system indices that may lead to projected savings for the utility (we neglect the cost of construction in our study). However, it is must be noted that adding a new source of supply without the installation of reclosers are useless, since there would be no ability to isolate the faults and transfer the unaffected customers from one source to the others available. In this case, the reliability of the distribution feeder has improved significantly with adding automatic reclosers (AR), where the optimal place to install them is suggested by the software to be between nodes 832-888, among many options projected as shown in Table 1. Both SAIDI and SAIFI have shown substantial reductions. For the option of installing AR at the above specified location, SAIFI has been reduced from 5.34 to 4.20 interruptions per customer, accounts to around 22% improvement, while SAIDI has been improved by 27% from 687.95 minutes per year/customer to 504.30. The outage cost is provided by the software for each option based on the assumption that the value of power loss to customers is $10/kWh [16]. The results indicated significant savings, reaching $114,646 at highest when the AR is installed in the best location as suggested above. The savings were calculated based on the difference of the outage costs for the original IEEE 34-node system (without making any case modification or constructing new station) which were originally provided by the software as $251,769.

The costs of the installation of the recloser would repay itself within less than one year, assuming the current values of its installation [17]. However, it is not a practical solution to recommend installing a new source of supply to improve the reliability in the distribution grids. The real capital cost would be higher since it includes the construction of new feeders, a substation with its associated auxiliary equipment, in addition to the costs of manpower, and the required land and time that it would take to complete such a project. In the next case study of this work, we show that the application of the smart grid, represented by the installation of the DG units, offer much great benefits, with more reasonable logics than the traditional approach (which is by building a new substation) may achieve.

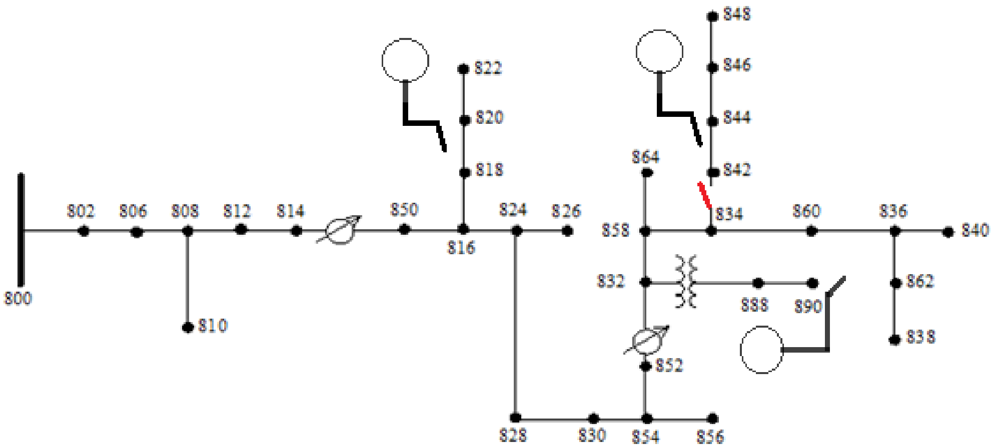

Fig. 2. The modified tests system with three DG units with the optimal location of AR.

Table 2. Modelling the effect of adding distributed generator at nodes 890, 844, 820

Case Description	SAIFI	SAIDI	CAIDI	ASAI	EUE (kW)	Outage Costs ($)
Base Case + 3 DGs	5.35187	650.94885	121.63016	0.998544812	17728	176,779.00
Add AR [834-842]	3.53278	425.52283	120.44984	0.99919039	11583	115,427.00
Add AR [842-844]	3.65604	440.31363	120.43468	0.999162257	11994	119,501.00
Add AR [834-860]	4.84965	589.5625	121.56792	0.9988783	16056	160,110.00
Add AR [860-836]	4.90973	597.58228	121.71393	0.998863041	16274	162,286.00

4.2. Case study 2: The reliability impact of the distributed generators on the radial feeder

In this case study, we quantify the effects of DGs by modeling different units' sizes on the test system using DISREL. The base case would be the modified system shown in Fig. 2; with the only exception of the AR located between 834-844, that is added later based on the software suggestion. First, we modified the test system by adding three distributed generators; two of them are 1 MW at nodes 890 and 844, with additional DG rated at 500 kW at 822. These locations are chose based on the number of customers and density of load in the test system. The results of the simulation are shown in Table 2. The first scenario is with installing the DGs only (no AR), where in this scheme there would be no benefits from the DGs in case of any outages, due to the absence of the isolation device that can help in keeping the service to the unaffected parts of the feeder. After that, we model the modified test system to obtain several scenarios of adding ARs in different locations, where DISREL has the intelligence to suggest these locations optimally. It is noted that when we combine the distributed generators with an AR between nodes 834-842, as shown in Fig. 2, the system experienced significant improvements in reliability indices, resulting at the same time in great revenue for the electric provider. Based on the results, the system's SAIDI would decrease from 927.25 minutes (obtained in the IEEE original feeder) to 425.52 minutes, which correspond to over 54% in SAIDI improvements. For SAIFI index, the modified system has reduced the frequency of interruptions from 5.352 to 3.532 per customer, marking a 34% reduction in SAIFI. However, we noticed that there is no significant change applied to CAIDI, which shows that we cannot consider CAIDI a real measuring for system reliability improvements. Fig. 3 shows the savings obtained by installing the three DG units on the distribution feeder. In the case when adding the automatic recloser between 834-842 or 842-844, it is projected that the utility will experience the greatest savings among other options, which can be seen by the fact that the system will be able to reconfigure in order to maintain service to a substantial number of customers during outages.

Fig. 4 shows the number of interruptions for the feeder's customers per year when considering the installation of the AR between 842-844 along with the DG units. In this case, the interruptions events have been reduced from 4346 to 2869, saving the utility from experiencing a total number of 1477 interruptions, which accounts to almost 34% in improvements. Fig. 5 illustrates the reductions to SAIFI index when considering the DG units with each of the suggested optimal locations for the automatic recloser. We also run DISREL to obtain the optimal locations for adding another automatic recloser to check if there would be further enhancement on the system. However, based on the obtained results, installing another automatic recloser in our specific case (the given IEEE system) can add further improvement to the reliability of the distribution grid but are not significant from the one obtained in the previous case where we install only one AR. Thus, it is recommended, in case of this feeder only, that one automatic recloser would be enough to achieve the targeted reliability goal, and to isolate a proper portion of the network as a small islanded microgrid during outages. The reduction in the SAIDI and SAIFI indices could be attributed to the fact that the DG units have another virtue in improving reliability by taking the form of peak shaving, where the DG units can generate more on-site power than the demand on the feeder, allowing more power to support the grid during normal operation. The savings in Table 3 compares the revenue the utility could achieve by considering each option separately. Again, the savings here are calculated based on the outage costs that the software provides.

Table 3. The savings in case of connecting three DG units

Case Description	Savings ($)
Base Case + 3 DGs	74,990.00
Add AR [834-842]	136,342.00
Add AR [842-844]	132,268.00
Add AR [834-860]	91,659.00
Add AR [860-836]	89,483.00
Add AS [834-860]	86,558.00
Add AS [860-836]	84,141.00

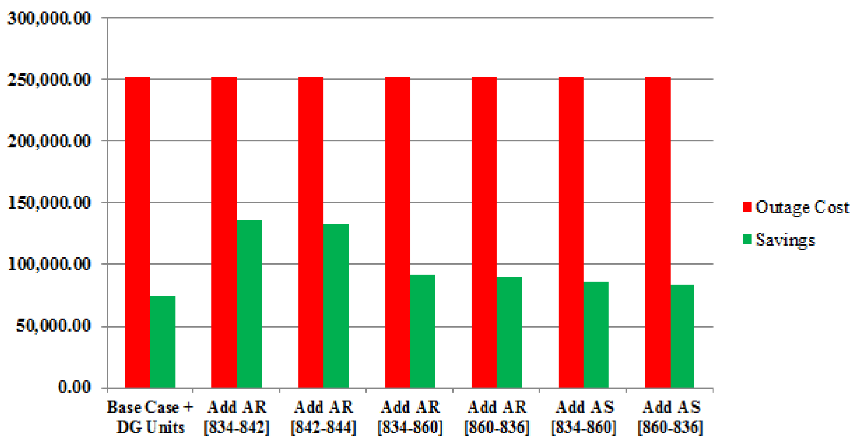

Fig. 3. The savings vs outage costs for case no. 2.

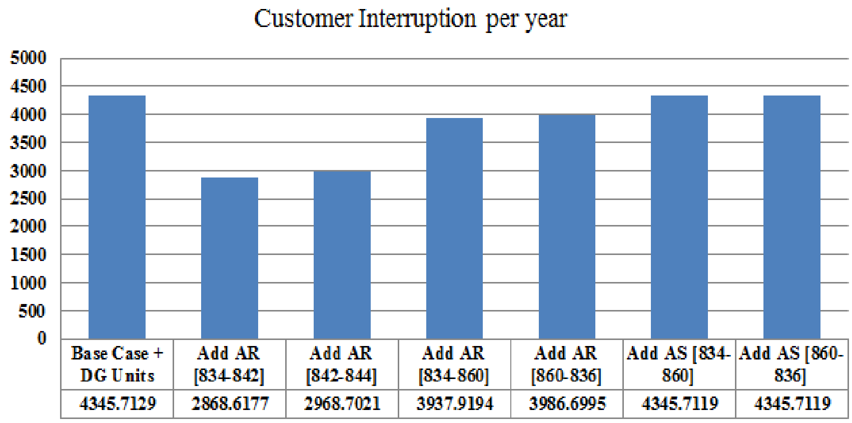

Fig. 4. The resulted customer interruptions for each option in case study 2.

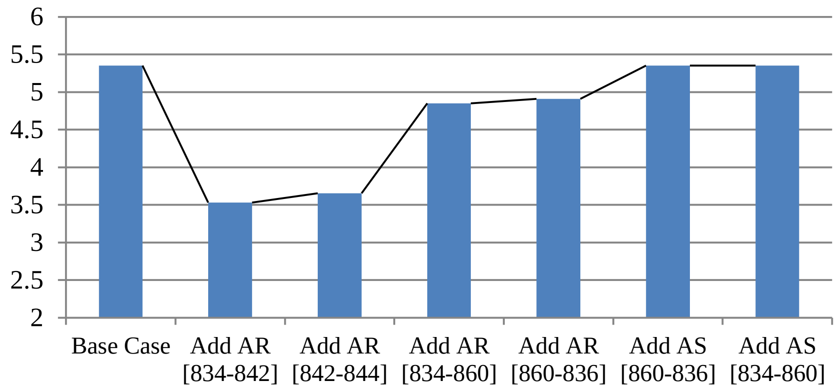

Fig. 5. SAIFI reductions for case study 2.

5. Conclusion

The installation of the DG units would be a more attractive choice for the utilities to achieve higher reliability goals than building another source of supply in the existing grid, which accounts for more costs and potential loading issues in the future. In addition, the DG units would offer reconfiguration schemes for the feeder during outages, maintaining service to a substantial number of customers and improving the utilities indices. In this work, we modified the IEEE 34 node test system to model the system in two cases. The first is to account for construction of a traditional distribution substation to support the system operation and reliability, while the other case is to install three DG units in different locations on the feeder. The reliability indices and outage costs are provided in the work for several scenarios and configurations. According to the results obtained, DG units are considered the best option for a utility to improve its reliability indices and generate potential revenues. Based on our results, it is suggested that both SAIDI and SAIFI could witness great improve that reached 54% and 34% in our study, respectively, where the best scenario is to install three DGs in different locations with AR at node 834-844. This substantial reduction in the reliability indices is attributed to the fact that customers in healthy parts of the feeder would remain in services even during major outages, and to the virtue of peak shaving and congestion reduction the DGs can make during peak demand hours. Therefore, it is highly observed in this paper that the DGs will play major role in applying the concepts of the smart grid efficiently, helping in improving the reliability and operation of the distribution system and providing the utilities with self-healing power grids that keep services to customers during major outages and blackouts.

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