International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878, Volume-3 Issue-4, September 2014

Reliability Analysis of the Unbalanced Distribution Systems Considering Distributed Generators

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Abstract: The distribution system is prone to failures and disturbances due to weather related issues and human errors. The distributed generation is expected to play a key role in the power system. The reliability of the power supply can be improved in the presence of distributed generation (DG). In this paper, general assessment of the impact of distributed generation (DG) on the distribution system reliability is presented. The reliability improvement is measured by reliability indices. A typical case study is presented where distribution system reliability indices are calculated for an existing system without DG and compared with insertion of DG in the system.

Keywords: Reliability, Distributed Generation, SAIFI, SAIDI, CAIDI, ASAI

I. INTRODUCTION

The main objective of a power system is to supply electricity to the load requirement of the customers with a reasonable assurance of continuity and quality. The ability of the system to provide an adequate supply of electrical energy is usually designated by the term of reliability. The cost of interruptions and power outages has severe economic impact on the utility and its consumers. So, it became necessary to plan and maintain reliable power systems. The concept of reliability is extremely broad and covers all aspects of the ability of the system to satisfy the customer requirements. Reliability assessment is primarily focused on an analysis of the healthy states of the system. The two basic aspects of system reliability which are system adequacy and security deals with the static and dynamic conditions of the system respectively [1]. Most of the probabilistic techniques presently available for power-system reliability evaluations are in the domain of adequacy assessment. The three subsystems of generation, transmission and distribution can be designated as power system functional zones. Reliability evaluations of the power system are usually conducted in each of these functional zones or in the combinations that gives the hierarchical levels. The reliability evaluations of the power system are usually conducted separately in the of generation, transmission and distribution. The total system generation capacity is examined to determine its adequacy to meet the total system load requirement in

Revised Manuscript Received on 30 September 2014.
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generation system reliability evaluation. Generation adequacy analysis is not intended to provide the reliability indices for individual load points. This activity is usually termed as "generating capacity reliability evaluation".
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Assessments are also made in the combined generation and transmission systems. In this, the adequacy of a system including the impact of various reinforcement alternatives at both the generation and transmission levels on bulk load point and overall system indices can be accessed. This type of analysis is usually termed as "composite system or bulk transmission system evaluation". Customer interruptions caused by generation and transmission system failures are normally only about 20 percent of the total load point interruptions. The remaining 80 percent of customer interruptions occur within distribution systems. Power system reliability assessment without considering distribution systems therefore recognizes only a small part of the total outage costs. Thus, the improvement of the system performance in terms of reliability becomes more important in this functional zone [2]. Distribution system is usually analyzed as a separate entity. Distribution system reliability evaluation can be used to obtain quantitative adequacy indices at the actual customer load points. These indices reflect the topology of the network, components used, the operating philosophy and other particular functions. The effect of the bulk system on the distribution system is usually ignored in the analysis. The study concentrates on the distribution system, it is assumed that there is always sufficient power supplied by the substations. The failures of components within the substation, such as transformers and switches, are taken into account. Therefore the main focus is on the availability of the distribution facilities required to transport the power to customer load points. The distribution companies which violate these reliability limits have to pay price for it like economic compensation for the affected customers [3]. Many distribution systems have been built unbalanced where single and three phase distribution transformers, secondary distribution and customer connections are extensively used. They have three phase sections and laterals with one, two or three phases. The extensive use of single phase distribution components such as fuses, cut-outs, disconnectors etc. may cause unbalance. Any one of these components opens or it fails, an unbalanced outage occurs. Since 70 - 80% of the failures that affect the distribution systems are single phase and only small percentage of failure are due to three phase [4]. The important cause of unbalance is that most of the failures are single phase.

Generally, the customers affected by outage depends on the type of outage i.e., single phase, two phase and three phase outages and low voltage and the type of the connection of the distribution transformer. If the connection of transformer is phase to earth or phase to neutral, the customers connected to the faulty phase are affected. If a three phase transformer with delta - star connection, the customers with single phase connection to any of the phases with abnormal voltage are considered without service. For customers with three phase connection, the three-phase loads will be interrupted when the load connected to the phases with abnormal voltage. The three phase outages are usually balanced outages. In order to suggest realistic results, the studies have to include the real constructive and operative aspects present in the systems; one of these aspects is the unbalance nature of the distribution system. When unbalance is included in the reliability assessment it is necessary to define the probability of single and double phase failures. If a single-phase failure occurs it can be on any one of the phases A, B or C. If the failure occurred is of double-phase failure occurs it can be on any two of the phases A-B, B-C or A-C. These probabilities can change during the year in accordance with seasons and also due to the location of the phases.

II. RELIABILITY BENEFITS OF DG

The reliability benefits are appreciated from a costumer point of view, when a DG is installed, operated and properly located for the improvement of reliability of energy supply. The presence of DG became essential where the interruption of service is unacceptable economically or where health and safety is impacted. Small customers do not really care about supply interruptions because they do not feel it as a great risk. However, for the large customers who made high investment do not expect minimum interruptions because of huge loss. Thus some industries which where reliable power supply is important may find the reliability of the grid too low and would be willing to invest in DG. The liberalization of energy markets which makes customers more aware of the value of reliable electricity supply. Distributed generation technologies may provide protection against power interruptions, i.e. fuel cells and backup systems combined with uninterruptible power supply. In addition gas and diesel engines combined with a fly wheel to cover the start up time are being commercialized. The calculation of reliability indices can be examined by using commercial software packages. A reliability analysis using DISREL – a computer program to calculate predictive reliability indices for an electric distribution system which shows the impact of distributed generation on distribution system reliability [5]. Further, the different modeling techniques for DG are proposed and their applications to a radial network using commercial software tools that shows improvement in the reliability indices [6]. An analytical approach to calculate the reliability of the system that included some intrinsic attributes of the DG and the distribution system including DG failure, component failure and change in load demand [7]. Many factors were considered for the reliability indices calculation in this technique. An analytical and probabilistic approach to calculate the reliability for momentary interruptions is discussed [8]. In this, the reliability cost evaluation technique that unifies sustained and momentary interruptions costs is also presented. The author of [9] presented the positive and negative impacts of DG on reliability indices and power quality. The positive impacts included faster restoration and reduced voltage sags, while the negative impacts could be sympathetic tripping and increased fuse blowing. In [5], the intentional islanding impacts of DG for reliability improvement are discussed. The basic data for reliability assessment of distribution system which contains basic results of continuity studies for a range of sensitivity analysis and alternate configurations [10].

III. RELIABILITY INDICES

The basic function of a distribution system is to supply electrical energy from a substation to the individual customer load points. Service continuity is an important criterion in a distribution system. Service continuity can be described by three basic load point indices and a series of system indices. The three basic load point reliability indices usually used are the average failure rate 'λ', the average outage time 'r' and the average annual unavailability or average annual outage time 'U'. These load point indices can be aggregated to provide an appreciation of the system performance using a series of system indices. Analytically, these indices are calculated using the following equations

$$\lambda_L = \sum \lambda_i \quad (1)$$

$$r_L = \frac{\sum \lambda_i r_i}{\sum \lambda_i} \quad (2)$$

$$U_L = \lambda_L r_L \quad (3)$$

Where 'i' refer the number of feeder sections connecting the load point to the supply and s is the name of this load point. The most common indices are System average interruption frequency index, *(SAIFI)*, System average interruption duration index *(SAIDI)*, Customer average interruption duration index *(CAIDI)*, Average service availability Index *(ASAI)*

$$SAIFI = \frac{\sum_{i=1}^{R} \lambda_i N_i}{\sum_{i=1}^{R} N_i} \quad (4)$$

$$SAIDI = \frac{\sum_{i=1}^{R} U_i N_i}{\sum_{i=1}^{R} N_i} \quad (5)$$

$$CAIDI = \frac{\sum_{i=1}^{R} U_i N_i}{\sum_{i=1}^{R} N_i \lambda_i} \quad (6)$$

$$ASAI = \frac{\sum_{i=1}^{R} 8760\, N_i - \sum_{i=1}^{R} U_i N_i}{\sum_{i=1}^{R} 8760\, N_i} \quad (7)$$

Where λ_i is the failure rate, U_i is the annual outage time, N_i is the number of customers at load point i, R is the set of load points in the system and 8760 is the number of hours in a calendar year.

IV. PROBLEM FORMULATION

To evaluate SAIFI, SAIDI, CAIDI and ASAI of a distribution circuit, the failure rate (λ_i), average annual outage time (U_i) and average repair time (r_i) of all sections and distributor laterals must be identified.

In this study, once the parameters λ_i, U_i and r_i of all sections and distributor laterals are determined, the failure rate of each load point can be calculated by adding the failure rates of all sections and distributors ($\Sigma\lambda_i$) that contribute to the unavailability of load point 'L'. This can be analyzed by using the fig. 7.3.

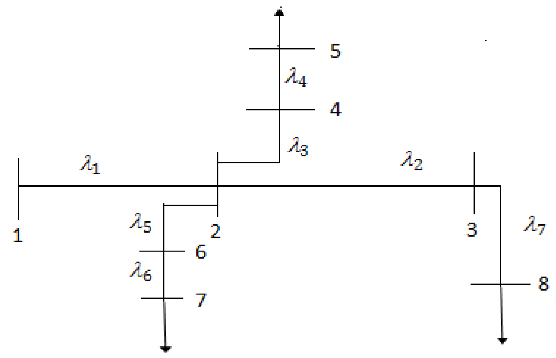

Fig. 7. 3. A Typical Distribution System

$$\lambda_{L_2} = \lambda_1$$
$$\lambda_{L_3} = \lambda_1 + \lambda_2$$
$$\lambda_{L_4} = \lambda_1 + \lambda_3$$
$$\lambda_{L_5} = \lambda_1 + \lambda_3 + \lambda_4$$
$$\lambda_{L_6} = \lambda_1 + \lambda_5$$
$$\lambda_{L_7} = \lambda_1 + \lambda_5 + \lambda_6$$
$$\lambda_{L_8} = \lambda_1 + \lambda_2 + \lambda_7$$

Where λ is the line failure rate and λ_L load point indices

V. RESULTS AND ANALYSIS

The structure of the distribution system under study is shown in Fig 7.4. This test system was proposed in [11]. System data and reliability indexes are presented in [12]. In this section, the overall system indices are evaluated for the two different cases. In the first case, the system indices are evaluated and compared by placing DG unit at various distances from the distribution substation. In the second case, system reliability indices resulting from an aggregated DG unit and several distributed DG units located at several locations across the system are compared.

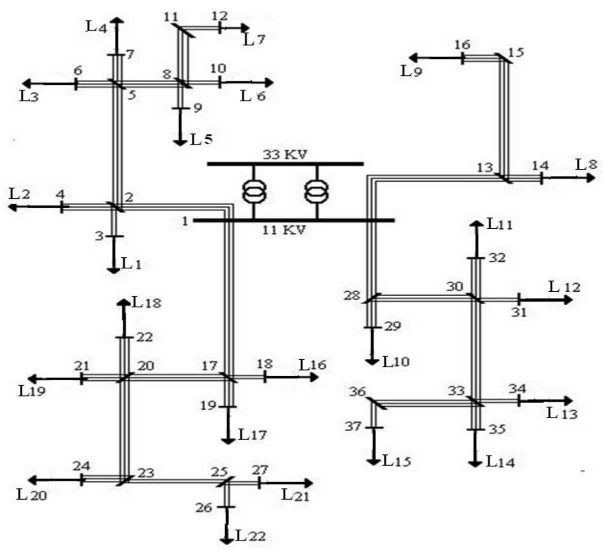

Fig. 1 Unbalanced RBTS System

A. Case I

In this case study, the system reliability indices are evaluated by following the procedure given below

Step 1: Read the system data
Step 2: Evaluate the reliability indices for the base case
Step 3: Place the Distributed Generator near substation
Step 4: Evaluate the reliability indices
Step 5: Repeat Step 4 by placing DG at different locations away from the substation
Step 6: Compare the indices with base case

The reliability indices SAIFI, CAIDI, ASAI and SAIDI are calculated and are shown in Tables I, II, III and IV respectively.

TABLE I: SAIFI (SYSTEM AVERAGE INTERRUPTION FREQUENCY INDEX)

DG Location	Bus Number	SAIFI
I	1	0.2577
II	11	0.2477
III	35	0.2277
IV	24	0.1577

TABLE II CAIDI (CUSTOMER AVERAGE INTERRUPTION DURATION INDEX)

DG Location	Bus Number	CAIDI
I	1	5.3163
II	11	4.3197
III	35	3.3377
IV	24	2.3462

TABLE III ASAI (AVERAGE SERVICE AVAILABILITY INDEX)

DG Location	Bus Number	ASAI
1	1	0.9998
2	11	0.9999
3	35	0.9999
4	24	1.0000

TABLE IV SAIDI (SYSTEM AVERAGE INTERRUPTION DURATION INDEX)

DG Location	Bus Number	SAIDI
I	1	1.37
II	11	1.07
III	35	0.76
IV	24	0.37

It can be seen from Tables I, II, III and IV that the DG unit that is installed at the start of the circuit (location I, which is at substation) will not improve the reliability indices of the system regardless of the DG. This is because the failure in any section or distributor laterals within the circuit will not be mitigated as the DG unit will just act as an additional source to the distribution substation. In case of power interruptions from the main substation, the DG can be used to supply power to the system. However, this contribution does not reflect on the system reliability indices such as SAIDI, CAIDI, SAIFI and ASAI. Significant improvements in the reliability indices can also be observed as the DG unit is placed away from

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the substation i.e from location I and closer to the end of the system. Table V summarizes the improvement in reliability indices when DG of is placed from the distribution substation toward the end of the system.

TABLE V IMPROVEMENT IN RELIABILITY INDICES

DG Location	SAIFI	CAIDI	ASAI	SAIDI
II	4%	18.7%	0%	21.8%
III	11.6%	37.2%	0%	44.5%
IV	38.8%	55.8%	0%	58.4%

From Table V, it is observed that, the average interruption frequency for the system (SAIFI) improves by 39% as the DG is moved from the start to the end of circuit (location IV). Similar improvements are observed for the average interruption duration index for customers (CAIDI) and average interruption duration index for system (SAIDI). In addition, the system indices which are based on the load points failure rate namely, average service availability index ASAI remained the same for the three cases studied.

B. Case 2

The structure of the distribution system under study is shown in Fig.1. For the study, two distributed generators DG1 and DG2 are considered. The impact of the distributed generators on the reliability of the system under study is investigated as follows:

First, the overall system indices are evaluated not considering the both DG units. Then, the same analysis was performed with either of the two generators is running and the second is unavailable. Finally, the system analysis is performed with both the two DG units running in parallel with the system.The system reliability indices are evaluated for the above different conditions and are presented in table VI.

TABLE VI SYSTEM RELIABILITY INDICES

Index	Without DG	With 1 DG	With 2 DGs
SAIFI	0.2577	0.1577	0.0393
CAIDI	5.3163	2.3412	2.0356
ASAI	0.9998	1.0000	1.0000
SAIDI	1.3700	0.3700	0.0800

The comparison between the results obtained for the different conditions indicates that the system indices which are based on the load points failure rate namely, average service availability index ASAI remained the same for the three different conditions. The main contribution of the DG to the system reliability is the improvement in the system average interruption frequency index (SAIFI), customer average interruption duration index (CAIDI) and the system average interruption duration index (SAIDI). Although the frequency of interruption of the system is the same for all cases, the duration of these interruptions become shorter as the number of DG units in the system increases. Both the customers and the utilities are benefiting from this improvement in the duration of interruptions.

VI. CONCLUSIONS

In this paper, the impact of distributed generation on the distribution system reliability was investigated. The analysis of the studied system has proven that that the presence of DG will enhance the system reliability. In order to perform the realistic studies, the reliability assessment is done for the three phase unbalanced distribution system. The most frequent events that affect power system operation are Single and double phase outages and they do not necessarily affect all customer demand as three-phase outages do. These important facts have to be included in the reliability assessment. By installing small-scale distributed generators, the system reliability indices can be improved depending on the locations of DGs, the number of customers and the sizes of the loads. The indices are improved when the DGs are located closer to the end of circuit. The reliability indices are improved for the load points at which multiple DGs are installed. This is because if one DG fails the other DG can still serve the load points partially. This improvement in the system reliability is reflected on the duration of interruptions per customer per year and the duration of system interruptions per year.

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