Reliability worth Assessment of Active Distribution System Considering Protective Devices and Multiple Distributed Generation Units

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ABSTRACT

Reliability worth assessment is a primary concern in planning and designing of electrical distribution systems those operate in an economic manner with minimal interruption of electric supply to customer loads. Renewable Energy Sources (RES) based Distributed Generation (DG) units can be forecasted to penetrate in distribution networks due to advancement in their technology. The assessment of reliability worth of DG enhanced distribution networks is a relatively new research area. This paper proposes a methodology that can be used to analyze the reliability of active distribution systems (DG enhanced distribution system) and can be applied in preliminary planning studies to compute the reliability indices and statistics. The reliability assessment in this work is carried out with analytical approach applied on a test system and simulated results validate that installation of distributed generators can improve the distribution system reliability considerably.

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1. INTRODUCTION

The key drivers for the reconfiguration of electrical distribution networks are network ageing and reliability issues; also the load capacity, circumstantial factors and several other issues such as voltage drops, losses, and short-circuit currents play their role in the evaluation of reconfiguration. Reliability worth is one of the main drivers in the electricity distribution reinforcement because of the necessity of the distribution system on reliable power supply. Distribution networks are typically of radial configuration or meshed configurations that are operated as radial networks. In radial configured networks, outage of a supply point, distribution line, distribution transformer or any other component connected in series will result in loss of all load points connected downstream of the outage. In such situations, reliability of the system can be improved by installing distributed generation units that offer an alternate point of supply to loads connected directly or indirectly by reducing the overall loading of the distribution feeders [1].

Distributed generation (DG) is a small modular generation of capacity ranging from few kilowatts to few megawatts. With advances in power electronics and renewable energy sources, penetration of DG units is projected. DG may be installed at the generation substation, at any point on a distribution feeder or at customer load points. Renewable energy sources (RES) include hydro, wind turnine power generation, solar photovoltaic generation, fuel cells and micro turbines. The major applications of DG units in distribution networks includes as an independent generation, standby or backup power in the event of utility supply interruption, for peak shaving, release of system capacity, net metering, reliability improvement, voltage support, power loss minimization, combined heat and power etc [2].

2. LOAD POINT AND SYSTEM RELIABILITY INDICES

Reliability Indices are the functions of various factors such as failure rate, repair time, switching time, etc. of various components. As factors are random in nature, reliability indices are also random in nature. The predictive reliability assessment of distribution systems requires the evaluation of two groups of indices namely, load point indices and system performance indices. The load point indices are the average load point failure rate (l failures/year), the average load point outage rate (r hr/failure) and the average annual load point outage time or average annual unavailability (U hr/year) [3]. Analytically, these indices are calculated using the following in (1).

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

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

$$U_S = \lambda_S r_S \quad (3)$$

Where i is the number of feeder sections (main or laterals) connecting the load point to the supply and s is the name of this load point. These indices do not always give a complete representation of system behavior and response. The system performance indices are the weighted averages of the load point indices [4]. The descriptions of the power distribution reliability indices are summarized in Table 1:

Table 1. Distribution System Reliability Indices for Reliability Assessment

Name of the index	Description	Analytical expression to evaluate the index
SAIFI	System Average Interruption Frequency Index (SAIFI): The average number of interruptions per customer served per year	$SAIFI = \frac{Total\ Number\ of\ Customer\ Interruptions}{Total\ number\ of\ customers\ served} = \frac{\sum \lambda_i N_i}{\sum N_i}$
CAIFI	Customer Average Interruption Frequency Index (CAIFI): The average number of interruptions per customer affected per year	$CAIFI = \frac{Total\ Number\ of\ Customer\ Interruptions}{Total\ number\ of\ customers\ affected} = \frac{\sum \lambda_i N_i}{\sum N_a}$
SAIDI	System Average Interruption Duration Index (SAIDI): The average interruption duration per customer served per year	$SAIDI = \frac{Sum\ of\ Customer\ Interruption\ Durations}{Total\ number\ of\ customers} = \frac{\sum U_i N_i}{\sum N_i}$
CAIDI	Customer Average Interruption Duration Index (CAIDI): The average interruption duration per customer interruption	$CAIDI = \frac{Sum\ of\ Customer\ Interruption\ Durations}{Total\ number\ of\ customer\ interruptions} = \frac{\sum U_i N_i}{\sum \lambda_i N_i}$
ASAI & ASUI	Average Service Availability Index (ASAI): The rating of the total number of customer hours that service was available during a year to the total customer hours demanded.	$ASAI = \frac{Customer\ Hours\ of\ Available\ Service}{Customer\ Hours\ demanded} = \frac{8760\sum N_i - \sum U_i N_i}{8760\sum N_i}$ $ASUI = 1 - ASAI = \frac{Customer\ Hours\ of\ Unavailable\ Service}{Customer\ Hours\ demanded} = \frac{\sum U_i N_i}{8760\sum N_i}$
AENS	Average Energy Not Supplied (AENS): The average energy not supplied per customer served per year	$AENS = \frac{Total\ Energy\ not\ supplied}{Total\ number\ of\ customers} = \frac{\sum U_i L_i}{\sum N_i}$

Name of the index	Description	Analytical expression to evaluate the index
ECOST	Expected Interruption Cost Index at Load Point (ECOST): the cost of not supplying energy at that load point.	$ECOST = \sum_{i=1}^{n} L_i C_i \lambda_i$
EENS	Expected Energy Not Supplied Index (EENS): The amount of energy not supplied to customer	$EENS = P_i - U_i$
IEAR	Interrupted Energy Assessment Rate Index (IEAR): The IEAR at a load point shows how vulnerable is that load point in cost terms.	$IEAR = \frac{ECOST_i}{EENS_i}$

3. TEST SYSTEM DESCRIPTION AND METHODODLOGY

In this section, the impact of distributed generation units from renewable energy sources on reliability of the distribution system was considered by calculations. The assessment consisted of four case studies. The objective of this paper is to study the influence of distributed generation on improvement of reliability indices of distribution networks. The following are the case studies performed in this work [5].

Case A: Base Case - Distribution system with out DG units

Case B: Distribution system with DG units connected at end of each feeder

Case C: Distribution system with DG units connected at end of each feeder and circuit breaker at beginning of every lateral

Case D: Distribution system with DG units as an isolated micro grid

Assumptions for the case studies:

1. DG units from renewable sources can provide nominal power continuously.
2. Six renewable source based DG units are connected to the distribution network at end of each section.
3. DG units can provide load points in the connected feeder with required power.
4. If any failure occurs on main feeder, load points in the lateral feeder sections will be supplied with electric power after protective devices separate laterals from main feeder.

3.1. Description of the test distribution system–case a: base case (without DG units)

The single line diagram of the test distribution system is shown in Figure 1. The Case A determines base case results of the distribution system without distributed generation (DG) units from renewable energy sources. The test system shown in Figure 1 consists of two main feeders M1 and M2. The feeder M1 represents the distribution system of rural environment which doesn’t have switches or protecting devices at the beginning and end of each section, whereas the feeder M2 represents distribution system of urban environment which has switches at both beginning and end of each section [6].

The feeders M2 provide isolation of the faulted section of the grid and consequently maintain an uninterrupted power supply to the rest of the distribution network, which is not possible in the rural environment i.e. with feeder M1 because there are no switches at the beginning and the end of every section. Therefore that power outage of any section in feeder M1 will affect a larger number of consumer load points. Another major difference between the urban and the rural environment feeder shown in this example is the inability to supply customer load points from multiple directions in the case of a rural network (feeder M1). Multiple DG units must be optimally located and sized in the distribution network considering the configuration of system [7].

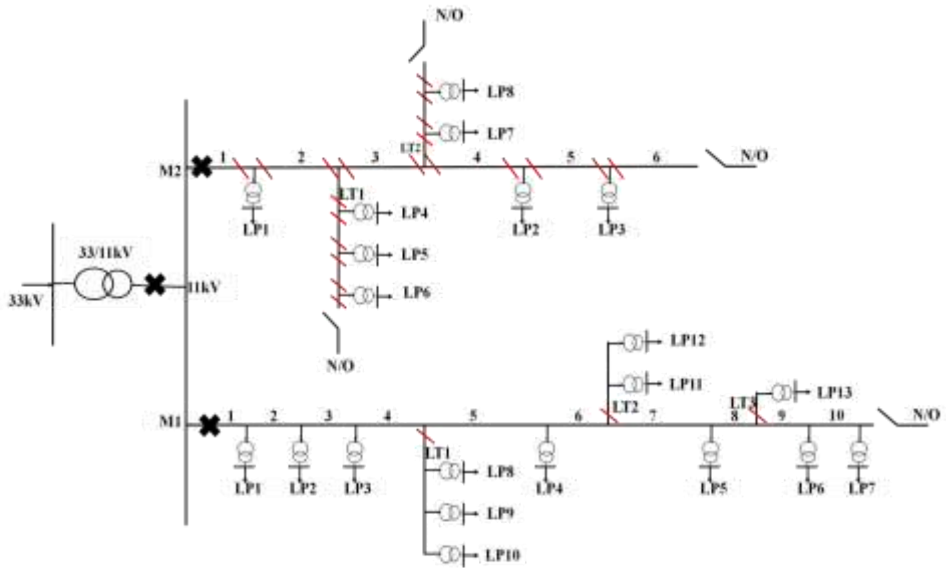

Figure 1. Single line diagram of test distribution system with out DG units-case A

3.2. Description of the test distribution system–case B: distribution system with DG units

The single line diagram of the test distribution system for this case study is shown in Figure 2. The Case B determines assessment results of the distribution system with distributed generation (DG) units from renewable energy sources. Six renewable sources based DG units are connected to the distribution system at the end of every feeder and it is considered that DG units in the feeder can supply the required power to all the load points [8].

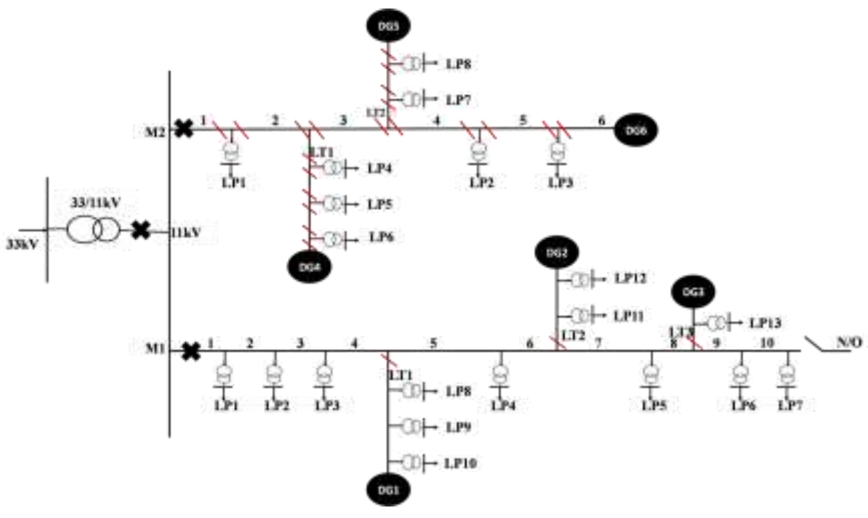

Figure 2. Single line diagram of test distribution system with DG units-case B

3.3. Description of the test distribution system–case C: distribution system with DG units and circuit breakers

The single line diagram of the test distribution system for this case study is shown in Figure 3. The Case C determines assessment results of the distribution system with distributed generation (DG) units from renewable energy sources and switches at beginning of each lateral are replaced by circuit breakers. In case of any failure on main feeder, circuit breaker allows almost a momentary separation of laterals from main feeder.

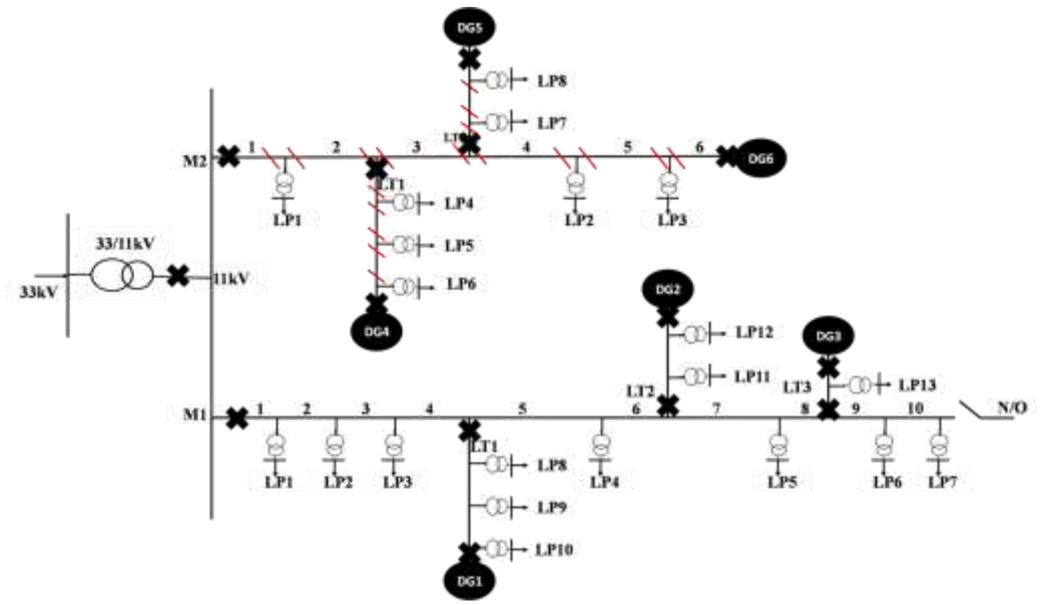

Figure 3. Single line diagram of test distribution system with DG units and circuit breakers-case C

In case B, the switches used as protection devices require a longer period of fault interruption. But in this case C, under the event of fault on main feeder, the circuit breakers used as protective devices allows momentary separation of faults and prevents the entry of load points and DG units into islanded mode.

3.4. Description of the test distribution system–case D: distribution system with DG units as an isolated micro grid

The single line diagram of the test distribution system for this case study is shown in Figure 4. The Case D determines assessment results of the distribution system with distributed generation (DG) units from renewable energy sources and the system under study is considered as an isolated micro grid. In this case, it is assumed that a momentary failure occurs on main feeder will allow circuit breaker to isolate the consumer load points instantly from main grid. Hence the consumers positioned in newly formed isolated micro grid will be supplied by electric power from the DG units connected at the end of laterals.

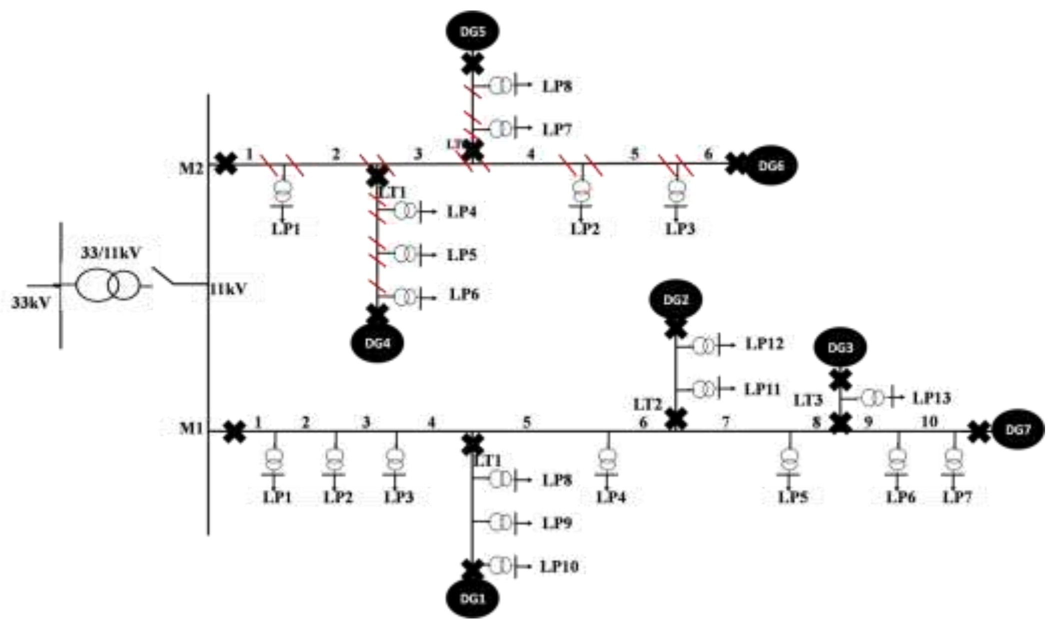

Figure 4. Single line diagram of test distribution system with DG units as isolated micro grid-case D

4. ASSESSMENT RESULTS

This section presents the calculated results for all the case studies. Analytical method was used for assessment of different reliability indices of test distribution system under various case studies.

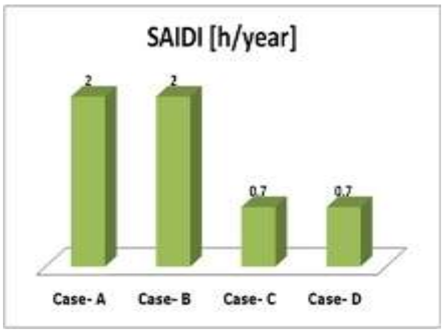

Figure 5. Reliability index–SAIDI of feeder M2

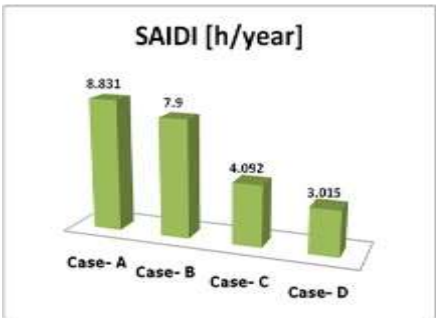

Figure 6. Reliability index–SAIDI of feeder M1

The System Average Interruption Duration Index (SAIDI) value decreases through various cases. It can be observed that the value of SAIDI has no change through Cases A & B. That means installation of DG units in test distribution system has not influenced SAIDI due to presence of large number of switches in the feeder as this feeder is in urban environment. The failure occurred on the feeder can be limited to small section of the feeder. Other load points can be supplied through DG units connected at other end of the laterals. The reason for reduction in value of SAIDI in cases C & D is installation of circuit breakers in the laterals which are responsible for minimization of interruption duration.

Installation of DG units and allowing the system to operate in islanding mode improves the SAIDI of the test distribution system. Improvement of SAIDI can be observed after insertion of circuit breakers from cases C&D in Figure 7. System Average Interruption Frequency Index (SAIFI) is constant for all the four cases A,B,C & D as the installed DG units can't influence the frequency of interruptions.

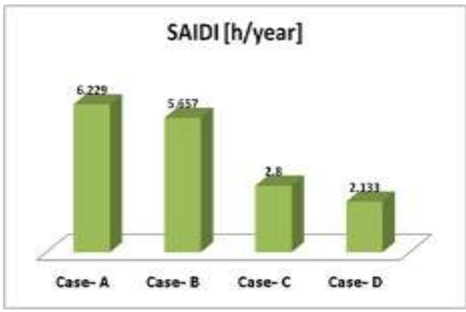

Figure 7. Reliability index–SAIDI of test distribution system

Figure 8. Reliability index–SAIFI of test distribution system

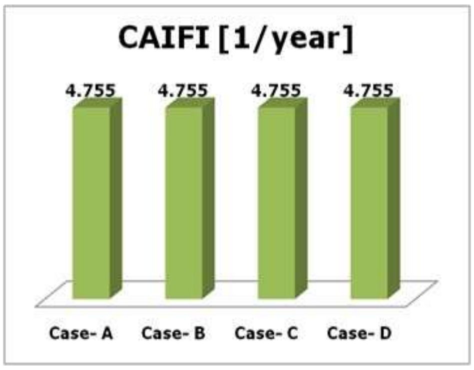

Figure 9. Reliability index–CAIFI of test distribution system

The Customer Average Interruption Frequency Index (CAIFI) is constant through all four cases due to the reason that installed DG units can't affect the number of interruptions or frequency of occurance of failures. It affects only the duration of restoation of power supply. By analyzing the Figure 10, installed DG units are responsible for reduction of Customer Average Interruption Duration Index (CAIDI). A much reduction in CAIDI can be observed through cases B & C, which can be achieved by replacement of switches with circuit breakers. The replaced circuit breakers allow faster separation of faulty laterals and restoration of supply to consumers from installed DG units in islanded mode of operation.

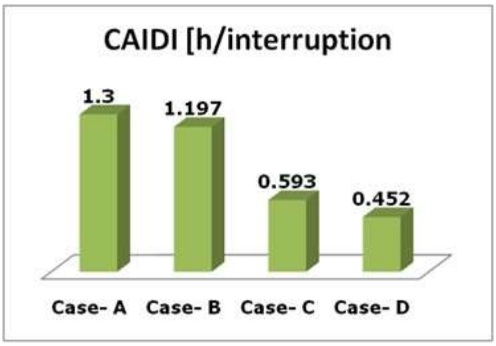

Figure 10. Reliability index–CAIDI of test distribution system

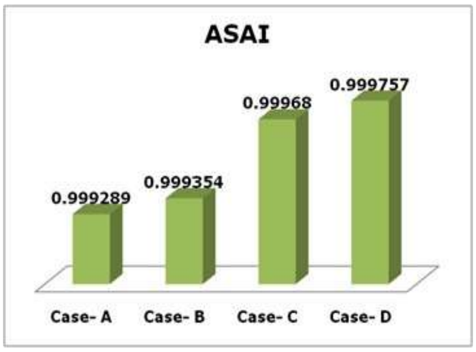

Figure 11 Reliability index–ASAI of test distribution system

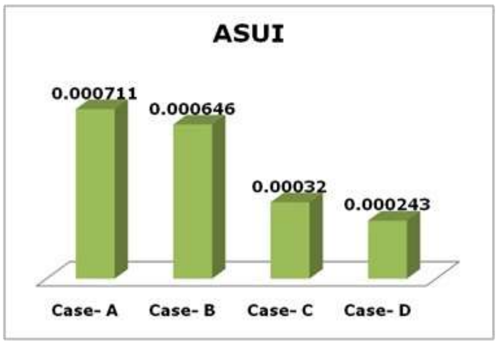

Figure 12 Reliability index–ASUI of test distribution system

The Average System Availability Index (ASAI) increases through all the four cases and its complementary index Average System Unavailability Index (ASUI) decreases through all the four cases.

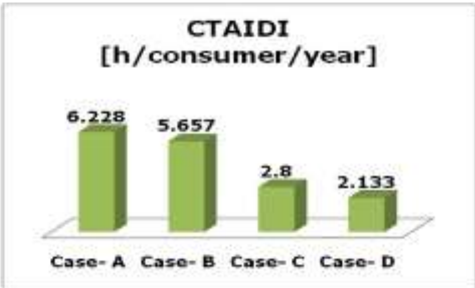

Figure 13. Reliability index–CTAIDI of test distribution system

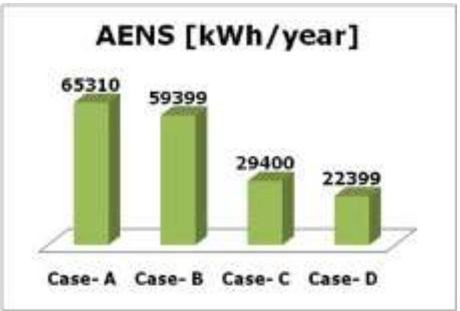

Figure 14. Reliability index–AENS of test distribution system

Another reliability index customer total average interruption duration index (CTAIDI) also reduced through all four case studies. Another index of reliability analyzed in this paper is average energy not served (AENS), which has reduced through all cases due to direct connection of DG units with profit generated through energy distribution.

5. CONCLUSION

By analyzing the assessed indices of test distribution system through all four case studies, it can be observed that supplying electric power to consumers through renewable based DG sources in islanded mode of operation during the time of failure occured on main feeder. Reliability calculations in this paper demonstartes many positive impacts on the distribution network. One of the impact is significant improvement of system reliability. Also, reliability index AENS shows that additional profit will be achieved by shortening the duration of power outages.

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