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Impact of Single DG on the Reliability of the distribution system

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Abstract:*Electrical distribution system is crucial in electric power system because it is directly related to customers and power utilities. Reliability is essential in an electric power system that can be defined as supplying power to the system according to customer satisfaction. Distributed Generation (DG) provides on-site services for customers and supports the distribution network. In this research, different reliability tests have been carried out based on various reliability indices. Through different reliability tests, optimum location to install DG in distribution system is found out. Here introducing installation of single DG at optimum location has more positive impact than installation of multiple DGs in the same feeder at different locations on distribution system reliability. To evaluate the reliability indices Roy Billinton test system is used and modeled using Electrical Transient Analyzer Program (ETAP).*
Keywords: *DG, distribution system, reliability indices, distributed generation*

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I. Introduction

Electricity is the most important and basic necessity for humans in every aspect of life, but it's considered as one of the most complex systems consist of structures, connections, components, equipment's etc. The demand for electricity is usually fulfilled by electrical power plants. Power plant generates electricity and distributes to the consumers through the interconnected transmission lines. There are so many difficulties arise in distribution of electrical power system. Taking all the problems into account, the most fundamental problems that emerged in different stages are quality, reliability, continuity and power.

Distributed Generation (DG) system are considered as providing an enhancement or an alternative to the traditional electric power system by using small scale power storage technology.It's typically within the range of 1kW to 10000kW. Renewable and non-renewable technologies can be used as DG. It plays a significant role in the electric distribution system. Globally rate of electricity consumption is overgrowing result in increasing penetration level of distributed generation units in distribution system.As an advanced technology,DG has high efficiency, cost- effective, and substantially contributing electricity generation worldwide.

DG technologies are more reliable and efficient and their incorporation into a modern power system helps to meet consumer's demands for load with acceptable quality and continuity. The factors that led to all available renewable energy resources which are being utilized to generate a sufficient amount of electricity that will also cover consumer's demands for load. This way the attention will be shifted to using DG units in an attempt to meet consumers' demands for load. In power system, the achievement of such objectives will incur a costly need for entities to get engaged in penetration, planning, and coordination.

In [1], the authors proposed a methodology to estimate the impact of DG on the reliability indices of distribution networks by considering isolated and interconnected operation of DG. In [2], the authors proposed explicit expressions for analyzing the reliability of distributed generation. In [3], the authors proposed reliability evaluation method of power distributions system by considering the momentary interruption and concentrated on reliability evaluation method and reliability cost evaluation. In [4], the authors described situations and develop methods to analyze positive and negative impact of DG system and discussed how to model the reliability impact of various DG applications in commercial software tools. In this paper, impacts of DG implementation on distribution system reliabilityinvestigated by using a distribution test system and a probabilistic analytical approach is proposed [5]. In [6], the effect of distributed generation on the reliability level of distribution system is discussed and built three state model of DG. In [7], differential search algorithm implemented to find optimum location in radial distribution feeder, also differential search algorithm compared with other well-established algorithms.

This paper presents an analytical approach for analyzing and evaluating the impact of single DG on the reliability of distribution system which is applied to RBTS Bus 2. The test system can be performed without DG, with single DG & multiple DGs of distribution system at different locations.

II. Distributed Generation:

To produce electricity close to end users, DG occupies small-scale technologies. Distributed Generation reduces the amount of energy loss in transmitting electricity because generated electricity is near the point of consumption. It'scost-effective and higher power reliability than traditional power generators. Different countries use different terms for DG. In Asia and Europe, people often use Decentralized Generation to define DG, while in Anglo-Saxon, they often use Embedded Generation as another term of DG. In North America, DG is ascertain as Dispersed Generation [8].

In electric power distribution system Distributed Generation plays a fundamental role in the residential, industrial, and commercial sectors. Industries may find the reliability of grid power supply is too low and they will decide to invest in distributed generation units to improve their overall reliability of power supply to an ideal level [9]. There are various benefits of distributed generation which include reliability enhancement, reduce transmission and distribution line losses, increased security of supply, improve the voltage profile in remote end of line distribution circuits, utilization of renewable energy to avoid carbon emission, and so on.

III. Distribution System Reliability:

3.1 Reliability parameters:

Active failure rate (λ_A):

λ_A is a measure of the frequency of per unit failures occurring in one year and also known as the active failure rate. The active failure rate is related to the component failure mode which is responsible for the activation of the indiscriminative primary protection zone operation which in turn results in the elimination of the malfunctioning as well as the well-functioning components and branches.

Passive failure rate (λ_P):

λ_P is a measure of the frequency of failures occurring in one year and also known as the passive failure rate. It is also related to the component failure mode but unlike its counterpart, it does not affect the well-functioning components since it has no control over the operation of the protection breakers.

Mean Time to Repair (MTTR):

Mean time to repair (in hours) is the expected time to repair a system and restore it to full functionality.

$$\text{MTTR} = \frac{\text{Total maintenance time}}{\text{Total number of repairs}}$$

Mean Time to Failure (MTTF):

It is the expected time (in years) to failure for a non- repairable system.

$$\text{MTTF} = 1/(\lambda_A + \lambda_P)$$

Mean Repair Rate (μ):

μ is the mean repair rate in the number of repairs per year.

$$\mu = 8760/\text{MTTR}$$

Forced Outage Rate (FOR):

It is the number of hours the unit is on forced outage over the total number of hours in a year.

$$\text{FOR} = \text{MTTR}/(\text{MTTR} + 8760/(\lambda_A + \lambda_P))$$

3.2 Reliability Indices:

There are two basic groups of reliability indices in distribution system. There are load point indices and System based indices. First group contains three basic Load point indices consists of failure rate, annual outage time, and outage duration. On other group System based indices consists of System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Expected Energy Not Supplied (EENS), Customer Average Interruption Duration Index (CAIDI), System Customer Total Average Interruption Duration Index (CTAIDI),Average Service Unavailability index (ASUI), Average Service Availability Index (ASAI), Average Energy Not Supplied (AENS) [10,11] ,and so on.

Reliability indices are usually used to measure the reliability of the system. To quantify reliability indices of distribution circuit, three basic indices are:

Failure rate: $\lambda_s = \sum \lambda_i$

Annual outage time: $U_s = \sum \lambda_i r_i$

Average outage time $r_s = \frac{U_s}{\lambda_s}$

Where,

λ_i = The failure rate of load point i.

r_i = The average repair time of load point i.

Although Basic indices are important, but they do not provide overall information, so customer related additional indices are required to provide overall information of the system performance. Customer related additional indices are:

System Average Interruption Frequency Index (SAIFI):

$$SAIFI = \frac{\text{Total number of customer interruption}}{\text{Total number of customers served}}$$

$$= \frac{\sum \lambda_i N_i}{\sum N_i} \text{ (f/ customer. yr)}$$

System Average Interruption Duration Index (SAIDI):

$$SAIDI = \frac{\text{Sum of all customer interruption durations}}{\text{Total number of customers served}}$$

$$= \frac{\sum U_i N_i}{\sum N_i} \text{ (hr/ customer. yr)}$$

Customer Average Interruption Duration Index (CAIDI):

$$CAIDI = \frac{\text{Sum of all customer interruption durations}}{\text{Total number of customer interruptions}}$$

$$= \frac{SAIDI}{SAIFI}$$

$$= \frac{\sum U_i N_i}{\sum \lambda_i N_i} \text{ (hr/ customer interruption)}$$

Customer Total Average Interruption Duration Index (CTAIDI):

$$CTAIDI = \frac{\text{Sum of durations of customer interruptions}}{\text{Number of distinct customers interrupted}}$$

$$= \frac{\sum U_i N_i}{N_{io}} \text{ (hr/ customer. yr)}$$

Energy Not Supported (ENS):

$$ENS = \sum \text{Load} * \text{Outage duration}$$

$$= \sum L_{a(i)} U_i \text{(MW hr/ yr)}$$

Average Energy Not Supplied (AENS):

$$AENS = \frac{(\sum L_{a(i)} U_i)}{\sum N_i} \text{ (MW hr/ customer. yr)}$$

Average Service Availability Index (ASAI):

$$ASAI = \frac{(\sum N_i * 8760 - \sum U_i N_i)}{\sum N_i * 8760} \text{ (pu)}$$

Average Service Unavailability Index (ASUI):

$$ASUI = \frac{\sum U_i N_i}{\sum N_i * 8760} \text{ (pu)}$$

ASUI = 1- ASAI

Where,

λ_i= Average failure rate at load point i.

U_i= The annual outage time at load point i.

N_i= The no of customers at load point i.

IV. Distributed Generation Technologies:

Distributed Generation technologies are a kind of modular generating units, which are used to provide an alternative scheme of traditional power system to reduce power interruption. Renewable and non-renewable energy sources can be used as DG technologies. Reciprocating engines, gas turbines, micro-turbines, and steam turbines are considered as non-renewable DG technologies. Non-renewable technologies use fossil-based fuels. However, the burning of fossil fuels contributes the most to global warming, greenhouse gas emission and acid rain; all of these are global concerns. Non-renewable resources are unsustainable and have limited reserves. Renewable DG technologies directly connected with low or medium voltage users load in the distribution system. Solar power, photovoltaic (PV), geothermal power, Small/Micro/Pico hydropower and wind turbines are consider as renewable technologies.

In this work, wind turbine generator (WTG) is considered as DG system. In table 1 shows reliability data of WTG.

Table 1: Reliability data of WTG

Unit	Failure rate(f/yr)	Repair time(hr)	Switching time(hr)
1MW	0.02	60	1.0

V. Distribution Network Modeling:

Roy Billintonintroduced a test system for academic purposes at University of Saskatchewan, Canada [12, 13] which called Roy Billinton Test System (RBTS). In this research, a portion of RBTS Bus 2 is modeled using ETAP. ETAP considered as most widespread analysis platform for power generation, distribution, and industrial power system to design, simulation, analysis, optimization, operation, and automation[14]. ETAP model for a portion of RBTS Bus 2 shows in figure 1. Table 2 provided consumers data while table 3 shows reliability data regarding active failures rate and passive failures of each components which are selected as per RBTS own data.

Table 2: Consumers data

Load points	Types of consumer	Load (MVA)	No of consumers
L1	Residential	0.535	100
L2	Residential	0.454	50
L3	Commercial	0.566	10
L4	Govt. & Inst.	0.454	1
L5	Govt. & Inst.	0.454	2
L6	Office & bldg.	0.535	10
L7	Industrial	0.566	2
L8	Commercial	1.000	20
L9	Industrial	1.000	1

Table 3: Components reliability data

Components	Active Failure rate (f/yr)	Passive Failure rate(f/yr)	Repair time	Switching time
Breakers				
33KV	0.0015	0.002	4	1
11 KV	0.004	0.006	4	1
Transformers				
33/11 KV	0.015	0.015	200	1
11/0.415KV	0.015	0.015	200	1
Busbars				
33KV	0.001	0.001	2	1
11KV	0.001	0.001	2	1
Cables				
11KV	0.04	0.04	30	3

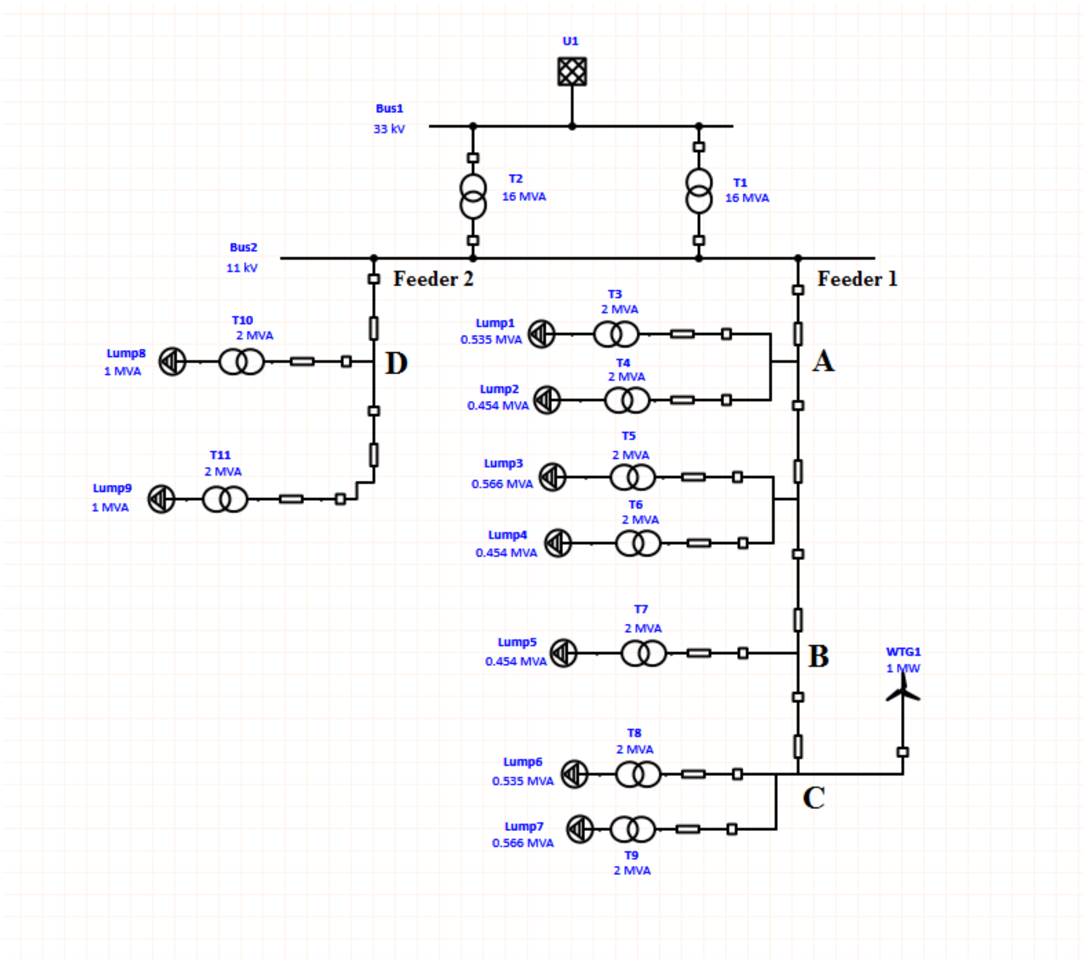

Figure 1 - A portion of RBTS Bus 2

VI. Results and Discussion:

In this research, the reliability of a portion of RBTS Bus 2 is assessed using four cases.

A. Reliability analysis when no DG is installed:

In this case, reliability analyses are done when no DG is installed in the distribution network. Table 4 lists the reliability indices.

Table 4: Reliability indices without DG

Reliability Indices	Without DG
SAIFI	0.9013
SAIDI	11.9462
CAIDI	13.254
CTAIDI	11.946
EENS	1249.315
ASAI	0.9986
ASUI	0.00136
AENS	6.3741

B. Reliability analysis when single DG is installed at different locations:

In this case, DG has been installed at several different locations and individually recorded system reliability indices. Table 5 lists the reliability indices.

Table 5: Reliability Indices with single DG at different locations

Reliability Indices	At point A	At point B	At point C	At point D
SAIFI	0.2097	0.1867	0.1808	0.249
SAIDI	4.3968	3.8914	3.7408	5.3696
CAIDI	20.969	20.844	20.686	21.568
CTAIDI	4.397	3.891	3.741	5.37
EENS	409.146	398.755	396.448	540.674
ASAI	0.9995	0.9996	0.9996	0.9994
ASUI	0.0005	0.00044	0.00043	0.00061
AENS	2.0875	2.0345	2.0227	2.7585

The result depicts that with installation of DG at different locations, the reliability of system improved. Thus from these four locations, best or optimum location is found as point C at which system is more reliable.

C. Reliability analysis when multiple DG are installed at same location:

In this case, Multiple DG (two DG units) have been installed at point C, and compared with single DG unit at point C. Table 6 lists the reliability indices.

Table 6: Reliability Indices with single DG and Multiple DG at same locations

Reliability Indices	Single DG at point C	Multiple DG at point C
SAIFI	0.1808	0.1811
SAIDI	3.7408	3.7417
CAIDI	20.686	20.663
CTAIDI	3.741	3.742
EENS	396.448	396.463
ASAI	0.9996	0.9996
ASUI	0.00043	0.00043
AENS	2.0227	2.0228

The result represents that installing single DG at point Chas positive effect on reliability while installing multiple DG at the same point have adverse effect on distribution system reliability.

D. Reliability analysis when multiple DG are installed at different locations:
In this case, multiple DG has been installed at point A, B & C and recorded system reliability indices, and compared with single DG unit at point C. Table 7 lists the reliability indices.

Table 7: Reliability Indices with Multiple DG at different point

Reliability indices	Single DG at point C	Multiple DG at C & A	Multiple DG at point C & B	Multiple DG at point C & A & B
SAIFI	0.1808	0.1839	0.1809	0.1839
SAIDI	3.7408	3.753	3.7409	3.7532
CAIDI	20.686	20.408	20.682	20.404
CTAIDI	3.741	3.753	3.741	3.753
EENS	396.448	398.14	396.454	398.146
ASAI	0.9996	0.9996	0.9996	0.9996
ASUI	0.00043	0.00043	0.00043	0.00043
AENS	2.0227	2.0313	2.0227	2.0314

The results depict from table 7 that Installation of multiple DG at C&A, C&B, C&A&B has adverse impact while installation of single DG at point C has positive impact. It is obvious from table 7 and figure 1 that installation of single DG at optimum location has more positive impact than installation of multiple DG in the same feeder at different locations.

VII. Conclusions:

In this empirical research, a portion of RBTS Bus2 has been modeled in ETAP. Different reliability tests have been conducted based on various reliability indices. Wind turbine generator considered as a DG source. Various reliability indices of radial distribution system with and without distributed generation has been done. According to this work, the reliability improved after considering the installation of DG. Through different reliability tests, the optimum location to install DG in distribution system found out. Installing single DG at point C has positive effect on reliability while installing multiple DG at the same point has adverse effect on distribution system reliability. However, it is obvious from table 7 and figure 1 that installation of single DG at optimum location has more positive impact than installation of multiple DGs in the same feeder at different locations. These results can be helpful for power generation enterprises to utilize distributed generation for future power system expansion reasonably.

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