Analyzing Distributed Generation Impact on the Reliability of Electric Distribution Network

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***Abstract*—With proliferation of Distribution Generation (DG) and renewable energy technologies the power system is becoming more complex, with passage of time the development of distributed generation technologies is becoming diverse and broad. Power system reliability is one of most vital area in electric power system which deals with continuous supply of power and customer satisfaction. Distribution network in power system contributed up to 80% of reliability problems. This paper analyzes the impact of Wind Turbine Generator (WTG) as a distribution generation source on reliability of distribution system. Injecting single WTG and close to load point has positive impact on reliability, while injecting multiple WTGs at single place has adverse impact on distribution system reliability. These analyses are performed on bus 2 of Roy Billinton Test System (RBTS).**

Keywords—Distribution Generation; Electric Power System Reliability; Wind Turbine Generator; Interruptions; Reliability Assessment

I. INTRODUCTION

Around the world, existing power system is going through different issues like, rising electrical energy demand, growing fuel cost, depletion of fossil fuel and environmental pollution. These issues smoothens way for generation of electrical power at the vicinity of its utilization by means of modular power methods like , micro turbines, fuel cell , photovoltaic cells [1]-[2]. This method of electrical power generation is known as distributed generation.

Reliability is defined as the capability of a system to execute its function in different conditions for given period of time. Customers are directly affected by the interruption in electric power distribution systems, and therefore it is given foremost importance [3].

Usually, each customer in healthy electrical distribution system is energized. In the case of any fault, electric power supply to the customers is interrupted, which is known as outage. Natural causes like lighting, trees and wind, life cycle of equipment and maintenance are some factors that interrupt standard operating condition [4]–[7]. As the utilization of nonconventional or renewable energy resources increases for generation of electric power, many investigative studies are carried out to establish their viability as DGs. The Interruptions due to different causes as mentioned earlier can be reduced by injection of DG unit and thus improves the power system reliability.

In this paper the impact of DG on reliability is analyzed through increasing number of DG units and varying the distance of DG from feeder. This paper has five sections. Section 1 explains research overview. Section 2 has brief explanation on reliability of distribution system. Section 3 describes the problem formulation and steps for evaluating reliability. Section 4 and 5 explains results and conclusion respectively.

II. RELIABILITY OF DISTRIBUTED SYSTEM

Foul climatic conditions highly influence electric distribution system, winds and lighting are main factors contributing towards outages and failure. Many distribution networks are of radial type. Failure of single section may affect several loads due to radial nature of distribution network. Therefore in such systems reliability is of great concern. IEEE has defined certain indices to assess the reliability of distribution system. Performances are measured by means of these indices [8].

1) System Average Interruption Frequency Index (SAIFI):

$$SAIFI = \frac{\Sigma U_i\, N_i}{\sum N_i} f/Customer.yr$$

2) System Average Interruption Duration Index (SAIDI):

$$SAIDI = \frac{\Sigma U_i\, \lambda_i}{\sum N_i} hr/Customer.yr$$

3) Customer Average Interruption Duration Index (CAIDI):

$$CAIDI = \frac{\Sigma U_i \ N_i}{\sum N_i \ \lambda_i} hr/Customer\ Interruption$$

4) Average Service Availability Index (ASAI):

$$ASAI = \frac{\Sigma N_i \ \times 8760 - \sum U_i \ \times N_i}{\sum N_i \ \times 8760} P.U$$

5) Average Service Unavailability Index (ASUI):

$$ASUI = 1 - ASAI = \frac{\Sigma N_i \ \times 8760 - \sum U_i \ \times N_i}{\sum N_i \ \times 8760} P.U$$

6) System Expected Energy Not Supplied (EENS):

$$EENS = \sum EENS_i \ MWhr/yr$$

Where,

$$EENS_i = P_i \ U_i$$

P_i is the load of load Point i .

7) Average Energy Not Supplied (AENS):

$$AENS = \frac{\Sigma EENS_i}{\sum N_i} MWhr/Customer.yr$$

Where,

N_i= Number of Consumers at load point i.

λ_i = Average failure rate at load point i.

U_i= Unavailability.

III. Problem Formulation

To analyze the reliability of distribution system with and without DG bus 2 of RBTS is modeled and analyzed. RBTS is developed by university of saskatewan, Canada for reliability research activities [11]. A portion of Bus 2 is modeled in electrical transients analysis program (Etap) for analysis. Etap is fully integrated DC and AC electrical power software tool.[12]. All Passive and active failure rates of each component are taken as per RBTS. Section data, load data, and components reliability data is given in table 1, 2, and 3 subsequently.

Average reliability indices are estimated as:

$$\lambda_t = \sum_i \lambda_i \quad (1)$$

$$U_t = \sum_i \lambda_i \ r_i \quad (2)$$

$$r_t = \frac{\sum_i \lambda_i \ r_i}{\sum_i \lambda_i} \quad (3)$$

Where,

r_t= Average outage time

λ_t = Average Failure time

U_t= Average annual outage time

A. Reliability Indices Assessment

Below steps are used to evaluate the reliability indices:

1) Failed portion and its location are identified.

2) Load points affected due to failed portion and its duration of failure is determined.

3) After calculating load indices from equation 1 and 3 system indices are resolved.

TABLE I. Feeder Data for Portion of Bus 2 RBTS

No	Length in KM	Feeder Section
1	0.80	C4, C7, C11, C12, C15, C17, C22, C23, C25.
2	0.75	C1, C3, C6, C8, C9, C14, C16, C19, C24.
3	0.60	C2, C5, C10, C13, C18, C20, C21.

TABLE II. Customer Type, Load and Number Data

Type of Customer	Load (MVA)	No of Customers
Residential		
Residential 1	0.535	210
Residential 2	0.535	210
Residential 3	0.450	200
Residential 4	0.450	200
Residential 5	0.450	200
Residential 6	0.450	200
Governmental & Institutions (G & I)		
G & I 1	0.566	1
G & I 2	0.566	1
G & I 3	0.566	1
G & I 4	0.566	1
Commercial		
Commercial 1	0.454	10
Commercial 2	0.454	10
Commercial 3	0.454	10
Industrial		
Industrial 1	1.13	1
Industrial 2	1.30	1
Total	**8.926**	**1256**

TABLE III. COMPONENTS RELIABILITY DATA

Component	Failure Rate (F/Yr)	Repair Time (Hr)	Switching Time (Hr)
Transformers			
33KV / 11 KV	0.0150	15.0	1.0
11 KV / 220 V (LT)	0.0150	10.0	1.0
Breakers			
33 KV	0.0020	4.0	1.0
11 KV	0.0060	4.0	1.0
Busbars			
33 KV	0.0010	2.0	1.0
11 KV	0.0010	2.0	1.0
Feeders			
11 KV	0.650	5.0	1.0

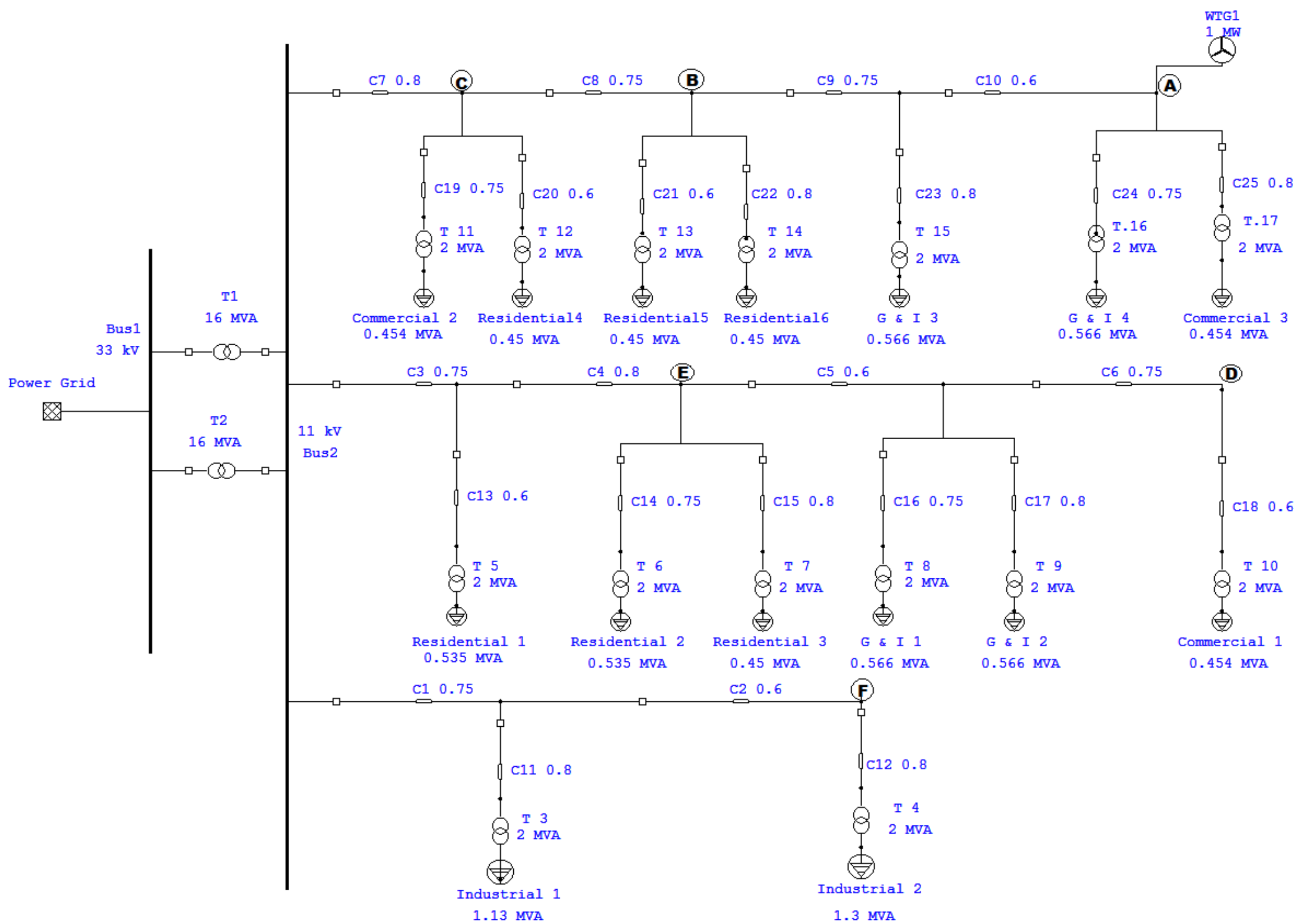

Fig. 1. A portion of Bus 2 of RBTS modeled in Etap

B. DG Reliability Data

WTG is considered as DG source. The WTG is placed at different locations so that the system reliability indices can be recorded. Table 4 lists the reliability data for WTG.

TABLE IV. THE RELIABILITY DATA FOR WTG

Type of Unit	Failure Rate	Repair Time	Switching Time
1 MW (WTG)	0.020 F/Yr	50.0 Hr	1.0 Hr

IV. MODELING AND ANALYSIS

Reliability analysis on bus 2 of RBTS is done using three cases, analysis without DG, analysis with single and multiple DG units, and lastly analyzing reliability by varying DG distance from feeder.

A. Case 1

1) Reliability Analysis without DG

In this case analyses are done without DG and reliability indices are calculated. Table 5 and 6 lists the indices.

TABLE V. RELIABILITY INDICES SAIFI, SAIDI AND CAIDI WITHOUT DG

SAIFI F/ Customer. Yr	SAIDI Hr/ Customer. Yr	CAIDI Hr/ Customer Interruption
3.8680	19.9352	5.154

TABLE VI. INDICES ASAI, ASUI, EENS AND AENS WITHOUT DG

ASAI P.U	ASUI P.U	EENS MWH/Yr	AENS MWH/Customer. Yr
0.9977	0.00228	191.578	0.1525

B. Case 2

1) Reliability VS Penetration of One DG

In this case One DG unit is injected at point A the system indices are calculated. Table 7 and 8 lists the indices.

TABLE VII. RELIABILITY INDICES SAIFI, SAIDI AND CAIDI WITH DG

Point of Injection	SAIFI F/ Customer. Yr	SAIDI Hr/ Customer. Yr	CAIDI Hr/ Customer Interruption
A	1.9957	12.1453	6.086

TABLE VIII. INDICES ASAI, ASUI, EENS AND AENS WITH DG

Point of Injection	ASAI P.U	ASUI P.U	EENS MWH/Yr	AENS MWH/Customer. Yr
A	0.9986	0.00139	120.028	0.0956

The result show positive improvement in reliability indices with injection of one DG unit.

2) Reliability VS Penetration of Multiple DG

With injection of Two DG units at location A the system indices are calculated and results are compared with One DG unit. Table 9 and 10 lists the indices.

TABLE IX. RELIABILITY INDICES SAIFI, SAIDI AND CAIDI

Point of Injection A	SAIFI F/ Customer. Yr	SAIDI Hr/ Customer. Yr	CAIDI Hr/ Customer Interruption
Single DG	1.9957	12.1453	6.086
Multiple DG	1.9959	12.1540	6.090

TABLE X. INDICES ASAI, ASUI, EENS AND AENS

Point of Injection A	ASAI P.U	ASUI P.U	EENS MWH/Yr	AENS MWH/Customer. Yr
Single DG	0.9986	0.00139	120.028	0.0956
Multiple DG	0.9986	0.00139	121.048	0.0964

The results depicted that by injecting multiple DG units at same location in distribution network has adverse effect on the reliability of distribution system.

C. Case 3

1) Reliability VS Distance

In case of one DG penetration at different locations the system indices are calculated and compared with Case1.Table 11 and 12 lists the comparisons.

TABLE XI. RELIABILITY INDICES SAIFI, SAIDI AND CAIDI

	SAIFI F/ Customer. Yr	SAIDI Hr/ Customer. Yr	CAIDI Hr/ Customer Interruption
Without DG	3.8680	19.9352	5.154
A	1.9957	12.1453	6.086
B	2.0119	12.5311	6.228
C	2.2438	14.0404	6.258
D	1.9877	12.1064	6.091
E	2.0036	12.4975	6.238
F	2.5714	15.3795	5.981

TABLE XII. INDICES ASAI, ASUI, EENS AND AENS

	ASAI P.U	ASUI P.U	EENS MWH/Yr	AENS MWH/ Customer. Yr
With Out DG	0.9977	0.00228	191.578	0.1525
A	0.9986	0.00139	120.028	0.0956
B	0.9986	0.00143	131.961	0.1051
C	0.9984	0.00160	143.035	0.1139
D	0.9986	0.00138	122.629	0.0976
E	0.9986	0.00143	132.892	0.1058
F	0.9982	0.00176	140.906	0.1122

The results portray that the reliability indices improve when DG is placed near to the load points, the indices shows that optimum location for planting DG in context of reliability is point A.

V. CONCLUSION AND FUTURE WORK

By conducting different reliability tests on Bus 2 of RBTS the results show diverse impact of DG on the reliability of distribution network. The indices clearly shows that reliability of power system improves by injection of DG into distribution system, injecting DG more close to load points or far from feeder improves the reliability further. However injection of multiple DG units on same location has negative impact on the reliability of distribution network. Furthermore reliability worth assessment can be performed using different renewable or non-renewable energy resources.

REFERENCES

[1] M. Makandar, C. S. R. Atla and S. Velamuri, "Reliability assessment of distribution system with renewable Distributed Generation," 2016 Biennial International Conference on Power and Energy Systems: Towards Sustainable Energy (PESTSE), Bengaluru, India, 2016, pp. 1-5.

[2] T. Ackerman, G. Anderson and L. Soder, "Distributed Generation: A Definition", Electric Power Systems Research, vol. 57, December 2001 pp. 195-204.

[3] C.A Warren, "Distribution Reliability-What is it", Rural Electric Power Conferece, April 1995, pp 1-6.

[4] M.E. Baran and F.F. Wu, "Network Reconfiguration in Distribution Systems for loss reduction and Load Balancing", IEEE Transactions on Power Delivery, Vol. 4, No. 2, April 1989, pp 1401-1407.

[5] P.P. Barker, De Mello, "Determining the Impact of Distributed Generation on Power Systems.I. Radial Distribution Systems", Power Engineering Society Summer Metting, Vol. 3, July 2000, pp 1645-1656.

[6] R.E. Brown and L.A Freeman, "Analyzing the Reliability Impact of Distributed Generation", IEEE Power Engineering Society Summer Meeting, vol. 2, July 2001, pp 1013-1018.

[7] AC. Neto and M.G. da Silva, "Impact of Distributed Generation on Reliability Evaluation of Radial Distribution Systems under Network Constraints", Proc. Of 9th International Conference on Probablistic Methods Applied to Power Systems, June 2006, pp 1-6.

[8] R. K. Mathew, Ashok S. and Kumaravel S., "Analyzing the effect of DG on reliability of distribution systems," Electrical, Computer and Communication Technologies (ICECCT), 2015 IEEE International Conference on, Coimbatore, 2015, pp. 1-4.

[9] R. Billinton, Reliability Evaluation of Engineering Systems, Plenum Press, New York 1996.

[10] Y.Sun, M.H..T. Bollen and G.Ault, "Improving Distribution System Reliability by means of Distributed Generation", 19th International Conference on Electricity Distribution, May 2007, pp 1-4.

[11] R. Billinton and S. Jonnavithula, "A test system for teaching overall power system reliability assessment," in IEEE Transactions on Power Systems, vol. 11, no. 4, pp. 1670-1676, Nov 1996.

[12] Prakash, Prem, Vivek Anand Verma, and R.C. Jha. "Distribution System Reliability Analysis Using ETAP".isrjournal, vol. 02, no. 1, pp. 24-29, Mar 2014.