Evaluation of Distributed Generation Impact on Reliability of a Distribution System using DIgSILENT PowerFactory

Ravishankar B S, Vijayendra V K, K. T. Veeramanju

Abstract: ***As an effective supplement to the centralized fossil fuel based traditional generation, Distributed Generation (DG) has become an effective alternative choice and has been rapidly increasing since past few years due to growing demand for electricity and the new policies of governing bodies for usage of green energy. In overall power system, distribution systems are more vulnerable to faults and reliability aspects of such systems becomes an important issue. With higher penetration of DG into the distribution network, it will be necessary to study the impact of such generation on the various aspects of distribution system. Thus, increase in rate of penetration DGs into the distribution system on one side and increased faults in distribution network on another side, will make the study of impact of DG integration on distribution system reliability an interesting topic of research. The present work focuses on evaluation of impacts of integration of such DGs on reliability of local distribution network, typically in an urban scenario By using the simulation method using DIgSILENT PowerFactory software, the impacts of integration of DG in terms of enhancement in distribution system reliability indices and reduction in system losses for different scenarios are studied and presented in this paper. Based on the simulation results obtained and after analysis of the distribution system, overall results are summarized by focusing on the installation of suitable capacity of DG and the location of DG which are important factors affecting the system losses and system reliability indices.***

Keywords: ***Distributed Generation (DG), RBTS, Simulation, DIgSILENT PowerFactory. Radial distribution system.***

I. INTRODUCTION

The Distribution systems which were passive in nature earlier with uni-directional power flows are transforming into active distribution systems with bidirectional power flows in the present scenario due to gradual increase in integration of small-scale DGs [1]. Integration of DG into the distribution system results in increased system availability and improved reliability of the system. Also, there is possibility of increased system complexity and problem of increased losses due to improper placement, sizing of DGs in distribution networks.

About 65-70% of the losses occurring in the power system can be attributed to distribution system losses [30].

In order to reduce these losses, DGs integrated to the distribution system will be a good option. DGs may be based on renewable energy or non-renewable energy technologies. However, with the increased environmental concerns, renewable energy based DGs are gaining more importance. Renewable energy based DGs have many techno-economical and environmental advantages. Due to increased customers demand for reliable and quality power supply, evaluation of the impact of DG integration to improve performance of the system, especially reliability and reduction of losses is gaining more importance in the present distribution system operating scenario. Improvement in reliability and reduction in losses can be achieved only by optimal selection, placement and sizing of DGs. This will in turn have added benefit of improved voltage profile, better power quality, optimum system loadability, enhanced system security. This will also lead to reduced capital investments, repair and maintenance costs, fuel cost for conventional units and operational costs. Renewable energy based DGs will have advantage of no-emissions, free availability and so on. With increase in DG, the integration of such DGs into the distribution networks has to be taken care and it is necessary to study the impacts of DG integration in terms of reliability and system losses. Otherwise, if DGs are not properly installed at proper locations, it may lead various problems viz. increased losses, protection co-ordination problem, power quality issues. This problem of optimal selection, sizing and siting of DGs has been dealt with in literature using several techniques. Analytical techniques are suitable for small systems and not performing well for complex systems. Various meta-heuristic techniques are developed for large and complex system which provides good results. Many simulation techniques are adopted by using different power system simulation software which also provides good output indicators to arrive at suitable conclusions based on the simulation results. Simulation studies are carried out using Neplan software in [1], [24], [26] using ETAP in [3], [8], [12], [16], [17], [18], [19], [21] DigSILENT PowerFactory in [7], [14], [25], [28]. [29], using MiPower in [6],[15], using DISREL in [30] and using MATLAB in other works. Real time feeder data has been considered in [4], [13], [14], [17], [24], [27] for case studies. Along with the objective of improvement of reliability of the system, reduction in system loss and improvement in voltage profile has been considered as the objective in [2], [3], [4], [6], [8], [9], [10], [11], [15], [20], [25]. Concept of DSM has been considered in [7], [22]. Solar PV has been considered as choice for DG in most of the literature.

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Energy storage has been considered in [1], micro hydro in [13], Diesel generator in [26] and wind in [7], [9], [12], [13], [15], [18], [22], [26].

This present work addresses to assess the reliability of distribution system in presence of DGs for RBTS test distribution system and practical system of 11kV feeders emanating from 66/11 kV Hebbal sub-station coming under Karnataka Power Transmission Corporation Limited (KPTCL), Mysuru and distribution feeders coming under the jurisdiction of Chamundeshwari Electricity Supply Company (CESC), Mysuru. Both test system and practical system feeders are modeled using DIgSILENT PowerFactory. Failure rates are taken as per the test system values. Reliability indices of the test system and practical system are determined for different cases of DG integration. Simulation results are summarized by focusing on the installation of suitable capacity of DGs and the location of DGs which are important factors affecting the system losses and system reliability indices

This paper has been organized into IV sections. This introduction section is followed by section-II which provides overview of Reliability analysis of a distribution system; section-III provides the problem formulation for DG integration, section-IV provides both test system and practical system data, simulation and analysis for difference cases, section-V deals with results and discussion and section-VI provides conclusions based on case study results.

II. RELIABILITY ANALYSIS OF A DISTRIBUTION SYSTEM

This work mainly concentrates on radial distribution system. IEEE standard 1366 provides a set of indices for determining reliability of power distribution system. Data related to reliability for set of power system components, load points and customers are statistically interpreted using reliability indices. These indices are classified into load point indices and system indices [18].

A. Basic load point reliability indices

Average failure rate (λ_s), average outage time (r_s) and average annual unavailability (U_s) are the basic elementary indices called load point indices [5]. These indices denote the average values. Average failure rate provide information regarding the number of failures happening at load point for the specific time interval. Average failure time interval at the load point is expressed by average outage time. Average supply outage at the load point for a period of one year is termed as average annual outage time.

Depending on failure rates for each system components, repair times and feeder configurations, these basic indices are expressed using the following equations:

$$\lambda_s = \sum \lambda_i \quad \text{f/yr} \;\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$U_s = \sum \lambda_i \gamma_i \quad \text{hrs/yr}\ldots\ldots\ldots\ldots(2)$$

$$\gamma_s = \frac{U_s}{\lambda_s} = \frac{\sum \lambda_i \gamma_i}{\lambda_i} \quad \text{hrs}\ldots\ldots\ldots(3)$$

Where, λ_i and r_i are the failure rate and the average repair time of component-i, and U_i is the annual unavailability at the load point i.

B. System reliability indices

For complete understanding of the system, system oriented and energy oriented reliability indices are required in addition to basic indices. These system oriented indices, namely System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI), Customer Average Interruption Duration Index (CAIDI), Average System Availability Index (ASAI), Average System Unavailability Index (ASUI) considered in the present work are represented by (4)-(8) and energy oriented indices namely Average System Interruption Frequency Index (ASIFI), Average System Interruption Duration Index (ASIDI) and Energy Not Supplied (ENS) are represented by the (9)-(11).

$$SAIFI = \frac{\text{Sum of no. of cust interrutpions}}{\text{Total no. of cust served}} = \frac{\sum \lambda_i N_i}{\sum N_i} \text{ f/Ca}\ldots\ldots (4)$$

$$SAIDI = \frac{\text{Sum of cust interrutpion duration}}{\text{Total no. of cust served}} = \frac{\sum U_i N_i}{\sum N_i} \text{ h/Ca.. } (5)$$

$$CAIDI = \frac{\text{Sum of cust interrutpion duration}}{\text{Sum of no. of cust interrutpions}} = \frac{\sum U_i N_i}{\sum \lambda_i N_i} \text{ hrs}\ldots\ldots\ldots\ldots (6)$$

$$ASAI = \frac{\text{Customer hours of available service}}{\text{Customer hours demanded}} = \frac{\sum N_i x8760 - \sum U_i N_i}{\sum N_i x8760} \text{ .. } (7)$$

ASUI = 1-ASAI……………………………………………(8)

$$ASIFI = \frac{\text{Sum of connected kVA of load interrupted}}{\text{Total connected kVA served}} \ldots\ldots\ldots\ldots (9)$$

$$ASIDI = \frac{\text{Sum of connected kVA durations of load interrupted}}{\text{Total connected kVA served}} (10)$$

$$ENS = \sum L_a x U_i \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (11)$$

Where, λi is the failure rate of the components i = 1,2,3……N Where Ni is the number of customers at the load point i = 1,2,3…….N. Ui is the annual unavailability at the load point i = 1,2,3…….N.

$$L_a = \frac{\text{Total energy demand in the period of interest}}{\text{Period of interest}}$$

III. PROBLEM FORMULATION

With higher penetration of DGs, distribution system are becoming similar to transmission systems where load and generation node points are mixed and reliability of such systems are becoming important. Evaluation of the DG integration impact on reliability of distribution system is important from both utility and consumer point of view.

This present paper addresses to evaluate the reliability of distribution system in presence of DGs by simulation method using DIgSILENT PowerFactory. RBTS test distribution system and practical system pertaining to Hebbal sub-station is modeled using DIgSILENT PowerFactory. Reliability indices of the test system are determined for different cases of DG integration.

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The cases considered are: i) Without DGs (Base Case), ii) With one DG (Synchronous / PV) to determine optimal size, iii) With two DGs (PV / Synchronous DG) to determine optimal size, iv) DGs at different distance from the source to determine optimal location.

The objective in all the case studies above is to reduce the system losses and to improve the reliability indices of the given system. The impacts of DG integration on reliability are analyzed through simulation method using DIgSILENT Power Factory software. The system losses and the reliability indices obtained from the above case studies are used to illustrate the impact of DG integration and in improving the reliability of the distribution system. Step by step methodology adopted for the carrying out the work is: i) Modeling of RBTS test distribution system and practical Hebbal system using DIgSILENT PowerFactory software, ii) Determination of the real power loss in the system without DG integration, iii) Determination of the reliability indices of the test system using reliability analysis tool without DG integration, iv) Carrying out case studies with one DG and two DGs and determine the power losses and reliability indices, v) Carrying out case studies by placing the DGs at different distances from the source to determine the optimal location, vi) Carrying out case studies to determine optimal size of the DG for individual feeders of test system.vii) comparison of results for test and practical system. Flow chart showing the proposed methodology is shown in the fig.1.

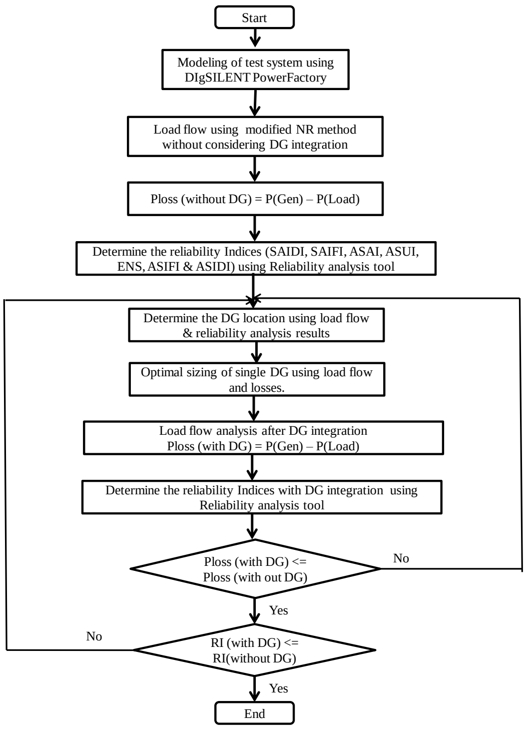

Fig. 1.Flow chart showing the proposed methodology.

IV. SYSTEM DATA AND ANALYSIS

A. RBTS system data

RBTS bus2 system is considered in this work. RBTS Bus2 system consists of 4 numbers of 11 kV feeders (F1-F4) with a total of 22 load points with voltage level of 11 kV. 11/0.415kV distribution transformers are modeled for residential, commercial and Government installation load points and loads are shown lumped at 415V level. For industrial bulk consumers, loads are shown lumped at 11kV level itself. Overall system peak load is 20MW and average load is 12.29MW with total of 1908 customers at 22 load points Feeder-wise peak and average loads considered for RBTS is show in the table-I. The defined average load is based on the fact that this will be value at the load point due to diversity factor between customers and normal load variations throughout the day and through the year [35].

Table- I: Feeder-wise data for RBTS Bus2 system

Feeder No.	Line length in km	Load Points	Peak load (in MW)	Avg load (in MW)	No. of customers
F1	2.85	LP1-7	5.934	3.645	652
F2	2.35	LP8-9	3.5	2.15	2
F3	2.9	LP10-15	5.046	3.106	632
F4	2.9	LP16-22	5.521	3.39	622
Total		**22**	**20.001**	**12.291**	**1908**

Line lengths, transformer capacities, load data are considered as per the RBTS data in [35]. The reliability data considered for 33kV and 11kV system components are shown in the table-II.

Table- II: Reliability relate data for 33kV and 11kV system components

33/11 kV Transformers	
Active Failure Rate in f/yr.km	0.015
Repair time in hrs	15
11 / 0.433 kV Distribution transformer	
Active Failure Rate in f/yr.km	0.015
Repair time in hrs	200
11 kV lines	
Active Failure Rate in f/yr.km	0.065
Repair time in hrs	5

The line parameters and transformer parameters considered are shown in the table-III and table-IV respectively.

Table- III: Line parameters for 11 kV OH lines

Conductor type	Coyote	Rabbit
Rated Voltage (in kV)	11	11
Rated Current (in A)	386	183
Resistance (Ω/km)	0.248	0.616
Reactance (Ω/km)	0.337	0.366

Table- IV: Transformer parameters for RBTS

Parameters	Value
Rated Power	2 MVA
Rated Voltage	11/0.433kV
Vector group	Dyn11
% impedance	6%

B. Hebbal practical system data

The practical system identified for study is 66/11 kV Hebbal Sub-station (SS) coming under the jurisdiction of KPTCL, Mysuru.

The 66/11 kV Hebbal SS is fed from 66 kV transmission line emanating from upstream 220 kV Hootagally Receiving Station (RS). The upstream network has been modeled as grid for analysis purpose Modeling and Simulation 3 Nos. of 11 kV Feeders viz. F1-HPCL, F2-Hebbal and F4-Birla which connected to 11kV Bank-1 at 66/11 kV Hebbal SS has been considered for practical system study. 11kV Bank-1 and above 11 kV feeders are connected to 66/11 kV, 12.5 MVA Transformer-1 at the SS.Line lengths, transformer capacities, load data are considered as per the actual field data collected. The line parameters are as per table-3 and transformer parameters considered are as per table-V.

Table- V: Transformer parameters for Hebbal System

Parameters	Values			
Rated Power (in kVA)	63	100	250	500
Rated Voltage	11/0.433kV			
Vector group	Dyn11	Dyn11	Dyn11	Dyn11
% impedance	4.5%	4.9%	5%	6%

The reliability data considered for 66kV and 11kV system components are shown in the table-VI.

Table- VI: Reliability data for 66kV and 11kV system components of Hebbal system

66/11 kV Transformers	
Active Failure Rate in f/yr.km	0.015
Repair time in hrs	15
11 / 0.433 kV Distribution transformer	
Active Failure Rate in f/yr.km	0.015
Repair time in hrs	200
11 kV lines	
Active Failure Rate in f/yr.km	0.065
Repair time in hrs	5

Few assumptions are made for modeling the system and to carry out the load flow studies and reliability studies using DIgSILENT PowerFactory. Assumptions for load flow studies are i) Network above 33kV voltage for RBTS and 66 kV for practical system is represented by grid, ii) Modeling is limited and truncated at 415V level, iii) DTCs (Distribution Transformers Centers) i.e. 11/0.415kV transformers are modeled and all the loads are assumed to be lumped at distribution transformer LV (Low Voltage) side i.e., at 415V level, iv) Residential, commercial and government installation loads are metered on the LV side and the transformer belongs to utility and hence included in the analysis. The bulk user loads are metered on the HV (High Voltage) side and the transformer belongs to customer and hence not considered for analysis, v) Loads are placed on 11 kV bus itself for small users, vi) All the 11kV lines are assumed to be overhead with Coyote conductor for trunk lines and Rabbit conductor for spur lines, vii) Modified Newton-Raphson method is used for carrying out load flow which provides acceptable results for distribution systems. Assumptions for reliability studies are i) The feeder operation is considered to be radial mode with normally open sectionalizers if provided, ii) This work focuses on DG as a source rather than technology and is considere that DG is used with its full capacity. In order to isolate the DG in fault condition, DG is connected to distribution network with a circuit breaker iii) It is assumed that, the operation of the breaker is 100% reliable and it operates in case of any fault in the system and isolates the faulty portion so that power supply is available for the other customers of the healthy portion of the system, iv) Either a synchronous DG (for 1-DG studies) or PV-DG with synchronous-DG (for 2-DG studies) is considered for case studies.

The RBTS system and Hebbal feeder-1 system modeled using the DIgSILENT PowerFactory is as shown in the fig.2 and fig.3 respectively.

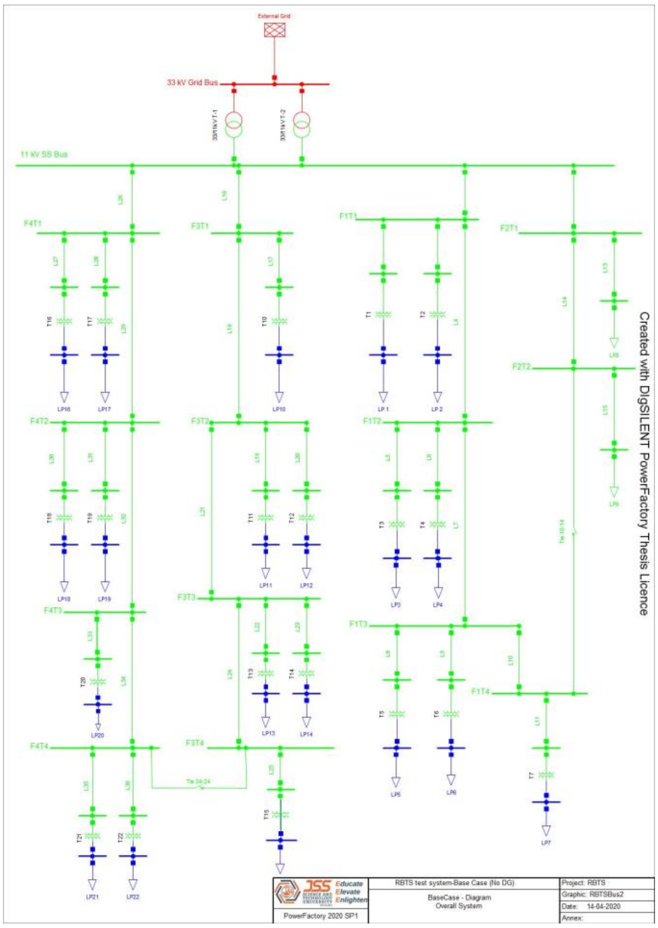

Fig. 2.RBTS Bus2 system modeled using PowerFactory.

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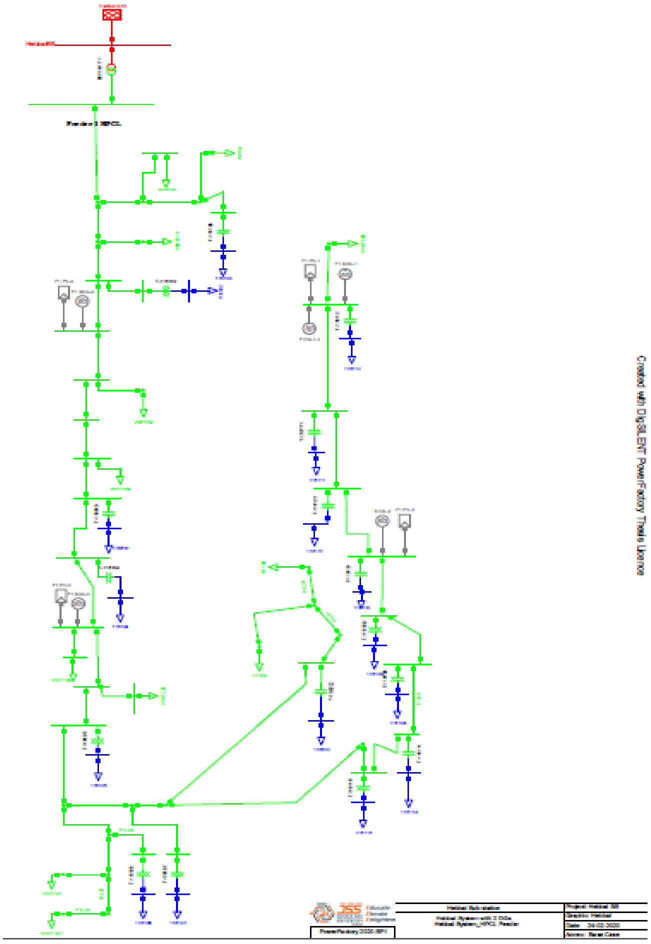

Fig. 3. Hebbal system modeled using PowerFactory

C. Steps for carrying out the analysis

For carrying out case studies for individual feeders, following steps are adopted. i) For base case study, the existing system without any DG interconnections is considered, ii) For studying the impact of DG integration on the feeder, case studies are performed with different capacities of DGs at different locations on the feeder, iii) Initially, 1-DG with a capacity of approximately 15% of the loading is considered and gradually increased in steps 15%, iv) Single DG will be placed at the tail end of the main trunk line initially which will be considered as the tail end case or 100% of the line length case, v) Initially for lower capacity of DGs, there will be reduction in system losses along with improvement in reliability.vi) Gradually, the capacity of DG is increased such that beyond a certain capacity of DG, there will be increase in the system losses. This capacity of the DG is considered to be the optimal capacity for the feeder beyond which there is increase in the system losses, vii) Case studies with different capacities of DGs are repeated for DG placement at 75%, 50% and 25% of line lengths for each feeder, viii) Case studies are also repeated with 2-DGs considered at different locations i.e. Both at the tail end, 1-DG at tail end and 1-DG at 75% line length, 1-DG at tail end and 1-DG at 50% line length, 1-DG at tail end and 1-DG at 25% line length, 1-DG at 75% line length and 1-DG at 50% line length, viii) The reliability indices are also determined for different capacities of DG placement to measure and quantify the effect on the system performance.

D. Analysis with single DG

Only Feeder-1 is considered for study with all other feeders being out of service. Load flow analysis and reliability evaluation has been carried out for base case i.e. without any DGs connected to the feeder and for different scenarios with DGs connected. In the base case, only the system components on feeder-1 are considered without any DGs. The system losses and reliability indices for RBTS feeder-1 base-case are presented in table-VII.

Table- VII: Base case loss & reliability indices for RBTS feeder-1

Parameters	Base case (No DG)
MW Losses in MW	0.09
SAIFI (1/Ca)	0.13041
SAIDI (h/Ca)	3.577
CAIDI (hrs)	27.429
ASAI	0.999592
ASUI	0.000408
ENS (MWh/a)	13.679
ASIFI (1/a)	0.165572
ASIDI (h/a)	3.752859

Initially, 1-DG with a capacity of 500 kW is placed at the tail end of the main trunk line. System losses and reliability indices are determined. Gradually, the capacity of DG is increased in steps of 500kW such that beyond a certain capacity of DG, there will be increase in the system losses. The system losses and reliability indices for placing different capacities of DG at tail end are presented in the table-VIII.

Table- VIII: Loss & Reliability indices for Feeder-1 (With 1-DG at tail end).

Parameters \ DG capacity	Base case (No DG)	1-DG on F1 (1000 kW)	1-DG on F1 (2000kW)	1-DG on F1 (2370kW)	%age improvement w.r.t base
Loss in MW	0.09	0.07	0.06	0.07	33.33
SAIFI	0.13041	0.125883	0.125568	0.108754	16.61
SAIDI	3.577	3.554	3.553	3.469	3.02
ASAI	0.999592	0.999594	0.999594	0.999604	0.001
ASUI	0.000408	0.000405	0.000405	0.000395	3.04
ENS	13.679	12.94	12.359	12.186	10.91
ASIFI	0.165572	0.124991	0.093108	0.083636	49.49
ASIDI	3.752859	3.549957	3.390541	3.343181	10.92

From the above, the following observations are noted. There is improvement in the reliability with placement of 1-DG at tail end. Losses will decrease to an extent of 33% with placement of DG capacity up to 2370kW. For DG capacity ≥2370kW, there will be increase in system losses.

Hence optimal DC capacity can be considered as 2370 kW i.e. around 65% of loading on the feeder. Further, the system losses and reliability indices are determined by placing different capacities of 1-DG at 75%, 50% and 25% of the line lengths. The bar chart showing percentage loss reduction and percentage improvement in reliability indices for single DG placed at different locations is shown in the fig.4.

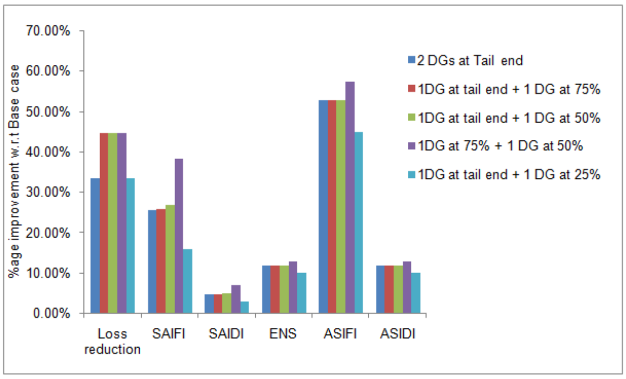

Fig. 4. %age loss reduction and %age improvement in reliability indices for single DG placed at different locations.

Based on the case studies with single DG, following conclusions are drawn. i) The optimal capacity for maximum loss reduction would be 2370 kW (i.e about 65-70% of the loading of the line). Ii) For maximum loss reduction and reliability improvement, it is optimal to place DG between 75% of line length towards the tail end for lower DG capacities below optimal, iii) For higher DG capacity, it is best feasible to place the DG between 50% to 75% of the line length for better reliability improvement, iv) It is not feasible to place the DG nearer to the source in view of both higher losses and poor reliability compared to placing DG away from the source.

The case studies presented above with single DG for feeder-1 of RBTS bus2 system are carried out for all the other RBTS feeders i.e. feeder-2, 3 & 4. Also, the case studies are carried out for all the feeders of practical Hebbal system.

E. Analysis with two DGs

For carrying out case studies with 2 DGs, initially 2 DGs (1 synchronous + 1 PV or both synchronous DGs) are placed at the tail end of main trunk line. System losses and reliability indices are determined. Gradually, the capacity of DG is increased in steps of 500kW such that beyond certain combined DG capacity, there will be increase in the system losses. The system losses and reliability indices for placing different capacities of DGs at tail end are presented in the table-IX.

Table- IX: Loss & Reliability indices for Feeder-1 (With 2-DGs at tail end).

Parameters \ DG capacity	Base case (No DG)	2DGs (500+500)	2DGs (1000+1000)	2DGs (1570+1000)	%age improvement w.r.t base
Loss in MW	0.09	0.07	0.06	0.07	33.33
SAIFI	0.130410	0.125887	0.125564	0.097326	25.37
SAIDI	3.577	3.554	3.553	3.412	4.61
ASAI	0.9995	0.999594	0.999594	0.999610	0.002

	91				
ASUI	0.000408	0.000405	0.000405	0.000389	4.63
ENS	13.679	12.947	12.352	12.091	11.61
ASIFI	0.165572	0.125383	0.092745	0.078428	52.63
ASIDI	3.752859	3.551917	3.388726	3.317139	11.61

From the above, the following observations are noted: i) When 2 DGs are placed at the tail end, loss reduction is almost same as that of placing an equal capacity single DG at tail end. Ii) From loss point of view, combined capacity can be increased up to 2570kW i.e. 70% of loading when synchronous DG and PV DG is considered. iii) If both DGs are synchronous DGs, then the optimal capacity is same as that of single DG, i.e. 65% of loading. iv) Reliability improvement in terms of all indices are comparatively much better than placing an equal capacity single DG.

Further, the system losses and reliability indices are determined by placing 2-DGs at different locations i.e. 1-DG at tail end and 1-DG at 75% line length, 1-DG at tail end and 1-DG at 50% line length, 1-DG at 75% line length and 1-DG at 50% line length, 1-DG at tail end and 1-DG at 25% line length. The bar chart showing percentage loss reduction and percentage improvement in reliability for two DGs placed at different locations is shown in the fig.5.

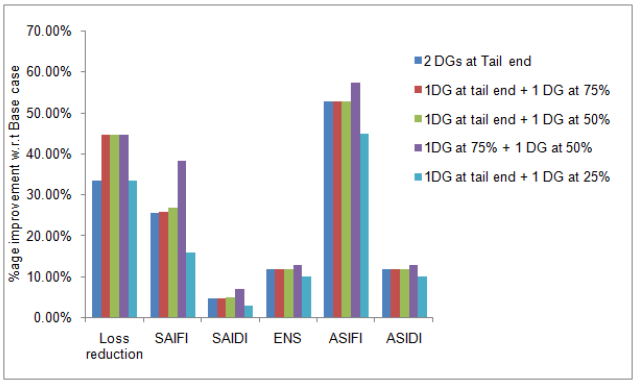

Fig. 5.%age loss reduction and %age improvement in reliability indices for two DGs placed at different locations.

Based on the case studies with two DGs, following conclusions are drawn. i) Reliability will further improve with 2-DGs when compared to 1-DG placement, ii) For maximum loss reduction and reliability improvement, it is optimal to place DG between 75% of line length towards the tail end for lower DG capacities below optimal, iii) For higher combined DG capacity, it is best feasible to place the DGs between 50% to 75% of the line length for better reliability improvement, iv) It is not feasible to place the DGs nearer to the source in view of both higher losses and poor reliability compared to placing DGs away from the source.

V. RESULTS AND DISCUSSIONS

The case studies presented above with two DGs for feeder-1 of RBTS bus2 system are carried out for all the other RBTS feeders i.e. feeder-2, 3 & 4.

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Also, the case studies are carried out for all the feeders of practical Hebbal system.

The percentage loss reduction, optimal capacity of DG than can be connected, percentage improvement in reliability in terms of SAIFI, SAIDI, ENS, ASIFI and ASIDI for RBTS bus2 system feeders and Hebbal feeders with single DG are presented in the table-X.

Table- X: Comparison of %age loss reduction, optimal DG capacity and %age improvement in reliability for RBTS Bus2 feeders & Hebbal system feeders with 1-DG.

Parameters / Feeders	**RBTS Bus2 system**				**Hebbal System**		
	F1	***F3***	***F4***	***F2***	***F1***	***F2***	***F4***
Optimal capacity	65.0	66.0	74.0	80.0	55.0	50	74
Loss reduction	33.3	37.5	44.4	50.0	40.0	20	66.6
SAIFI	16.6	23.4	47.8	57.8	60.7	24.0	76.3
SAIDI	3.0	4.6	9.4	57.9	18.0	10.6	30.5
ENS	10.9	11.5	14.1	60.3	32.6	5.41	37.7
ASIFI	49.4	55.2	58.8	60.4	52.2	12.6	81.5
ASIDI	10.9	11.5	14.1	60.4	32.6	5.41	37.7

The above values are represented in the form of bar chart as shown in the fig.6.

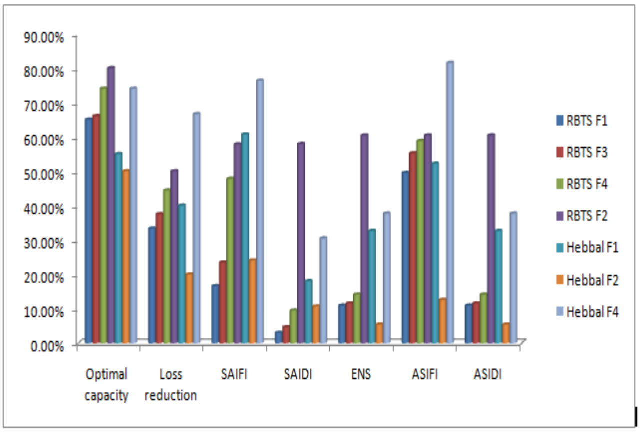

Fig. 6.Optimal capacity, %age loss reduction and %age improvement in reliability indices w.r.t base case for RBTS bus2 feeders (with 1-DG).

From the above results and comparison, following conclusions are drawn. i) The optimal capacity of DG connection with 1-DG may be increased up to 50%-74% of feeder peak loads. This also coincides with the general 2/3 rule. ii) Loss reduction with 1-DG interconnection will be in the range of 20-44% normally, iii) SAIFI improvement will be between 16-48%, SAIDI between 3-10%, ENS between 10-15%.

ASIFI between 49-60% and ASIDI 10-15%, iv) In case of RBTS feeder-2 and Hebbal feeder-4 which are predominantly industrial or bulk consumer feeders, optimal capacity of DG connected can be between up to 74-80% of feeder peak, v) For RBTS feeder-2 and Hebbal feeder-4, reliability improvement will be much higher than normal feeders.

Similarly, the percentage loss reduction, optimal capacity of DG that can be connected, percentage improvement in reliability in terms of SAIFI, SAIDI, ENS, ASIFI and ASIDI for RBTS and Hebbal system feeders for two DG case are presented in the table-XI and the bar chart in the fig.7.

Table- XI: Comparison of %age loss reduction, optimal DG capacity and %age improvement in reliability for RBTS Bus2 feeders & Hebbal system feeders with 2-DGs.

Parameters / Feeders	RBTS Bus2 system				Hebbal System		
	F1	F3	F4	F2	F1	F2	F4
Optimal capacity	70.00	72.00	80.00	90.00	60.00	50.00	77.00
Loss reduction	33.33	37.50	44.44	50.00	60.00	20.00	66.67
SAIFI	25.37	29.87	52.81	62.76	55.59	24.05	79.00
SAIDI	4.61	5.94	10.47	62.70	16.47	10.65	31.55
ENS	11.61	12.24	14.51	65.05	35.08	5.41	38.34
ASIFI	52.63	58.41	60.43	65.04	56.15	12.59	82.86
ASIDI	11.61	12.24	14.51	65.04	35.10	5.41	38.33

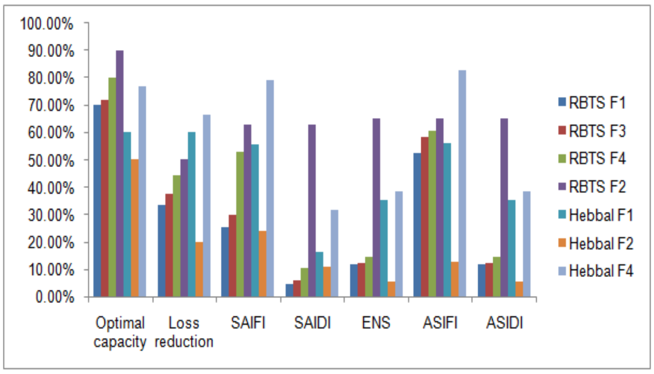

Fig. 7.Optimal capacity, %age loss reduction and %age improvement in reliability indices w.r.t base case for RBTS bus2 feeders (with 2-DGs).

From the above results and comparison, following conclusions are drawn. i) The optimal capacity of DG connection with 2-DGs may be increased up to 70-84% of feeder peak loads, ii) Loss reduction with 2-DG interconnection will be less than that of 1-DG case and will be in the range of 33-44% normally, iii) SAIFI improvement will be between 25-62%, SAIDI between 4-11%, ENS between 11-15%. ASIFI between 52-60% and ASIDI 11-15%, iv) In case of RBTS feeder-2 and Hebbal feeder-4 being predominantly industrial or bulk consumer feeder, optimal capacity of DG connected can be between 77-90% of feeder peak. v) For RBTS feeder-2 and Hebbal feeder-4, reliability improvement will be much higher than normal feeders.

The actual value of indices depends on lots of factors such as, location of placing the DGs, length of the feeder, number of customers connected to each load points which is different for different feeders and network configuration. Hence there will be variation in the indices for different feeders due to above factors.

VI. CONCLUSIONS

The DG integration impact on distribution system in terms of improvement in reliability indices and reduction in system losses for different scenarios are determined by simulation method using DIgSILENT PowerFactory Software. Simulations have been performed for individual feeders of RBTS test system and practical Hebbal system feeders. Based on the study results obtained from simulations and analysis of the distribution system, overall results are summarized by focusing on the installation of suitable capacity of DG and the location of DG which are important factors affecting the system losses and system reliability indices

Summary of results for individual feeder studies are as follows, i) the optimal capacity for maximum loss reduction with single DG would be 50-74% of the loading of the line. This is in line with 2/3 rule for the radial feeders. This can be improved up to 70-84% in case of 2 DGs, ii) Loss reduction with 2-DG interconnection will be less than that of 1-DG case, iii) Reliability will further improve with 2-DGs when compared to 1-DG placement, iv). For maximum loss reduction and reliability improvement, it is optimal to place DG between 75% of line length towards the tail end for lower DG capacities below optimal, v) For higher DG capacity, loss reduction is much better in case of placing DG at 50% line length. Hence, it is best feasible to place the DG between 50% to 75% of the line length for better reliability improvement, vi) It is not feasible to place the DG nearer to the source in view of both higher losses and poor reliability compared to placing DGs away from the source. These simulation results will provide the network operators a good tool to anticipate the system performance in presence of DGs and to evaluate the reliability of the system before allowing for interconnections. Simulation results have demonstrated that the proposed method can be an effective means for considering DG placement in the distribution system. The decision regarding the DG placement and sizing can be taken based on the study results. The advantage of the present method is that it takes into account both the system losses and the reliability of the system in presence of DGs.

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