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Frequency Stability Analysis of Radial and Looped Distribution Network with Distributed Generation Cosidering Loadability

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***Abstract*— Due to the increased penetration of renewable energy resources, today's distribution networks have become active in nature. Frequency and voltage stability analysis of distribution networks have gain utmost importance due to increased penetration and intermittent nature of renewable resources. This manuscript presents a brief comparison between radial and looped distribution networks with distributed generation on the basis of frequency deviation, voltage drop and loadability. Continuation power flow (CPF) method is used for calculation and analysis of the test network. IEEE 33 and 69 bus systems are used as test systems in this paper. All simulations are carried out in Power System Analysis Toolbox (PSAT) in MATLAB simulation environment.**

Keywords*— Voltage stability; Frequency stability; Continuation power flow; Looped distribution system; Radial distribution system; PSAT; Loadability.

I. Introduction

Continuous load growth is putting immense pressure on distribution network, causing stability issues for utilities. This is also a well-known fact that transmission system of most countries is old and saturated [1]. The increased transfer of power from centralized generation to the distribution network is not possible through such a system, such a power transfer will result into bottleneck of the old transmission system. To overcome this problem researchers have proposed reconfiguration of power distribution system containing high penetration of distributed generation [2]. In future, distribution networks are evolving into compact modules like microgrid (MG) which can sustain independently and can work in groups like multi-micro grids. With the integration of DGs our distribution networks are no longer passive in nature, they have evolved into active distribution networks [3].

As the penetration of renewable resources is increasing in distribution side, stability issues related to voltage and frequency also arise due to intermittent nature of renewable resources. Now in active distribution systems voltage, loadability and frequency analysis have gained much importance. While talking about compact module of the future power system like MG that can operate in islanded mode, it should be noticed that frequency and voltage control should be monitored closely for improved power quality since MG can be termed as a weak electrical grid in islanded mode [4].

The [5] presents a method for placement of DG in order to improve voltage profile, reduce power losses, increase power transfer capability and loading margin. In [6] an algorithm for placement of DG in IEEE 33 bus radial distribution System based on voltage stability is presented. Modal analysis and CPF methods are used to determine the weakest buses for DG's placement. An efficient CPF method based on forward/backward load flow method is used for analysis and compared with Newton-Raphson based CPF method [7].

Paper [8] has used real power margin to rank the buses for DGs placement. Index is calculated using CPF and test system is IEEE 33 bus radial distribution system. A CPF based new methodology is introduced for the placement of multi DG units into medium voltage distribution network for improvement of voltage stability and loadability [9].

The [10] discusses different strategies for maintaining balance between generation and demand within acceptable frequency/voltage ranges for islanded microgrids. Two main control strategies are used in this study namely PQ inverter controller and voltage source inverter (VSI) controller. Stability and modeling analysis using improved CPF method for distribution network having higher penetration of DGs is discussed in [11] and the proposed method is validated through case studies on IEEE 33 bus system. Results show that DG penetration and control strategy significantly influence maximum loadability of distribution network. The [12] includes frequency as state element for performing simulations of IEEE 30 bus system using Gauss-Seidel power flow method.

In literature so far, maximum number of papers have discussed voltage profile against loadability or frequency profile from control point of view. They have not discussed frequency stability with load growth. This limitation serves a s a motivation for this research. The novelty of this paper is the study of frequency deviation with voltage stability and loadability while examining the effect of DG on frequency deviation.

Methodology is discussed in section II. Simulations for different cases and their results are presented in section III. Section IV carries discussion on simulation results while key points of conclusion are highlighted in section V.

II. Methodology

A. DG Placement and Sizing

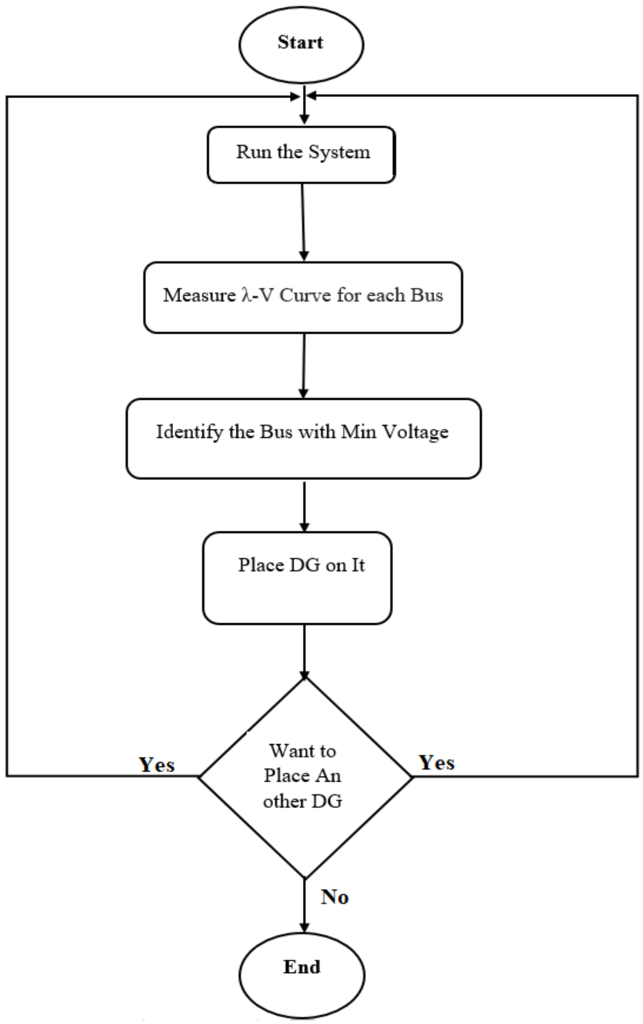

Fig. 1. Flow Chart for placement of DG.

In this work, frequency stability of distribution network is analyzed by using CPF method. This paper analyzes frequency from load growth point of view. Frequency deviation from standard value is measured and analyzed against the increment in loadability. For placement of DG on radial network, first base system without DG is simulated and λ-V curve on each bus is observed and bus with lowest voltage characteristic is identified. DG is placed on bus with lowest voltage characteristic. Now for placement of second DG, system with one DG is simulated and whole process is repeated again. DG placement process is same for loop network as well. Size of DG is referred from [13] where auther has analyzed voltage stabilty for radial distribution network.

B. Frequency Measurement on PSAT

Simulations are performed on MATLAB toolbox PSAT whose special Simulink library also have frequency measuring block. In PSAT, frequency is calculated by CPF method. CPF method use its predictor corrector approach to find out the solution. In first Step, new values are forecasted based on the previous values by predictor method and then forecasted value is corrected to get real solution by corrector method. Main feature of CPF is that it remains well conditioned even at bifurcation point. CPF introduces continuation parameter to the ill jacobian matrix to avoid singularity which causes the power flow method to remain well conditioned at bifurcation point.

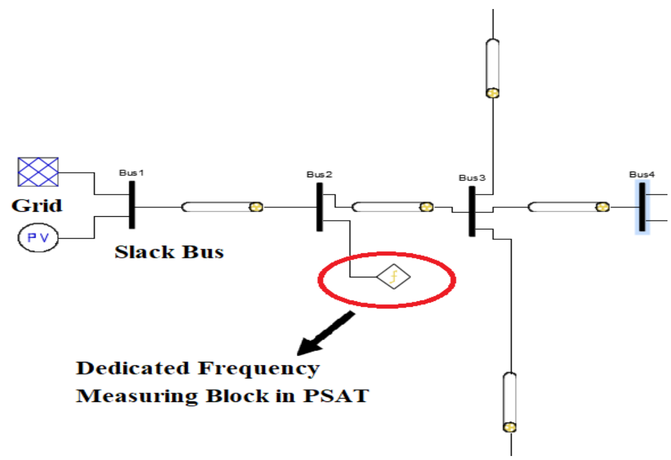

Fig. 2. Frequency Measurement Block.

Special graphical user interface of PSAT gives the freedom of plotting frequency, voltage and loading parameter against each that gives better overview and comparison between these quantities.

III. Simulations

Simulations are performed on MATLAB toolbox for comparison and validation of results. IEEE standard 33 bus and 69 bus test system is taken as reference. Simulation tests are performed on both radial and loop configurations and results are compared. Frequency measuring block is placed on the bus next to the slack bus, so that overall effect on system frequency can be measured.

Three cases are considered for frequency analysis.

a. Case 1: Standard IEEE bus network without any DG.
b. Case 2: Integration of single DG to test system.
c. Case 3: Integration of two DGs to test system

A. IEEE 33 Bus SSystem

The parameters for 33 bus system are the data sheet which To change the system configuration from radial to loop there are five possible tie switches used in literature [14]. For single loop configuration, switch number five (TS-5)

TABLE I. IEEE 33 BUS SYSTEM PERSENTAGE CHANGE IN LOADABALITY AND FREQUENCY DEVIATION.

IEEE 33 bus System	Value of DG (KVA)	Loading Factor		% Increase in loadability	Total Frequency Deviation around Mean Value (60 HZ)		% Change in Frequency
		Radial System	*Loop System*		*Radial System*	*Loop System*	
Without DG	——	3.44	3.529	2.52	0.00414	0.00416	0.48
With One DG	3623.9	4.118	12.39	66.76	0.01593	0.0199	19.95
With Two DG	1313.9 2212.3	8.837	12.67	30.74	0.00803	0.01153	30.36

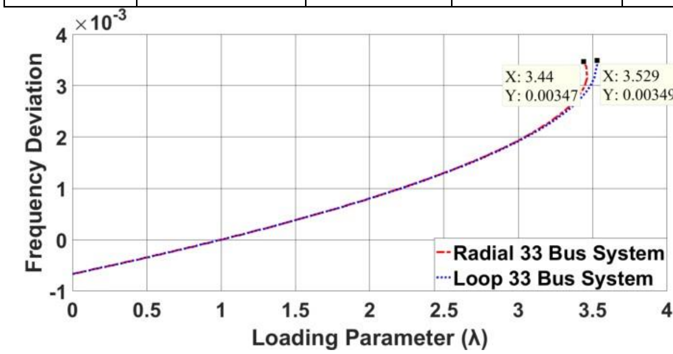

Fig. 3. IEEE 33 bus system λ -F curve without DG.

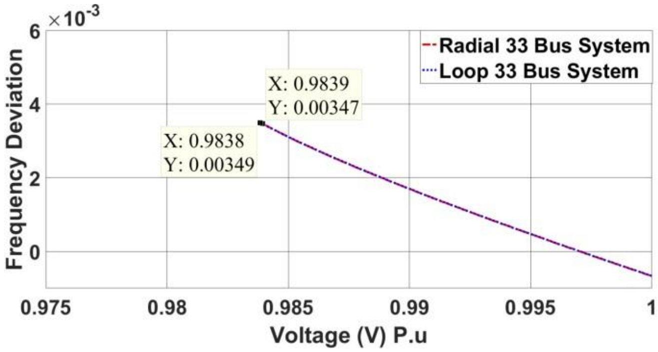

Fig. 4. IEEE 33 bus system F-V curve without DG

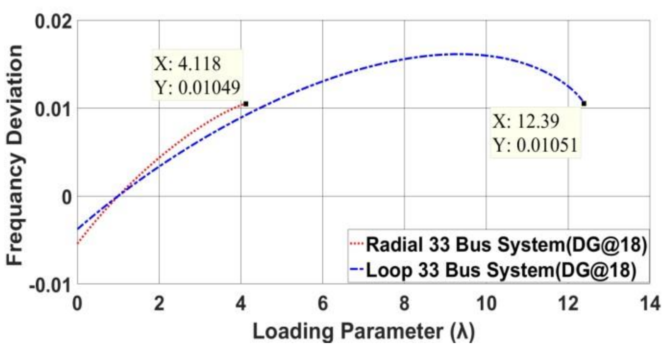

Fig. 5. IEEE 33 bus system λ -F curve with one DG.

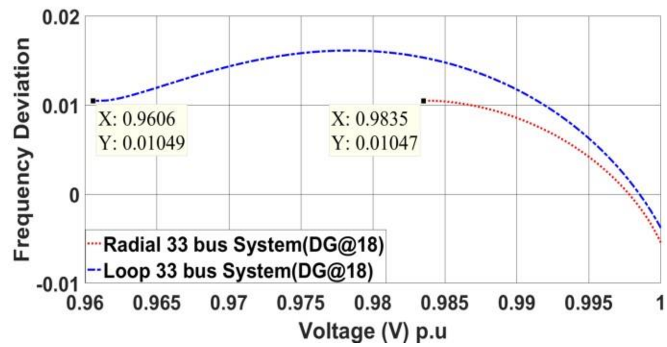

Fig. 6. IEEE 33 bus system F-V curve with one DG.

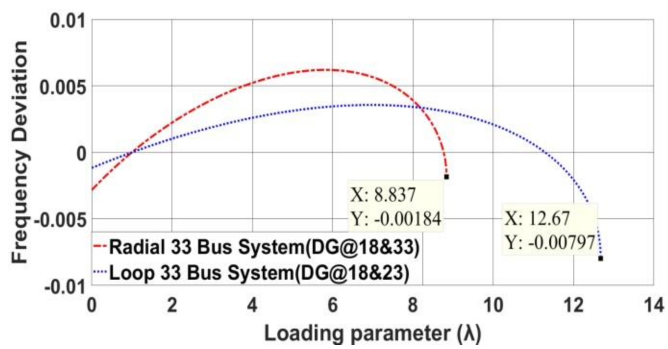

Fig. 7. IEEE 33 bus system λ -F curve with Two DG.

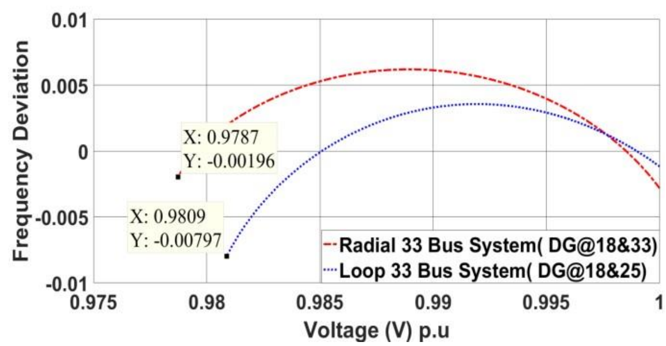

Fig. 8. IEEE 33 bus system F-V curve with Two DG.

TABLE II. IEEE 33 BUS SYSTEM FREQUENCY DEVATION COMPARISON.

IEEE 33 bus System	Value of DG (KVA)	Frequency Deviation			
		Radial System		***Loop System***	
		Max Frequency Dip	*Max Frequency Over Shoot*	*Max Frequency Dip*	*Max Frequency Over Shoot*
Without DG	——	-0.00067	0.00347	-0.00067	0.00349
With One DG	3623.9	-0.00544	0.01049	-0.00378	0.01612
With Two DG	1313.9 2212.3	-0.00184	0.00619	-0.00797	0.00356

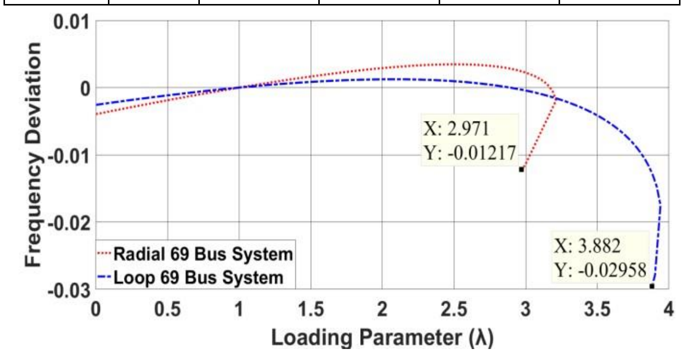

Fig. 9. IEEE 69 bus system weakest buses λ -F curve without DG.

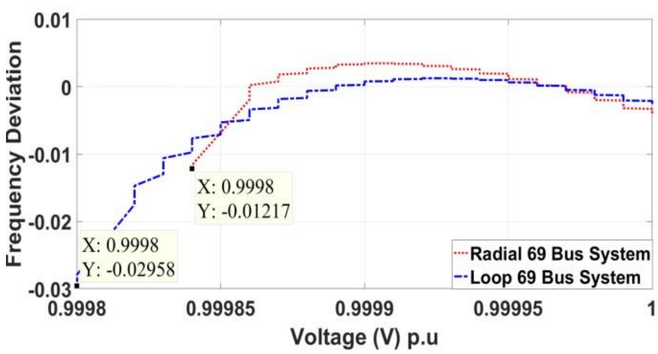

Fig. 10. IEEE 69 bus system weakest buses F -V curve without.

between bus number 18 and bus number 33 is closed which is the optimal choice.

a) Case 1:

In first case also named as base case which contains both radial and loop system without DG is simulated and results are shown in Fig .2 and Fig .3 for comparison. In Fig.2 frequency deviation from original values is plotted against the loading parameter of system while in Fig.3 frequency deviation is plotted against voltage drop of system for both radial and looped networks.

a) Case 2:

In second case one DG is placed on bus 18 which is found weakest from voltage stability point of view during analysis of base case. Fig.5 shows frequency deviation against loading parameter while Fig.6 shows frequency deviation against voltage drop for both radial and looped networks.

b) Case 3:

Case 3 evaluates system with two DG's. Second DG is placed on bus with lowest voltage characteristics after placement of first DG, which is bus 27 in case of radial configuration and bus 18 in case of loop configuration. Fig.7 have shown frequency deviation against loading parameter for case three comparing both radial and loop configuration. In Fig.8 frequency stability verses voltage drop in per unit is shown

B. 69 bus System

IEEE 69 bus system is also designed on PSAT and values of line parameter are taken from [15].

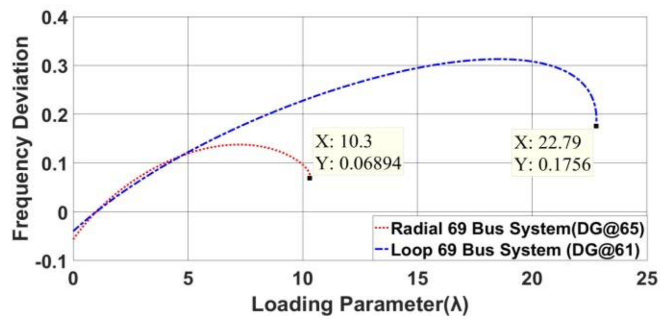

Fig. 11. IEEE 69 bus system weakest buses λ -F curve with one DG.

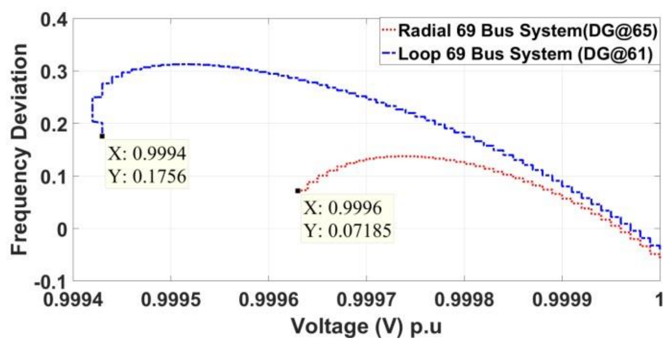

Fig. 12. IEEE 69 bus system weakest buses F-V curve with one DG.

Same above three cases which are used in 33 bus system are considered for 69 bus system.

a) Case 1:

In this case, 69 bus system without any DG is analyzed. Both radial and loop configured system are simulated in PSAT and their graphs are shown. In Fig.9 frequency of 69 bus system against loadability is shown while in fig.10 frequency deviation with per unit voltage are shown for both radial and looped networks.

a) Case 2:

DG having value of 3684.7 KVA is integrated to 69 bus system on weakest bus. Weakest bus is different for loop and radial configuration. For radial it is bus number 65 while in loop system bus 61 is the weakest bus. Graph of frequency

TABLE III. IEEE 69 BUS SYSTEM PERSENTAGE CHANGE IN LOADABALITY AND FREQUENCY DEVIATION.

IEEE 69 Bus System	Value of DG (KVA)	Loading Factor		% Increase in loadability	Total Frequency Deviation Around Mean Value (60 HZ)		% Change in Frequency
		Radial System	*Loop System*		Radial System	Loop System	
Without DG	____	3.2121	3.941	18.50	0.01563	0.03081	49.27
With One DG	3684.7	10.319	22.7951	54.73	0.19416	0.3526	44.94
With Two DG	3685.1 547.6	7.033	14.4023	51.17	0.14947	0.22429	33.36

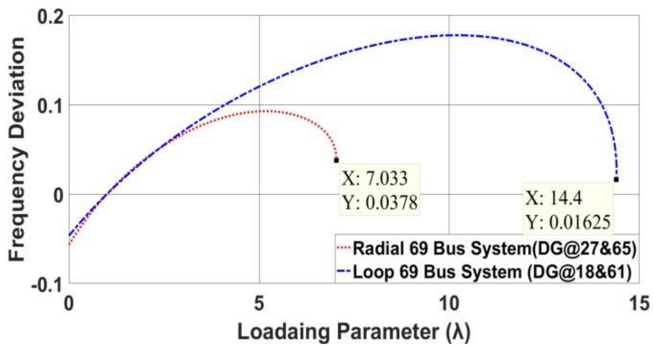

Fig. 13. IEEE 69 bus system weakest buses λ -F curve with two DGs.

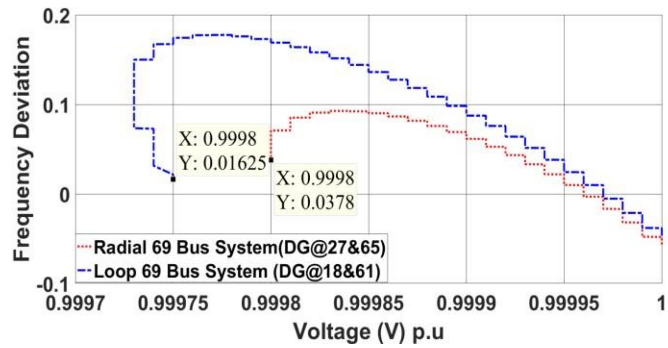

Fig. 14. IEEE 69 bus system weakest buses F-V curve with one DG.

deviation versus loading parameter of system is shown in Fig.11 while frequency deviation against voltage is shown in Fig.12.

b) Case 3:

In Case 3 69 bus system is evaluated with two DG. For radial system second DG placed at bus number 27 and for loop system DG is placed on bus 18. frequency deviation for 69 bus is shown in Fig.13 where both loop and radial cases are compared. Frequency deviation against per unit voltage is shown in Fig.14.

TABLE IV. IEEE 69 BUS SYSTEM FREQUENCY DEVATION COMPARISON.

IEEE 69 bus System	Value of DG (KVA)	Frequency Deviation			
		Radial System		*Loop System*	
		Max Frequency Dip	*Max Frequency Over Shoot*	*Max Frequency Dip*	*Max Frequency Over Shoot*
Without DG	——	-0.01217	0.00346	-0.02958	0.00123
With One DG	3684.7	-0.05656	0.1376	-0.0398	0.3128
With Two DG	3685.1 547.6	-0.05677	0.0927	-0.04669	0.1776

IV. RESULTS AND DISCUSSION

In this paper two IEEE distribution test systems i.e. 33 bus system and 69 bus system are considered as benchmark to analyze the three key parameters i.e. voltage, frequency and loadability of distribution System. Conventional radial system and new looped system are compared on the basis of above mentioned key parameters. This paper mainly focuses on frequency stability of distribution system. To measure the frequency stability, CPF method is used and frequency deviation is plotted against loading parameter and voltage for different cases. Three cases are considered for both 33 and 69 systems. First one is simple system without having any DG, second one includes one DG while in third case two DGs are integrated to the system.

Radial and looped system shows almost same characteristic for base case while evaluating frequency deviation with loading parameter. Frequency deviation and loading parameter is slightly higher for loop system in base case. Loading parameter is 2.52 % and frequency deviation is 0.57 % higher for loop system. In the next case, DG of value 3623.9 is installed at weakest bus which is bus 18 for both radial and loop system. By installing DG, loading parameter as well as frequency deviation of loop system increases significantly as compared to radial system. Loading parameter of radial is increased from 3.44 to 4.118 and for loop its increased from 3.529 to 12.39. Frequency of radial system deviate from 59.9946 to 60.0105 and for loop its value swing between 59.9962 and 60.0161. For third case DG's of value 1313.9 and 2212.3 KVA are placed on bus 33 and 18 for radial and bus 23 and 18 for loop system.

Loading parameter of loop increases a bit from one DG's value while loading parameter of radial becomes almost twice then it was with one DG. From the frequency trend it is observed that frequency deviation increases as system is moved from no DG to one DG and then decreased again for two DG. Reason behind it, is that when one DG is integrated system loadability increases with greater ratio while stability with less ratio and vice versa with installation of second DG.

In 69 bus system loop system shows better loading Charteristics than radial system. loading parameter of loop system is 18.5 % greater than loop and with integration of one DG at weakest bus loading parameter of both systems increases significantly but this effect is more prominent in loop system where loading parameter increase 80.71% from 3.941 to 22.795 while it is 68.87% from 3.2121 to 10.319 for radial. With integration of two DGs loading parameter of both systems fall.it come from 22.795 to 14.4023 for loop and for radial it drops to 7.033 from10.319.

Frequency deviation of loop system in 69 bus is also grater than radial system and this difference decreases with increasing number of DGs. For base case frequency deviation of loop system is 49.27 %, this difference decreases to 44.94% with integration of one DG and it decreases further to 33.36% with integration of two DG. this deviation increases to one DG and decrease with integration of second DG. This trend is same for both radial and loop system.

V. Conclusion

A comparison between radial distribution system and looped distribution system in the context of frequency stability and loadability is discussed in this paper. CPF method is used for calculation and analyses of the IEEE 33 and 69 test systems. Loading parameter of 33 bus system increases as DG is integrated to system and it increases further when number of DG's are increased from one to two. Frequency deviation is also increased with number of DG's. For 69 bus system loading parameter increases with DG but value of loading parameter with two DG is less than with one DG. Frequency deviation of loop system is greater than radial system and this difference decreases with increasing number of DG's in 69 bus system and increases in 33 bus system. However this deviation is in allow able limit.

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