Sensitivity Analysis for Optimal Distributed Generation Placement in Port Harcourt 33kv Power Distribution System

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Abstract: In this paper loss sensitivity factor method is used to identify the optimal placement of DG units in power distribution system. Simulations are conducted on 73-bus Port Harcourt 33 kV Power distribution system modelled in Electrical Transient Analyzer program (ETAP 12.6) software using Newton Raphson (N-R) load flow method. The results obtained showed that 35 load buses are outside the statutory voltage constraint limit (0. 95p.u – 1. 05p.u) that is 31.35KV-34.65KV. Gas turbine synchronous generators (DGs) of 25MW are placed at the optimal position of the candidate buses identified by sensitivity analysis. To verify the efficacy of the proposed method, load flow analysis was repeated for the test system. The result obtained after DG placement reveals improvement in voltage profile and loss reduction.

Keywords: Distribution system, Loss sensitivity factor, Distributed Generation, load flow, Newton Raphson, ETAP.

1. INTRODUCTION

Loss sensitivity factor is the key method for the optimal DG placement in distribution system. It provides the sequence in which the candidate buses are to be considered for DG placement.

Distributed generation (DG) is a new trend that can be used to improve availability of power and reliability of the power network. Currently, there is no unified definition of distributed generation which is also known as embedded generation or dispersed generation or decentralised generation. In this paper, distributed generation (DG) implies the use of small, modular, decentralized, off- grid or grid connected generators spotted throughout a power system network, providing the electricity locally to load customers (Thomas et al., 2001). The recent literatures relating to optimal placement of DG using sensitivity analysis are:

Graham et al. (2000) applied loss sensitivity factor method (LSF) based on the principle of linearization of the original nonlinear equation (loss equation) around the initial operating point, which helps to reduce the amount of solution space. Optimal placement of DG units is determined exclusively for the various distributed load profiles to minimize the total losses. They iteratively increased the size of DG unit at all buses and then calculated the losses; based on loss calculation they ranked the nodes. Top ranked nodes are selected for DG unit placement

Kanth et al. (2013) implemented sensitivity analysis and PSO on standard IEEE 15 bus test system for determining the location and size of DG in the distribution networks in order to reduce the real power losses of the system. To include the presence of harmonics, PSO was integrated with a harmonic power flow algorithm (HPF).

Nalini et al. (2014) presented a heuristic optimization technique named particle swarm optimization (PSO) as a working tool to minimize simultaneously the economic cost of overall system by changing sitting and varying sizes of DGs. With respect to voltage profile THD and loss reduction by using the sensitivity analysis.

Lakshyabhat et al. (2015) presented sensitivity analysis for 14 bus systems in a distribution network with distributed generators. An analysis is carried out by selecting the most optimum location in placing the Distributed Generators through load flow analysis and seeing where the voltage profile rises. Matlab programming is used for simulation of voltage profile in the respective buses after introduction of DG's. A tolerance limit of +/-5% of the base value has to be maintained. To maintain the tolerance limit, 3 methods are used. Sensitivity analysis of 3 methods for voltage control is carried out to determine the priority among the methods.

Singh et al. (2015) tested various indices and using effective techniques for the optimal placement and sizing of the DG unit by minimizing power losses and voltage deviation. They applied two sensitivity-based methods namely loss sensitivity analysis and voltage sensitivity analysis on 33- bus radial distribution system.

Divya et al. (2016) used sensitivity analysis to determine the location of DG and particle swarm optimization to determine the size of DG to minimize the power losses in the distribution network. The result, so obtained show the improvement of voltage profile, reduction of real power loss using MATLAB.

Kumar et al. (2018) presented loss sensitivity factor method to identify optimal placement of DGs to minimize the power losses and to improve voltage profile and reliability in distribution system. Methodology is applied to IEEE 33-bus Radial Distribution System and the obtained results are compared.

Suresh et al. (2018) proposed dragonfly algorithm to determine the optimal DG placement for benefit maximization in distribution networks and also compared with loss sensitivity factors for 33-bus system.

Newton Raphson Load flow programs compute the voltage magnitudes and phase angles at each bus of the network under steady state operating conditions. These programs also compute real and reactive power in each of the line and power losses for all equipment, including transformers and distribution lines; thus overloaded transformers and distribution lines are identified and remedial measures can be implemented. The software used for the analysis is ETAP 12.6 is a fully graphical Electrical Transient Analyzer Program that provides a very high level of reliability, protection and security of critical applications. Among ETAP's most powerful features are the composite network and motor element. Composite elements allow you to graphically nest network elements within themselves to an arbitrary depth. For example, a composite network can contain other composite networks, providing the capability to construct complex electrical networks while still maintaining a clean, uncluttered diagram that you want to emphasize. ETAP provides five levels of error checking. The active error viewer appears when you attempt to run a study with missing or inappropriate data.

2. MATERIALS

The materials are: Distribution line data, bus data, load readings of the distribution feeders, installed capacity of transmission substations, injection substations, power rating of distribution transformers connected to the injection substations and Port Harcourt 33kv power distribution network diagram.

Software's (MATLAB, ETAP).

TABLE 1: LINE DATA FOR PORT HARCOURT POWER DISTRIBUTION NETWORK

FROM	TO	FROM BUS	TO BUS	LENGTH (KM)	CIRCUIT TYPE	R(P.U)	X(P.U)	B (P.U)
AFAM	PH MAIN (PHZ2)	1	2	36.80	DC	0.0394	0.014	0.167
AFAM	PH TOWN (PHZ4)	1	3	42.0	DC	0.0394	0.014	0.167
AFAM	ELELEWO (EL)	1	4	20.0	DC	0.0394	0.014	0.167
PHZ2	RUMUOSI (RU)	2	5	25.7	DC	0.0394	0.014	0.167
PHZ2	TIA (Z2)	2	6	0.42	DC	0.0394	0.0017	0.206
PHZ2	T2A (Z2)	2	7	0.42	DC	0.0394	0.0017	0.206
PHZ2	T3A (Z2)	2	8	0.42	DC	0.0394	0.0017	0.206
PHZ4	T1A (Z4)	3	9	0.30	DC	0.0394	0.0017	0.206
PHZ4	T2A (Z4)	3	10	0.30	DC	0.0394	0.0017	0.206
PHZ4	T2B (Z4)	3	11	0.30	DC	0.0394	0.0017	0.206
EL	T1(EL)	4	12	0.30	DC	0.0394	0.0017	0.206
EL	T2 (EL)	4	13	0.30	DC	0.0394	0.0017	0.206
RU	T1(RU)	5	14	0.30	DC	0.0394	0.0017	0.206
RU	T2(RU)	5	15	0.30	DC	0.0394	0.0017	0.206
TIA (Z2)	OYIGBO	6	16	11.71	DC	0.0394	0.0017	0.206
TIA (Z2)	RUMUODUMAYA	6	17	49.25	DC	0.0394	0.0017	0.206
TIA (Z2)	ABULOMA	6	18	11.40	DC	0.0394	0.0017	0.206
T1A (Z2)	WOJI	6	19	4.65	DC	0.0394	0.0017	0.206
T2A (Z2)	TRANS AMADI (RSPUB)	7	20	8.19	DC	0.0394	0.0017	0.206
T2A (Z2)	RAINBOW	7	21	5.8	DC	0.0394	0.0017	0.206
T3A (Z2)	GOLDEN ILY(RUMUOLA)	8	22	35.32	DC	0.0394	0.0017	0.206
T3A (Z2)	AKANI	8	23	0.22	DC	0.0394	0.0017	0.206
T3A (Z2)	OLD AIRPORT	8	24	187.98	DC	0.0394	0.0017	0.206
TIA (Z4)	SILVERBIRD	9	25	3.50	DC	0.0394	0.0017	0.206
TIA (Z4)	UTC	9	26	3.00	DC	0.0394	0.0017	0.206

T1A (Z4)	BOLOKIRI	9	27	11.04	DC	0.0394	0.0017	0.206
TIA (Z4)	RUMUOLUMENI	9	28	12.3	DC	0.0394	0.0017	0.206
T2A (Z4)	UST	10	29	15.15	DC	0.0394	0.0017	0.206
T2B (Z4)	SECRETARIAT	11	30	151.24	DC	0.0394	0.0017	0.206
T1(EL)	ELEME	12	31	65.4	DC	0.0394	0.0017	0.206
TI(EL)	IGBO ETCHE	12	32	9.0	DC	0.0394	0.0017	0.206
T1(EL)	IRIEBE	12	33	70.0	DC	0.0394	0.0017	0.206
T2 (EL)	BORI	13	34	60	DC	0.0394	0.0017	0.206
T2 (EL)	RSTV(ELELEWO)	13	35	50.0	DC	0.0394	0.0017	0.206
T2 (EL)	BRISTLE	13	36	20	DC	0.0394	0.0017	0.206
T1(RU)	NEW AIRPORT	14	37	38	DC	0.0394	0.0017	0.206
T1 (RU)	RUKPOKWU	14	38	15	DC	0.0394	0.0017	0.206
T2 (RU)	NTA	15	39	5	DC	0.0394	0.0017	0.206
T2 (RU)	UPTH	15	40	4.0	DC	0.0394	0.0017	0.206
OYIGBO FDR	AWETO GUEST HOUSE	16	41	7.19	DC	0.0394	0.0017	0.206
OYIGBO FDR	SHELL RES	16	42	8.5	DC	0.0394	0.0017	0.206
RUMUODUMA YA FDR	AGIP/ OKPORO	17	43	35.6	DC	0.0394	0.0017	0.206
RUMUODUMA YA FDR	UNIPORT	17	44	55.6	DC	0.0394	0.0017	0.206
RUMUODUMA YA FDR	CHOBA	17	45	55.6	DC	0.0394	0.0017	0.206
ABULOMA FDR	STALLION PHASE 2	18	46	2.0	DC	0.0394	0.0017	0.206
ABULOMA FDR	GULF ESTATE	18	47	5.0	DC	0.0394	0.0017	0.206
TRANS AMADI (RSPUB) FDR	FIRST ALLUMINIUM	20	48	2.46	DC	0.0394	0.0017	0.206
TRANS AMADI (RSPUB) FDR	ELF NIG	20	49	4.1	DC	0.0394	0.0017	0.206
TRANS AMADI (RSPUB) FDR	BEKEMS PROPERTY	20	50	5.8	DC	0.0394	0.0017	0.206
TRANS AMADI (RSPUB) FDR	TRANS AMADI GARDENS	20	51	8.19	DC	0.0394	0.0017	0.206
TRANS AMADI (RSPUB) FDR	GALBA	20	52	60	DC	0.0394	0.0017	0.206
TRANS AMADI (RSPUB) FDR	RIVOC	20	53	5.8	DC	0.0394	0.0017	0.206
TRANS AMADI (RSPUB) FDR	AIR LIQUID	20	54	8.19	DC	0.0394	0.0017	0.206
TRANS AMADI (RSPUB) FDR	STALLION 1	20	55	6.2	DC	0.0394	0.0017	0.206
TRANS AMADI (RSPUB) FDR	OIL INDUSTRY	20	56	7.0	DC	0.0394	0.0017	0.206
TRANS AMADI (RSPUB) FDR	ONWARD FISHERY	20	57	9.70	DC	0.0394	0.0017	0.206
RAINBOW FDR	ELEKAHIA	21	58	7.0	DC	0.0394	0.0017	0.206
RUMUOLA FDR	SHELL. INDUSTRIAL	22	59	5.2	DC	0.0394	0.0017	0.206
RUMUOLA FDR	PRESIDENTIAL HOTEL	22	60	21.0	DC	0.0394	0.0017	0.206
OLD AIRPORT FDR	ENEKA	24	61	30.0	DC	0.0394	0.0017	0.206
OLD AIRPORT FDR	BIG TREAT	24	62	35.0	DC	0.0394	0.0017	0.206
SILVERBIRD	SHELL KIDNEY ISLAND	25	63	0.3	DC	0.0394	0.0017	0.206

UTC FDR	WATER WORKS	26	64	6.0	DC	0.0394	0.0017	0.206
BOLOKIRI FDR	EASTERN BYPASS	27	65	9.0	DC	0.0394	0.0017	0.206
RUMUOLUMENI FDR	SCHOOL OF NURSING	28	66	29.5	DC	0.0394	0.0017	0.206
RUMUOLUMENI FDR	U.O.E	28	67	20.5	DC	0.0394	0.0017	0.206
RUMUOLUMENI FDR	NAVAL BASE	28	68	32.8	DC	0.0394	0.0017	0.206
RUMUOLUMENI FDR	MASTER ENERGY	28	69	4.3	DC	0.0394	0.0017	0.206
UST	AGIP HOUSING ESTATE	29	70	5.0	DC	0.0394	0.0017	0.206
UST	NAOC AGIP BASE	29	71	3.2	DC	0.0394	0.0017	0.206
SECRETARIAT	JUANUTA	30	72	35.6	DC	0.0394	0.0017	0.206
SECRETARIAT	MARINE BASE	30	73	7.0	DC	0.0394	0.0017	0.206

Source: Port Harcourt electricity distribution company (PHEDC)

TABLE 2: DATA FOR 73- BUS PORT HARCOURT POWER DISTRIBUTION SYSTEM

BUS NO	**BUS NAME**	**BUS TYPE**	**V(P.U)**	**PHASE (DEQ)**	**P(MW)**	**Q(MVAR)**
1	AFAM	1	1.00	0.00	150.0	0.00
2	PH MAINS (PHZ2)	2	1.00	0.00	70.0	0.00
3	PH TOWN (PHZ4)	2	1.00	0.00	75.0	0.00
4	ELELEWO (EL)	2	1.00	0.00	45.0	0.00
5	RUMUOSI (RU)	2	1.00	0.00	30.0	0.00
6	TIA(Z2)	3	0.00	0.00	30.5	18.3
7	T2A(Z2)	3	0.00	0.00	39.8	23.9
8	T3A(Z2)	3	0.00	0.00	46.6	28.0
9	TIA(Z4)	3	0.00	0.00	34.5	20.7
10	T2AZ4)	3	0.00	0.00	21.2	12.7
11	T2B(Z4)	3	0.00	0.00	28.9	17.3
12	TI(EL)	3	0.00	0.00	31.6	19.0
13	T2(EL)	3	0.00	0.00	32.0	19.2
14	T1(RU)	3	0.00	0.00	30.0	18.0
15	T2(RU)	3	0.00	0.00	31.2	18.7
16	OYIGBO	3	0.00	0.00	12.2	7.6
17	RUMUODUMAYA	3	0.00	0.00	24.0	14.9
18	ABULOMA	3	0.00	0.00	9.7	6.0
19	WOJI	3	0.00	0.00	10.8	6.7
20	TRANS AMADI	3	0.00	0.00	29.5	18.3
21	RAINBOW	3	0.00	0.00	17.3	10.7
22	GOLDEN LILY(RUMUOLA)	3	0.00	0.00	18.2	11.3
23	AKANI	3	0.00	0.00	14.9	9.2
24	OLD AIRPORT	3	0.00	0.00	21.8	13.5
25	SILVERBIRD	3	0.00	0.00	16.0	9.9
26	UTC	3	0.00	0.00	10.8	6.7
27	BOLOKIRI	3	0.00	0.00	9.8	6.1
28	RUMUOLUMENI	3	0.00	0.00	13.8	8.6
29	UST	3	0.00	0.00	22.8	7.9
30	SECRETARIAT	3	0.00	0.00	16.2	10.04
31	ELEME	3	0.00	0.00	20.3	12.6
32	IGBO ETCHE	3	0.00	0.00	26.6	16.5
33	IRIEBE	3	0.00	0.00	8.9	5.5
34	BORI	3	0.00	0.00	11.4	7.1
35	RSTV (ELELEWO)	3	0.00	0.00	18.5	11.5

36	BRISTLE	3	0.00	0.00	10.8	6.7
37	NEW AIRPORT	3	0.00	0.00	20.9	13.0
38	RUKPOKWU	3	0.00	0.00	12.1	7.5
39	NTA	3	0.00	0.00	18.0	11.2
40	UPTH	3	0.00	0.00	13.6	8.4
41	AWETOGUEST HOUSE	3	0.00	0.00	10.1	6.3
42	SHELL RES	3	0.00	0.00	12.4	7.7
43	AGPIP/ OKPORO	3	0.00	0.00	11.2	6.9
44	UNIPORT	3	0.00	0.00	10.0	6.2
45	CHOBA	3	0.00	0.00	6.5	4.0
46	STALLION PHASE 2	3	0.00	0.00	8.9	5.5
47	GULF ESTATE	3	0.00	0.00	7.4	4.6
48	FIRST ALLUMINIUM	3	0.00	0.00	10.6	6.6
49	ELF NIG	3	0.00	0.00	12.0	7.4
50	BEKEMS PROPERTY	3	0.00	0.00	10.5	6.5
51	TRANS AMADI GARDENS	3	0.00	0.00	11.4	7.1
52	GALBA	3	0.00	0.00	10.9	6.8
53	RIVOC	3	0.00	0.00	12.3	7.6
54	AIR LIQUID	3	0.00	0.00	10.5	6.5
55	STALLION 1	3	0.00	0.00	13.4	8.3
56	OIL INDUSTRY	3	0.00	0.00	12.2	7.6
57	ONWARD FISHERY	3	0.00	0.00	13.8	8.6
58	ELEKAHIA	3	0.00	0.00	14.8	9.2
59	SHELL. INDUSTRIAL	3	0.00	0.00	13.8	8.6
60	PRESIDENTIAL HOTEL	3	0.00	0.00	10.7	6.6
61	ENEKA	3	0.00	0.00	7.9	4.9
62	BIG TREAT	3	0.00	0.00	8.7	5.4
63	SHELL KIDNEY ISLAND	3	0.00	0.00	5.2	3.3
64	WATER WORKS	3	0.00	0.00	3.8	2.4
65	EASTERN BYPASS	3	0.00	0.00	11.6	7.2
66	SCHOOL OF NURSING	3	0.00	0.00	3.7	2.3
67	U.O.E	3	0.00	0.00	13.2	8.2
68	NAVAL BASE	3	0.00	0.00	10.1	6.3
69	MASTER ENERGY	3	0.00	0.00	7.9	4.9
70	AGIP HOUSING ESTATE	3	0.00	0.00	8.8	5.5
71	NAOC AGIP BASE	3	0.00	0.00	9.8	6.1
72	JUANUTA	3	0.00	0.00	11.0	6.8
73	MARINE BASE	3	0.00	0.00	8.7	5.4

Source: Port Harcourt Electricity Distribution Company (PHEDC)

Key: 1 (Slack bus)

2 (PV bus)

3 (PQ bus)

3 METHODOLOGY

The methodology adopted are:

i. Modelling of 73 bus network of 33kV Port-Harcourt power Distribution Network using Electrical Transient Analyzer Program (ETAP 12.6) software for load flow analysis.

ii. Steady state assessment of the network through load flow Analysis using Newton-Raphson (N-R) method.

iii. Loss sensitivity factor method.

Newton Raphson load flow will be simulated in ETAP software. This will be used to come up with the candidate buses for DG placement using loss sensitivity factor method.

3.1 COMPUTATIONAL PROCEDURE FOR NEWTON-RAPHSON METHOD

The computational procedure for Newton-Raphson method using polar coordinate is as follows:

1. Form Y_{bus}.
2. Assume initial values of bus voltages / V_i /^{0} and phase angles δ°_i for i = 2, 3, … n for load buses and phase angles for PV buses. Normally we set the assumed bus voltage magnitude and its phase angle equal to slack bus quantities / V_1 / = 1.0, $\delta_1 = 0^o$.
3. Compute P_i *and* Q_i for each load bus from the following equations:

$$P_i = \sum_{k=i}^{n} V_i V_k Y_{ik} \cos(\delta_i - \delta_k - \theta_{ik}) \quad \text{… …………………. (3.1.1)}$$

$$Q_i = \sum_{k=i}^{n} V_i V_k Y_{ik} \sin(\delta_i - \delta_k - \theta_{ik}) \quad \text{………………………..(3.1.2)}$$

4. Compute the scheduled error ΔP_i and Q_i for each load bus from the following relations.

$$\Delta P_i^{(r)} = P_{i\,sp} - P_{i(cal)}^{(r)} \qquad i = 2,3,\ldots n \qquad \text{……………….. (3.1.3)}$$

$$\Delta Q_i^{(r)} = Q_{i\,sp} - Q_{i(cal)}^{(r)} \qquad i = 2,3,\ldots n \quad \text{………………………(3.1.4)}$$

For PV buses, the exact value of Qi is not specified, but its limits are known. If the calculated value of Qi is beyond the limits, then an appropriate limit is imposed and Δ Qi is also calculated by subtracting the calculated value of Qi from the appropriate limit. The bus under consideration is now treated as a load (PQ) bus.

5. Compute the elements of the Jacobian matrix

$$\begin{vmatrix} H & N' \\ M & L' \end{vmatrix}$$

Using the estimated I Vi I and δ_i from step 2

6. Obtain $\Delta\delta$ and Δ / Vi / from equation

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} H & N' \\ M & L' \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \dfrac{\Delta V}{V} \end{bmatrix} \quad \text{…………………………………………………. (3.1.5)}$$

7. Using the value of $\Delta\delta_i$ and Δ I V_i I calculated in step 6, modify the voltage magnitude and phase angle at all load buses by the equations

$/ V_i^{(r+1)} / = I/V_i^{(r)} / + \Delta I/V_i^{(r)} /$ …………………………………………… (3.1.6)

$\delta_i^{(r+1)} = \delta_i^{(r)} + \Delta\delta_i^{(r)}$ ………………………………………………….(3.1.7)

Start the next iteration cycle at step 2 with these modified $/ V_i /$ and δ_i.

8. Continue until scheduled errors $\Delta P_i^{(r)}$ and $\Delta Q_i^{(r)}$ for all load buses are within a specified tolerance, that is,

$\Delta P_i^{(r)} < \varepsilon, \quad \Delta Q_i^{(r)} < \varepsilon$

Where ε denotes the tolerance level for load buses.

9. Calculate line flows and power at the slack bus exactly in the same manner as in the GS method.

The flowchart for Newton-Raphson method using polar coordinates for load flow solution is given in Fig. 3.1

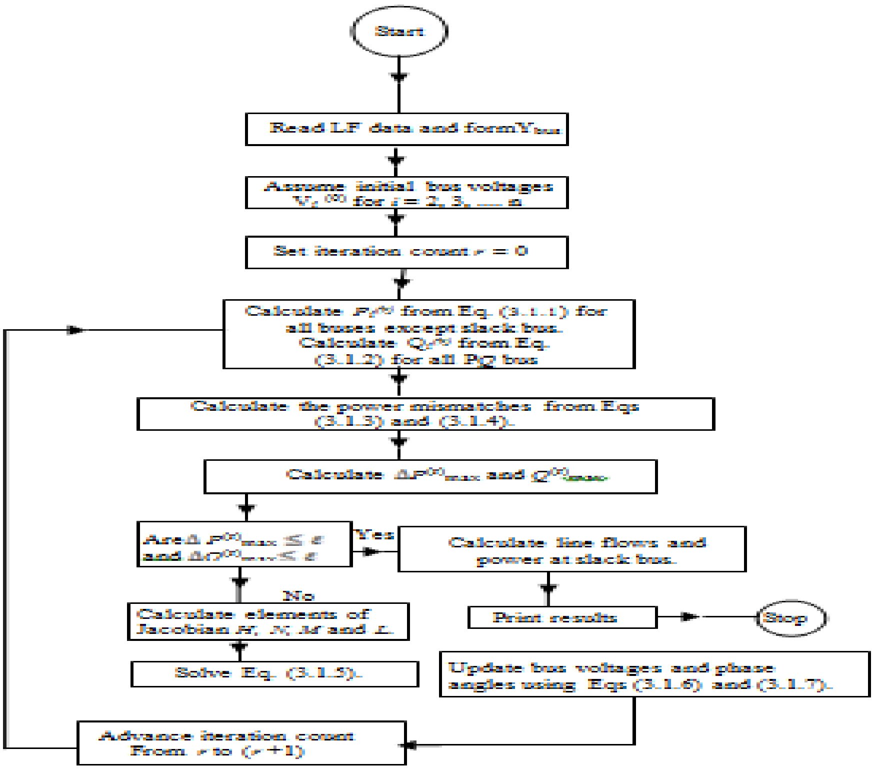

Fig. 3.1. Flowchart for load flow solution using NR method in polar coordinates.

3.2 SENSITIVITY ANALYSIS FOR OPTIMAL PLACEMENT OF DISTRIBUTED GENERATION

Loss sensitivity factor method (LSF) is applied to Port Harcourt power distribution network to determine the candidate buses for optimal DG placement and the sequence in which buses are to be considered for DG placement. The loss sensitivity factors reduce the search space by finding the few best locations which saves the cost of the DGs in optimizing the losses in the distribution system as a whole.

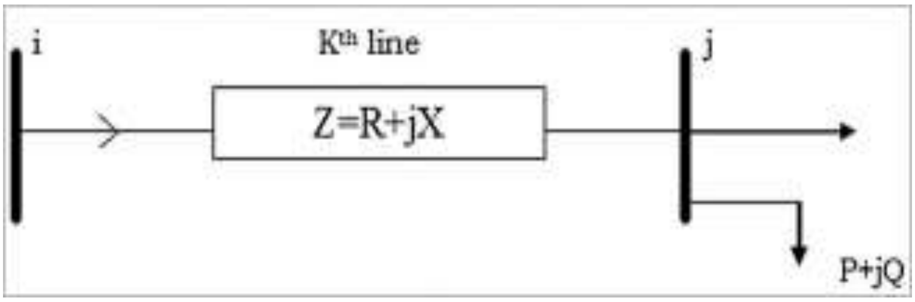

Figure 3.2. A distribution line with connected load

Considering a distribution link shown in figure 3.2. The link represents a distribution line connecting two buses, and j of Port Harcourt distribution system. The magnitude of the two bus voltages, vi and vj are known by load flow study. The real and reactive power losses in each of the line and power flow are obtained by load flow studies.

The real power loss in distribution line can be expressed as

$$PL_{(j)} = \frac{\left[P_{(j)}^2 + Q_{(j)}^2\right] * R_{(k)}}{V_{(j)}^2} \qquad (3.1.8)$$

(3.85)

Similarly, reactive power loss in the distribution line can be expressed as

$$QL_{(j)} = \frac{\left[P_{(j)}^2 + Q_{(j)}^2\right] * X_{(k)}}{V_{(j)}^2} \qquad (3.1.9)$$

LSF value can be expressed by derivative of the equations (3.1.8)

$$\frac{\partial PL}{\partial p} = \frac{2 * P_{(j)} * R_{(k)}}{V_{(j)}^2} \qquad (3.1.10)$$

$$LSF = \frac{2 * P_{(j)} * R_{(k)}}{|V|^2} \qquad (3.1.11)$$

Loss sensitivity for all the candidate buses will be calculated using equation (3.1.11).

Few topmost load ranked buses will be selected for optimal DG placement in the test system. Synchronous generator based DGs will be placed on this bus and the load flow analysis repeated on the entire system to determine the voltage profile and the system losses.

4. SIMULATION RESULTS AND DISCUSSION

Table 4.1: LOSS SENSITIVITY FACTORS FOR 35 BUS SYSTEM

(Source: Calculated Result)

Bus No	P_i (pu)	R(pu)	V_i (pu)	LSF	LSF Ranking
BUS 7	0.398	0.857	0.914	0.817	22
BUS 9	0.345	0.612	0.919	0.500	25
BUS 16	0.102	0.612	0.914	0.149	32
BUS 20	0.216	0.612	0.856	0.361	27
BUS 21	0.122	0.612	0.841	0.211	28
BUS 25	0.128	0.612	0.894	0.196	29
BUS 26	0.089	0.612	0.91	0.132	34

BUS 27	0.081	0.612	0.909	0.120	35
BUS 28	0.097	0.612	0.837	0.169	30
BUS 31	0.102	8.568	0.947	1.949	7
BUS 37	0.216	11.424	0.929	5.718	1
BUS 39	0.122	0.612	0.946	0.167	31
BUS 41	0.128	4.080	0.904	1.278	13
BUS 42	0.216	2.856	0.854	1.692	8
BUS 44	0.081	2.448	0.948	0.441	26
BUS 48	0.097	4.896	0.851	1.312	11
BUS 49	0.102	2.244	0.855	0.626	23
BUS 50	0.089	7.140	0.954	1.396	10
BUS 51	0.122	2.448	0.854	0.819	21
BUS 52	0.128	2.448	0.855	0.857	19
BUS 53	0.089	6.324	0.846	1.573	9
BUS 54	0.081	4.488	0.851	1.004	15
BUS 55	0.097	2.244	0.854	0.597	24
BUS 56	0.102	4.080	0.851	1.149	14
BUS 57	0.216	6.324	0.845	3.826	3
BUS 58	0.122	6.528	0.833	2.296	6
BUS 59	0.128	10.608	0.944	3.047	4
BUS 63	0.089	0.612	0.895	0.136	33
BUS 64	0.081	4.284	0.909	0.840	20
BUS 65	0.097	4.080	0.894	0.990	17
BUS 66	0.102	3.060	0.837	0.891	18
BUS 67	0.216	8.160	0.83	5.117	2
BUS 68	0.122	2.856	0.834	1.002	16
BUS 69	0.128	6.528	0.835	2.397	5
BUS 71	0.089	6.528	0.949	1.290	12

Table 4.2: Load flow Comparative results of the candidate bus Voltage Magnitude Before and After DG Placement (source: Simulation result)

S/N	Bus No	P.U Value of calculated voltage without DG (base)	P.U Value of calculated voltage with DG
1	BUS 7	0.91	1.02
2	BUS 9	0.92	0.99
3	BUS 16	0.91	0.98
4	BUS 20	0.86	0.98
5	BUS 21	0.84	0.99
6	BUS 25	0.89	0.97
7	BUS 26	0.91	0.99
8	BUS 27	0.91	0.98
9	BUS 28	0.84	0.99
10	BUS 31	0.94	1.00
11	BUS 37	0.93	1.00
12	BUS 39	0.89	0.96
13	BUS 41	0.81	0.97
14	BUS 42	0.78	1.00
15	BUS 44	0.78	0.95
16	BUS 48	0.64	0.97
17	BUS 49	0.63	0.98
18	BUS 50	0.61	0.97
19	BUS 51	0.60	0.98

20	BUS 52	0.59	0.98
21	BUS 53	0.57	1.00
22	BUS 54	0.56	0.97
23	BUS 55	0.55	0.97
24	BUS 56	0.54	0.97
25	BUS 57	0.53	1.00
26	BUS 58	0.51	1.00
27	BUS 59	0.57	1.00
28	BUS 63	0.50	0.97
29	BUS 64	0.50	0.98
30	BUS 65	0.48	0.97
31	BUS 66	0.45	0.99
32	BUS 67	0.43	1.00
33	BUS 68	0.43	0.99
34	BUS 69	0.42	1.00
35	BUS 71	0.47	0.95

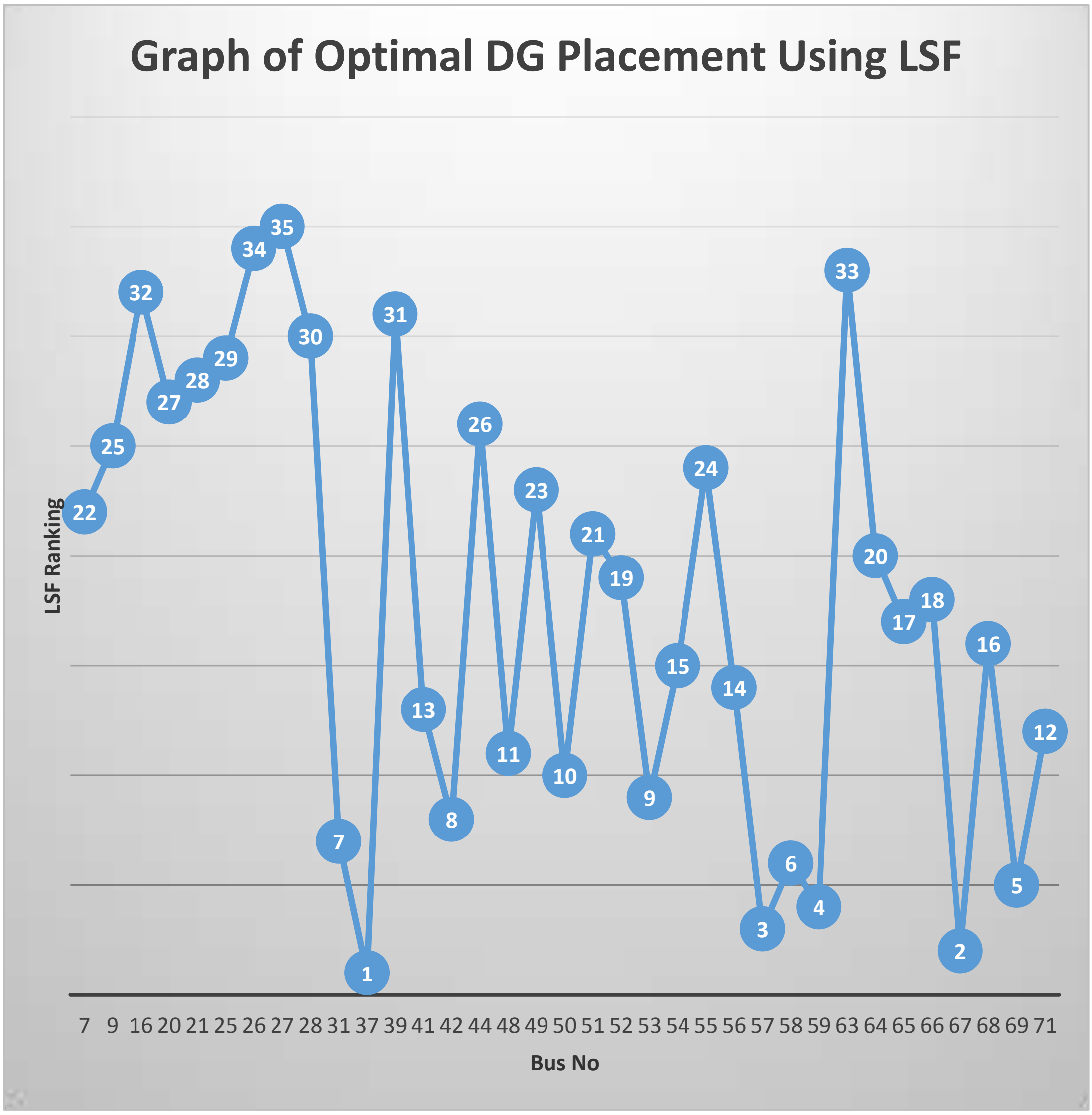

FIGURE 1.0: Graph of optimal DG placement using LSF(Source: simulation result)

TABLE 4.3: SUMMARY OF RESULT BETWEEN BASE CASE LOAD FLOW AND LOSS SENSITIVITY FACTOR METHOD

Study ID	BASE CASE LOAD FLOW	LOSS SENSITIVITY METHOD
Study Case ID	LF	LS
Buses	73	73
Power Grids	1	1
Load-MW	657.046	721.905
Load-Mvar	623.596	569.062
Generation-MW	657.046	721.905
Generation-Mvar	623.596	569.062
Loss-MW	37.817	21.648
Loss-Mvar	239.832	135.081

5. DISCUSSION

After performing the load flow analysis of the 73-bus test distribution system under review using ETAP12.6 software, an alert summary report was generated which shows 35 candidate load bus are outside the statutory voltage constraint limit (0. 95p.u – 1. 05p.u) that is 31.35KV- 34.65KV.

Loss sensitivity factor was performed on all the candidate buses. The findings on the obtained ranking demonstrate that few topmost load buses were appropriate for the placement of DGs as shown in fig.4.1. The candidate buses identified are: BUS 31, BUS37, BUS42, BUS53, BUS57, BUS58, BUS59, BUS67, BUS 69. Distributed generation units of 25MW gas turbine synchronous generator (DG_{1-9} units) were placed at these buses and load flow simulation repeated. The results are showed in table 4.2 with improvement in voltage profile and reduction of power losses in the distribution lines.

6. CONCLUSION

The loss sensitivity factor method is useful in reducing the search space for optimal DG placement and particle swarm optimization. One consideration in determining the best placement for DG is its effect on losses and voltage profile. When the DGs were optimally placed at the candidate buses identified by loss sensitivity factor, there was an acceptable improvement in the entire distribution network in terms of loss minimization and voltage profile enhancement.

Distributed generation (DG) is a new trend that can be used to improve availability of power and reliability of the power network.

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