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# Enhancement of Voltage Profile by Optimal Placement of Distributed Generators with UPFC in Distribution Networks

**Rudresh B. Magadum, D.B.Kulkarni**

***Abstract*: *The Distributed generation and fast operating power electronic devices are attracting more attention due to their effective solution for improvement in the voltage profile, to meet the increasing power consumption, reduction in the power loss, enhancement in the power transfer capacity of the transmission lines, reducing the overloading of the entire network. The optimal placement of DG and FACTs devices plays key role in improvement of the network reliability and voltage stability. In this paper exhaustive load flow analysis is carried out for optimal placement of DG and UPFC. The proposed method is tested on 40 bus distribution network. The obtained results are satisfactory in terms of improvement in the overall performance of the distribution network.***

***Index Terms*: *Distributed generators; voltage profile; unified power flow controller; power loss; distribution network; reliability; exhaustive load flow analysis; transmission capacity.***

**Nomenclature:**

| | |
|---|---|
| DG | Distributed generation |
| UPFC | Unified Power Flow Controller |
| $P_{Loss}$ | Total power loss in the network |
| N | Number of transmission lines |
| Gk | Conductance of $k^{th}$ node connects between nodes m and n. |
| δm, δn | Voltage angle magnitudes at nodes m and n |
| SVC | Static Var Compensator |
| FKBC | Fuzzy Knowledge based controller |
| $R_n$ | Resistance of the $n^{th}$ branch |
| $V_{max}$ | Maximum Voltage |
| UPQC | Unified Power Quality Conditioner |
| TCSC | Thyristor Controlled static Compensator |
| $I_n$ | Current flowing in the branch n |
| Vm, Vn | Voltage magnitudes at bus m and n |
| RDS | Radial Distribution Systems |
| $V_{min}$ | Minimum Voltage |
| k,m,n | Nodes |
| FACTS | Flexible AC Transmission Systems |
| MW | Mega watts |
| SSSC | Static Synchronous Series Compensator |
| LFA | Load Flow Analysis |

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* Correspondence Author

**Rudresh. B. Magadum*,** Research Scholar, Department of Electrical and Electronics Engineering, KLS Gogte Institute of Technology, Belagavi, Karnataka, India.

**Dr. D.B.Kulkarni,** Professor, Department of Electrical and Electronics Engineering, KLS Gogte Institute of Technology, Belagavi, Karnataka, India.



## I. INTRODUCTION

Now a day's electricity is also acting as a one of the basic need in the modern life. Every year 8-12% increased in the power consumption makes over loading of the generation, transmission and distribution [1-4]. With expansion of power system network also creates some issues like over loading of line. Droop in the voltage profile, transient instability, line outages, more power losses etc [5-7]. Although old electrical infrastructure makes weak electrical network, with small disturbance may leads to failure of the entire grid. Because of these reasons, power system is gaining more attention for new innovations to address these issues [8-11].

Many researchers are working in different angles to address these issues by incorporating new controlling mechanisms, installing fast operating efficient devices, upgradation of network, interconnecting potential available sources etc [12-15].

In this paper on site power generation with UPFC is used to improve the voltage followed by power loss reduction. Generating 20-25% of the existing power close to the load centers reduces the over loading of the network. Connecting optimal size with desirable location of DG makes enhancement in the voltage profile reducing current in the network i.e., reducing the $I^2R$ losses. Installation of UPFC also boosts the voltage profile and helps to monitor the power flow in the network. The combination of both UPFC and DG will helps to increase the overall efficiency of the network. The 40 bus distribution network is chosen as test network. The obtained results are better in terms of efficient, stable and reliable operation of the network.

## II. ORGANIZATION OF THE PAPER

Section III discusses the methodology. Section IV introduces the simulation results and discussions. Section V discusses the conclusion.

## III. METHODOLOGY

The main objectives of DG and UPFC placement are maximization of the voltage profile with power loss reduction. The power loss in the network is given by,

$$\text{Min}\{P_{Loss}\}= \text{Min}\{\textstyle\sum_{k=1}^{N}(Vm^2 + Vn^2 - 2Vm * Vn * \cos(\delta m - \delta n)\} \quad (1)$$

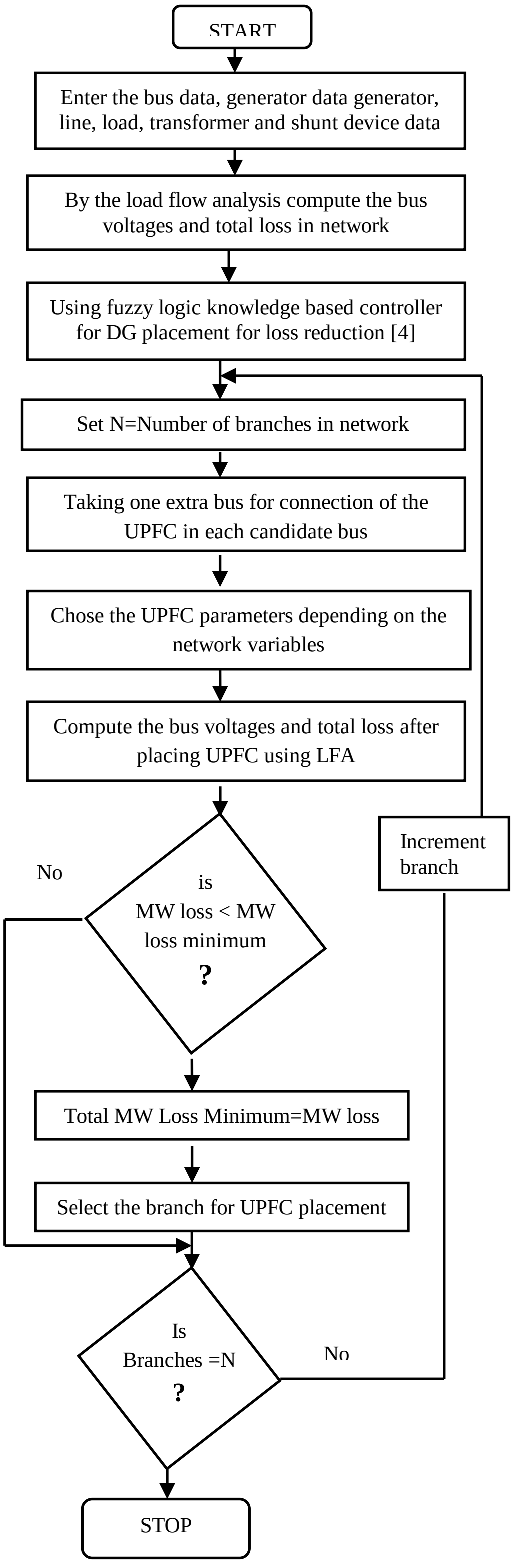


**Fig.1 Flow chart for DG and UPFC placement**

Fig.1 shows the flow of optimal placement of DG and UPFC placement for power loss reduction with improvement of the voltage stability.

## IV. RESULTS AND DISCUSSIONS

For DG placement fuzzy knowledge based controller is used. The 40 bus system consists of two generators placed at bus 24 and 40 with 1.0 p.u. specified voltage and also it is connected with14 transformers, 27 transmission lines and total 19 loads are connected across the network with total load of 25.89MW of active power and 5.9MVar of reactive power. The LFA is carried out using MiPower software. The single line diagram of 40 bus system is as shown in the Fig.1.The system is converged in four iterations with tolerance of 0.001.The LFA results in terms of line flows with line losses and transformer flow and transformer losses are as shown in the Table.1 and Table 2 respectively.

**Table.1 Line flows and line losses**

| From bus | To bus | Forward power flow | | Power loss | |
|---|---|---|---|---|---|
| | | Real Power in MW | Reactive Power in MVar | Real Power in MW | Reactive Power in MVar |
| 3 | 9 | 2.444 | 1.454 | 0.0039 | 0.0014 |
| 3 | 5 | 1.519 | 0.975 | 0.0025 | 0.0003 |
| 3 | 26 | 1.100 | 0.604 | 0.0025 | 0.0003 |
| 3 | 6 | 4.544 | 3.059 | 0.0085 | 0.0037 |
| 4 | 15 | 3.251 | 2.133 | 0.0131 | 0.004 |
| 4 | 7 | 3.373 | 2.678 | 0.0041 | 0.0018 |
| 4 | 8 | 7.207 | -5.392 | 0.0066 | 0.0083 |
| 4 | 24 | -5.781 | 1.812 | 0.0378 | 0.024 |
| 9 | 25 | 1.103 | 0.499 | 0.0064 | 0.0008 |
| 9 | 12 | 1.337 | 0.954 | 0.0011 | 0.0001 |
| 10 | 13 | 1.336 | 0.945 | 0.0012 | 0.0002 |
| 10 | 27 | -1.336 | -0.945 | 0.0028 | 0.0004 |
| 6 | 14 | 3.273 | 2.159 | 0.032 | 0.0098 |
| 7 | 27 | 2.761 | 2.231 | 0.0055 | 0.002 |
| 7 | 16 | 0.607 | 0.445 | 0.0015 | 0.0002 |
| 17 | 22 | 0.120 | 0.070 | 0.0001 | 0.0001 |
| 18 | 23 | 0.120 | 0.070 | 0.0001 | 0.0001 |
| 24 | 31 | 1.821 | 1.319 | 0.0038 | 0.0005 |
| 24 | 32 | 0.86 | 0.562 | 0.0011 | 0.0001 |
| 28 | 38 | 0.068 | -0.184 | 0.0001 | 0.0001 |
| 28 | 33 | 0.25 | 0.15 | 0.0003 | 0.0002 |
| 29 | 38 | 0.058 | -0.083 | 0.0001 | 0.0000 |
| 29 | 34 | 0.10 | 0.05 | 0.0001 | 0.0000 |
| 30 | 38 | 0.376 | 0.518 | 0.0015 | 0.0014 |
| 30 | 35 | 0.25 | 0.15 | 0.0003 | 0.0002 |
| 40 | 1 | 9.723 | 6.84 | 0.0214 | -0.0092 |
| 40 | 2 | 8.105 | 1.564 | 0.0103 | -0.031 |

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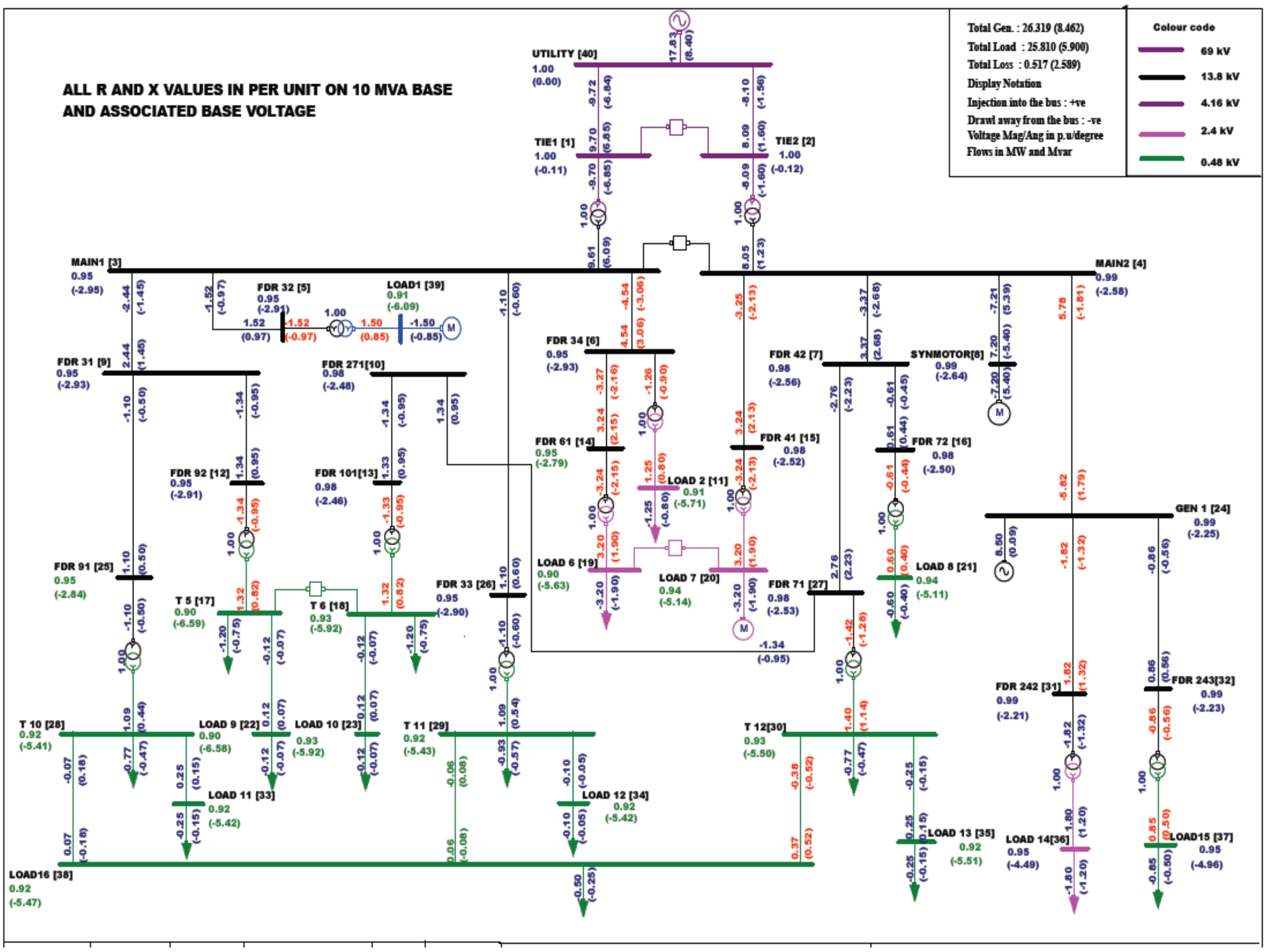


Fig.1 Single line diagram of 40 bus system

**Table.2 Transformer power flow and transformer losses**

| From bus | To bus | Forward power flow | | Power loss | |
|---|---|---|---|---|---|
| | | Real Power in MW | Reactive Power in MVar | Real Power in MW | Reactive Power in MVar |
| 1 | 3 | 9.702 | 6.849 | 0.0947 | 0.757 |
| 2 | 4 | 8.094 | 1.595 | 0.0456 | 0.364 |
| 5 | 39 | 1.517 | 0.974 | 0.0166 | 0.1244 |
| 6 | 11 | 1.262 | 0.897 | 0.0121 | 0.0969 |
| 12 | 17 | 1.336 | 0.954 | 0.0157 | 0.1336 |
| 13 | 18 | 1.335 | 0.945 | 0.0147 | 0.1252 |
| 14 | 19 | 3.241 | 2.149 | 0.0413 | 0.2489 |
| 15 | 20 | 3.238 | 2.129 | 0.038 | 0.2289 |
| 16 | 21 | 0.606 | 0.445 | 0.0056 | 0.0449 |
| 25 | 28 | 1.097 | 0.498 | 0.0088 | 0.0618 |
| 26 | 29 | 1.098 | 0.604 | 0.0095 | 0.0662 |
| 27 | 30 | 1.417 | 1.283 | 0.0207 | 0.1449 |
| 31 | 36 | 1.817 | 1.319 | 0.017 | 0.1186 |
| 32 | 37 | 0.859 | 0.562 | 0.0088 | 0.0619 |

Fig.2 shows the voltage magnitude in p.u. at each bus. From the LFA analysis it is observed that, minimum voltage in the network is 0.902p.u. at bus 17 and maximum voltage value is 1 p.u. at generators buses i.e., bus 24 and 40.If the voltage profile is low then loads will draws the more reactive power and more power loss will taken placed in terms of $I^2R$.

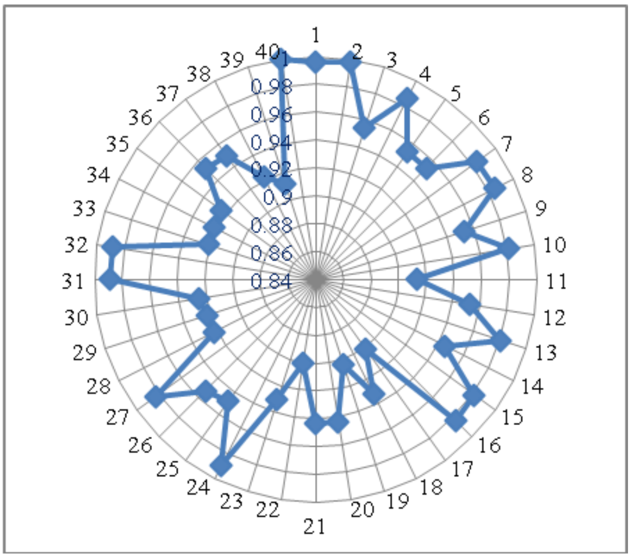


Fig.2 Voltage profile of 40 bus system

**Table.3 Voltage value in p.u in different scenarios**

| Bus No. | Voltage in p.u. | After connecting DG at bus 5 | Connecting UPFC between 6 and 14 | DG with UPFC |
|---|---|---|---|---|
| 1 | 0.9965 | 0.9968 | 0.9966 | 0.9986 |
| 2 | 0.9983 | 0.9986 | 0.9988 | 0.9995 |
| 3 | 0.9545 | 0.9621 | 0.9556 | 0.9685 |
| 4 | 0.9853 | 0.9862 | 0.9872 | 0.9912 |
| 5 | 0.9533 | 1.0000 | 0.9539 | 1.0000 |
| 6 | 0.9530 | 0.9823 | 0.9581 | 0.9923 |
| 7 | 0.9843 | 0.9852 | 0.9845 | 0.9902 |
| 8 | 0.9852 | 0.9864 | 0.9853 | 0.9881 |
| 9 | 0.9532 | 0.9632 | 0.9534 | 0.9762 |
| 10 | 0.9812 | 0.9824 | 0.9814 | 0.9886 |
| 11 | 0.9134 | 0.9256 | 0.9238 | 0.9345 |
| 12 | 0.9526 | 0.9538 | 0.9624 | 0.9685 |
| 13 | 0.9806 | 0.9825 | 0.9828 | 0.9845 |
| 14 | 0.9452 | 0.9564 | 0.9586 | 0.9614 |
| 15 | 0.9819 | 0.9835 | 0.9886 | 0.9884 |
| 16 | 0.9826 | 0.9834 | 0.9884 | 0.9896 |
| 17 | 0.9020 | 0.9120 | 0.9248 | 0.9312 |
| 18 | 0.9317 | 0.9412 | 0.9416 | 0.9514 |
| 19 | 0.9045 | 0.912 | 0.9213 | 0.9285 |
| 20 | 0.943 | 0.9435 | 0.9445 | 0.9506 |
| 21 | 0.9429 | 0.9534 | 0.9438 | 0.9587 |
| 22 | 0.9010 | 0.9200 | 0.9023 | 0.9289 |
| 23 | 0.9309 | 0.9386 | 0.9352 | 0.9408 |
| 24 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 25 | 0.9483 | 0.9496 | 0.9495 | 0.9587 |
| 26 | 0.9527 | 0.9623 | 0.9581 | 0.9728 |
| 27 | 0.9827 | 0.9828 | 0.985 | 0.9886 |
| 28 | 0.9228 | 0.9345 | 0.9256 | 0.9312 |
| 29 | 0.9231 | 0.9332 | 0.9235 | 0.9412 |
| 30 | 0.9261 | 0.9345 | 0.9268 | 0.9345 |
| 31 | 0.9885 | 0.9894 | 0.9886 | 0.9912 |
| 32 | 0.989 | 0.9892 | 0.9895 | 0.9990 |
| 33 | 0.9216 | 0.9218 | 0.9315 | 0.9338 |
| 34 | 0.9225 | 0.9318 | 0.9321 | 0.9412 |
| 35 | 0.9249 | 0.928 | 0.9312 | 0.9387 |
| 36 | 0.9526 | 0.955 | 0.9628 | 0.9689 |
| 37 | 0.9503 | 0.9526 | 0.9618 | 0.9687 |
| 38 | 0.9231 | 0.9285 | 0.93.00 | 0.9405 |
| 39 | 0.9118 | 0.9218 | 0.9216 | 0.9312 |
| 40 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |

Table.3 shows the voltage comparison of different conditions. In base case it is observed that, the minimum voltage 0.9010p.u. at bus number 22 and maximum voltages in the network is 1.0 at generator buses. The analytical method is used for the DG placement considering the acceptable voltage enhancement with power loss minimization. By connecting appropriate size of the DG at bus-5, it is observed 0.912 p.u. as minimum voltage at bus number 22. The voltage profile in the network is improved upto 5-10%.

The UPFC placement also carried out, to verify the effectiveness in the voltage profile by analytical method. It is observed that, line between 6 and 14 is weakest point in the network. Hence it is chosen for the UPFC connection taking bus 41 as a UPFC connecting bus. After connecting UPFC the minimum voltage in the network is 0.9023p.u. at bus-22.The combination of DG with UPFC is also tested and it is observed that acceptable improvement in the voltage profile with reduction in the total power loss of the distribution network. Fig.3 shows the voltage comparison of 40 bus distribution network. Four cases are considered here mainly base case with UPFC, with DG and combination of DG-UPFC. In all three cases enhancement of the voltage profile is observed. Connecting combination of DG with UPFC increases overall efficiency of the network with maintaining the voltage stability in the network.

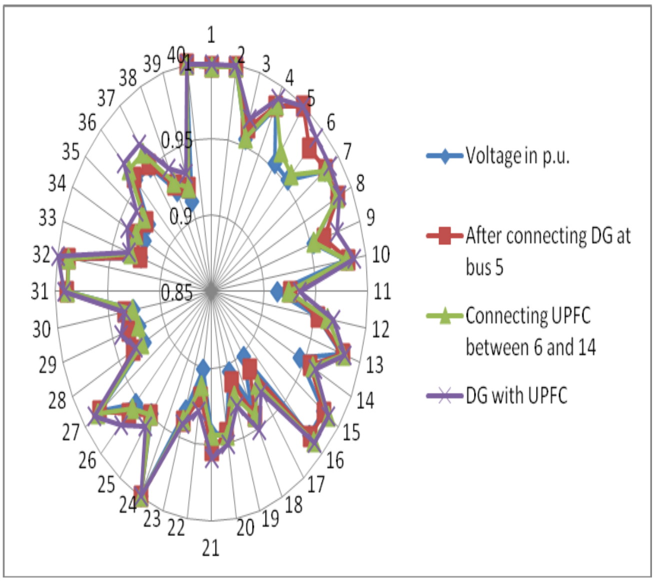


**Fig.3 Voltage profile in p.u. base case with DG, UPFC and combination of DG-UPFC**

## V.CONCLUSION

In this paper improvement of the voltage profile with total power loss is minimized using optimal placement of DG with UPFC. The MiPower software tool is used for the analysis. The 40 bus distribution network is used as test system. The obtained results are very effective for the stable and healthy and efficient operation of the distribution network.

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## AUTHORS PROFILE

**Mr.Rudresh.B.Magadum** was born in Sankeshwar, Karnataka, India Jul 09, 1987. He obtained his B.E and M.Tech from VTU Belagavi in 2010 and 2012 respectively. Presently he is pursuing Ph.D at KLS Gogte institute of technology, Belagavi. His area of interests includes distributed generation, micro grid, smart grid, power quality and HVDC.

**Dr. D.B. Kulkarni** was born in Belagavi, Karnataka, India on Feb 10, 1966. He obtained his B.E and M.E degrees from Walchand college of Engineering, Sangli, Maharashtra, India in 1986 and 1993 respectively & Ph.D in the area of Power quality from VTU, Belagavi in 2012.Currently working as professor in Electrical and Electronics Engineering department, KLS Gogte Institute of Technology, Belagavi. His areas of interest include Power quality, FACTS, HVDC transmission and Power systems.

## APPENDIX

Table.5 Line data

| From bus | To bus | Resistance in p.u. | Reactance in p.u. |
|---|---|---|---|
| 3 | 9 | 0.0044 | 0.00161 |
| 3 | 5 | 0.0070 | 0.00091 |
| 3 | 26 | 0.0146 | 0.0019 |
| 3 | 6 | 0.00257 | 0.00113 |
| 4 | 15 | 0.00844 | 0.00257 |
| 4 | 7 | 0.00217 | 0.00095 |
| 4 | 8 | 0.00079 | 0.00099 |
| 4 | 24 | 0.0100 | 0.00636 |
| 9 | 25 | 0.0395 | 0.00512 |
| 9 | 12 | 0.00355 | 0.00046 |
| 10 | 13 | 0.00431 | 0.00056 |
| 10 | 27 | 0.0102 | 0.00133 |
| 6 | 14 | 0.0189 | 0.00576 |
| 7 | 27 | 0.00423 | 0.00154 |
| 7 | 16 | 0.0256 | 0.00332 |
| 17 | 22 | 0.0582 | 0.02430 |
| 18 | 23 | 0.0464 | 0.02390 |
| 24 | 31 | 0.00732 | 0.00095 |
| 24 | 32 | 0.0104 | 0.00135 |
| 28 | 38 | 0.0321 | 0.02930 |
| 28 | 33 | 0.0291 | 0.0230 |
| 29 | 38 | 0.0424 | 0.03870 |
| 29 | 34 | 0.0451 | 0.0130 |
| 30 | 38 | 0.0321 | 0.02930 |
| 30 | 35 | 0.0291 | 0.0230 |
| 40 | 1 | 0.0015 | 0.00296 |
| 40 | 2 | 0.0015 | 0.00296 |

Table.6 Bus data

| BUS NO. | BUS kV | BUS NO. | BUS kV |
|---|---|---|---|
| 1 | 69.0 | 21 | 0.48 |
| 2 | 69.0 | 22 | 0.48 |
| 3 | 13.8 | 23 | 0.48 |
| 4 | 13.8 | 24 | 13.8 |
| 5 | 13.8 | 25 | 13.8 |
| 6 | 13.8 | 26 | 13.8 |
| 7 | 13.8 | 27 | 13.8 |
| 8 | 13.8 | 28 | 0.48 |
| 9 | 13.8 | 29 | 0.48 |
| 10 | 13.8 | 30 | 0.48 |
| 11 | 2.40 | 31 | 13.8 |
| 12 | 13.8 | 32 | 13.8 |
| 13 | 13.8 | 33 | 0.48 |
| 14 | 13.8 | 34 | 0.48 |
| 15 | 13.8 | 35 | 0.48 |
| 16 | 13.8 | 36 | 2.40 |
| 17 | 0.48 | 37 | 0.48 |
| 18 | 0.48 | 38 | 0.48 |
| 19 | 2.40 | 39 | 4.16 |
| 20 | 2.40 | 40 | 69.0 |

| Table.7 Load data | | | |
|---|---|---|---|
| Sl.No. | Node | Real power in MW | Reactive power in MVar |
| 1 | 39 | 1.50 | 0.85 |
| 2 | 11 | 1.25 | 0.80 |
| 3 | 8 | 7.20 | -5.40 |
| 4 | 17 | 1.20 | 0.75 |
| 5 | 18 | 1.20 | 0.75 |
| 6 | 19 | 3.20 | 1.90 |
| 7 | 20 | 3.20 | 1.90 |
| 8 | 21 | 0.60 | 0.40 |
| 9 | 22 | 0.12 | 0.07 |
| 10 | 23 | 0.12 | 0.07 |
| 11 | 33 | 0.25 | 0.15 |
| 12 | 34 | 0.10 | 0.05 |
| 13 | 35 | 0.25 | 0.15 |
| 14 | 36 | 1.80 | 1.20 |
| 15 | 37 | 0.85 | 0.50 |
| 16 | 38 | 0.50 | 0.25 |
| 17 | 28 | 0.77 | 0.47 |
| 18 | 29 | 0.93 | 0.57 |
| 19 | 30 | 0.77 | 0.47 |

| Table.8 Transformer data | | | | | |
|---|---|---|---|---|---|
| From Node | To node | R(p.u.) | X(p.u.) | Nominal Tap | MVA rating |
| 1 | 3 | 0.0066 | 0.0533 | 1.00 | 15.0 |
| 2 | 4 | 0.0066 | 0.0533 | 1.00 | 15.0 |
| 5 | 39 | 0.0464 | 0.348 | 1.00 | 1.73 |
| 6 | 11 | 0.0458 | 0.367 | 1.00 | 1.50 |
| 12 | 17 | 0.0529 | 0.450 | 1.00 | 1.50 |
| 13 | 18 | 0.0529 | 0.450 | 1.00 | 1.50 |
| 14 | 19 | 0.0244 | 0.147 | 1.00 | 3.75 |
| 15 | 20 | 0.0244 | 0.147 | 1.00 | 3.75 |
| 16 | 21 | 0.0958 | 0.767 | 1.00 | 0.75 |
| 25 | 28 | 0.0548 | 0.383 | 1.00 | 1.50 |
| 26 | 29 | 0.0548 | 0.383 | 1.00 | 1.50 |
| 27 | 30 | 0.0548 | 0.383 | 1.00 | 1.50 |
| 31 | 36 | 0.0329 | 0.230 | 1.00 | 2.50 |
| 32 | 37 | 0.0821 | 0.575 | 1.00 | 1.00 |