PERFORMANCE ANALYSIS OF DISTRIBUTED GENERATION ON RADIAL DISTRIBUTION NETWORKS – A CASE STUDY

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Abstract- *Though India has seen rapid expansion of power lines for electrifying rural areas in past decade, most of the rural lines are affected from high technical losses, low voltage profiles and lesser hours of service availability. Distributed Generation could be a best solution for improving voltage profiles and reducing line losses along with increasing reliability and reserve capacity of the system. Apart from explaining present scenario of Indian power sector, this paper aims to analyse the distribution system performance with and without Distributed Generation. A simple methodology for finding optimal location and sizing of DG unit is proposed in this paper. A rural 126 bus network of 'The Northern Power Distribution Company of Telangana Limited' (TSNPDCL) is considered for the case study and it is modeled using ETAP 6.0 software.*

Keywords: *Distributed Generation (DG), Technical and Non-technical losses, optimal location and sizing of DG, ETAP.*

1. Introduction

As of 30th September 2017, the total installed capacity of electricity generation in India is 329.29 GW [1]. Major portion of it is contributed by large conventional plants. In 2014-15, India faced power deficit of 3.6% in base load and 4.7% in peak loads [2]. It is anticipated that electricity demand in India would reach 779 GW by 2032 (considering 8% growth in GDP). To meet this ever increasing electricity demands, generation is to be increased proportionally.

Out of total installed capacity, coal fired thermal power plants contribute nearly 60%. As a result, the net coal import dependency raised to 23% in 2014 which was a fraction in 1990 [3]. Hydro Power depends on rain fall and nuclear power has its own cons. Dwindling fossil fuels, environmental issues and evacuation of power hurdles the growth of conventional plants.

India has seen rapid expansion of power lines for electrifying rural areas in past decade. But ensuring reliable and quality of power to citizens has become a main challenge. As of 2014, only 55% of rural households have access to electricity [3]. Even in low access, rural areas suffer from low power quality and inconsistency of power supply.

With the enactment of electricity Act 2003, Indian power sector is going through many reformations. In order to bridge the gap between supply and demand by ensuring reliable and quality of supply along with considering environmental and other aspects, there is a need to go for alternative technologies. Apart from unbundling of electricity sector there is a need to integrate Distributed Generation to the existing system [5].

1.2 Literature Survey:

The interest of research on DG arose in late1990's. Different benefits with DG integration and issues that must be considered for effective allocation of DG in distribution network are discussed in [18]. Studies are conducted to analyse the impact of DG placement at weak nodes and junction nodes are carried out in [19] at different Penetrations. Line losses and voltage imbalances are calculated for IEEE 34 node system using Dig SILENT. Weak bus is chosen based on its voltage profile only.

A methodology for optimal placement of DG is proposed using genetic algorithm in [15] considering an IEEE 13 node feeder network.

Voltage and line losses of 12 node test radial network is examined in [20] considering different types of generating units based on their active and reactive power injection / absorption characteristics. DG capacity is fixed at 25% of load for the entire study.

Voltage stability index method for placement of DG on different test bus systems is carried out in [16]. [17] Summarized few methods for the same studies. Though many methods are proposed for DG placement, very few considered practical networks. In this context, this paper tries to analyse the performance of distribution network by optimally allocating the DG unit appropriating the technical aspects of considered system.

This paper is organized as follows: Section 2 briefs the Distributed Generation. Section 3 explains the base case system. Algorithm for optimal placement and sizing of DG is described in section 4. Impact of DG placement is analysed in section 5 and concluding points are given in section 6.

2. Distributed Generation

Distributed Generation is not a new concept. Pearl Street station which supplied for 59 consumers is not only the first example of power system network but also an example of first Distributed Generation. DG can be defined as "*the integrated use of small generation units directly connected to a distribution network or on the consumer side of the meter"* [5]. DG is not centrally planned. In general these are connected on the LV side of power system network with capacities less than 30 MW.

Various technologies are in practice for DG. Based on the resources used, they are classified as follows [5].

i) Renewable
- Solar
- Wind
- Bio fuels
- Hydro (SHP)

ii) Non Renewable [5]
- Internal Combustion engines fueled by diesel or natural gas
- Micro turbines fueled by natural gas
- Fuel cells fueled by natural gas.

Integrating DG ensures numerous benefits such as- improvements in reliability, voltage profiles, reserve capacity and power quality along with reduction in line losses and providing electricity at low cost.

India has huge potential of Renewable Energy Sources (RES), which can be effectively utilized for this small scale integration. Table 1 provides the list of few RES with their potential and installed capacity in India as of 30th June 2017 [1].

Table 1

Potential and Installed capacities of few RES

Resource	Potential (MW)	Installed capacity (MW)
Small Hydro Power (SHP)	19794	4384.55
Wind	102772	32508.17
Bio power/ cogeneration	20090 + (5000 from bagasse)	8295.78

3. Base Case System

Indian rural distribution networks lags in terms of consistency of supply, power quality, low voltage profiles and high line losses.

In this paper, a simple "Weak Bus Placement method" has been adopted for finding optimal location of DG.

A rural 126 bus network from 'The Northern Power Distribution Company of Telangana Limited' (TSNPDCL) is taken as a case study. Out of 126 buses, 57 are load buses. The maximum load on the system is 4.15 MVA. Table 2 gives complete information about total connected load.

Table2

Connected Load

S.No	Transformer Size (KVA)	Qty	Connected load (KVA)	Total Load (KVA)
1	15	9	13.8	124.2
2	25	12	23	276
3	63	6	60	360
4	100	26	96	2496
5	160	3	150	450
6	250	1	230	230

Technical specifications of network and Electrical Transient Analyser Program (ETAP) modeling of the circuit is provided in Appendix I and II. Three phase load flow studies are conducted using Newton Raphson method on the network.

Eq (1) & (2) explains the basic load flow equations.

$$P_i = P_{Gi} - P_{Li} = \sum_{i=1}^{n} V_i V_j Y_{ij} \cos(\phi_i - \phi_j - \theta_{ij}) \text{....(1)}$$

$$Q_i = Q_{Gi} - Q_{Li} = \sum_{i=1}^{n} V_i V_j Y_{ij} \sin(\phi_i - \phi_j - \theta_{ij}) \text{....(2)}$$

Where Pi and Qi are the net active and reactive power injections at bus i after supplying for the load PL & QL. Vi, Vj and Φi , Φj are the voltage magnitudes and phase angles at buses i & j respectively.

Constraints of bus voltage magnitude and line loading are considered as given in equations (3) – (4) for the analysis.

$$V_i^{\min} \le V_i \le V_i^{\max} \text{.....(3)}$$

$$S_{ij} < S_{ij}^{\max} \text{...(4)}$$

S_{ij} is the power carrying capacity rated in MVA of line connecting buses i & j.

Power loss (i^2R) in a line connecting buses i & j is calculated as:

$$P_{Loss} = P_i - P_j \text{.....(5)}$$

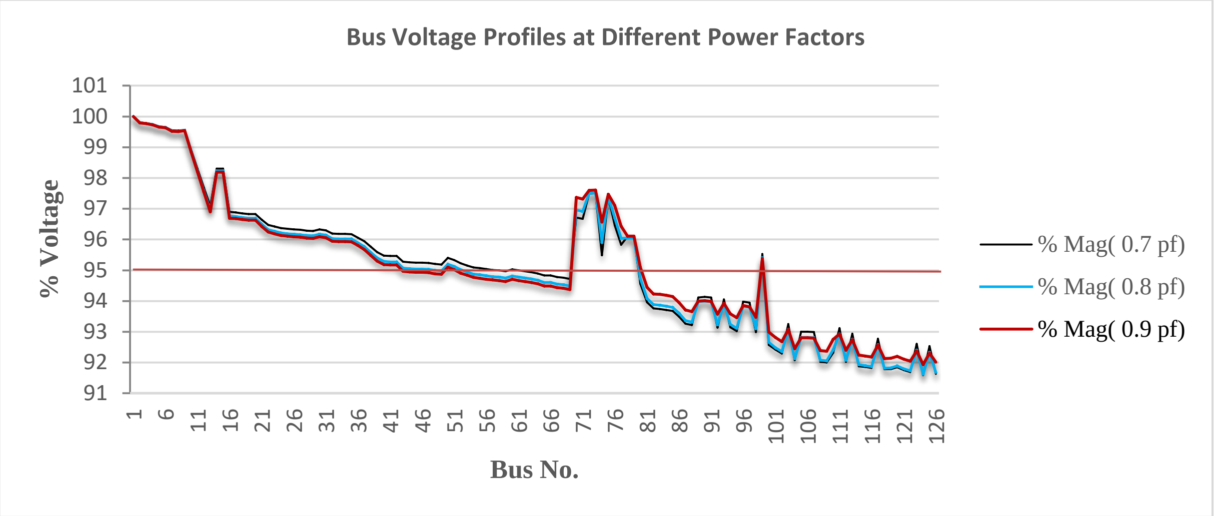

Fig 1: Bus Voltage profiles of considered distribution network at different power factors

Load flow results of base case depicted that system operation is not satisfactory with high voltage and power losses and over loading of many lines.

Figure 1 shows the performance of rural network at different power factors. Line at 95% indicates critical limit of voltage. Even when system operating at 0.9 pf, voltage magnitude of most of the buses are below 0.95pu and most of the lines are found to be overloaded.

Under voltages in the system causes mal operation & damage of consumer equipment and power losses decreases the efficiency of the system. In this paper, DG is given as solution to mitigate the above issues.

4. Optimal Sizing And Placement Of DG Unit

Improper placement and sizing of DG unit while integrating it to distribution network may result in negative impact on the system performance. For example, connecting a DG unit to 440V side of the system resulted in increased losses when compared with connecting to 11 KV side. So placing DG in optimal location with appropriate size (capacity) is must while integrating a DG unit.

4.1 Methodology Adopted

The following methodology is adopted for finding optimal location of DG unit [6]-

Step I: Run base case load flows.

Step II: Place a DG unit to one bus at a time and calculate Power losses by performing load flows.

Step III: Prepare a Priority List of buses in ascending order based on power losses with DG Integration (from buses with lower power losses to buses with higher power losses).

Step IV: Based on Priority list of Step III and voltage profile of the prioritized buses (without DG connection), prepare final list of buses which are sensitive for DG placement from which optimal placement of DG can be known.

From the procedure mentioned in step II and III, a priority list (first five) based on power losses is prepared when the system is operating at 0.7 pf with 2 MW injection from DG unit and is as shown in table 3.

Table 3

Priority list of buses by considering Power losses (ascending order) with 2 MW power injection.

Priority	Bus Number
1	53, 54
2	55,60
3	61
4	63
5	64

From the priority list (table 3) and considering the voltage profiles of prioritized buses when DG is not connected (we prefer buses with low voltage profile for integrating DG), a final list is prepared and is as shown in table 4.

Table 4

Final priority list

Priority	Bus Number
1	**54**
2	53
3	55,60

Though, bus 53 and 54 give lower power losses (table 1) when DG unit is connected to them, voltage drop at bus 54 is more than bus 53. *So, bus 54 is considered as optimal location for placing DG unit* in the considered system.

After finding appropriate location for DG placement, MW injection of DG unit is varied from 1 MW – 2.5 MW. Voltage profiles are observed at different buses with different injections when system operating at 0.9 pf. The minimum injection at which system voltages goes to acceptable limit will be the Optimal Size of that DG unit. Figure 2 shows bus voltage profiles when DG injection is varied from 1 MW to 2.5 MW. From figure 2, system voltages attained acceptable limit when DG injection is 1.5 MW. *So, 1.5 MW is* considered as optimal *size that can be installed in the system.*

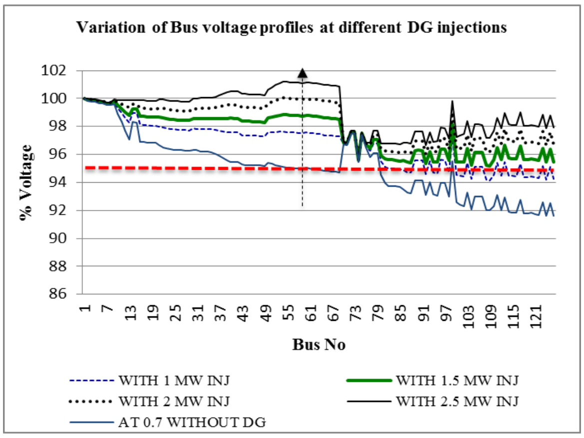

Fig 2: System voltage profiles at different injections

5. Impact of DG on Radial Distribution Network.

5.1 Voltage Profiles

With optimal placement of DG unit of 1.5 MW at bus 54, voltage levels are found to be raised to acceptable limit. Figures 3 to 5 shows variation in voltage profiles at different buses with and without DG integration when system operating at 0.9pf, 0.8pf and 0.7pf respectively. The red colour line at 95% of voltage indicates the critical limit of voltage.

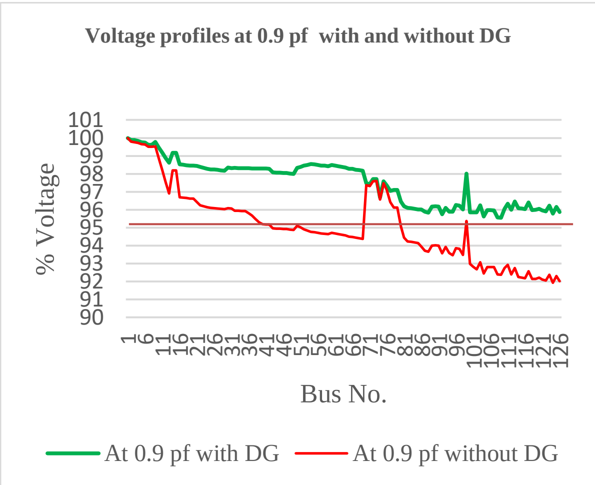

Fig 3: Comparison of voltage profiles at 0.9pf with and without DG

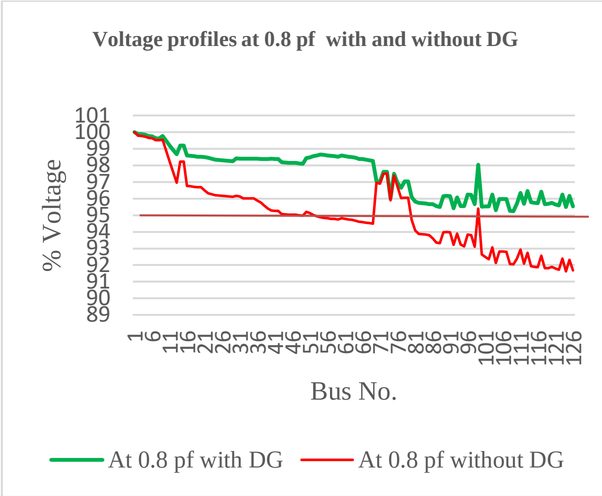

Fig 4: Comparison of voltage profile at 0.8pf with and without DG

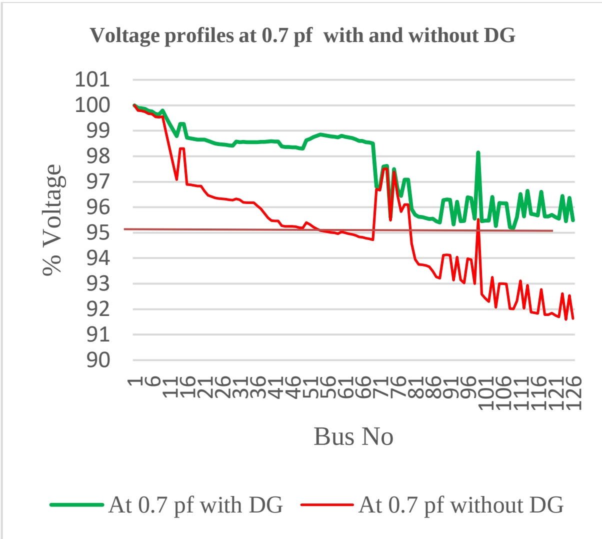

Fig 5: Comparison of voltage profiles at 0.7pf with and without DG

From the above results (Fig 3 –Fig 5) it is evident that integration of DG has improved the voltage profiles of the system. Table 5 shows variation of voltage profiles of weakest bus in the system at different power factors with and without DG.

Table 5

Variation of voltage magnitudes of weakest bus with and without DG

P.F	Weakest bus no.	%Voltage magnitude without DG	%Voltage magnitude with DG
0.7	124	91.593	95.45
0.75	124	91.583	95.448
0.8	124	91.622	95.488
0.85	124	91.728	95.592
0.9	124	91.932	95.789

With integration of DG, voltage profiles are in acceptable limit (> 95% of rated voltage) even when system operating at 0.7pf.

5.2 Power losses

Apart from low voltage profiles, rural networks often suffer from high losses. Total losses in distribution network are the sum of technical losses (i^2R losses) and non-technical losses (power theft, unmetered power, inaccuracies in metering etc.). Non-technical losses in the system are assumed to be 10%. The total losses are found to be 16.695% (6.695% technical and 10% non-technical losses). Figure 6 shows variation in technical losses with and without DG connection when system operating at different power factors.

Figure 6 shows that integration of DG has reduced total losses. Technical losses decreased to 2.3 times when system operating at 0.7pf. By considering 0.9pf and 16 hours of service availability in a day, integration of DG resulted in energy saving of about 1800 units per day from being lost (technical losses). However losses can be further minimised by replacing old energy meters, providing Advanced Metering Infrastructures etc. [14].

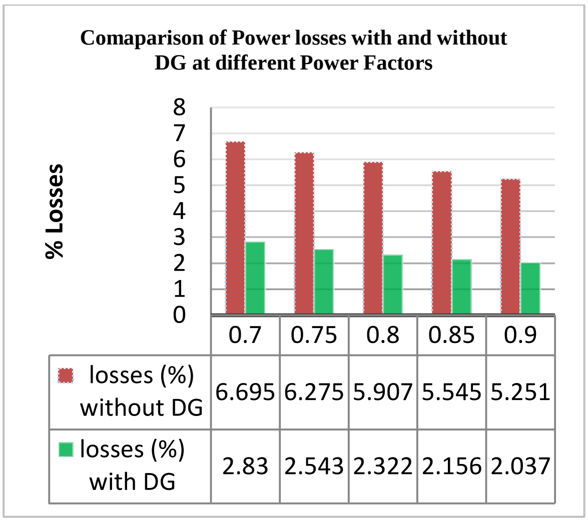

Fig 6: Comparison of technical losses with and without DG connection

Table 6 summarises the impact of DG on the considered 126 bus radial network.

Table 6

Comparison of various parameters with and without DG

Issue	Without DG	With DG
Demand on Grid (0.9 pf)	3.466 MW	1.886 MW
Voltage at weakest bus	91.593%	95.454%
Technical losses	6.696%	2.911%
Total losses	16.696%	12.911%

6. Conclusion

In this paper, benefits of distributed generation integrated to rural areas are examined. Apart from rural electrification and decreasing power demand on grid, appropriate sizing and location of DG assures improvement in voltage profiles and reduction in technical losses. From the studies conducted on the considered 126 bus network by optimally placing a generator of 1.5 MW capacity to bus 54, the following conclusions are made:

- Voltage Profiles are improved to acceptable limit without overloading any line.
- Technical losses are reduced to 2.3 times with DG integration saving nearly 1800 units per day.
- Dependency on grid for electricity has decreased nearly 45% when system operating at 0.9p.f.

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APPENDIX – I

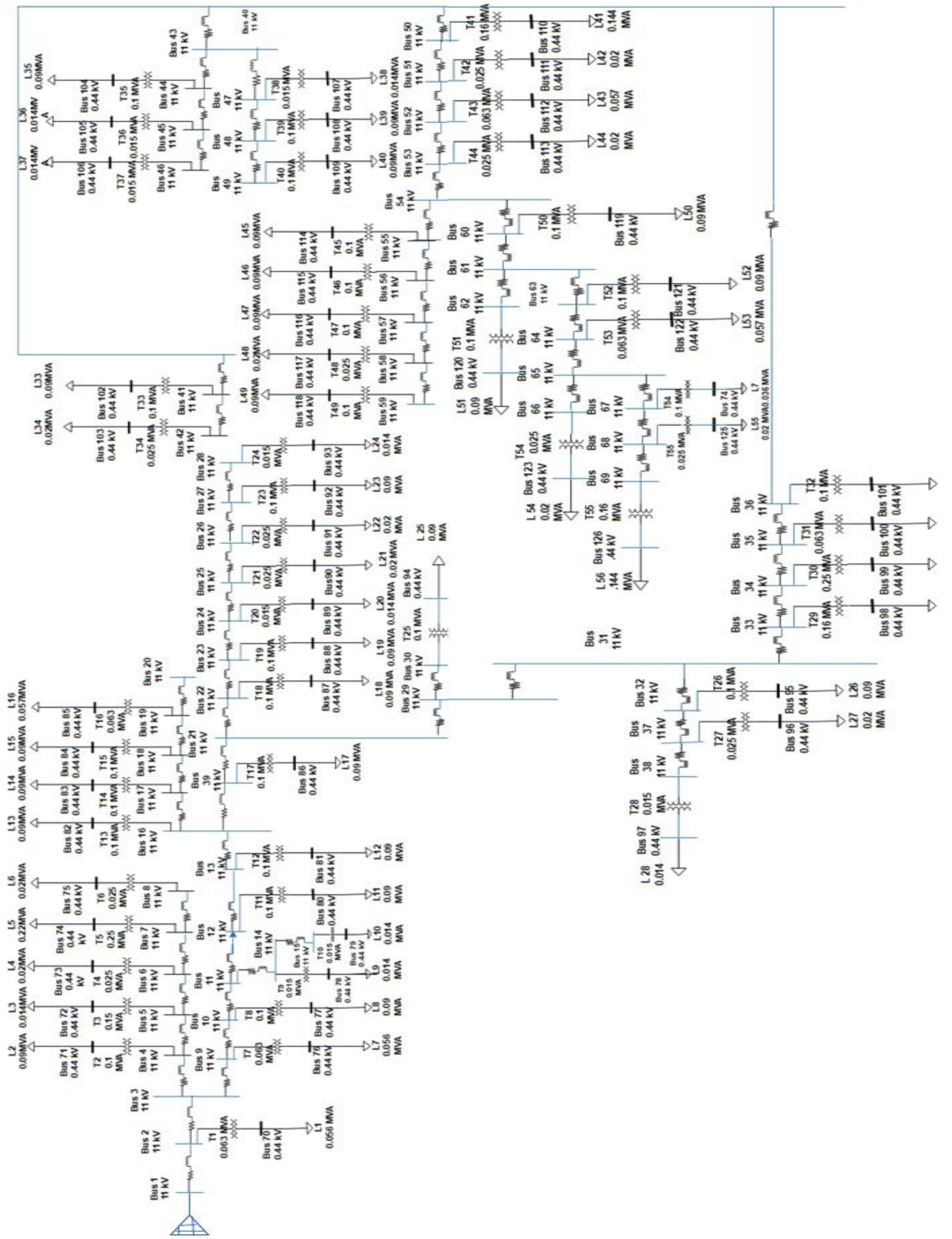
TECHNICAL SPECIFICATIONS

a) DG Unit

Capacity - 1.5 MW
Operating power factor - 0.85 lag
Rated Voltage - 11 KV

b) Line data

Conductor type - AAAC
Conductor size - 55 mm2
Span - 65 meters
Resistance - 0.598 Ω / Km
Reactance -0.36254Ω/Km



APPENDIX II