OPTIMAL ALLOCATION OF DG USING HARMONY SEARCH ALGORITHM IN RADIAL DISTRIBUTION SYSTEM

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Parul Singh
(801341014)

Under the Guidance of

Dr. Smarajit Ghosh
Professor, EIED

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Electrical and Instrumentation Engineering Department

Thapar University, Patiala

(Declared as Deemed-to-be-University u/s 3 of the UGC Act., 1956)

Post Bag No. 32, Patiala – 147004

Punjab (India)

DECLARATION

I hereby certify that the work which is presented in dissertation entitled **"Optimal Allocation of DG using Harmony Search Algorithm in Radial Distribution System"** in the partial fulfillment of the requirement for the degree of **Master of Engineering** in **Power Systems,** submitted in Electrical and Instrumentation Engineering department, Thapar University, Patiala is an authentic work carried out under the guidance of **Dr. Smarajit Ghosh**, Professor EIED, Thapar University. It refers other researcher's work, which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, either in part or in full to any other degree to any other university or institute except as reported in text and references.

Date: 15th July, 2015 | **(PARUL SINGH)**

Place PATIALA | **Roll No. 801341014**

It is certified that the above statement made by the student is correct and true to the best of my knowledge and belief.

15-7-2015

(Dr. Smarajit Ghosh)
Professor
Electrical & Instrumentation Engineering
Department
Thapar University,
Patiala

Counter Signed By:

(Dr. Ravinder Agarwal)
Professor & Head
Electrical & Instrumentation Engineering Department
Thapar University, Patiala

(Dr. S.S. Bhatia)
Dean (Academic Affairs)
Thapar university, Patiala

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DEDICATED TO MY PARENTS

ABSTRACT

In recent few years, the implementation of distributed generator into a distribution system has been increasing rapidly in many parts of the world, due to the liberalization of the electricity markets, constraints on constructing a new distribution network, transmission lines and environmental concerns. Technical advancement in small generators, power electronics and energy storage devices have promoted the use of DG unit. DG units, basically, are small generating units, which are placed closer to the point of consumption. The utilization of a DG unit placed on-site of the load demand in the system which provides evident power losses reduction, stability improvement, and voltage profile improvement along with accelerating sustainability of environmental issues. Distributed Generation is the power generation at the point of consumption. Instead of providing power centrally, generating the power on-site decreases the cost, less complex, independent, and efficient transmission and distribution. Using this system, some of the controls such as distributed generation, distributed telephony i.e. using mobile phone shifts to the consumer. It is, basically an electric power source connected to the distribution system directly. Before the installation, its effects on line losses, voltage profile, short-circuit current, amount of harmonics injected and the reliability should be computed. In order to obtain the efficient compensated system factors like type of network, best technique used, no. and capacity of units to be used, best location etc. should be taken into account. This thesis work focuses on the minimization of real power loss and voltage profile improvement of a radial distribution network using suitable DG units. Here, a 33-node radial distribution system has been used as the test system and Harmony Search Algorithm has been implemented to find the optimal location of DG unit and Loss sensitivity Method has been used to obtain the optimal size of DG in order to reduce real power losses and improve voltage profile.

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CHAPTER 1

INTRODUCTION

1.1 ELECTRIC POWER DISTRIBUTION SYSTEM

Distribution Systems is defined as the sequential flow of the activities, procedures and systems designed and linked to facilitate along with monitoring the movement of services and goods from the source to the consumer. Distribution is all about providing the products and services to the end user whenever and where ever they require. The main objective of power distribution system is to provide power to individual consumer area. The distribution of electrical power is done with much low voltage level.

It is the final stage of electric power delivery. It carries electricity to individual consumers from the transmission system. Distribution substations lowers the transmission voltage up to a medium voltage range i.e. 2 kV-35 kV using transformers connecting them to transmission system.

Primary distribution lines carry the medium voltage power to distribution transformer which is located nearest to the customer's premises.

Distribution transformers further lowers the voltage value to the utilization level of household appliances and feed several customers, typically, through the secondary distribution lines at this voltage.

From secondary distribution lines commercial and residential customers are connected through the service drops. Direct connection is provided for customers demanding a much larger amount of power to the primary distribution or sub-transmission level.

Electric power distribution is done by distribution networks consisting following main parts:

- Distribution substation,
- Primary distribution feeder
- Distribution Transformer
- Distributors
- Service mains.

For primary distribution purpose, the electric power transmitted is stepped down in substations and then this power is fed to the distribution transformer via primary distribution feeders. Support to over-head primary distribution feeders is provided, mainly, by supporting iron pole (preferably rail pole). The conductors used are, preferably, strand aluminum conductors and are mounted on the arms of the pole using pin insulators. In congested places, underground cables are used for primary distribution. Distribution transformers are basically 3-phase pole mounted type. Secondary of the transformer is connected with the distributors. Service mains feed electric power to different consumers. These service mains are tapped from different distributor points. The distributors are further categorized as distributors and sub-distributors. Distributors are directly connected with the secondary of distribution transformers whereas sub-distributors are tapped from distributors. Based on the position and agreement of consumers, service main of the consumers could be connected either to distributors or sub distributors. Feeder and distributor both carry the electrical load, but one basic difference is that feeder feeds power from one point to another without any tapping from any intermediate point. And because of no-tapping point in between, sending-end current is equal to that of receiving-end of the conductor. Whereas, the distributors are being tapped at different points for feeding different consumers, provides varying current along their entire length.

1.2 CLASSIFICATION

Distribution systems can be classified in various ways:

1.2.1 Based on the character of service:

- General light and power
- Industrial power
- Railway
- Street lighting etc.

1.2.2 Based on the type of construction the distribution systems

- Overhead distribution system
- Underground distribution system.

Due to low cost, overhead type system is generally employed. In case of impracticality, Underground distribution system is used.

1.2.3 Based on the number of wires:

- Two wire
- Three wire
- Four wire distribution systems
- For DC supply, 3-wire distribution system is generally employed because of its advantages over 2-wire distribution system. In case of the AC supply, 3-phase 3-wire system is used for balanced loads like power loads.3-phase 4-wire system is preferred for unbalanced loads like light and power loads combined and single-phase 2-wire system is employed for lighting and small power appliances.

1.2.4 Based on scheme of connections:

- Radial
- Ring
- Inter-connected distribution systems

1. Radial System

It is the simplest and cheapest since the distributors are fed at one end only and it is employed when the power station is situated at the center of the load and electrical energy is generated at low voltage.

Because of following disadvantages, this system is rarely used:

- There would be heavy loading at the end of the distributor nearest to the supply end.
- In correspondence to the variations in load, the consumers at the farthest end of distributor will experience serious voltage fluctuations.
- All the consumers are dependent on a single feeder therefore when a fault occurs on feeder or distributor they have to cuts-off the supply to all the consumers.

2. The Ring Main System

Each consumer is supplied via two feeders in this system and the arrangement of this system is similar to two feeders arranged paralleled on different routes.

This system has following advantages:

- Requirement of copper is less.

- Fluctuations in voltage are less.

More reliable as during the fault on any one section, by isolating the faulty section, the supply to all consumers can be maintained continuously.

Factors deciding number of feeders connected to the system are:

- Maximum demand of the system
- Total length of ring main distributors
- Required voltage regulation

3. Interconnected System

In this system, there are two or more generating stations connected together and during overload hours, any area could be fed from another power stations leading to following advantages:

- Reduction in required reserved capacity
- More reliable supply
- Improved load factor
- Increased efficiency

1.3 REQUIREMENT OF POWER DISTRIBUTION SYSTEM

The basic requirements of a reliable and stable distribution system are:

- Continuity in the power supply.
- Specified consumer voltage should not vary more than the prescribed limits i.e. not beyond ± 5 % of the specified voltage, as per the Indian Electricity Rules.
- Efficiency of lines must be as high as possible.
- There should not be any leakage in the system i.e., it should be safe from consumer point of view must not be overloaded.
- The layout must not affect the appearance of the site.
- The system should be economical.

Mostly the AC transmission and distribution is used, still for some applications DC supply is required, such as, electrochemical work, batteries, DC motors, electric traction etc. Therefore, DC distribution is also equally important along with AC distribution. DC generators are used in a DC distribution in the generating stations. Sometimes, AC is converted into DC using the converters at the substations. Then, as per the consumer's requirement, DC supply is distributed.

1.4 DISTRIBUTION GENERATION

It is the power generation at the point of consumption. Instead of providing power centrally, generating the power on-site decreases the cost, less complex, independent, and efficient transmission and distribution. Using this system, some of the controls such as distributed generation, distributed telephony i.e. using mobile phone shifts to the consumer.

1.4.1 DEFINITION OF DISTRIBUTED GENERATION

Distributed generation (DG) basically refers to a small-scale (generally between 1 kW and 50 MW) electric power generators which produces electricity at a site that is close to customers or which is tied to a distribution system.

These distributed generators includes induction generators, reciprocating engines, fuel cells, wind turbines , solar photovoltaic, combustion gas turbines, synchronous generators , micro turbines (combustion turbines which runs with high-energy fossil fuels like oil, natural gas, propane, diesel or gasoline).

1.4.2 ADVANTAGES OF DISTRIBUTED GENERATING SYSTEM:

Distributed generating system is really beneficial because of the following reasons:

- Because of the small size the overall capital cost quite less of the system, although the investment cost (per kVA) of one could be much higher in comparison to the power plant.
- Less need for the construction and up gradation of large infrastructure construction as the DG could be constructed on the load location itself.
- Reduction in pressure on the distribution and transmission lines since DG provides

power for local use.

- Increment in power reliability as stand-by or back-up power to the customers.
- Provide customers a choice to meet their energy requirement

1.5 LOAD-FLOW

In electrical power engineering, load-flow study is the numerical analysis of flow of electric power in an interconnected system. In a power-flow study, usually, simplified notation such as a one-line diagram and per-unit system are used and focus is on various aspects of AC power parameters, like voltages, voltage angles, real power and reactive power. It analyzes a power system in the normal steady-state conditions. It is an analysis of the system capability to adequately supply connected load providing total system losses and individual line losses.

Load-flow study is important for planning future expansion of the power systems as well as to determine the best operation of the existing systems. The prime information obtained from the load-flow study is magnitude and phase angle of the voltage at each bus also real and reactive power flowing in each line.

Commercial power systems are, generally, too complex to allow a hand solution of the power flow. Therefore, special purpose network analyzers were built in between 1929 and 1960in order to provide a laboratory-scale physical model of power systems. Analog methods with numerical solutions were replaced by large-scale digital computers.

In addition to the load-flow study, computer programs perform many related calculations such as short-circuit fault analysis, stability studies under transient & steady-state conditions, economic dispatch and unit commitment. Specifically, some programs uses linear programming to find out the optimal power flow and the conditions, which give the lowest cost per kilowatt-hour delivered.

Load-flow study is, mainly, valuable for the systems with multiple load centers, like a refinery complex. Performing a load-flow on an existing system provides the insight and recommendations as to system operation and the optimization of control settings in order to obtain the maximum capacity while minimizing the cost of operation. Results of such an analysis are obtained in terms of real power, reactive power, magnitude of voltage and phase angle.

1.5.1 BUS CLASSIFICATION

Load flow problem is concerned with finding the static operating conditions for an electric power transmission system, while satisfying constraints are specified for the power and/or voltage at network buses.

Generally, buses are classified as of 4 types as shown presented in Table 1.1.

Table 1.1: Showing known quantities for each type of bus

Bus Type	Specified Quantities
Swing/slack Bus	Δ |V|
PV Bus	P |V|
PQ or Load Bus	P Q
Generator Bus	P |V| Qmax, Qmin

Each bus is modeled by two equations, for 'n' numbers of buses and 'p' numbers of PV and generator buses 2n equations in 2n unknowns are there, which are |V| and δ for load buses, Q and δ for generator and PV buses and the P and Q for slack bus. It requires only to obtain the phase angle i.e. δ and voltage magnitudes i.e. V for all the buses and then don't need to find any other unknowns. Since, slack bus is the reference bus a value of 0 degrees has been assigned for its δ. The voltage magnitudes, V are already specified for the slack bus, the PV buses and the generator buses. Therefore, the number of unknowns that required to be found out is 2n – 2 – p. Once |V| and δ are evaluated for all the buses, P and Q at the slack bus and Q for the generator and PV bus then can be calculated.

1.6 LITERATURE REVIEW

Alemi and Gharehpetian [1] introduced an analytical method to obtain minimized losses and improved voltage profile by evaluating losses and voltage profile using load flow method for radial a distribution network. This proposed method included the sizing and the allocation of distribution generators (DGs).

Singh and Choudhury [2] represented the analysis of performance to place DG optimally for power loss reduction and voltage profile improvements at nodes in the distribution system. While optimally allocating DG to reduce the real power losses and sustaining the voltage profile within already specified limits using GA in distribution network, that method also presented the effect of change of loads along with voltage and frequency.

Parizad *et al.* [3] aimed at allocation of distribution generator to achieve improved voltage profile, minimize losses and reduction in harmonic distortion for distribution network using harmony search algorithm. The fast harmonics method load-flow method applied is based on injection of equivalent current using BIBC and BCBV matrices

Amanifar [4] used heuristic optimization technique named Particle Swarm Optimization (PSO).In that technique, power losses were minimized in addition to investment cost of DGs. The proposed technique was basically hybrid of Particle Swarm Optimization (PSO) and Harmonic Power Flow algorithm (HPF).That approach provided improvement in voltage profile and reduction in THD and power losses.

Abu-Mouti and El-Hawary [5] used ABC algorithm to optimally place the DG-units, their sizing and improved p.f. gave minimum real power loss of system. It is a meta-heuristic optimization approach based on population, which was derived from intelligent foraging behavior of the honeybee swarm. This technique found to be more efficient and able of handling problems based on mixed integer non-linear optimization.

Reddy and Kumar [6] proposed a technique to optimally place capacitors on the primary feeders of a RDS, used a new two-stage methodology, consisting fuzzy and Harmony search algorithm (HSA) to get reduced the power losses and improved the voltage profile.

To find optimal capacitor locations, fuzzy approach was used and to find the optimal sizes of the capacitors Harmony search algorithm used.

Hussain and Roy [7] used a new meta-heuristic approach which was population based namely Modified Artificial-Bee-Colony algorithm (ABC), in order to reduce real power losses and improve supply quality and the system reliability. It also reduced green-house effects, improved voltage profile, and reduced line loss and environment impact. Better solutions were achieved with the advantages of less time-consumption from CPUs and high quality of solutions. That method was found to be superior and had more ability to solve complex power system problems.

Nasiraghdam and Jadid [8] used an Improved Harmony Search algorithm to assess the load model effect on the optimal sizing and allocation of distributed generation (DG). That paper was successfully verified the effect of voltage dependent loads on system power characteristics.

Shrivastava *et al.* [9] proposed a method to optimally locate and size multiple DG units in an RDS, used classical grid-search based on successive load flow in order to minimize active power losses and to improve the voltage profile. That technique was significant due to the fact that there will be more decrement in total active power losses and maximum voltage drop of the system is also decreased performing integration of DG units at various locations.

Murthy and Kumar [10] presented a comparison of novel method, combined power loss sensitivity, voltage sensitivity index, and the index vector methods to optimally allocate and size the DG in RDS.

Nekooei *et al.* [11] presented a new approach named as Improved Multi-objective Harmony Search by using a multiple objective framework of planning. In this approach, the optimum sizes and the locations of DGs were found by taking objective functions as losses and the voltage profile and qualitative comparison was made against Non-dominated Sorting

Genetic Algorithm II.

Baghaee *et al.* [12] presented a novel approach to optimally place multi-type FACTS devices was presented in the first part of paper, which was based on HSA and in second part, the HSA was proposed for the optimization of harmonic in multi-level inverters. Implementation simplicity, precision, fast speed in the global convergence were some of the advantages of HSA over GA.

Liu *et al.* [13] dealt with the optimization of DG planning to obtain minimized power loss, reduced voltage deviation and maximum voltage stability margin. A meta-heuristic HSA was improved with fast non-dominated sorting approach to solve comprehensive multi-objective harmony search (MOHS).

Naik. S *et al.* [14] used an analytical method for minimization of real power loss of distribution networks. This was done by injection of power by the DG, operating at a given p.f. The technique did not need Z-bus matrix calculation or calculation of inverse of Y-bus matrix or Jacobean matrix and, therefore, taken less computation time.

Seker and Hocaoglu [15] aimed at placement of DG-unit and its sizing by performing a meta-heuristic approach, which was derived from foraging behavior of the honey bee swarms called Artificial-Bee-Colony (ABC) algorithm. The method successfully implemented to determine the optimal place and size of DG-unit.

Sangeetha and Jalendiran[16] used a meta-heuristic HSA considering musical progression of searching for a flawless harmony ceremonial, which described the sensitivity analysis for proof of identity of optimal locations of distribution generation units to reduce the power loss and improvement of voltage profile in the RDS. Objective function included constraints of voltage profile, branch current and radial structure of the system.

Muttaqi *et al.* [17] discussed improvement of the voltage profile in RDS by the installment of a DG at a suitable location and with most suitable size. Based on the algebraic equations an analytical approach was developed for the uniformly distributed loads in order to conclude optimal operation, the location and the size of DG to get required level of network voltage profile. Proposed method was simple to use for the conceptual design and distribution system expansion analysis with DG and it is suitable for the quick estimation of the DG parameters in a RDS.

Naik *et al.* [18] used an analytical approach for optimum allocation and sizing of DG in RDS to reduce real and reactive power losses. Suitable analytical expressions had been derived for this purpose, which was based on change in active and reactive components of branch currents caused by DG placement. Firstly, capacity of DG was determined causing maximum benefit at different buses and the bus equivalent to the highest benefits was designated as the best location. To determine the optimal size of DG unit(s), that method needed the results for base case load-flow only.

Kaur *et al.* [19] aimed at the nonlinear and non-convex optimization problem of placement DG using two methods, which are MINLP and heuristic approach created Improved Harmony Search (IHS).Both of the algorithms were implemented for optimal placement of DG units. Using MINLP formulation by sensitivity analysis the potential locations were obtained to cut the search space and afterwards, for optimal sizes and locations the problem is solved. Because of its non-monotonic solution surface results were also obtained with HIS.

Biswas *et al.* [20] demonstrated artificial bee colony algorithm successfully utilized in order to solve optimal DG placement problem, which considered both technical and economic aspects. Technical objectives tried to minimize the line loss, effect of the voltage sag problem, and variation in the node voltage deviation in a distribution network. Economic objectives tried to minimize the operational cost of DG placement

1.7 RESEARCH GAP

Literature survey of the previous research work regarding the effect of distributed generation in radial distribution system has been carried in chapter 2. From the discussion carried out in chapter 2 it can be concluded that there is a still possibility to obtain optimum location of DG units to be placed in a radial distribution network using harmony search algorithm and a suitable analytical method can be implemented to obtain optimal size and location of DG with reduced power losses and improved voltage profile.

1.8 OBJECTIVE OF THE DISSERTATION WORK:

The purpose of the work is to obtain the optimal location and size of Distribution Generator in order to minimize the power losses and get an improved voltage profile in a Radial Distribution Network. For optimal sizing and allocation of DG, an analytical method is used for load-flow analysis to obtain power losses integrated with Harmony Search Algorithm in order to reduce power losses and improve the voltage profile.

1.9 ORGANIZATION OF THE THESIS

CHAPTER 1: It includes an overview of distribution generation, literature review, objective of the dissertation work and organization of thesis.

CHAPTER 2: Discusses the propose methods used to achieve the objective of the work.

CHAPTER 3: Illustrates problem formulation to compute the desired results.

CHAPTER 4: Gives the results for 33-node radial distribution system and discusses the results obtained.

CHAPTER 5: Includes the conclusion of the work done and suggests the future scope.

References consists the papers studied and used in the thesis work.

Appendix-A represents the system data for a 33-node radial distribution system.

CHAPTER-2

PROPOSED METHOD

2.1 LOAD-FLOW CALCULATION

Load-flow techniques are very important for the analysis of power systems and are used in operational and planning stages, as well. Some applications, specifically, in distribution automation and optimization require repeated load-flow solutions. As the power distribution networkismore complex, demand for efficient and reliable system operation increases. Consequently, load-flow studies must be having the capability to handle the various system configurations with adequatespeed and accuracy. In most cases, radial distribution systems are unbalanced because of the single-phase, two-phase and three phase loads. Therefore, load flow solution for an unbalanced situationis required and, hence a special treatment is needed for solving such networks. In the present work, radial distribution system is assumed to be balanced.

2.2 POWER LOSS SENSITIVITY FACTOR METHOD

This method is based on principle of linearization of non-linear equations around the starting operating point, which helps to reduce the number of solution space or minimize the search space.

Sensitivity factors are evaluated at each bus, firstly using the values obtained from the base case power flow. The buses are ranked in descending order of the values of their sensitivity factors to form a priority list. The top-ranked buses in the priority list are the first to be studied alternatives location. This is generally done to take into account of the effect of nonlinearities in the system. The first order sensitivity factor are based on linearization of the original nonlinear equation around the initial operating condition and is biased towards function, which has higher slope at the initial condition, that might not identify the global optimum solution.

The sensitivity factor will reduce the solution space to less no. of buses, which constitute the top ranked buses in priority list. Effect of number of buses taken in the priority will have effect the optimum solution obtained for some system. For each bus in priority list, DG is placed and the size is varied from minimum (0 MW) to a higher value until the minimum system losses is found with the DG size. In this study, 30% of the total number of buses is considered in preparing the priority list for each case. The process is computationally demanding as one needs a large number of load flow solution.

The main steps of this algorithm are:

STEP 1: Run the base case load-flow.

STEP 2: Compute the sensitivity factor and rank the sensitivity in decreasing order to form the priority list.

STEP 3: Select bus with highest priority and place DG at that bus.

STEP 4: Change the size of DG in very small step and calculate loss for each by running load-flow.

STEP 5: Store size of DG with the minimum losses.

STEP 6: Compare the losses with the previous solution. If losses are less than previous solution, store the new solution and discard the previous solution.

STEP 7: Repeat Steps 4, 5 and 6 for all buses in priority list.

2.3 HARMONY SEARCH ALGORITHM

It is a new meta-heuristic population search technique. The technique was derived from a natural phenomenon of musicians' behavior, when they all collectively play their musical instruments i.e. population members to produce a pleasing harmony i.e. global optimal solution. The state is determined by an aesthetic standard i.e. fitness function.

Although, the harmony estimation is aesthetic and subjective but there are several theorists who have provided us with the standard of harmony estimation- a Greek mathematician and philosopher, Pythagoras (582–497BC) worked out the frequency ratios or string length ratios with equal tension to found out that they had a particular mathematical relationship, after researching what notes sounded pleasant all together.

In other words, it is the real parameter optimization algorithm which is derivative-free and draws inspiration from the musical improvisation process to search for a perfect state of harmony. Musical performances seeks for a best state i.e. fantastic harmony which is determined by aesthetic estimation and as the optimization algorithms seek for the best state i.e. global optimum minimum cost or maximum benefit or efficiency, which is determined by the objective function evaluation. Whereas, the aesthetic estimation is determined by a set of the sounds played by joined instruments, just the way, objective function evaluation is determined by a set of the values produced by the component variables. The sounds for better aesthetic estimation could be improved by practice after practice, just as the values for a better objective function evaluation can be improved by iteration by iteration.

It is simple algorithm in concept which is less in parameters and easy in implementation. It has already been successfully applied to various real-world and benchmark problems such as pipe-network design [21], and structural optimization [22], the vehicle routing problem [23], the combined heat [24] and the scheduling of a multiple dam system [25] and so on.

The basic steps of this algorithm are as follows:

1.Initializing the algorithm and problem parameters.

2. Initializing the harmony memory.

3. Improvising a new harmony.

4. Updating the harmony memory.

5. Checking the termination criterion.

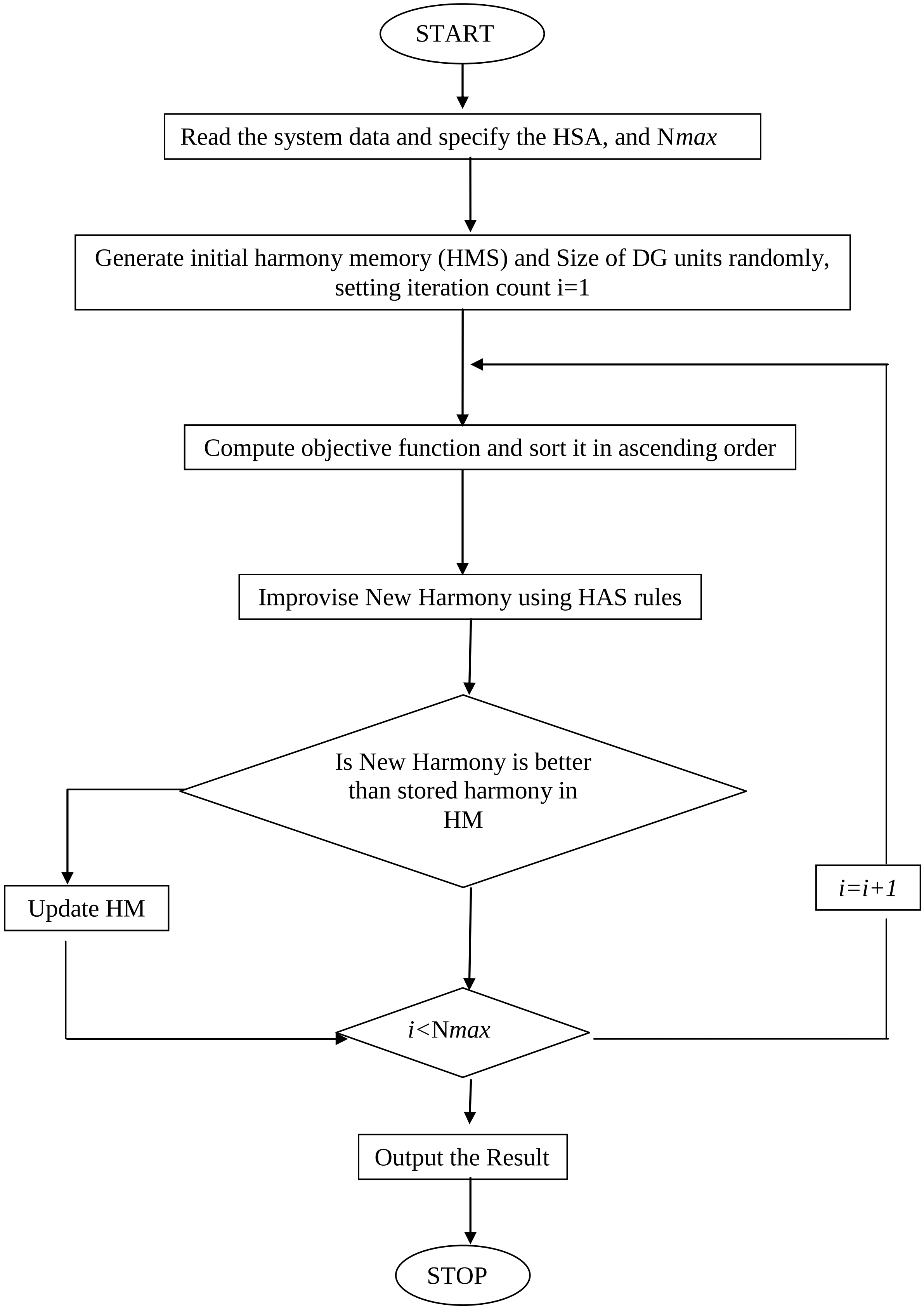

Figure 2.1– Flow chart for HSA

CHAPTER 3

PROBLEM FORMULATION

3.1 LOAD-FLOW CALCULATION

The prime assumption made here is that the taken three-phase radial distribution network is balanced and they can be represented by their single-line diagrams by simply neglecting the charging capacitances at the distribution voltage levels.

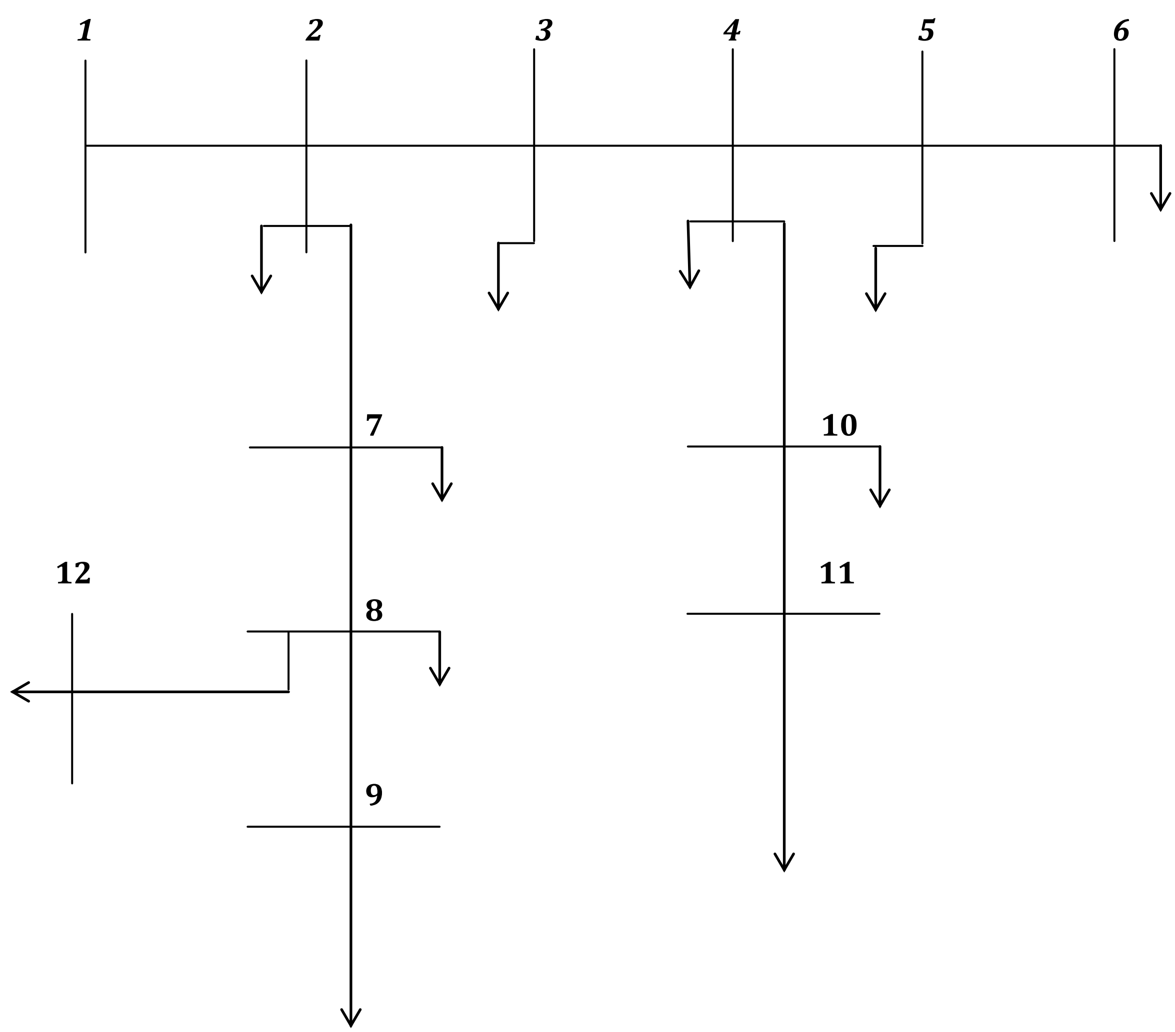

Figure 3.1: Single-line diagram for a radial distribution network [26]

Consider branch-1, the receiving-end node voltage can be written as:

V (2) = V(l) -I (1) Z(1)

(3.1.1)

Similarly, for branch-2:

V(3) =V(2) -I (2) Z (2) (3.1.2)

Substation voltage V(1) is known, so if Z(l) is known i.e. current of branch-1, it would be easy to calculate V(2) from eqn. (3.1.1).

Similarly, Once V(2) is calculated, if the current through branch-2 is known, it is easy to calculate V(3) from eqn. (3.1.2)

Voltage at nodes 4, 5, ..., NB can be calculated, if all the branch currents are known.

Hence, a generalized equation for receiving-end voltage, sending-end voltage, branch current and branch impedance is

V(m2) = V(m1) - I (jj) Z (jj) (3.1.3)

m2 = IR (jj) (3.1.4)

ml = IS (jj) (3.1.5)

where,

jj is the branch number.

Eq. (3)could be evaluated for jj = 1, 2, ..., LN1 (LN1 = NB- 1 = number of branches). Current passing through branch-1 is equal to the sum of load currents of all the nodes beyond branch-1 add up the sum of the charging currents of all the nodes beyond the branch-1, i.e.

$$I(1)=\sum_{i=2}^{LN1} IL(i) + \sum_{i=2}^{LN1} IC(i) \qquad (3.1.6)$$

The current passing through branch-2 is equal to the sum of load currents of all the nodes which are beyond branch-2 plus sum of charging currents of all the nodes which are beyond branch-2, i.e.

I(2) = IL(3) + IL(4) + IL(5) + IL(6)+ IL(10) + IL(11)
+ IC(3) + IC(4) + IC(5) + IC(6) + IC(10) + IC(11) (3.1.7)

Therefore, if it is possible to identify nodes which are beyond all the branches, it is possible to compute all branch currents.
The load current of node i is

$$IL(i) = \frac{PL(i) - jQL(i)}{V*(i)} \qquad i = 2, 3, \ldots, N \qquad (3.1.8)$$

The charging current at node i is

$$IC(i) = y_0(i)V(i) \qquad i = 2, 3, \ldots, NB \qquad (3.1.9)$$

Load currents and charging currents are calculated iteratively. Initially, flat voltage of all the nodes is assumed and the load currents and the charging currents of all the loads are computed using eq. (3.1.8) and eq. (3.1.9).
The active and reactive power loss of branch jj are given as:

$$LP(jj)=|I(jj)|^2R(jj) \qquad (3.1.10)$$

$$LQ(jj)=|I(jj)|^2X(jj) \qquad (3.1.11)$$

Once all the nodes beyond each branch are identified, the current flowing through each branch can be calculated very easily. For this purpose, the load current and the charging current of each node are computed by using eq. (3.1.8) and eq. (3.1.9). The expression of branch current is given by:

$$I(jj)=\sum_{i=1}^{N(jj)} IL\{IE(jj,i)\} + \sum_{i=1}^{N(jj)} IC\{IE(jj,i)\} \qquad (3.1.12)$$

After calculating the new values of the voltages of all the nodes, convergence of the solution is checked. In case, it does not converge, then load and charging currents are calculated using the most recent values of the voltages and the whole procedure is repeated. The convergence criterion of this proposed method is that if the maximum difference of voltage magnitude i.e. DVm-axis less than 0.000lp.u., in successive iterations, the solution has converged.

3.2 FORMULATION OF THE OBJECTIVE FUNCTION

In order to obtain minimized real power losses and improved voltage profile, the objective function is formulated to maximize the real power loss reduction, which is given as

Maximize $f = max\ (\Delta P_{Loss}^{R} + \Delta P_{Loss}^{DG})$

subjected to $V_{min} \leq |V_k| \leq V_{max}$

and $|I_{k,k+1}| \leq |I_{k,k+1,max}|$

$\sum_{k=1}^{n} P_{Gk} \leq \sum_{k=1}^{n} (P_k + P_{Loss,k})$

det(A)=1 or -1 (radial system)

det(A)=0 (not radial)

There are a number of techniques proposed for the optimal placement of DG in radial distribution system.

3.3 SIZING OF DG AT VARIOUS LOCATIONS

Method used for siting of distributed generator is power loss sensitivity method and is explained as follows:

The real power loss in a system is given by:

$$P_L = \sum_{i=1}^{N} \quad \sum_{j=1}^{N}[\alpha_{ij}(P_iP_j + Q_iQ_j) + \beta_{ij}(Q_iP_j - P_iQ_j)] \tag{3.3.1}$$

This is referred to as 'exact loss' formula [1].

where,

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos(\delta_i - \delta_j)$$

$$\beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin(\delta_i - \delta_j)$$

and *rij* + *jxij* = *Zij* are the *ij*th element of [Zbus] matrix with [Zbus] = $[\text{Ybus}]^{-1}$.

The sensitivity factor of real power loss w.r.t. real power injection from DG is given by

$$\alpha_i = \frac{\partial P_L}{\partial P_i} = 2\sum_{i=1}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j) \tag{3.3.2}$$

The total power loss against injected power is a parabolic function and at minimum losses the rate of change of losses with respect to injected power becomes zero.

$$\frac{\partial P_L}{\partial P_i} = 2\sum_{j=1}^{N}(\alpha_{ij}P_j - \beta_{ij}Q_j) = 0 \tag{3.3.3}$$

It follows that

$$\alpha_{ii}P_i - \beta_{ii}Q_i + \sum_{j=1, j\neq i}^{N}\left(\alpha_{ij}P_i - \beta_{ij}Q_j\right) = 0 \tag{3.3.4}$$

$$P_i = \frac{1}{\alpha_{ij}}\left[\beta_{ii}Q_i + \sum_{j=1, j\neq i}^{N}\left(\alpha_{ij}P_i - \beta_{ij}Q_j\right)\right] \tag{3.3.5}$$

where,

Pi is the real power injection at node *i*, which is the difference between real power generation and the real power demand at that node:

Pi=(PDGi-PDi)

where,

*PDGi*is the real power injection from DG placed at node *i*, and

PDi is the load demand at node *i*.

By combining eq.(3.3.4) and eq. (3.3.5) we can get eq.(3.3.6):

$$P_{DGi} = P_{Di} + \frac{1}{\alpha_{ij}}\left[\beta_{ii}Q_i + \sum_{j=1, j\neq i}^{N}\left(\alpha_{ij}P_i - \beta_{ij}Q_j\right)\right] \tag{3.3.6}$$

The above equation gives the optimum size of DG for each bus *i*, for the loss to be minimum. Any size of DG other than *PDGi* placed at bus *i*, will lead to higher loss. This loss, however, is a function of loss coefficient α and β. When DG is installed in the system, the values of loss coefficients will change, as it depends on the state variable voltage and angle. Updating values of α and β again requires another load flow calculation. But numerical result shows that the accuracy gained in the size of DG by updating α and β is small and is negligible. With this assumption, the optimum size of DG for each bus, given by eq. (3.3.6) can be calculated from the base case load flow (i.e. without GD case).

3.4 PLACEMENT OF DG

Here used is Harmony Search Algorithm and, in next 5 sections, its steps are explained

i) **Algorithm and problem parameters initialization:**

The optimization problem is formulated as:

Minimize f(x)

subjected to $x_i \in X_i$, *i= 1, 2, . . .,N.*

where

f(x) is a scalar objective function to be optimized;

x is a solution vector composed of decision variables *to* x_i;

X_i is the set of values for each decision variable *to* x_i, i.e., $L^{x_i} \leq X_i \leq U^{x_i}$;

L^{x_i} and U^{x_i} are lower and upper bounds for each decision variable, respectively;

N is the number of decision variables.

The control parameters of HSA are:

- HM size (HMS) i.e., the number of solution vectors in the HM;
- HM considering rate;
- Pitch-adjusting rate;
- Number of improvisations or stopping criterion.

ii) **HM initialization**

Each component of each vector in parental HM, i.e. size of HMS, initialized with a uniformly distributed random number in between upper and lower bounds i.e. $[L^{x_i}, U^{x_i}]$, where

$1 \leq i \leq N$

This is done for *i*th component of *j*th solution vector using following equation:

$x_i^j = L^{x_i} + rand(0, 1) \cdot (U^{x_i} - L^{x_i})$

where

$j = 1, 2, 3 \ldots, \text{HMS}$.

rand(0, 1) is a uniformly distributed random number lies between 0 and 1.

iii) **New harmony improvisation**

A new harmony vector

$\underset{x}{\rightarrow}' = (x_1', x_2', x_3', \ldots \ldots \ldots \ldots, x_N')$

has been generated based on 3 rules:

1} memory consideration;

2} pitch adjustment;

3} random selection.

Generating a new harmony is called improvisation, the value of first decision variable x_1' for new vector, in memory consideration, is chosen from any value already existing in current HM, i.e., from $\{x_1^1, \ldots, x_1^{HMS}\}$,with probability HMCR. The values of rest of the decision variables $x_1', x_2', x_3', \ldots \ldots \ldots \ldots, x_N{}'$are also selected in the same manner. HMCR, which varies between 0 and 1, is rate of selecting one value from previous set of values stored in HM, when (1 − HMCR) is rate of the randomly choosing a fresh value from possible range i.e.,

$$x_i{}' \leftarrow x_i \in \{ x_i^1, x_i^2, x_{i,}^3 \ldots \ldots \ldots \ldots \ldots, x_i^4 \} \quad \text{with probabilityof HMCR}$$

also, $$x_i{}' \leftarrow x_i \in \qquad \text{with probabilityof } (1 - \text{HMCR})$$

E.g. an HMCR=0.70 shows that HS algorithm will choose a decision variable value from already stored values in HM with 70% of probability or from entire possible range with 30% of probability. Each component obtained by this memory consideration is examined to decide whether it should be pitch adjusted or not. This process uses PARas follows:

Pitch-Adjusting Decision :

$$x_i{}' = x_i{}' \pm rand(0, 1)*bw \qquad \text{with probability PAR}$$

$$Also\ x_i{}' = x_i' \qquad \text{with probability } (1 - \text{PAR})$$

Where

bw shows an arbitrary distance bandwidth

rand () represents a uniformly distributed random number between 0 and 1.

This step is used to generate a new potential variation in algorithm and it is comparable to mutation in standard EAs.

iv) HM update

If new harmony vector

$\underset{x}{\rightarrow}' = (x_1', x_2', x_3', \ldots \ldots \ldots \ldots, x_N')$

is better than worst harmony in HM, in terms of the objective function, new harmony is included in HM, and already existing worst harmony is excluded from HM. This is a selection step of algorithm, where objective function value is evaluated in order to determine whether the new variation should be included in HM or not.

v) Check stopping criterion

If maximum NI is reached, the computation is terminated.
If not, step(iii) and step (iv) are repeated.

TEST SYSTEM

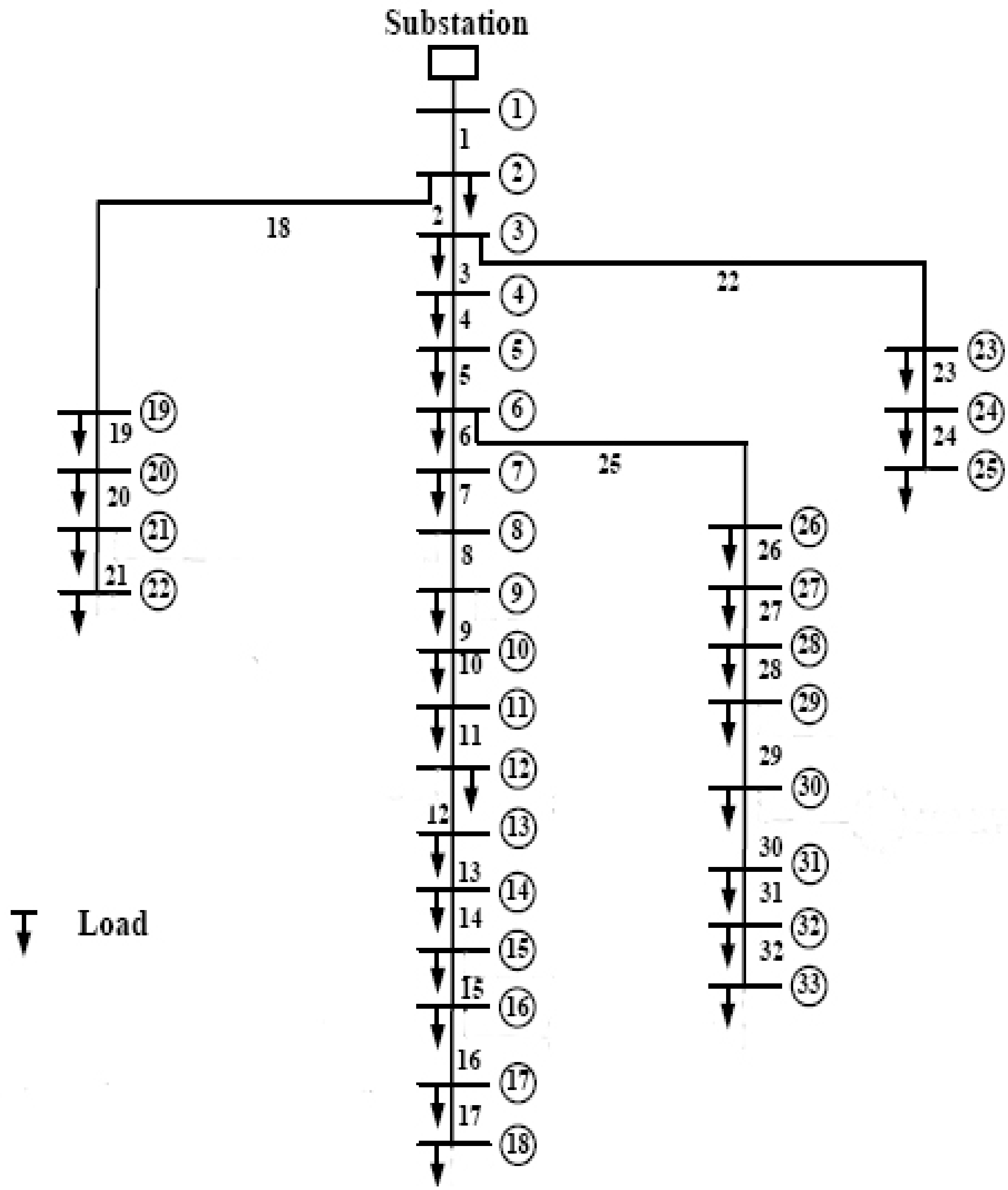

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Figure 3.2: Single-line diagram for 33-node radial distribution system [27]

CHAPTER 4

RESULTS

Results have been obtained in order to improve voltage profile and minimize real power losses for33-node radial distribution network considering radial distribution network is balanced.

BASE CASE

Total no. of nodes or buses = 33

Total no. of branches = 32

Bus No. 1 taken as Reference Bus

Base MVA = 100

Base kVA = 12.66

Without using any DG, the voltage magnitude in per unit at each node of the test system is shown in Table: 4.1

Table :4.1- Voltage magnitude at each node

Node No.	Voltage magnitude
	(p.u.)
1	1
2	0.9968
3	0.9816
4	0.9736
5	0.9658
6	0.9463
7	0.9426
8	0.9375
9	0.9309

10	0.9248
11	0.9238
12	0.9223
13	0.9158
14	0.9135
15	0.912
16	0.9106
17	0.9085
18	0.9078
19	0.9962
20	0.9921
21	0.9913
22	0.9836
23	0.9776
24	0.9702
25	0.9665
26	0.9443
27	0.9416
28	0.9295
29	0.9209
30	0.9171
31	0.9128
32	0.9118
33	0.9115

Bus with minimum voltage = 20

Minimum voltage = 0.9078 p.u.

Without using any DG, the Real and Reactive Power Losses at each branch of the test system is shown in Table: 4.2

Table :4.2- Real and Reactive power losses for Base Case without any DG

Branch.No.	Real Power Losses	Reactive Power Losses
	(kW)	(kVAR)
1	12.195	6.217
2	51.582	26.272

3	19.799	10.084
4	18.599	9.473
5	38.038	32.836
6	1.913	6.324
7	4.834	1.598
8	4.177	3.001
9	3.558	2.522
10	0.553	0.183
11	0.88	0.291
12	2.664	2.096
13	0.729	0.959
14	0.357	0.318
15	0.281	0.205
16	0.251	0.336
17	0.053	0.042
18	0.161	0.154
19	0.832	0.75
20	0.101	0.118
21	0.044	0.058
22	3.181	2.174
23	5.143	4.061
24	1.287	1.007
25	2.596	1.322

26	3.323	1.692
27	11.284	9.949
28	7.824	6.913
29	4.121	2.212
30	1.594	1.575
31	0.213	0.249
32	0.013	0.02

Total Real Power Losses = 202.18 kW

Total Reactive Power Losses = 135.011 kVAR

AFTER DG ALLOCATION

The voltage magnitude (in p.u.) at each node of the test system, using single and 2 DGs is shown in Table: 4.3

Table: 4.3- Node voltages at each node.

Node No.	without DG	with 1 DG	with 2 DG
1	1	1	1
2	0.9968	0.998	0.9985
3	0.9816	0.9891	0.9924
4	0.9736	0.9854	0.9887
5	0.9658	0.982	0.9852
6	0.9463	0.9723	0.9754
7	0.9426	0.9688	0.972
8	0.9375	0.9641	0.9673
9	0.9309	0.958	0.9612
10	0.9248	0.9523	0.9555
11	0.9238	0.9515	0.9547
12	0.9223	0.95	0.9532

13	0.9158	0.944	0.9472
14	0.9135	0.9418	0.945
15	0.912	0.9404	0.9436
16	0.9106	0.9391	0.9423
17	0.9085	0.9371	0.9403
18	0.9078	0.9365	0.9397
19	0.9962	0.9975	0.998
20	0.9921	0.9939	0.9944
21	0.9913	0.9932	0.9937
22	0.9836	0.9926	0.9931
23	0.9776	0.9855	0.9915
24	0.9702	0.9789	0.9902
25	0.9665	0.9756	0.9921
26	0.9443	0.9725	0.9756
27	0.9416	0.9728	0.9759
28	0.9295	0.9725	0.9754
29	0.9209	0.9728	0.9755
30	0.9171	0.9745	0.9771
31	0.9128	0.9705	0.9731
32	0.9118	0.9696	0.9722
33	0.9115	0.9693	0.972

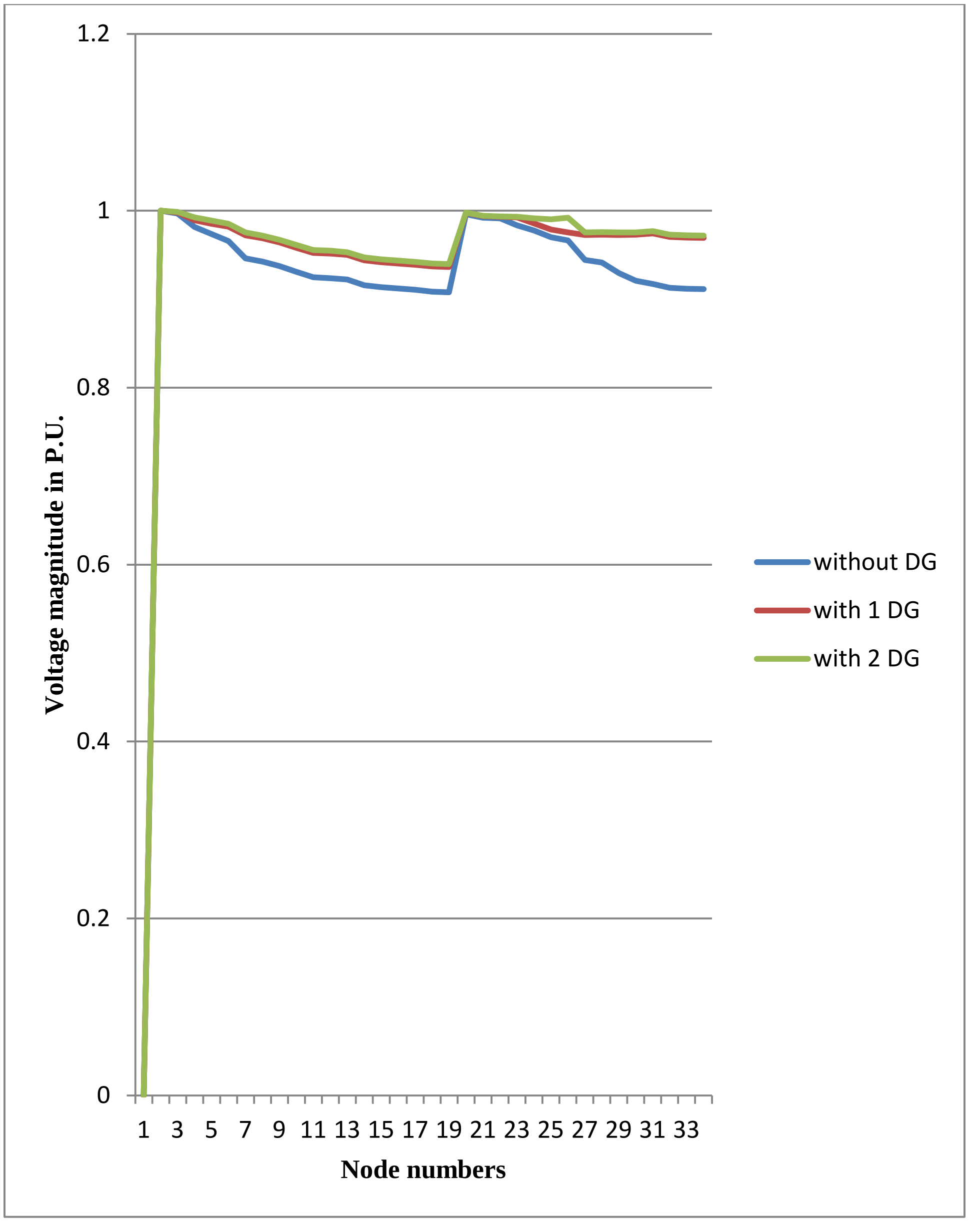

Figure 4.1: Plot showing improvement in bus voltages

USING SINGLE DG:

Node with Minimum Voltage = 20

Minimum Voltage = 0.9365

USING 2 DGs:

Node with Minimum Voltage = 20

Minimum Voltage = 0.9397

Size of DGs used is shown in Table: 4.4

Table: 4.4- Size of DGs

No. of DG(s)	Size of DG(s) (kW)
1	1456
2	1435 & 901

The Real Power Losses(in kW) for each branch of the test system, using single and 2 DGs is shown in Table: 4.5

Table: 4.5 Real Power Losses

Branch No.	Without DG	With 1 DG	With 2 DGs
	(kW)	(kW)	(kW)
1	12.195	6.1843	4.2379
2	51.582	24.183	16.3812
3	19.799	7.4493	7.5242
4	18.599	6.7219	6.7888

5	38.038	13.5669	13.6975
6	1.913	1.8224	1.8103
7	4.834	4.6034	4.5726
8	4.177	3.9762	3.9494
9	3.558	3.3859	3.363
10	0.553	0.5264	0.5228
11	0.88	0.8376	0.8319
12	2.664	2.5346	2.5173
13	0.729	0.6932	0.6885
14	0.357	0.3395	0.3372
15	0.281	0.2676	0.2658
16	0.251	0.2392	0.2376
17	0.053	0.0505	0.0502
18	0.161	0.1606	0.1605
19	0.832	0.8305	0.8297
20	0.101	0.1006	0.1005
21	0.044	0.0435	0.0435
22	3.181	3.1414	0.5767
23	5.143	5.0787	0.933
24	1.287	1.2711	1.5908
25	2.596	1.5718	1.5239
26	3.323	2.2458	2.1718
27	11.284	8.5935	8.2919

28	7.824	6.7801	6.5311
29	4.121	4.7744	4.582
30	1.594	1.4251	1.4174
31	0.213	0.1906	0.1896
32	0.013	0.0118	0.0117

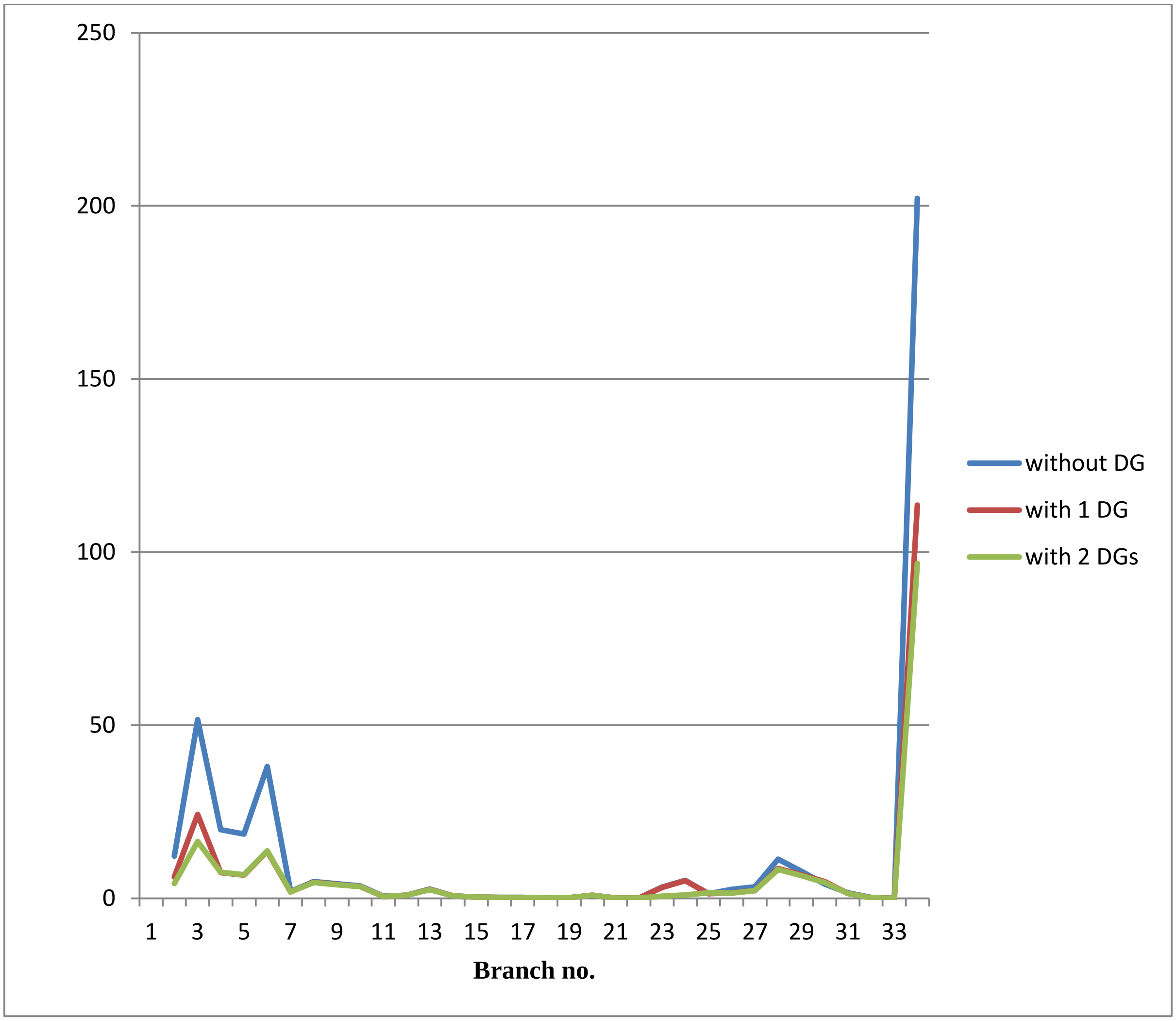

Figure 4.2: Plot showing reduction in real power losses

The Reactive Power Losses (in kVAR) for each branch of the test system, using single and 2 DGs is shown in Table: 4. 6

Table: 4.6 Reactive power losses

Branch No.	without DG	with 1 DG	with 2 DGs
	(kVAR)	(kVAR)	(kVAR)
1	6.217	3.1525	2.1603
2	26.272	12.3172	8.3434
3	10.084	3.7938	3.832
4	9.473	3.4236	3.4577
5	32.836	11.7116	11.8243
6	6.324	6.0241	5.9841
7	1.598	1.5213	1.5111
8	3.001	2.8567	2.8374
9	2.522	2.4	2.3837
10	0.183	0.174	0.1728
11	0.291	0.277	0.2751
12	2.096	1.9942	1.9806
13	0.959	0.9124	0.9062
14	0.318	0.3021	0.3001
15	0.205	0.1954	0.1941
16	0.336	0.3194	0.3172
17	0.042	0.0396	0.0393
18	0.154	0.1533	0.1531
19	0.75	0.7484	0.7476
20	0.118	0.1175	0.1174
21	0.058	0.0576	0.0575
22	2.174	2.1465	0.3941
23	4.061	4.0104	0.7367
24	1.007	0.9946	1.2448
25	1.322	0.8006	0.7762
26	1.692	1.1434	1.1058
27	9.949	7.5768	7.3108
28	6.913	5.991	5.771
29	2.212	2.5626	2.4594
30	1.575	1.4084	1.4008
31	0.249	0.2222	0.221
32	0.02	0.0183	0.0182

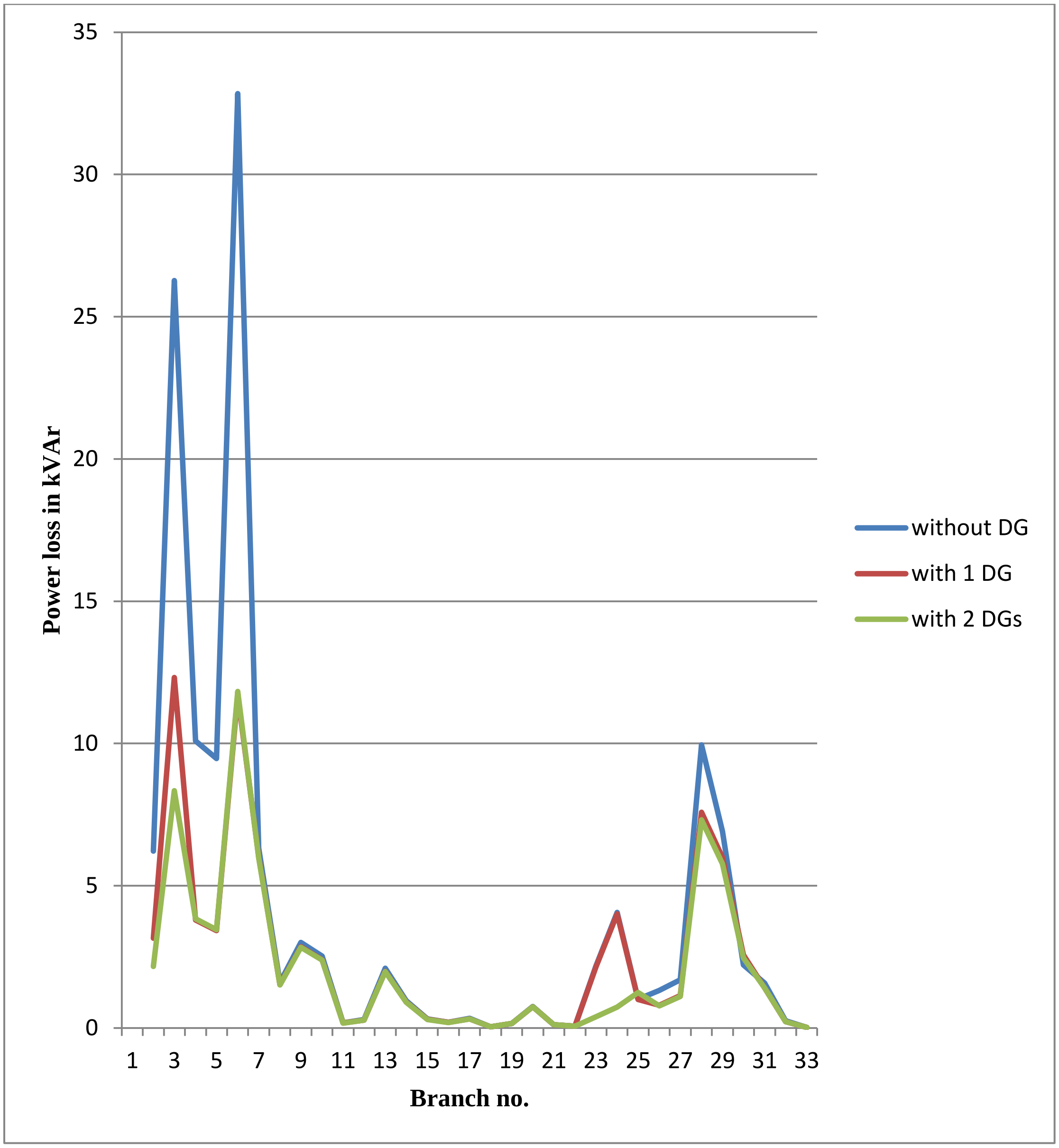

Figure 4.3: Plot showing reduction in Reactive Power Losses

USING SINGLE DG:

Total Real Power Losses = 113.6014 kW

Total Reactive Power Losses = 79.3665 kVAR

USING 2 DGs:

Total Real Power Losses = 96.7303 kW

Total Reactive Power Losses = 69.0338 kVAR

The location of DGs used are shown in Table: 4.7

Table: 4.7- Location of DG

No. of DG(s)	Location of DG(s) (Bus No.)
1	30
2	25 & 30

COMPARISON OF RESULTS

The Results obtained using the Proposed Method on 33-node Radial Distribution System are compared with Voltage Sensitivity Index Method and shown in Table: 4.8

Table: 4.8 Comparison of Results for 33-bus system

METHODS USED / PARAMETERS	Using Voltage Sensitivity Index Method	Using Proposed Method (1 DG)	Using Proposed Method (2 DGs)
Total Real Power Losses without DG (kW)	210.9761	202.18	202.168

Minimum Bus Voltage without DG (p.u.)	0.9040	0.9078	0.9078
DG Size (kW)	1000	1456	901 & 1435
DG Location (Bus No.)	16	30	25 & 30
Total Real Power Losses with DG (kW)	136.7553	113.6014	96.7303
Minimum Bus Voltage with DG (p.u.)	0.9318	0.9365	0.9397
Loss Reduction (%)	35.1797	43.8082	52.1535
Improvement in Voltage Profile (p.u.)	0.0278	0.0287	0.0319

CHAPTER 5

CONCLUSION & FUTURE SCOPE

5.1 CONCLUSION

The results obtained, i.e. optimal location and size of DGs, by integrating power loss sensitivity method and HSA in order to minimize real power losses and improve voltage profile are much better than the previous methods.

5.2 FUTURE SCOPE

Further work could be done on this thesis is to integrate some other pair or algorithms to obtain improved results.

Also, power factor could be considered in order to record results for different leading and lagging p.f. conditions.

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APPENDIX-A

Table (A.1): Line Data for 33-Bus Radial Distribution System [28]

Branch Number	Sending-end Bus	Receiving-end Bus	Branch Resistance(Ω)	Branch Reactance (Ω)
1	1	2	0.0922	0.0477
2	2	3	0.4930	0.2511
3	3	4	0.3660	0.1864
4	4	5	0.3811	0.1941
5	5	6	0.8190	0.7070
6	6	7	0.1872	0.6188
7	7	8	1.7114	1.2351
8	8	9	1.0300	0.7400
9	9	10	1.0040	0.7400
10	10	11	0.1966	0.0650
11	11	12	0.3744	0.1238
12	12	13	1.4680	1.1550
13	13	14	0.5416	0.7129
14	14	15	0.5910	0.5260
15	15	16	0.7463	0.5450
16	16	17	1.2890	1.7210
17	17	18	0.7320	0.5740
18	2	19	0.1640	0.1565
19	19	20	1.5042	1.3554
20	20	21	0.4095	0.4784
21	21	22	0.7089	0.9373
22	3	23	0.4512	0.3083
23	23	24	0.8980	0.7091
24	24	25	0.8960	0.7011
25	6	26	0.2030	0.1034
26	26	27	0.2842	0.1447
27	27	28	1.0590	0.9337
28	28	29	0.8042	0.7006
29	29	30	0.5075	0.2585
30	30	31	0.9744	0.9630
31	31	32	0.3105	0.3619
32	32	33	0.3410	0.5302

Table (A.2): Load Data for 33-Bus Radial Distribution System[28]

Bus Number	P(kW)	Q(kVAr)
1	0.0	0.0
2	100.0	60.0
3	90.0	40.0
4	120.0	80.0
5	60.0	30.0
6	60.0	20.0
7	200.0	100.0
8	200.0	100.0
9	60.0	20.0
10	60.0	20.0
11	45.0	30.0
12	60.0	35.0
13	60.0	35.0
14	120.0	80.0
15	60.0	10.0
16	60.0	20.0
17	60.0	20.0
18	90.0	40.0
19	90.0	40.0
20	90.0	40.0
21	90.0	40.0
22	90.0	40.0
23	90.0	50.0
24	420.0	200.0
25	420.0	200.0

26	60.0	25.0
27	60.0	25.0
28	60.0	20.0
29	120.0	70.0
30	200.0	600.0
31	150.0	70.0
32	210.0	100.0
33	60.0	40.0

(Base voltage = 12.66 kV, Base VA=100MVA)