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Optimal Placement of Distributed Generation on Radial Distribution System for Loss Minimisation & Improvement of Voltage Profile

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ABSTRACT: *This project implements the IDENTIFICATION OF OPTIMAL DG LOCATIONS BY SINGLE DG PLACEMENT algorithm. This method first evaluates the voltage profile using the Newton-Raphson method and then it calculates the total I^2R loss of the system. After that by placing the DG at each bus, it evaluates the corresponding total I^2R losses and hence obtained the optimal placement of DG for loss reduction and best suited voltage profile evaluation.*

I. INTRODUCTION

Over the past few years, developments have been made in finding digital computer solutions for power-system load flows. This involves increasing the reliability and the speed of convergence of the numerical-solution techniques. The characteristics and performance of transmission lines can vary over wide limits mainly dependent on their system. Hence, the load flow method is used to maintain an acceptable voltage profile at various buses with varying power flow. The state of any power system can be determined using load flow analysis that calculates the power flowing through the lines of the system. There are different methods to determine the load flow for a particular system such as: Gauss-Seidel, Newton-Raphson, and the Fast-Decoupled method.

Distributed Generation (DG) is a promising solution to many power system problems such as voltage regulation, power loss, etc. Distributed generation is small-scale power generation that is usually connected to or embedded in the distribution system. Numerous studies used different approaches to evaluate the benefits from DGs to a network in the form of loss reduction.

This project implements the IDENTIFICATION OF OPTIMAL DG LOCATIONS BY SINGLE DG PLACEMENT algorithm. This method first evaluates the voltage profile using the Newton-Raphson method and then it calculates the total I^2R loss of the system. After that by placing the DG at each bus, it evaluates the corresponding total I^2R losses and hence obtained the optimal placement of DG for loss reduction and best suited voltage profile evaluation.

II. POWER SYSTEM

II.1Introduction: The state of a power system and the methods of calculating this state are very important in evaluating the operation and control of the power system and the determination of future expansion for this system. The state of any power system can be determined using load flow analysis that calculates the power flowing through the lines of the system. There are different methods to determine the load flow for a particular system such as: Gauss-Seidel, Newton- Raphson Load, and the Fast-Decoupled method.

Over the past few years, developments have been made in finding digital computer solutions for power-system load flows. This involves increasing the reliability and the speed of convergence of the numerical-solution techniques. In routine use, even few failures to give first-time convergence for physically feasible problems can be uneconomical.

The characteristics and performance of transmission lines can vary over wide limits mainly dependent on their system. Hence, the load flow method is used to maintain an acceptable voltage profile at various buses with varying power flow.

The transmission system is loop in nature having low R/X ratio. Therefore, the variables for the load−flow analysis of transmission systems are different from that of distribution systems which have high R/X ratio.

II.2 Power System History: The development of the modern day electrical energy system took a few centuries. Prior to 1800, scientists like William Gilbert, C. A. de Coulomb, Luigi Galvani, Benjamin Franklin, Alessandro Volta etc. worked on electric and magnetic field principles. However, none of them had any application in mind. They also probably did not realize that their work will lead to such an exciting engineering innovation. They were just motivated by the intellectual curiosity. In England, Michael Faraday worked on his induction principle between 1821 and 1831. The modern world owes a lot to this genius. Faraday subsequently used his induction principle to build a machine to generate voltage. Around the same time American engineer Joseph Henry also worked independently on the induction principle and applied his work on electromagnets and telegraphs.

For about three decades between 1840 and 1870 engineers like Charles Wheatstone, Alfred Varley, Siemens brothers Werner and Carl etc. built primitive generators using the induction principle. It was also observed around the same time that when current carrying carbon electrodes were drawn apart, brilliant electric arcs were formed. The commercialization of arc lighting took place in the decade of 1870s. The arc lamps were used in lighthouses and streets and rarely indoor due to high intensity of these lights. Gas was still used for domestic lighting. It was also used for street lighting in many cities.

However with the increase in load large voltage and unacceptable drops were experienced, especially at points that were located far away from the generating stations due to poor voltage regulation capabilities of the existing dc networks. One approach was to transmit power at higher voltages while consuming it at lower voltages. This led to the development of the alternating current.

As a consequence of the electric utility industry deregulation and liberalization of electricity markets as well as increasing demand of electric power, the amount of power exchanges between producer and consumer are increases. In this process, the existing transmission lines are overloaded and lead to unreliable system. The countries like India with increasing demand of electric power day by day it is difficult to expand the existing transmission system due to difficulties in right of way and cost problem in transmission network expansion. So, we need power flow controllers to increasing transmission capacity and controlling power flows.

III. LOSSES IN POWER SYSTEM

III.1 Introduction: In India, average Transmission and Distribution losses, have been officially indicated as 23% of the electricity generated. However, as persample studies carried out by independent agencies, theselosses have been estimated to be as high as 50% in some states. In arecent study carried out by SBI Capital Markets for DVB, the Transmission and Distribution losses have been estimated as 58%. With the setting upof State Regulatory Commissions in the country, accurate estimation ofTransmission and DistributionLosses has gained importance as the level of losses directly affects the sales andpower purchase requirements and hence has a bearing on the determination ofelectricity tariff of a utility by the commission.

III.2. Transmission and Distribution Losses

III.2.1 Losses in Transmission lines: Losses in the transmission lines can be determined less complicated compared to transformers and distribution systems. The basic computation of it usually surrounds to the fundamentals of ohm's law. Due to the simplicity of the transmission lines configuration, solving for its line losses requires no advance knowledge in any electrical principles. However, there are also portion of these line losses that better understanding is necessary.

Total transmission lines losses can be broken down into three relevant parts namely; conductor losses, dielectric heating & radiation losses, and coupling & corona losses.It is because current flows through a transmission line and a line has a finite resistance there is an un-avoidable power loss. This is sometimes called conductor loss or conductor heating loss and is simply a power loss.

Conductor loss depends somewhat on frequency because of a phenomenon called the skin effect. In an AC system, the flow of current in the cross section of the wire is not uniformly distributed. Skin effect tends to make the current flow concentrated more in the outer layer of the conductor. Since a very small area of the wire carries that current, line resistance increases at the same time increases the dissipated power.

Corona is luminous discharge that occurs between the two conductors of a transmission line. When difference of potential between them exceeds the breakdown voltage of the dielectric insulator. Generally when corona occurs the transmission line is destroyed. If the separation between conductors in a metallic transmission line is appreciable fraction of wavelength. The electrostatic and electromagnetic fields that surround the conductor. Cause the line to act as if it were an antenna and transfer energy to any nearby conductive material. The energy radiated is called radiation loss and depends on dielectric material conductor spacing and length of transmission line. It reduces by properly shielding the cable e.g. STP and coaxial has less radiation loss It is also directly proportional to the frequency.

III.2.2. Losses in Distribution lines: The term "distribution line losses" refers to the difference between the amount of energy delivered to the distribution system from the transmission system and the amounts of energy customers' are billed. Distribution line losses are comprised of two types: technical and non-technical .

It is important to know the magnitude and causality factors for line losses because the cost of energy lost is recovered from customers. As a result of the composition and scale of the Hydro One distribution system it is not economic to provide metering and the supporting processes capable of measuring line losses directly. Since energy meters do not total data for the same periods, and load varies over time, a direct measurement of actual losses is not feasible. Instead, Hydro One relies on studies which are designed to calculate the magnitude, composition and allocation of system losses based on annual aggregate metering information for energy purchases, sales and system modeling methods. These studies are conducted with the energy assistance of industry experts in this field to ensure appropriate scientific methods and modeling techniques are utilized in establishing the magnitude, composition and allocation of losses.

III.3. Components of Transmission and Distribution losses

Energy losses occur in the process of supplying electricity to consumers due totechnical and commercial losses. The technical losses are due to energy dissipated in the conductors and equipment used for transmission, transformation,sub-transmission and distribution of power. These technical losses are inherentin a system and can be reduced to an optimum level. The losses can befurther sub grouped depending upon the stage of power transformation &transmission system as Transmission Losses (400kV/220kV/132kV/66kV), asSub transmission losses (33kV /11kV) and Distribution losses (11kV/0.4kv).The commercial losses are caused by pilferage, defective meters, and errors inmeter reading and in estimating unmetered supply of energy.

III.4. Reasons for Transmission and Distribution losses

Experience in many parts of the world demonstrates that it is possible to reduce the losses in a reasonably short period of time and that such investments have a high internal rate of return. A clear understanding on the magnitude of technicaland commercial losses is the first step in the direction of reducing T&Dlosses. This can be achieved by putting in place a system for accurate energyaccounting. This system is essentially a tool for energy management and helps in breaking down the total energy consumption into all its components. It aims at accounting for energy generated and its consumption by various categories ofconsumers, as well as, for energy required for meeting technical requirement ofsystem elements. It also helps the utility in bringing accountability and efficiency in its working.

III.4.1 Reasons for high technical losses: The following are the major reasons for high technical losses in our country: -

1. Inadequate investment on transmission and distribution, particularly in sub-transmission and distribution. While the desired investment ratiobetween generation and T&D should be 1:1, during the period 1956 -97 itdecreased to 1:0.45. Low investment has resulted in overloading of thedistribution system without commensurate strengthening and augmentation.
2. Haphazard growths of sub-transmission and distribution system with the short-term objective of extension of power supply to new areas.
3. Large scale rural electrification through long 11kV and LT lines.
4. Too many stages of transformations.
5. Improper load management.
6. Inadequate reactive compensation
7. Poor quality of equipment used in agricultural pumping in rural areas, cooler air conditioners and industrial loads in urban areas.

III.4.2 Reasons for commercial losses: Theft and pilferage account for a substantial part of the high transmission and distribution losses in India. Theft / pilferage of energy is mainly committed bytwo categories of consumers i.e. non consumers and bonafide consumers. Antisocial elements avail unauthorized/unrecorded supply by hooking ortapping the bare conductors of L.T. feeder or tampered service wires. Some ofthe bonafide consumers willfully commit the pilferage by way of damaging and / or creating disturbances to measuring equipment installed at their premises. Some of the modes for illegal abstraction or consumption of electricity aregiven below:

1. Making unauthorized extensions of loads, especially those having “H.P.” tariff.
2. Tampering the meter readings by mechanical jerks, placement of powerfulmagnets or disturbing the disc rotation with foreign matters.
3. Stopping the meters by remote control.
4. Willful burning of meters.
5. Changing the sequence of terminal wiring.
6. Bypassing the meter.
7. Changing C. T. ratio and reducing the recording.
8. Errors in meter reading and recording.
9. Improper testing and calibration of meters.

IV. LOAD FLOW STUDY

I.1 Introduction: In a three phase ac power system active and reactive power flows from the generating station to the load through different networks buses and branches. The flow of active and reactive power is called power flow or load flow. Power flow studies provide a systematic mathematical approach for determination of various bus voltages, there phase angle active and reactive power flows through different branches, generators and loads under steady state condition. Power flow analysis is used to determine the steady state operating condition of a power system. Power flow analysis is widely used by power distribution professional during the planning and operation of power distribution system.

3.2 Why we use it?

For planning the operation of a power system, its improvement and also its future expansion require following studies such as load flow studies, short circuit studies and stability studies. Load flow studies are used to ensure that electrical power transfer from generators to consumers through the grid system is stable, reliable and economic. Load flow studies are most important of all power system analysis, because these are used in planning studies of power system network to determine if and when specific elements will become overloaded. This is important, as the magnitudes of voltages at every bus are required to be held within a specified limit. The objectives of any load-flow study is to provide the following information-

•Voltage magnitude and phase angle at each bus.

•Real and Reactive power flowing in each element.

Once the bus voltage magnitudes and their angles are computed using the load flow, the real and reactive power flow through each line can be computed. Also based on the difference between power flow in the sending and receiving ends, the line losses in any particular line can also be calculated. It is helpful in determining the best location as well as optimal capacity of proposed generating station, substation and new lines. In the power flow problem, it is assumed that the real power P and reactive power Q at each Load Bus are known. For this reason, Load Buses are also known as PQ Buses. For Generator Buses, it is assumed that the real or active power generated P and the voltage magnitude V is known. For the Slack Bus, it is assumed that the voltage magnitude V and voltage phase angle of the buses are known. In this work Newton Raphson method for load flow is used, because of its reliability towards convergence and not sensitive nature to the starting solution. In large-scale power flow studies, the Newton raphson has proved most successful because of its strong convergence characteristics.

3.3 Reactive Power: Power factor is defined as the ratio of real power to apparent power. This definition is often mathematically represented as Kw/Kva ,where the numerator is the active (real) power and the denominator is the (active+reactive) or the apparent power

Power Factor = Active power/Apparent power = kW/kVA = Active power/ (Active Power +Reactive Power)
= kW/(kW+kVAr)

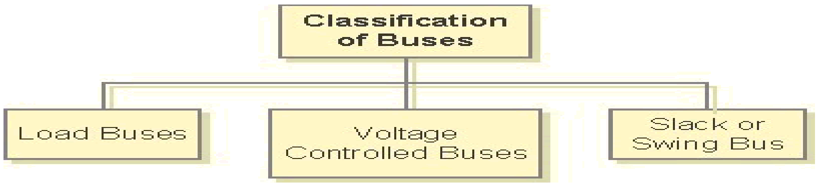
The higher kVAr indicates low power factor and vice versa.

3.4 Objective of load flow study: Power flow analysis is very important in planning stages of new networks or addition to existing ones like adding new generator sites, meeting increase load demand and locating new transmission sites.

- The load flow solution gives the nodal voltages and phase angles and hence the power injection at all the buses and power flows through interconnecting power channels.
- It is helpful in determining the best location as well as optimal capacity of proposed generating station, substation and new lines.
- It determines the voltage of the buses. The voltage level at the certain buses must be kept within the closed tolerances.
- System transmission loss minimizes.
- Economic system operation with respect to fuel cost to generate all the power needed
- The line flows can be known. The line should not be overloaded, it means, we should not operate the close to their stability or thermal limits.

3.5 Importance of maintaining bus Voltage Profile in power system: One of the major aims of system operator is to maintain system parameters within feasible operational margin. During certain period of time in a day-load changes very rapidly, especially when it tends to increase, a generalized voltage decrement and stressed conditions for reactive power sources occurs. Maintaining Voltage profile under varying load conditions is need of today under unpredictable load scenario.

3.6 Classification of buses in load flow analysis: For load flow studies it is assumed that the loads are constant and they are defined by their real and reactive power consumption. It is further assumed that the generator terminal voltages are tightly regulated and therefore are constant. The main objective of the load flow is to find the voltage magnitude of each bus and its angle when the powers generated and loads are pre-specified. To facilitate this the different buses of the power system are classified as shown in below.



III.6.1 Load Buses (PQ): In these buses no generators are connected and hence the generated real power P_{Gi} and reactive power Q_{Gi} are taken as zero. The load drawn by these buses are defined by real power $-P_{Li}$ and reactive power $-Q_{Li}$ in which the negative sign accommodates for the power flowing out of the bus. This is why these buses are sometimes referred to as ***P-Q bus***. The objective of the load flow is to find the bus voltage magnitude $|V_i|$ and its angle δ_i.

III.6.2 Voltage Controlled Buses (PV): These are the buses where generators are connected. Therefore the power generation in such buses is controlled through a prime mover while the terminal voltage is controlled through the generator excitation. Keeping the input power constant through turbine-governor control and keeping the bus voltage constant using automatic voltage regulator, we can specify constant P_{Gi} and $| V_i |$ for these buses. This is why such buses are also referred to as P-V buses. It is to be noted that the reactive power supplied by the generator Q_{Gi} depends on the system configuration and cannot be specified in advance. Furthermore we have to find the unknown angle δ_i of the bus voltage.

III.6.3 Slack or Swing Bus: Usually this bus is numbered 1 for the load flow studies. This bus sets the angular reference for all the other buses. Since it is the angle difference between two voltage sources that dictates the real and reactive power flow between them, the particular angle of the slack bus is not important. However it sets the reference against which angles of all the other bus voltages are measured. For this reason the angle of this bus is usually chosen as 0°. Furthermore it is assumed that the magnitude of the voltage of this bus is known.

Now considering a typical load flow problem in which all the load demands are known. Even if the generation matches the sum total of these demands exactly, the mismatch between generation and load will persist because of the line I^2R losses. Since the I^2R loss of a line depends on the line current which, in turn, depends on the magnitudes and angles of voltages of the two buses connected to the line, it is rather difficult to estimate the loss without calculating the voltages and angles. For this reason a generator bus is usually chosen as the slack bus without specifying its real power. It is assumed that the generator connected to this bus will supply the balance of the real power required and the line losses.

IV. Load Flow Solution

IV.1 Introduction: In Power System Engineering, the load flow study (also known as power flow study) is an important tool involving numerical analysis applied to a power system. Unlike traditional circuit analysis , a power flow study uses simplified notation such as a one line diagram and per unit system , and focuses on various forms of AC power (i.e. reactive ,real and apparent) rather than voltage and current. It analyses the power systems in normal steady state operation. There exist a number of software implementations of power flow studies.

IV.2 Formation of y-bus matrix by Direct Inspection method: The method of building network bus admittance and bus impedence matrix involves transformation and inversion of matrices .An alternative method for bus admittance matrix is based on the simple algorithm obtained by inspection of the network inter connections.

Bus admittance is often used in power system studies. In most of the power system studies it is required to form Y-bus matrix of the system by considering certain power system parameters depending upon the type of analysis.

Y-bus may be formed by inspection method, only if there is no mutual coupling between the lines. Every transmission line should be represented by Π -equivalent. Shunt impedances are added to diagonal element corresponding to the buses at which these are connected. The off diagonal elements are unaffected. The equivalent circuit of Tap changing transformer is included while formingY-busmatrix.

Conseder an *n* bus power system (excluding the ground).taking ground as referrance and considering the single phase equivalent of the balanced network.

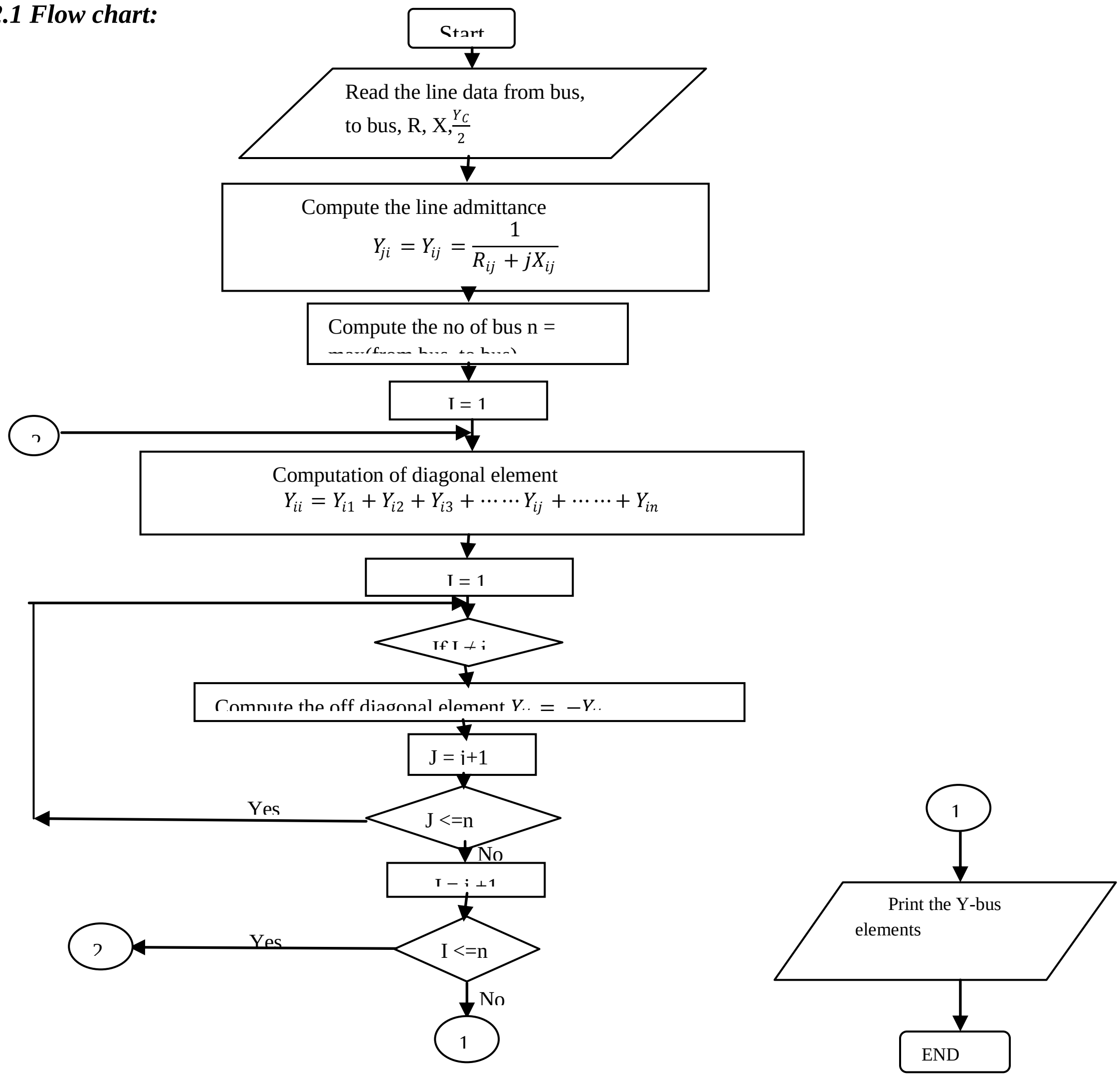
$$\text{Generalized Y-bus} = \begin{bmatrix} Y_{11} & \dots\dots\dots. & Y_{1n} \\ \vdots & \vdots & \vdots \\ Y_{n1} & \dots\dots & Y_{nn} \end{bmatrix}$$

Where,

Y_{ii}=Self admittance

Y_{ij}=Transfer admittance

IV.2.1 Flow chart:



- The diagonal element Yii of the bus admittance matrix is the sum of the admittances of all the elements incident on bus *i* ,including the element between bus *i* and ground.
- The off diagonal element Yii is negative of the admittances of the element connected between buses *i* and *j*.
-

IV.3 Methods of load flow solution: There are mainly three methods for load flow studies:

- Gauss Siedel method
- Newton Raphson method
- Fast decoupled method

IV.3.1 Gauss Seidel Method: The Gauss seidel method is a iterative algorithm for solving non linear algebraic equations.An initial solution vector is assumed,choosen from the past experience,statistical data or from practical considerations.At every subsequent iteration ,the solution is updated till the convergence is reached.

IV.3.1.1 Steps for Gauss Seidal method: **Step 1**: Initially assume all the buses are PQ buses,except the slack bus.This means that the (n-1) complex bus voltages have to be determined.
Step 2:The Slack bus is generally numbered one.
Step 3:PV buses are numbered in sequence and PQ buses are ordered next in sequence.
From the equation of complex power we have,

$Si^*=Vi^*(\sum_{k=1}^{n} YikVk)$

Or, $Pi-jQi=Vi^*(\sum_{k=1}^{n} YikVk)$

Or, $\frac{Pi-jQi}{Vi*}=(\sum_{k=1}^{n} YikVk)$

Or, $\frac{Pi-jQi}{Vi*}=YiiVi+\sum_{\substack{k=1\\k\neq 1}}^{n} YikVk$

Or, $Vi=\frac{1}{Yii}*[\frac{Pi-jQi}{Vi*}-\sum_{\substack{k=1\\k\neq 1}}^{n} YikVk]$........(a)

Above equation is an implicit equation,since the unknown variables appears on the both sides of the equation.Hence it needs to be solved by an iteration technique.

IV.3.1.2 Algorithm For Gauss Seidel Method: **Step1**: Prepare the required data.
Step2: Formulate the Ybus matrix by the method of direct inspection.
Step3: Assume initial voltages for all buses i= 2,3,4....n., (assume i=1 slack bus)
Step4: The complex bus voltagesand all n-1 buses(except the slack bus) are taken $1.0\angle 0\ p.u.$This is normally called a flat start.
Step5: Update the voltages in any (r+1)thiterations.The voltages are given by

$\mathbf{Vi(r+1)=\frac{1}{Yii}*[\frac{Pi-jQi}{Vi*}-\sum_{k=1}^{i-1} YikVk(r+1)-\sum_{k=i+1}^{n} YikVk(r)}$....(1)

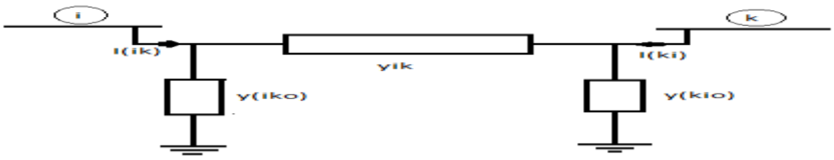
Step6: Continue the iterations till

$|\Delta Vi(r+1)|=|Vi(r+1)-Vi(r)|<\in$

Where $\in$ is the tolerance value..Generally we use 0.0001 p.u.
Step7: Compute slack bus power after voltages have conversed using

$\mathbf{Si^*=Vi^*(\sum_{k=1}^{n} YikVk)}$

Step8: Compute all line flows of a line (or transformer) between the buses.



The figure represents the π model of a transmission line or a transformer. Here

I(ik)=(Vi-Vk)y(ik)+Vi*y(iko)
I(ki)=(Vk-Vi)y(ik)+Vk*y(iko)
S(ik)=ViI(ik)*
S(ki)= VkI(ki)*

The complex power loss in the line is given by S(ik)+S(ki). The total loss in the system is calculated by summing the loss over all the lines.

IV.3.1.3 Gauss Seidel method when p-v buses are present: Some of the buses in an n-bus power system are voltage controlled buses where real power(P) and bus voltage value(|V|) are specified,but reactive power Qi and voltage angle δ are unknown.Hence it is necessary to first make an estimate of Qi.We can find the value of Qi by using the following equation- $Qi=-Im\{Vi^*\sum_{k=1}^{n} YikVk\}$
Where ,Im stands for imaginary part.

At any (r+1)thiteration,at the ith PV bus

Qi(r+1)= -Im{(Vi(r))*$\sum_{k=1}^{i-1} YikVk(r+1) + \left(Vi(r)\right) * \sum_{k=i}^{n} YikVk(r)$} ....(2))

The steps for ith PV bus are as follows:

Step1: Compute Qi(r+1) , using equation (2)

Step2:Calculate Vi using equation (1) with Qi = Q i(r+1)

Step3:Since |Vi| is specified at the PV bus,the magnitude of Vi obtained in step 2 has to be modified and set to the specified value |Vi,sp|.Therefore,

Vi(r+1)=|Vi,sp|$\frac{Vi(r+1)}{|Vi(r+1)|}$

Stated another way,

Vi(r+1)=|Vi,sp|$\angle \delta i(r+1)$

The voltage computation for PQ buses doesnot change.

IV.3.1.4 Q-limit violations : If the limit of reactive power i.e. the Q limit is violated at voltage controlled bus or PV buses during any iteration(say,(r+1)th iteration at ith bus),the Q value is either less than the minimum Q value(Qi,min) or greater than the maximum Q value(Qi,max).It means that the voltage cannot be maintained at the specified value due to the lack of reactive power support.This bus is then treated as a PQ bus in the (r+1)th iteration and the voltage is calculated with the value of Qi set as follows:

If Qi<Qi,min then Qi=Qi,min

If Qi>Qi,max then Qi=Qi,max

If in the subsequent iteration, Qi falls within the limits, the bus can be switched back to PV status.

IV.3.1.5 Acceleration of convergence: The number of iterations increases with the increase in the size of the system, while we use Gauss Seidel method. The number of iterations required can be reduced if the correction in voltage at each bus is accelerated, by multiplying with a constant α.$\alpha$is called the acceleration factor.

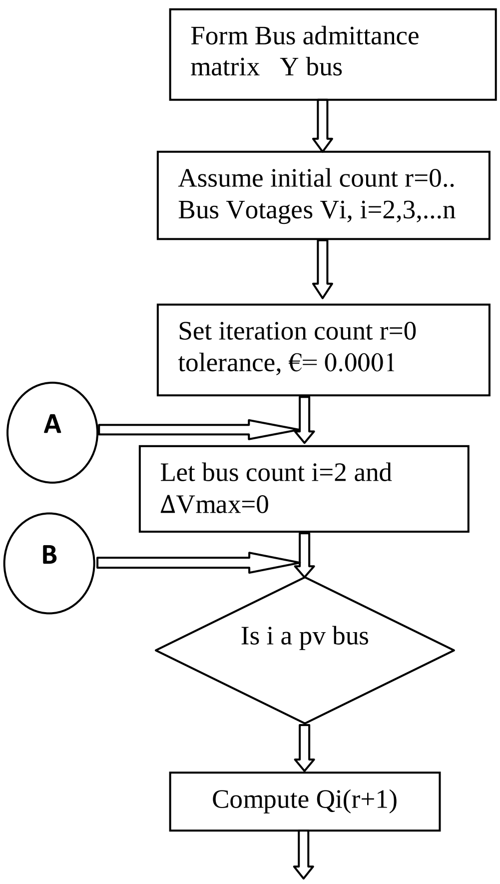
In the (r+1)th iteration we can write,

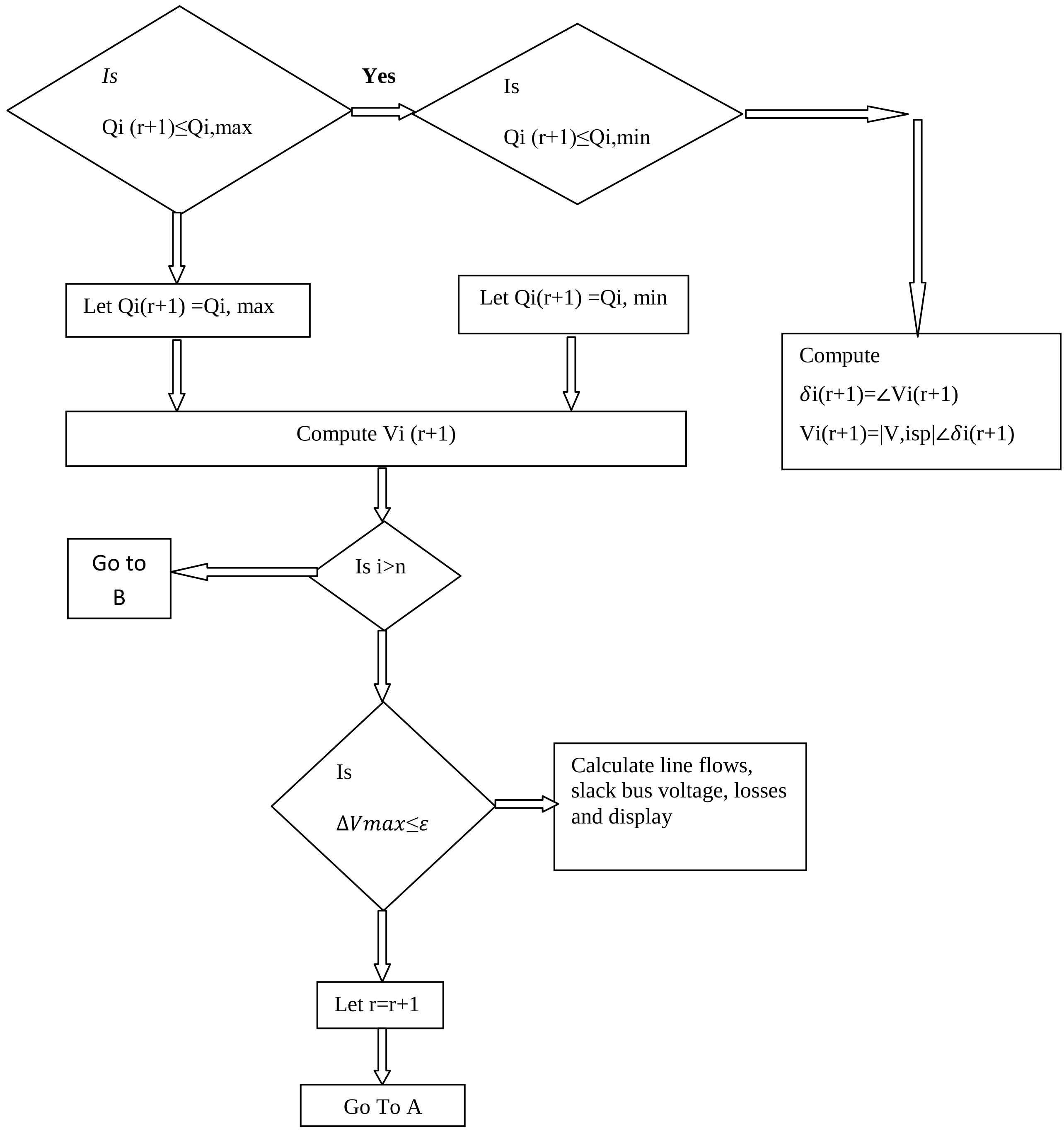
Accelerated Vi(r+1)=Vi(r)+α(Vi(r+1)-Vi(r)*),*

Where, α is a real number.When α=1, the value of Vi(r+1) is the computed value. If 1< α <2, then the value computed is extrapolated.Generally, α is taken between 1.6 to 2.0.A wrong value may lead to divergence of the solution.

At PQ buses (pure load buses) if the voltage magnitude violates the limit.It simply means that the specified reactive power demand cannot be supllied, with the voltage maintained within acceptable limits.

IV.3.1.6 Flow Chart for Gauss-Seidal method:





IV.3.2 Newton Raphson Method: In application of the NR method,we have to first bring the equations to be solved to the form f(x1,x2,...xn)=0,where x1,x2..xn are the unknown variables to be determined.Let us assume that the power system has n1 PV buses and n2 PQ buses.In polar co ordinates the unknown variable to be determined are.

IV.3.2.1 Steps for Newton-Raphson method: **Step1**: δi the angle of the complex bus voltage at bus i,at all the PV and PQ buses.This gives us n1+n2 unknown variables to be determined.

Step2: |Vi|, the voltage magnitude of bus i, at all PQ buses.This gives us n2 unknown variables to be determined.

Therefore the total number of unknown variables to be computed is n1+2n2 for which we n1+2n2 consistent equations to be solved. The equations to be solved are given by

$\Delta Pi = Pi,sp - Pi,cal = 0$

$\Delta Qi = Qi,sp - Qi,cal = 0$

Where,

ΔP =Active power residue

ΔQ= reactive power residue

Pi,sp =specified active power at bus i

Qi,sp =Specified reactive power at bus i

Pi, cal=calculated value of active power using voltage estimates
Qi, cal=calculated value of reactive power using voltage estimates

IV.3.2.2 Algorithm for N-R method: **Step1**: Formulate Bus Admittance Matrix Y bus.
Step2: Assume initial voltages as follows
Vi=|Vi, sp|∠0 (at all PV Buses) where Vi,sp=Specified voltage value
Vi=1∠0 (at all PQ buses)
Step3: At (r+1)th iteration calculate Pi(r+1),at all the PV and PQ Buses and calculate Qi(r+1) at all the PQ buses using Vi(r) values.
The formulae to be used are

$$Pi,cal=Gii|Vi|^2 + \sum_{\substack{k=1 \\ k\neq i}}^{n} |Vi||Vk|(Gik * \cos\delta ik + Bik * \sin\delta ik)$$

$$Qi,cal= Bii|Vi|^2 + \sum_{\substack{k=1 \\ k\neq i}}^{n} |Vi||Vk|(Gik * \sin\delta ik - Bik * \cos\delta ik)$$

Step4: Calculate the power mismatches i.e. Power residues
$\Delta Pi(r) = Pi,sp - Pi,cal(r+1)$ (at PV and PQ buses)
$\Delta Qi(r) = Qi,sp - Qi,cal(r+1)$ (at PQ buses)
Step5: Calculate the Jacobian [J(r)] using Vi(r)
Step6: Compute

$$\begin{matrix} \Delta\delta(r) \\ \frac{\Delta|V(r)|}{|V|} \end{matrix} = \frac{1}{[J(r)]} * \begin{matrix} \Delta P(r) \\ \Delta Q(r) \end{matrix}$$

Step7:Update the variables as follows-

$$\delta i(r+1) = \delta i(r) + \Delta\delta i(r) \quad \text{(at all buses)}$$

$$|Vi(r+1)|=|Vi|(r)+\Delta|Vi|(r)$$

Step8: Go to step 3 and iterate till the the power mismatches are within the acceptable limits.

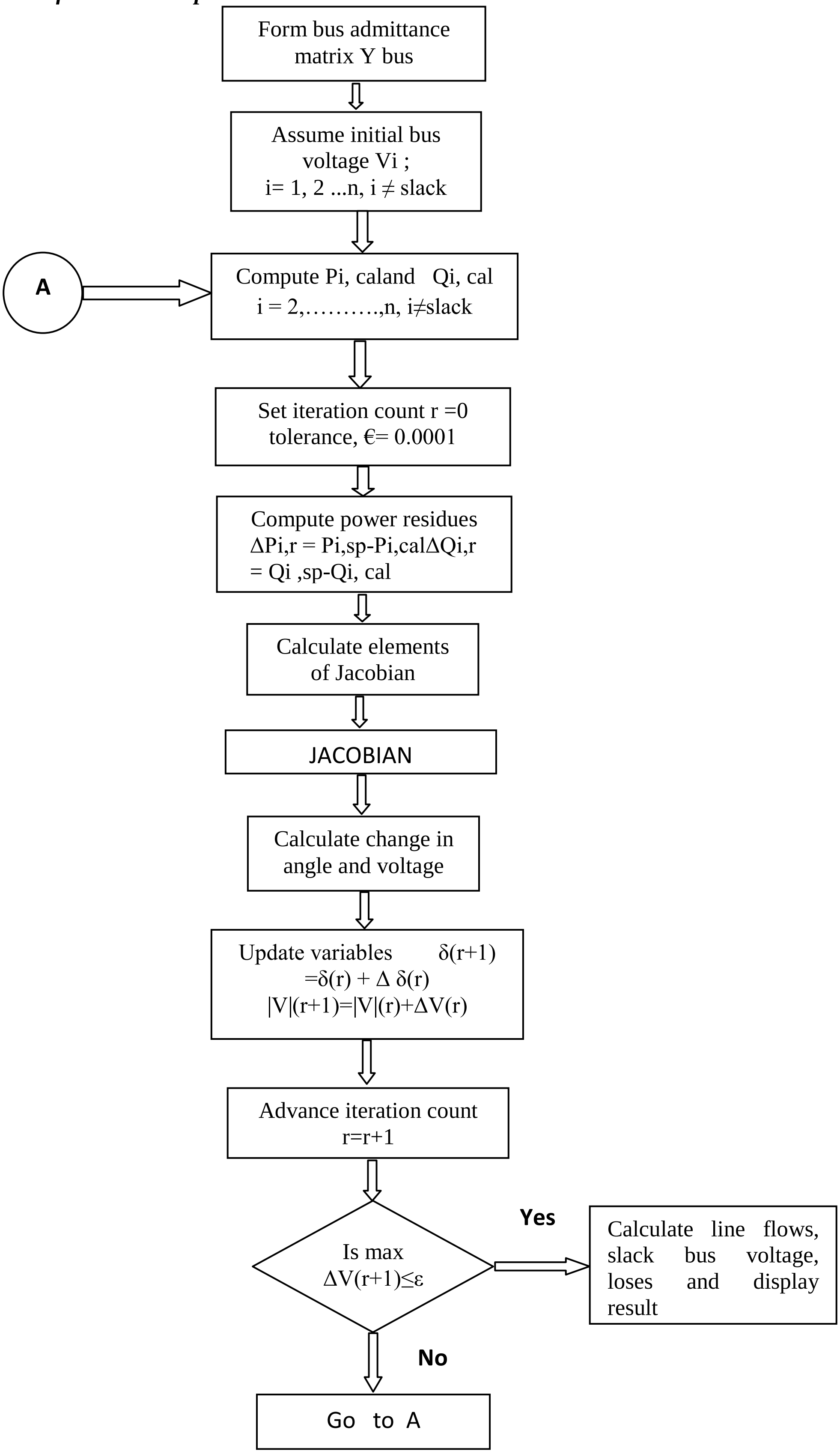
3.3.2.3 Formation of Jacobian:

$$\begin{bmatrix} \vdots \\ \Delta P_n^o \\ \vdots \\ --- \\ \vdots \\ \Delta Q_n^o \\ \vdots \end{bmatrix} = \begin{bmatrix} \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \frac{\partial P_n}{\partial \delta_{n-1}} & \frac{\partial P_n}{\partial \delta_n} & \frac{\partial P_n}{\partial \delta_{n+1}} & \vdots & \vdots & \vdots & \frac{\partial P_n}{\partial |V_{n-1}|} & \frac{\partial P_n}{\partial |V_n|} & \frac{\partial P_n}{\partial |V_{n+1}|} & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ - & --- & --- & --- & - & -- & -- & --- & --- & --- & - \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \frac{\partial Q_n}{\partial \delta_{n-1}} & \frac{\partial Q_n}{\partial \delta_n} & \frac{\partial Q_n}{\partial \delta_{n+1}} & \vdots & \vdots & \vdots & \frac{\partial Q_n}{\partial |V_{n-1}|} & \frac{\partial Q_n}{\partial |V_n|} & \frac{\partial Q_n}{\partial |V_{n+1}|} & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \end{bmatrix} \cdot \begin{bmatrix} \Delta\delta_{n-1}^o \\ \Delta\delta_n^o \\ \Delta\delta_{n+1}^o \\ --- \\ \Delta|V_{n-1}|^o \\ \Delta|V_n|^o \\ \Delta|V_{n+1}|^o \end{bmatrix}$$

There are some formulas given below for making the Jacobian in NR load flow method. theseare...

1) $\frac{\partial Pi}{\partial \delta i}$= -Qi-Bii$|Vi|^2$
2) $\frac{\partial Pi}{\partial \delta k}$= $|Vi||Vk|(Gik * \sin\delta ik - Bik * \cos\delta ik)$
3) $\frac{\partial Pi}{\partial Vk}|Vk|$= $|Vi||Vk|(Gik * \cos\delta ik + Bik * \sin\delta ik)$
4) $\frac{\partial Pi}{\partial |Vi|}|Vi|$ = Pi+Gii$|Vi|^2$
5) $\frac{\partial Qi}{\partial \delta i}$= Pi-Gii$|Vi|^2$
6) $\frac{\partial Qi}{\partial \delta k} = -|Vi||Vk|(Gik * \cos\delta ik + Bik * \sin\delta ik)$
7) $\frac{\partial Qi}{\partial |Vi|}|Vi|$ = Qi-Bii$|Vi|^2$
8) $\frac{\partial Qi}{\partial |Vi|}|Vk| = |Vi||Vk|(Gik * \sin\delta ik - Bik * \cos\delta ik)$

IV.3.2.4 Flow Chart for Newton Raphson method



IV.3.3 Fast Decoupled method

If the co efficient matrices are constant,the need to update the jacobian at every iteration is eliminated.This has resulted in development of fast decoupled load flow.Assumptions used in this method are-

- $B_{ij} \gg G_{ij}$ (Since,the X/R ratio of transmission lines is high in well desighned system.
- Real power changes are less sensitive to voltage magnitude changes and are most sensitive to changes in phase angle $\Delta\delta$.

i.e$\cos(\delta_i - \delta_j)\approx 1$ and $\sin(\delta_i - \delta_j)\approx 0$

- Similarly, reactive power changes are less sensitive to changes in angle and are mainly dependent on changes in voltage magnitude.
- Therefore the element of theJacobian matrix become

$$H_{ik=}L_{ik} = -|Vi||Vk|Bik(i \neq k)$$
$$H_{ii} = L_{ii} = -Bii|Vi|^2$$

With this value we can perfom the load flow analysis by taking less time.

V. DISTRIBUTED GENERATION

V.1 Introduction to Distributed Generation

What is Distributed Generation?

Distributed generation is an approach that employs small-scale technologies to produce electricity close to the end users of power. DG technologies often consist of modular (and sometimes renewable-energy) generators, and they offer a number of potential benefits. In many cases, distributed generators can provide lower-cost electricity and higher power reliability and security with fewer environmental consequences than can traditional power generators. Distributed generation, also called on-site generation, dispersed generation, embedded generation, decentralized generation, decentralized energy or distributed energy, generates electricity from many small energy sources. Distributed generation reduces the amount of energy lost in transmitting electricity because the electricity is generated very near where it is used, perhaps even in the same building. This also reduces the size and number of power lines that must be constructed.

In contrast to the use of a few large-scale generating stations located far from load centers--the approach used in the traditional electric power paradigm--DG systems employ numerous, but small plants and can provide power onsite with little reliance on the distribution and transmission grid. DG technologies yield power in capacities that range from a fraction of a kilowatt [kW] to about 100 megawatts [MW]. Utility-scale generation units generate power in capacities that often reach beyond 1,000 MW.

Distributed generation takes place on two-levels: the local level and the end-point level. Local level power generation plants often include renewable energy technologies that are site specific, such as wind turbines, geothermal energy production, solar systems (photovoltaic and combustion), and some hydro-thermal plants. These plants tend to be smaller and less centralized than the traditional model plants. They also are frequently more energy and cost efficient and more reliable. Since these local level DG producers often take into account the local context, the usually produce less environmentally damaging or disrupting energy than the larger central model plants.

V.2 Benefits of Distributed Generation

What are the Potential Benefits of DG Systems?

Consumer advocates who favor DG point out that distributed resources can improve the efficiency of providing electric power. They often highlight that transmission of electricity from a power plant to a typical user wastes roughly 4.2 to 8.9 percent of the electricity as a consequence of aging transmission equipment, inconsistent enforcement of reliability guidelines, and growing congestion. At the same time, customers often suffer from poor power quality—variations in voltage or electrical flow—that results from a variety of factors, including poor switching operations in the network, voltage dips, interruptions, transients, and network disturbances from loads. Overall, DG proponents highlight the inefficiency of the existing large-scale electrical transmission and distribution network. Moreover, because customers' electricity bills include the cost of this vast transmission grid, the use of on-site power equipment can conceivably provide consumers with affordable power at a higher level of quality. In addition, residents and businesses that generate power locally have the potential to sell surplus power to the grid, which can yield significant income during times of peak demand.

Beyond efficiency, DG technologies may provide benefits in the form of more reliable power for industries that require uninterrupted service. The Electric Power Research Institute reported that power outages and quality disturbances cost American businesses $119 billion per year. In 2001, the International Energy Agency (2002) estimated that the average cost of a one-hour power outage was $6,480,000 for brokerage operations and $2,580,000 for credit card operations. The figures grow more impressively for the semiconductor industry, where a two hour power outage can cost close to $48,000,000. Given these numbers, it remains no mystery why several firms have already installed DG facilities to ensure consistent power supplies.

Perhaps incongruously, DG facilities offer potential advantages for improving the transmission of power. Because they produce power locally for users, they aid the entire grid by reducing demand during peak times and by minimizing congestion of power on the network, one of the causes of the 2003 blackout. And by building large numbers of localized power generation facilities rather than a few large-scale power plants located distantly from load centers, DG can contribute to deferring transmission upgrades and expansions—at a time when investment in such facilities remains constrained. Perhaps most important in the post-September 11 era, DG technologies may improve the security of the grid.

Environmentalists and academics suggest that DG technologies can provide ancillary benefits to society. Large, centralized power plants emit significant amounts of carbon monoxide, sulfur oxides, particulate matter, hydrocarbons, and nitrogen oxides.

Finally, DG can help the nation increase its diversity of energy sources. Some of the DG technologies, such as wind turbines, solar photovoltaic panels, and hydroelectric turbines, consume no fossil fuels, while others, such as fuel cells, microturbines, and some internal combustion units burn natural gas, much of which is produced in the United States. The increasing diversity helps insulate the economy from price shocks, interruptions, and fuel shortages

V.3 Usage of Distributed Generation

How Much are Renewable and DG Systems Used in the American Electric Utility Sector?

Despite the immense environmental, technical, and financial promise of renewable energy systems, such generators still constitute a very small percentage of electricity generation capacity in the United States. Throughout the 1970s, some policy experts expected renewable energy systems to be used for much more generation capacity than they have. Dr. Arthur Rosenfeld, one of the five CEC commissioners serving from 2002 until the present, noted that President Carter had told him (during his presidency in the late 1970s) that he expected renewable energy systems to reach 10 percent of national electricity capacity by 1985. However, Carter's expectation went unfulfilled: excluding large hydroelectric generators, renewable energy technologies in 2003 comprised only about 2 percent of the U.S. electricity generation mix

The relatively minor use of renewable energy systems has created a general attitude among energy analysts, scholars, and laboratory directors that the technologies are not viable sources of electricity supply. For example, RodeySobin, former Innovative Technology Manager for the Virginia Department of Environmental Quality, argues that "in many ways, renewable energy systems were the technology of the future, and today they still are." Ralph D. Badinelli, a professor of Business Information Technology at Virginia Tech, explains that renewable energy technologies do not contribute significantly to U.S. generation capacity because "such sources have not yet proven themselves … Until they do, they will be considered scientific experiments as opposed to new technologies." Similarly, Mark Levine, the Environmental Energy Technologies Division Director at the Lawrence Berkeley National Laboratory, comments that despite all of the hype surrounding renewable energy, such systems are still only "excellent for niche applications, but the niches aren't large."

DG/CHP technologies have an only slightly better record. In 2004, the Energy Information Administration characterized only 3.1 percent of electricity generation capacity as commercial or industrial combined heat and power (33,217 MW out of 1.49 terrawatts [TW]). The EIA also estimated that in 2002 only 0.9 gigawatts (GW) of distributed generation capacity existed in the United States. Similarly, the EIA's 2005 Annual Energy Outlook projected that CHP systems are not widely used in the electric power sector, amounting to 0.053% of utility generation (197 billion kWh out of 3,700 billion kWh). Tom Casten, the Chair and Chief Executive Officer of Primary Energy, a manufacturer of fuel processing cogeneration steam plants, notes that even though CHP plants can reduce energy costs for industrial firms by over 40 percent, such plants remain "the exception instead of the rule."

V.4 Distriduted Generation in our system

5.4.1 Algorithm: The computational steps involved in finding the optimal Distribution Generator (DG) size and location to minimize the loss in a radial distribution system are summarized in following:

1. Perform the load flow analysis by using Newton Raphson method for determining the voltage profile and Total Loss for Radial Distribution system.
2. In load flow analysis obtain the branch current I_{ij} between two buses by using ,

$$I_{ij} = \frac{V_i - V_j}{R_{ij}} \qquad \text{Where, } V_i = Voltage\ of\ bus\ i$$

$$V_j = Voltage\ of\ bus\ j$$

$$R_{ij} = Resistance\ between\ bus\ i\ and\ j$$

3. Obtain the active component, I_a and reactive component, I_r of the branch currents I_{ij} .
4. We calculate total $I_a^2 R$ loss by using,

$$P_L = \sum_{i=1}^{n} I_i^2\, R_i$$

Where, $P_{La} = \sum_{i=1}^{n} I_{ai}^2\, R_{ij}$ Due to active component of the current,

$P_{Lr} = \sum_{i=1}^{n} I_{ri}^2\, R_{ij}$ Due to reactive component of the current,

5. We calculate the power loss P_{La}^{new} associated with the active component of branch current when DG is connected.It is given by

$$P_{La}^{new} = \sum_{i=1}^{n} (I_{ai} + D_i I_{DG})^2\, R_i \quad \text{where } D_i = 1; \text{ if branch } i\epsilon\alpha$$

$$= 0, \text{otherwise}$$

$'\alpha'$ is the set of branches connected between the source and the bus m where DG is placed.

6. Repeat **steps 1** to **steps 5** and calculate P_{La}(new) by placing DG at each bus.

7. Calculate the power saving by applying the formula given below

$$S = P_{La} - P_{La}^{new}$$

8. The DG current IDG that provides maximum saving can be obtained from

$$\frac{\partial S}{\partial I_{DG}} = -2\sum_{i=1}^{n} (D_i I_{ai} + D_i I_{DG})\, R_i = 0$$

9.Calculate DG current for maximum power saving and is given by

$$I_{DG} = -\frac{\sum_{i\epsilon\alpha} IaiRi}{\sum_{i\epsilon\alpha} Ri}$$

10.Calculate the corresponding DG Size to be placed at each bus ,is given by

At Bus m,

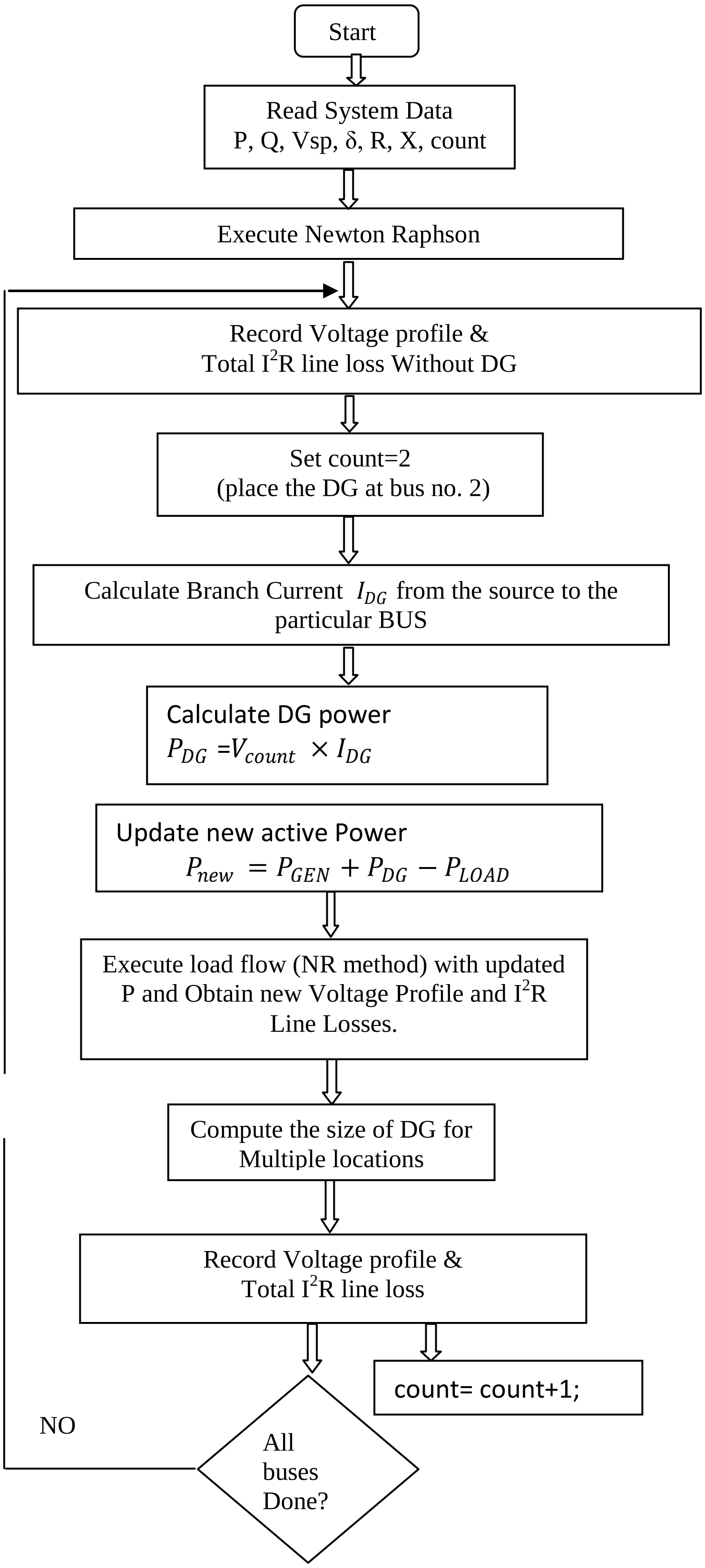
$P_{DG}=V_m I_{DG}$, where V_m is the Voltage Magnitude of Bus 'm'

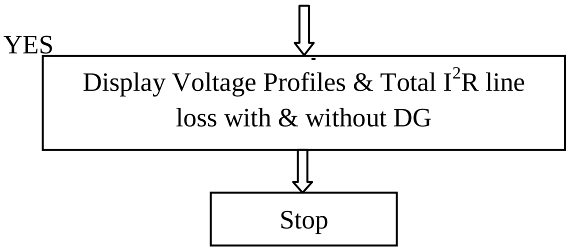
11.Update the active power component

$P_{new} = P_{GEN} + P_{DG} - P_{LOAD}$

12. Perform load flow analysis with updated active power component obtained in **step 11**.
13. Perform the **step 10** to **step 12 ,** and record the Voltage Profiles and Total line loss.
14. Obtain the Optomal location of Distributed Generation (DG) for Total line loss minimization and Voltage profile improvement.

V.4.2 Flow Chart





VI. TEST SYSTEM AND RESULTS

VI. 1 Test System (12-BUS Radial System)

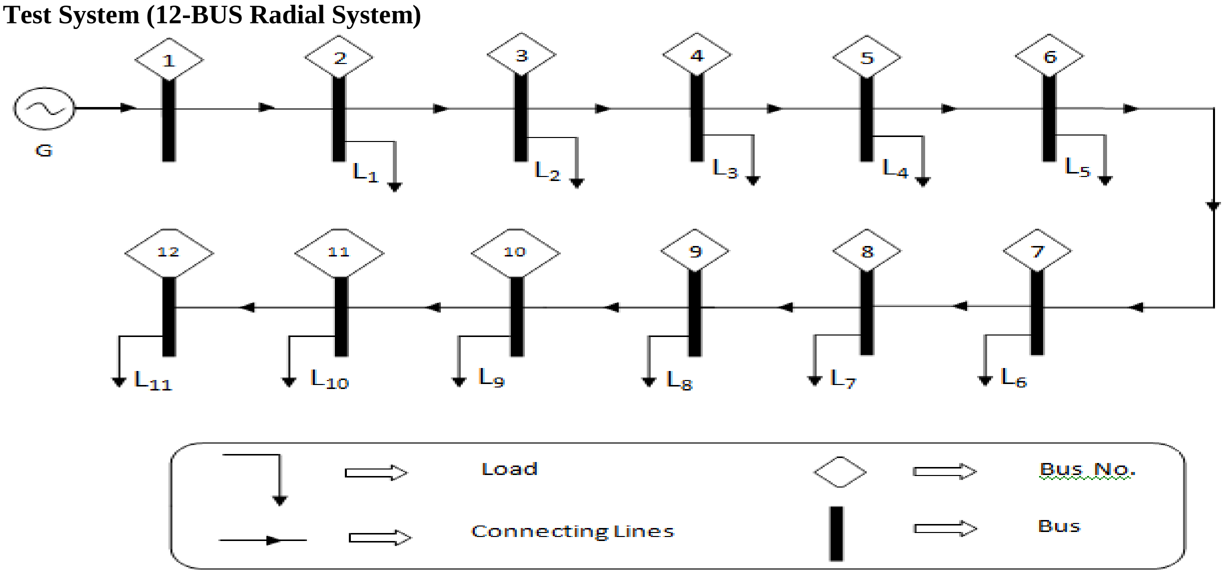


***Figure:** A Radial Distribution Line with connecting Loads*

Number of buses in the system = 12
Number of slack bus = 1
Number of PV buses = 11
Number of PQ buses = 0
Number of lines in the system = 11
Maximum convergence value = 0.0001
Base value = 1000
Coding used for Buses:
Slack Bus – 1; PV Bus – 2; PQ Bus – 3

VI.1.1 SPECIFICATION OF TEST SYSTEM:

Bus	Type	Vsp (in pu)	Power angle	PGi (in kW)	QGi (in kVAR)	PLi (in kW)	QLi (in kVAR)
1	1	1.06	0	0	0	0	0
2	3	1	0	0	0	60	60
3	3	1	0	0	0	40	30
4	3	1	0	0	0	55	55
5	3	1	0	0	0	30	30
6	3	1	0	0	0	20	15
7	3	1	0	0	0	55	55
8	3	1	0	0	0	45	45
9	3	1	0	0	0	40	40
10	3	1	0	0	0	35	30
11	3	1	0	0	0	40	30
12	3	1	0	0	0	15	15

VI.1.2 LINE DATA:

From Bus	To Bus	Resistence, R (in Ω)	Reactance, X (in Ω)
1	2	1.093	0.455
2	3	1.184	0.494
3	4	2.095	0.873

4	5	3.188	1.329
5	6	1.093	0.455
6	7	1.002	0.417
7	8	4.403	1.215
8	9	5.642	1.597
9	10	2.890	0.818
10	11	1.514	0.428
11	12	1.238	0.351

VII. RESULTS & DISCUSSIONS

Performing the experiment in MATLAB Environment for Optimal Placement of DG with loss minimization technique and Voltage Profile improvement, we are having the results as described below:

1. Optimal Placement of DG for Loss Minimization:

For finding the optimal location of DG for Total Loss Minimization we placed single DG at each Bus and Total loss obtained in each step is compared as such.

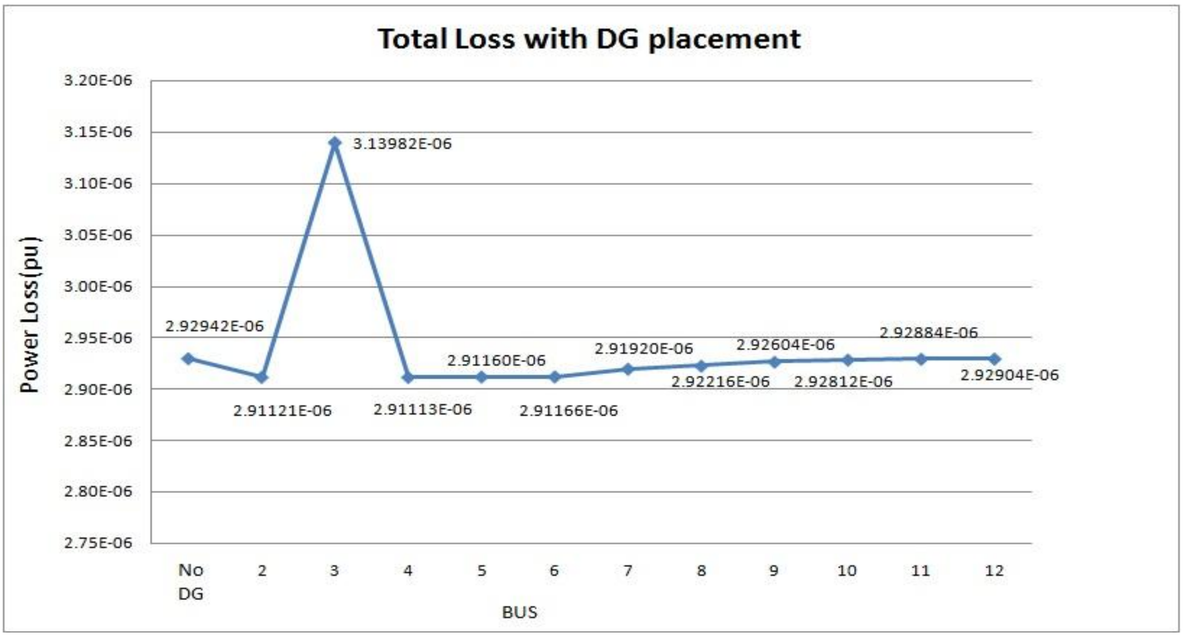


Fig: Optimal DG location for Total Line Loss minimization

- From the graph we observe that when we place DG at BUS No. 4 the Total Line Loss compared to DG placement at other buses is minimum. The Elapsed time for execution of the MATLAB program is 0.385176 seconds with total line loss = $2.91113X10^{-6}$ p.u.
- So, we can suggest that for Total Line Loss reduction in our test system, the optimal location for the single DG placement is at BUS No. 4

2. Optimal Placement of Voltage Profile Improvement:

For finding the optimal location of DG for Voltage Profile improvement we placed single DG at each Bus and compared the obtained voltage profile with the reference value (1 p. u)

	No DG	DG at										
		bus 2	bus 3	bus 4	bus 5	bus 6	bus 7	bus 8	bus 9	bus 10	bus 11	bus 12
BUS 1	1.06000	1.06000	1.06000	1.06000	1.06000	1.06000	1.06000	1.06000	1.06000	1.06000	1.06000	1.06000
BUS 2	1.00412	1.00430	1.00212	1.00430	1.00429	1.00429	1.00422	1.00419	1.00415	1.00413	1.00413	1.00412
BUS 3	1.00498	1.00516	1.00285	1.00516	1.00515	1.00515	1.00508	1.00505	1.00501	1.00499	1.00498	1.00498
BUS 4	1.00685	1.00704	1.00457	1.00704	1.00703	1.00703	1.00695	1.00692	1.00688	1.00686	1.00685	1.00685
BUS 5	1.01059	1.01078	1.00813	1.01078	1.01078	1.01078	1.01069	1.01065	1.01061	1.01059	1.01059	1.01058
BUS 6	1.01187	1.01207	1.00938	1.01207	1.01206	1.01206	1.01197	1.01193	1.01189	1.01187	1.01187	1.01186
BUS 7	1.01266	1.01286	1.01016	1.01286	1.01285	1.01285	1.01276	1.01272	1.01268	1.01266	1.01266	1.01265
BUS 8	1.02096	1.02116	1.01900	1.02115	1.02114	1.02114	1.02107	1.02102	1.02097	1.02095	1.02095	1.02095
BUS 9	1.03394	1.03409	1.03220	1.03408	1.03408	1.03408	1.03401	1.03398	1.03394	1.03393	1.03392	1.03392
BUS 10	1.04034	1.04047	1.03863	1.04046	1.04046	1.04046	1.04040	1.04037	1.04034	1.04032	1.04032	1.04032
BUS 11	1.04272	1.04285	1.04102	1.04284	1.04284	1.04284	1.04278	1.04275	1.04272	1.04271	1.04271	1.04270
BUS 12	1.04341	1.04353	1.04171	1.04353	1.04352	1.04352	1.04347	1.04343	1.04341	1.04340	1.04339	1.04339

Table: Voltage Profile before and after placing DG

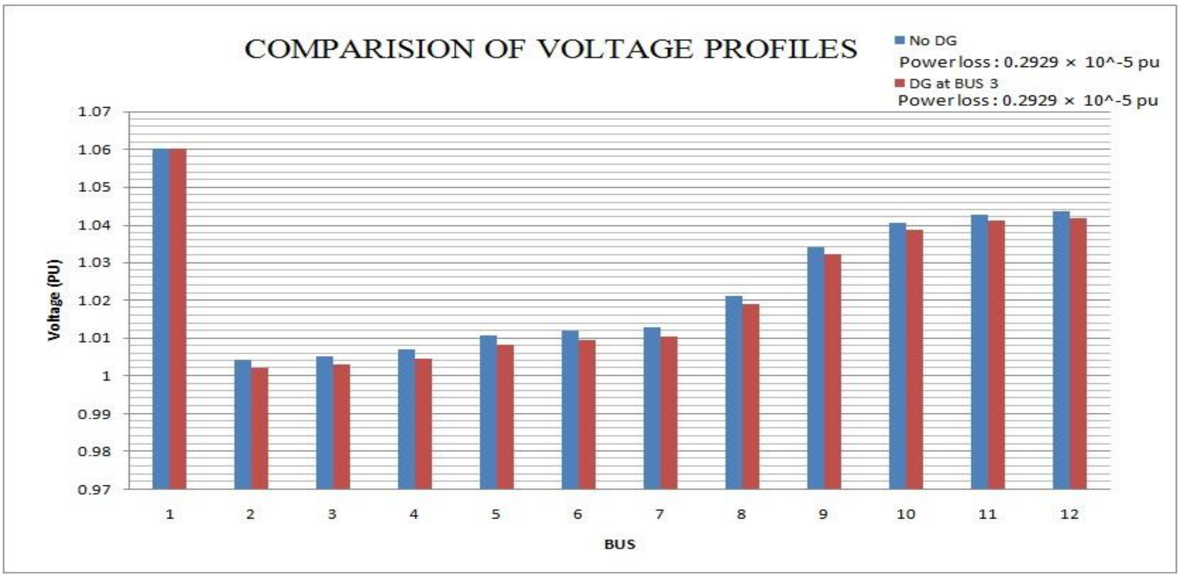


Figure: Optimal DG location for Voltage Profile improvement

[1]. In the graph Blue bar represents the voltage profile of the 12 Bus radial distribution system without DG placement and Red bar represents the voltage profile after placing the DG at bus no. 3
[2]. Comparing the two Voltage Profiles with reference value (1 pu), we observed that , when the DG is placed at Bus No. 3 the obtained voltage is much nearer to the reference value.

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