FAST DECOUPLED POWER FLOW FOR UNBALANCED RADIAL DISTRIBUTION SYSTEM

Thesis submitted in partial fulfillment of the requirements for the award of degree of

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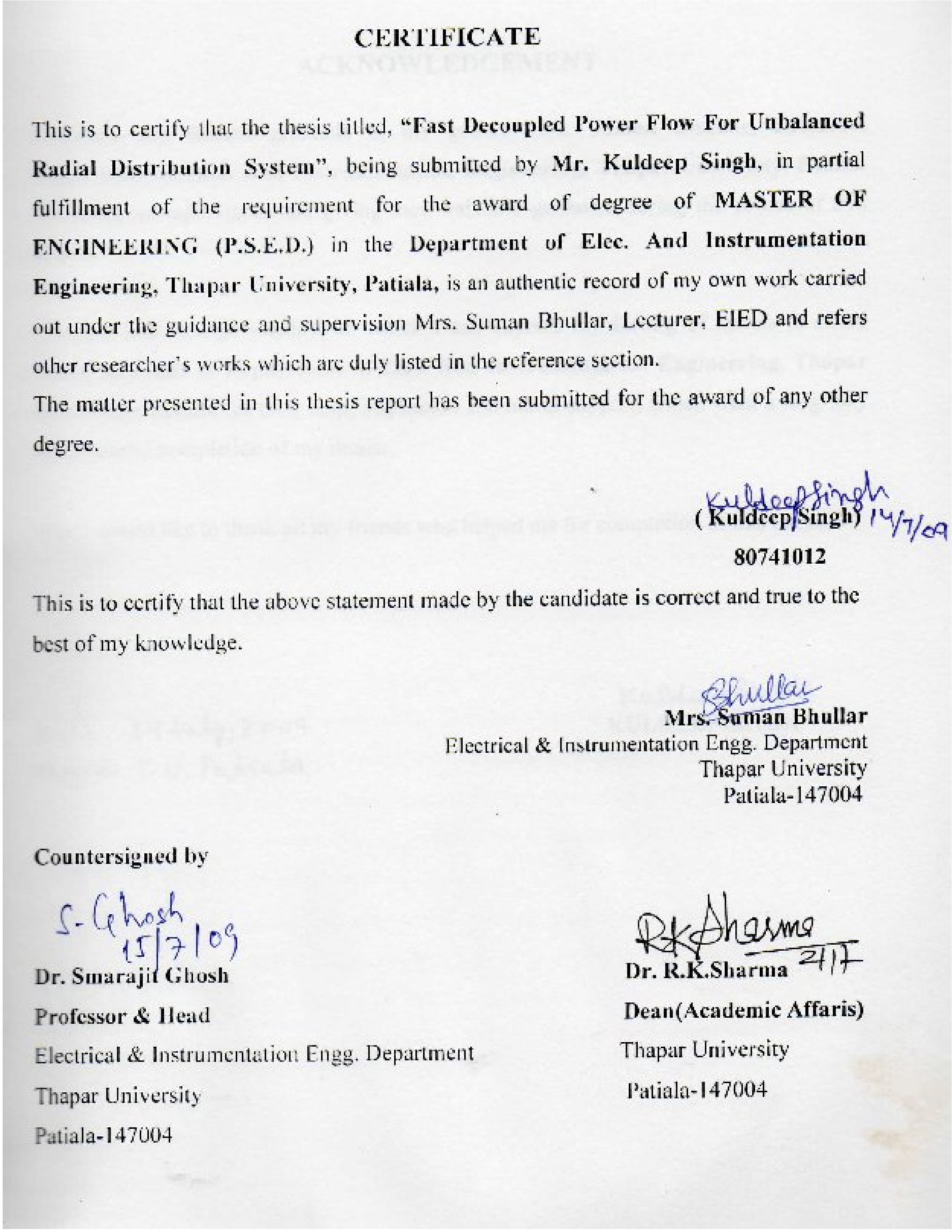

CERTIFICATE

This is to certify that the thesis titled, **"Fast Decoupled Power Flow For Unbalanced Radial Distribution System"**, being submitted by **Mr. Kuldeep Singh**, in partial fulfillment of the requirement for the award of degree of **MASTER OF ENGINEERING (P.S.E.D.)** in the **Department of Elec. And Instrumentation Engineering, Thapar University, Patiala,** is an authentic record of my own work carried out under the guidance and supervision Mrs. Suman Bhullar, Lecturer, EIED and refers other researcher's works which are duly listed in the reference section.

The matter presented in this thesis report has been submitted for the award of any other degree.

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ABSTRACT

Now these days load flow is a very important and fundamental tool for the analysis of any power system and is used in the operational as well as planning stages. Certain applications, particularly in distribution automation and optimization of a power system, require repeated load flow solutions. In these applications it is very important to solve the load flow problem as efficiently as possible. Since the invention and widespread use of digital computers and many methods for solving the load flow problem have been developed. Most of the methods have “grown up” around transmission systems and, over the years, variations of the Newton method such as the fast decoupled method, have become the most widely used.

The assumptions necessary for the simplifications used in the standard fast decoupled Newton method often are not valid in distribution systems. In particular, R/X ratios can be much higher. However, some work has been done to attempt to overcome these difficulties.

Some of the methods based on the general meshed topology of a typical transmission system are also applicable to distribution systems which typically have a radial or tree structure. Specifically, we will compare the proposed method to the standard Newton method, and the implicit *Zbus* Gauss method. These methods do not explicitly exploit the radial structure of the system and therefore require the solution of a set of equations whose size is of the order of the number of buses.

Our goal was to develop a formulation and solution algorithm for solving load flow in large three-phase unbalanced systems which exploits the radial *topological structure* to reduce the number of equations and unknowns and the *numerical structure* to further reduce computation as in the fast decoupled methods for distribution systems.

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LIST OF SYMBOLS

kV- Kilo Volts

kVA- Kilo volt ampere

kVAr - Amount of reactive power

kW- kilo watts

MW – Mega watts

MVAr – Amount of reactive power

NB - The total no. of nodes

MB – Number of voltage controlled buses

NR – Newton Raphson Method

FDPFM - Fast Decoupled Power Flow Method

PL - Active Power Load

QL - Reactive Power Load

V_i, V_j - Voltage magnitude at the i^{th} and j^{th} buses

CHAPTER-1

INTRODUCTION

1.1 Overview

To meet the present growing domestic, industrial and commercial load day by day, effective planning of radial distribution network is required. To ensure the effective planning with load transferring, the load-flow study of radial distribution network becomes utmost important. In this chapter, introduction of distribution system will be carried out at first followed by load-flow.

1.2 Distribution System

Electrical power is transmitted by high voltage transmission lines from sending end substation to receiving end substation. At the receiving end substation, the voltage is stepped down to a lower value (say 66kV or 33kV or 11kV). The secondary transmission system transfers power from this receiving end substation to secondary sub-station. A secondary substation consists of two or more power transformers together with voltage regulating equipments, buses and switchgear. At the secondary substation voltage is stepped down to 11kV. The portion of the power network between a secondary substation and consumers is known as distribution system. The distribution system can be classified into primary and secondary system. Some large consumers are given high voltage supply from the receiving end substations or secondary substation.

The area served by a secondary substation can be subdivided into a number of sub- areas. Each sub area has its primary and secondary distribution system. The primary distribution system consists of main feeders and laterals. The main feeder runs from the low voltage bus of the secondary substation and acts as the main source of supply to sub- feeders, laterals or direct connected distribution transformers. The lateral is supplied by the main feeder and extends through the load area with connection to distribution transformers. The distribution transformers are located at convenient places in the load area. They may be located in specially constructed enclosures or may be pole mounted. The distribution transformers for a large multi storied building may be located within the building itself. At the distribution transformer, the voltage is stepped down to 400V and power is fed into the secondary distribution systems. The secondary distribution system consists of distributors which are laid along the road sides. The service connections to consumers are tapped off from the distributors. The main feeders, laterals and distributors may consist of overhead lines or cables or both. The distributors are 3- phase, 4 wire circuits, the neutral wire being necessary to supply the single phase loads. Most of the residential and commercial consumers are given single phase supply. Some large residential and commercial consumer uses 3-phase power supply. The service connections of consumer are known as service mains.

The consumer receives power from the distribution system. The main part of distribution system includes:-

1. Receiving substation.
2. Sub- transmission lines.
3. Distribution substation located nearer to the load centre.
4. Secondary circuits on the LV side of the distribution transformer.
5. Service mains.

1.3 Power Flow

For distribution system the power flow analysis is a very important and fundamental tool. Its results play the major role during the operational stages of any system for its control and economic schedule, as well as during expansion and design stages. The purpose of any load flow analysis is to compute precise steady-state voltages and voltage angles of all buses in the network, the real and reactive power flows into every line and transformer, under the assumption of known generation and load.

During the second half of the twentieth century, and after the large technological developments in the fields of digital computers and high-level programming languages, many methods for solving the load flow problem have been developed, such as Gauss-Siedel (bus impedance matrix), Newton-Raphson’s (NR) and its decoupled versions. Nowadays, many improvements have been added to all these methods involving assumptions and approximations of the transmission lines and bus data, based on real systems conditions.

The Fast Decoupled Power Flow Method (FDPFM) is one of these improved methods, which was based on a simplification of the Newton-Raphson’s method and reported by Stott and Alsac in 1974. This method due to its calculations simplifications, fast convergence and reliable results became the most widely used method in load flow analysis. However, FDPFM for some cases, where high R/X ratios or heavy loading (Low Voltage) at some buses are present, does not converge well. For these cases, many efforts and developments have been made to overcome these convergence obstacles. Some of them targeted the convergence of systems with high R/X ratios, others those with low voltage buses. Though many efforts and elaborations have been achieved in order to improve the FDPFM, this method can still attract many researchers, especially when computers and simulations are becoming more developed and are now able to handle and analyze large size system.

1.4 Literature Survey

In the literature, there are a number of efficient and reliable load flow solution techniques, such as: Gauss-Seidel, Newton-Raphson's and Fast Decoupled Load Flow. Hitherto they are successfully and widely used for power system operation, control and planning. However, it has repeatedly been shown that these methods may become inefficient in the analysis of distribution systems with high R/X ratios or special network.

Zimmerman Ray D. and Chiang Hsiao-Dong [1] successfully presented and concluded a novel power flow formulation and an effective solution method for general unbalanced radial distribution system in this paper the authors exploited the radial structure (*physical property*) and the decoupling *numerical property* of a distribution system to develop a fast decoupled Newton method for solving unbalanced distribution load flow. The objective of this work was to develop a formulation and an efficient solution algorithm for the distribution power flow problem which takes into account the detailed and extensive modeling necessary for use in the distribution automation environment of a real world electric power distribution system.

The modeling includes unbalanced three-phase, two-phase, and single-phase branches, constant power, constant current, and constant impedance loads connected in Wye or Delta formations, co-generators, shunt capacitors, line charging capacitance, switches, and three-phase transformers of various connection types.

Bose A. and Rajicic D [2] tells that Fast Decoupled Method is probably the most popular because of its efficiency. Its reliability for most power systems 1s very high but ' it does have difficulties in convergence for systems with high ratios of branch resistance to reactance. Modifications, that retain the advantages of this method but can handle high r/x ratios, **are** of great interest and certain compensation techniques have been used forth is purpose. Both the series and parallel compensation techniques, however, give mixed results and a new modification is presented here that performed better on several test systems.

Zhu Y. and Tomsovic K [3] presented an adaptive distributed power flow solution method based on the compensation-based method. The comprehensive distributed system model includes 3-phase nonlinear loads, lines, capacitors, transformers, and dispersed generation units. This paper presents an adaptive distributed power flow solution method based on the compensation-based method. The comprehensive distributed system model includes 3-phase nonlinear loads, lines, capacitors, transformers, and dispersed generation units. It is illustrated that this adaptive method is especially appropriate for simulation of slow dynamics.

Wu W.C. and Zhang B.M [4] suggested theoretical formulation of the forward/backward sweep with compensation power flow method is presented. Subsequently, a novel solution of unbalanced three-phase power systems based on loop-analysis method is developed in this paper. This proposed method has clear theory foundation and takes full advantage of the radial (or weakly meshed) structure of distribution systems.

Augugliaro A. et al [5] purposed an efficient method for radial distribution networks solution. The method is based on an iterative algorithm with some special procedures to Increase the convergence speed. It uses a simple matrix representation for the network topology and branch current flow management. The method developed in has been again studied by Jasmon and Lee in order to improve it. The actual network, made of different lines, is reduced to a single line system; the equations used in the iterative process are the real and reactive powers injected in the equivalent line. Further modifications have been proposed by Chiang for networks constituted of a primary feeder and primary laterals.

Bandyopadhyay G. & Syam P [6] tells a diakoptic theory based fast decoupled load flow algorithm which is suitable for distributed computing. If computations for different subsystems of an integrated system are done concurrently using a number of processors load flow study can be done in a shorter time. Moreover, if distributed processing is done in real time, data is to be collected from local points only and a comparatively smaller data base is to be updated locally at regular intervals. Transmission of data over long distance to the central processing computer can thus be reduced.

A.M, Van Amerongen [7] presented the general purpose fast decoupled power flow, he tells that probably almost all the relevant known numerical methods used for solving the nonlinear equations have been applied in developing power flow models. Among various methods, ***power*** flow models based on the Newton- Raphson (NR) method have been found to be most reliable. Many decoupled polar versions of the NR method have been attempted for reducing the memory requirement and computation time involved for power flow solution. Among decoupled versions, the fast decoupled load flow (FDLF) model developed

Nanda J. et al [8] proposed a model of General Purpose Fast Decoupled Power Flow Model, all network shunts such as line charging, external shunts at buses, shunts formed due to ***II*** representation of off-nominal in-phase transformers etc. are treated as constant impedance loads. The effect of line resistances is considered while forming the ***[B']*** matrix. The main aim of the presented work was to develop a fast decoupled power flow (FDPF) model which suits both normal and ill-conditioned systems and also to show clearly the role of the line series resistances on the convergence behavior of the FDPF models.

Eid R. et al [9] presented an Improved Fast Decoupled Power Flow Method (IFDPFM) based on different strategies of updating the voltage angle (δ) and the bus voltage (V) in each iteration. This method was tested on many bus test systems. When compared with the Newton-Raphson's and with the classical Fast Decoupled methods, the IFDPFM resulted in large computing savings in the order of 70 %, thus in faster convergence.

Aravindhababu P [10] presented a new, robust, and fast technique to obtain the load flow solution in distribution networks. The proposed method is based on the Newton- Raphson's technique using equivalent current-injection and rectangular coordinates. The load flow problem is considered as an optimization problem and is decoupled into two sub-problems. The assumptions on voltage magnitudes, angles, and r/x ratios necessary for decoupling the network in the conventional FDPF are eliminated in the proposed method. This method is simple, insensitive to r/x ratios of the distribution lines, and uses a constant Jacobian matrix. It is solved similar to FDPF.

Kumar K Vinoth and Selvan M.P [11] proposed a simple approach for load flow analysis of a radial distribution network. The proposed approach utilizes forward and backward sweep algorithm based on Kirchoff's current law (KCL) and Kirchoff's voltage law (KVL) for evaluating the node voltages iteratively. In this approach, computation of branch current depends only on the current injected at the neighboring node and the current in the adjacent branch. This approach starts from the end nodes of sub lateral line, lateral line and main line and moves towards the root node during branch current computation. The node voltage evaluation begins from the root node and moves towards the nodes located at the far end of the main, lateral and sub lateral lines.

Mekhamera S.F. et al [12] presented a new method for solving the load flow problem for radial distribution feeder, without solving the conventional well-known load flow methods. They should have high speed and low storage requirement, especially for real time large system application; they should also be highly reliable especially for ill-conditioned problem, outage studies and real time application.

Semlyen A et al. [14] described a new power flow method for solving weakly meshed distribution and transmission networks, using a multi-port compensation technique and basic formulations of Kirchhoff's laws. This method has excellent convergence characteristics and is very robust. A computer program implementing this power flow solution scheme was developed and successfully applied to several practical distribution networks with radial and weakly meshed structure. This program was also successfully used for solving radial and weakly meshed transmission networks.

Stott B [15] presented a survey on the currently available numerical techniques for power system load-flow calculation using the digital computer. The review deals with methods that have received widespread practical application, recent attractive developments, and other methods that have interesting or useful characteristics. The analytical bases, computational requirements, and comparative numerical performances of the methods are discussed.

Stott B. and Alsac O [16] paper described a simple, very reliable and extremely fast load-flow solution method with a wide range of practical application. It is useful for accurate or approximate off- and on-line routine and contingency calculations for networks of any size, and can be implemented efficiently on computers with restrictive core-store capacities. It combines many of the advantages of the existing "good" methods. The algorithm is simpler, faster and more reliable than Newton's method, and has lower storage requirements for entirely in-core solutions. The method is equally suitable for routine accurate load flows as for outage-contingency evaluation studies performed on- or off-line.

Tinney William.F. and Hart Clifford E [17] presented and concluded ac power flow problem can be solved efficiently by Newton's method. Only five iterations, each equivalent to about seven of the widely used Gauss-Seidel method, are required for an exact solution. The iterative methods converge slowly and are subject to ill-conditioned situations. Their memory requirements are minimal and directly proportional to problem size, but the number of iterations for solution increases rapidly with problem size. However, for large problems only the iterative methods have proved practical. Now that larger systems than ever before are being studied, the need for a better method is becoming increasingly urgent. The purpose of this method is to described an improved version of one of the previously published direct methods which offers a definite margin of advantage over other methods for any size or kind of problem. The characteristics of this method is high speed, accurate and less memory requirement etc.

Das D. et al. [18] had proposed a load-flow technique for solving radial distribution networks by calculating the total real and reactive power fed through any node. They have proposed a unique node, branch and lateral numbering scheme which helps to evaluate exact real and reactive power loads fed through any node. Methods developed for the solution of ill-conditioned radial distribution systems may be divided into two categories. The first group of methods is based on the forward-backward sweep process for solution of ladder networks. On the other hand, the second group of methods is utilized by proper modification of existing methods such as Newton-Raphson's.

Rajicic D et al [20] presented a method for power flow solution of weakly meshed distribution and transmission networks. It is based on oriented ordering of network elements. That allows an efficient construction of the loop impedance matrix and rational organization of the processes such as: power summation (backward sweep), current summation (backward sweep) and node voltage calculation (forward sweep). The first step of the algorithm is calculation of node voltages on the radial part of the network. The second step is calculation of the breakpoint currents.

Ghosh S and Das D. [21] proposed a method involves only the evaluation of a simple algebraic expression of receiving-end voltages. The main aim of the authors has been to developed a new load-flow technique for solving radial distribution networks. The proposed method involves only the evaluation of a simple algebraic expression of receiving-end voltages. The proposed method is very efficient. It is also observed that the proposed method has good and fast convergence characteristics. Loads in the present formulation have been presented as constant power. However, the proposed method can easily include composite load modeling, if the composition of the loads is known. Several radial distribution feeders have been solved successively by using the proposed method. The speed requirement of the proposed method has also been compared with other existing methods.

Rajicic D and Tamura Y [22] a modification to the FDLF is presented named MFDLF. It is shown that its convergency is much better than that of FDLF for ill conditioned systems. In this, it is done by multiplying unitary (rotation) operators to the bus injection complex power and each row of the admittance matrix. In the literature, other methods have been proposed for improving FDLF's convergency. But these methods suffer from slower convergency if a transmission line is a part of a loop.

Hawkins E.S et al [24] described a computerized method of calculating unbalanced load flow or fault currents on multi-grounded radial distribution circuits. It was developed by engineers of the Baltimore Gas and Electric Company, and is now being used in operating and expanding their distribution system. The basic concept employed is that the electrical characteristics of any portion of an unbalanced 3-phase circuit can be represented by a 6-element wye-delta network. Program input consists of power and coincidence factors, source voltage, wire-size and length of branches, and loads of transformers. Program outputs can be any or all of the following: phase-to neutral voltages, phase and neutral amperes, phase angles, real and reactive line losses, and such quantities as kVA, kvar, and kW flow.

Willis L and Kersting W.M [28] presented the complete data for three four-wire wye and one three-wire delta radial distribution test feeders. The purpose of publishing the data was to make available a common set of data that could be used by program developers and users to verify the correctness of their solutions.

Mok H.M. et al [39] reported on an efficient method of power flow analysis for solving balanced and unbalanced radial distribution systems. The radial distribution system is modeled as a series of interconnected single feeders. Using Kirchhoff's laws, a set of iterative power flow equations was developed to conduct the power flow studies. For the purpose of power flow study, the radial distribution system is modeled as a network of buses connected by distribution lines or switches connected to a voltage specified source bus. Each bus may also have a corresponding bus load, compensating load (shunt capacitor or inductor), lateral load and/or co-generator connected to it.

Abu-Mouti F.S. and El-Hawary M.E. [43] presented a new procedure for solving the power flow for radial distribution feeders taking into account embedded distribution generation sources and shunt capacitors. The proposed algorithm procedures are tested on sample feeder systems. In this, the equations are modified and the iterative procedures proposed are completely different. Also, new approximation formulas are proposed to reduce the number of solution required iterations. The result improves the power flow algorithm performance. Three test feeder systems are considered and solved by this proposed technique and the results are compared with those of other methods. The complex voltages and currents solved by basic phase relations.

1.5 Structure of the Thesis

Chapter 1 presents the introduction of distribution system, load-flow, literature survey on load-flow and distribution system, objectives of the research, scope of the research and organization of the research.

Chapter 2 Introduction to distribution systems is given where various basics have been introduced. Types of existing distribution system models have also been discussed, a thorough analysis has been done on the existing methods. History of distribution system, modern distribution system, requirement of distribution system etc. is also explained in this chapter.

Chapter 3 In this chapter various assumptions, various load flow methods are first explained, followed by constraints concerned to load flow for distribution system. Significance of load flow, need of load flow, different types of load flow methods is also discussed.

Chapter 4 The role of power flow in distribution system is explained in this chapter thoroughly. The methods used for this purpose is also explained. Newton-Raphson’s and Fast Decoupled Load flow solutions are used to solve this purpose. The algorithm of both these methods are also explained.

Chapter 5 Results and Discussion.

Chapter 6 Conclusion and Scope for Future Work.

1.6 Aim of thesis

In this thesis work, the main aim was to develop a computer algorithm for radial distribution system based on an efficient load flow technique developed in Ref. [1]. The load flow technique used is Fast Decoupled Power Flow analysis for unbalanced radial distribution system. The proposed method has the capability to consider lateral branches. It also considers voltage constraint. We can calculate the reactive power, active power, path loss and voltage in each bus number in a radial distribution system.

CHAPTER-2

DISTRIBUTION SYSTEM

2.1 Electricity Distribution

Electrical Distribution is the final stage in the delivery of electricity to end users. A distribution system's network carries electricity from the transmission system and delivers it to consumers. Typically, the network would include medium-voltage (less than 50 kV) power lines, electrical substations and pole-mounted transformers, low-voltage (less than 1000 V) distribution wiring and sometimes electricity meters. So that the part of power system used for distribution of electric power for local use is known as distribution system.

In general, the distribution system is the electrical system between the substation fed by the transmission system and the consumers' meters.

2.2 Power Distribution System

Distribution networks have typical characteristics. The aim of this article is to introduce distribution networks design and establish the distinction between country and urban distribution networks.

2.2.1 Global Design of Distribution Networks

The electric utility system is usually divided into three subsystems which are generation, transmission, and distribution. A fourth division, which sometimes is made, is sub transmission. However, the latter can really be considered as a subset of transmission since the voltage levels and protection practices are quite similar. The distribution system is commonly broken down into three components: distribution substation, distribution primary and secondary. At the substation level, the voltage is reduced and the power is distributed in smaller amounts to the customers. Consequently, one substation will supply many customers with power. Thus, the number of transmission lines in the distribution systems is many times that of the transmission systems. Furthermore, most customers are connected to only one of the three phases in the distribution system. Therefore, the power flow on each of the lines is different and the system is typically ‘unbalanced’. This characteristic needs to be accounted for in load-flow studies related to distribution networks.

Figure 2.1 shows the single line diagram of a typical low tension distribution system.

(i) Feeders: A feeder is a conductor, which connects the sub-station (or localized generating station) to the area where power is to be distributed. Generally, no toppings are taken from the feeder so that the current in it remains the same throughout. The main consideration in the design of a feeder is the current carrying capacity.

(ii) Distributor: A distributor is a conductor from which tapping are taken for supply to the consumers. In Figure2.1, AB, BC, CD, and DA are the distributors. The current through a distributor is not constant because tapping are taken at various places along its length. While designing a distributor, voltage drop along its length is the main consideration since the statutory limit of voltage variations is ±10% of rated value at the consumer’s terminals.

(iii) Service mains: A service mains is generally a small cable which connects the distributor to the consumer’s terminals.

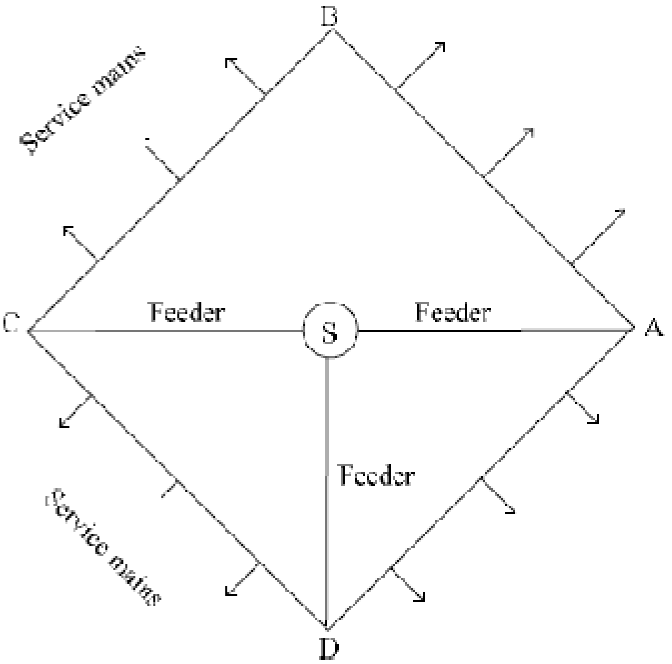


Figure 2.1 The single line diagram of a typical low tension distribution system.

2.3 History of Distribution System

In the early days of electricity distribution, direct current DC generators were connected to loads at the same voltage. The generation, transmission and loads had to be of the same voltage because there was no way of changing DC voltage levels, other than inefficient motor-generator sets. Low DC voltages were used (on the order of 100 volts) since that was a practical voltage for incandescent lamps, which were then the primary electrical load. The low voltage also required less insulation to be safely distributed within buildings.

The losses in a cable are proportional to the square of the current, the length of the cable, and the resistivity of the material, and are inversely proportional to cross-sectional area. Early transmission networks were already using copper, which is one of the best economically feasible conductors for this application. To reduce the current and copper required for a given quantity of power transmitted would require a higher transmission voltage, but no convenient efficient method existed to change the voltage level of DC power circuits. To keep losses to an economically practical level the Edison DC system needed thick cables and local generators.

2.4 Modern Distribution System

The modern distribution system begins as the primary circuit leaves the sub-station and ends as the secondary service enters the customer's meter socket. A variety of methods, materials, and equipment are used among the various utility companies, but the end result is similar. First, the energy leaves the sub-station in a primary circuit, usually with all three phases.

The most common type of primary is known as a **Wye configuration** (so named because of the shape of a "Y".) The Wye configuration includes 3 phases (represented by the three outer parts of the "Y") and a neutral (represented by the centre of the "Y".) The neutral is grounded both at the substation and at every power pole.

The other type of primary configuration is known as **delta**. This method is older and less common. Delta is so named because of the shape of the Greek letter delta, a triangle. Delta has only 3 phases and no neutral. In delta there is only a single voltage, between two phases (phase to phase), while in Wye there are two voltages, between two phases and between a phase and neutral (phase to neutral). Wye primary is safer because if one phase becomes grounded, that is, makes connection to the ground through a person, tree, or other object, it should trip out the circuit breaker tripping similar to a household fused cut-out system. In delta, if a phase makes connection to ground it will continue to function normally. It takes two or three phases to make connection to ground before the fused cut-outs will open the circuit. The voltage for this configuration is usually 4800 volts.

2.5 Requirement of Distribution system

A considerable amount of effort is necessary to maintain an electric power supply within the requirements of various types of consumers. Some of the requirements of a good distribution system are: proper voltage, availability of power on demand, and reliability

2.5.1 Proper Voltage: One important requirement of a distribution system is that voltage variations at consumers' terminals should be as low as possible. The changes in voltage are generally caused due to the variation of load on the system. Low voltage causes loss of revenue, inefficient lighting and possible burning out of motors. High voltage causes lamps to burn out permanently and may cause failure of other appliances. Therefore, a good distribution system should ensure that the voltage variations at consumers' terminals are within permissible limits. The statutory limit of voltage variations is ±10% of the rated value at the consumers' terminals. Thus, if the declared voltage is 230 V, then the highest voltage of the consumer should not exceed 244 V while the lowest voltage of the consumer should not be less than 216 V.

2.5.2 Availability of Power Demand: Power must be available to the consumers in any amount that they may require from time to time. For example, motors may be started or shut down, lights may be turned on or off, without advance warning to the electric supply company. As electrical energy cannot be stored, therefore, the distribution system must be capable of supplying load demands of the consumers. This necessitates that operating staff must continuously study load patterns to predict in advance those major load changes that follow the known schedules.

2.5.3 Reliability: Modern industry is almost dependent on electric power for its operation. Homes and office buildings are lighted, heated, cooled and ventilated by electric power. This calls for reliable service. Unfortunately electric power, like everything else that is man-made, can never be absolutely reliable. However, the reliability can be improved to a considerable extent by (a) inter-connected system, (b) reliable automatic control system and (c) providing additional reserve facilities.

2.6 Classification of Distribution System

A distribution system may be classified according to:

(i) Nature of current: According to nature of current, distribution system may be classified as (a) d.c. distribution system and (b) a.c. distribution system. Now-a-days a.c. system is universally adopted for distribution of electric power as it is simpler and more economical than direct current method.

(ii) Type of construction: According to type of construction, distribution system may be classified as (a) overhead system and (b) underground system. The overhead system is generally employed for distribution as it is 5 to 10 times cheaper than the equivalent underground system. In general, the underground system is used at places where overhead construction is impracticable or prohibited by the local laws.

(iii) Scheme of connection: According to scheme of connection, the distribution system may be classified as (a) radial system, (b) ring main system and (c) inter-connected system. Each scheme has its own advantages and disadvantages.

2.7 Essential Parts of Distribution System

Various type of distribution system have identical subsystems and components. These components can be connected and configured in various alternative ways depending upon the area covered, load density, type and importance of consumer, reliability and freedom from interruption desired, cost of land and right of way available.

A. Sub-transmission Circuits.
B. Distribution Substations.
C. Primary Distribution Circuit.
D. Distribution Transformers.
E. Secondary Distribution System.

TABLE 2.1 ELEMENTS OF DISTRIBUTION SYSTEMS

Sr. No.	ELEMENT	FUNCTION	REMARKS
1.	Sub transmission circuits	To receive power from main bulk power receiving station and delivering power to the distribution substations	1. 3 – phase 3 wire AC system at 50 Hz. 2. High voltage overhead lines 66kV/33kV. 3. Radial/loop/ring/mesh configurations.
2.	Distribution substations	1. To step down voltage received from sub transmission level. 2. To feed primary distribution circuits. 3. To arrange switching protection, metering, control.	1. Out door air insulated or indoor SF_6 gas insulated. 2. Two voltage level buses. 3. Located near load centre.
3.	Primary distribution system	To feed power to various distribution transformers trough primary feeder.	1. Radial modified radial, loop ring circuit. 2. High voltage for higher load densities.
4.	Distribution transformers	To step down voltage to secondary distribution level.	It steps down voltage to 415V level. Distribution transformers are generally pole mounted, foundation mounted. Typical rating of transformer is 100 KVA to 500 KVA.
5.	Secondary distribution system	To fed the consumer	1. Overhead + underground distribution lines. 2. Radial network. 3. 3 – phase 4 wire system with grounded neutral. 4. Service mains & service network.

2.8 A.C. Distribution System

Nowadays electrical energy is generated, transmitted and distributed in the form of alternating current. One important reason for the widespread use of alternating current in preference to direct current is the fact that alternating voltage can be conveniently changed in magnitude by means of a transformer. Transformer has made it possible to transmit a.c. power at high voltage and utilize it at a safe potential. High transmission and distribution voltages have greatly reduced the current in the conductors and the resulting line losses.

There is no definite line between transmission and distribution according to voltage or bulk capacity. However, the down sub-station is fed by the transmission system and the consumers' meters. The a.c. distribution system is classified into (i) primary distribution system and (ii) secondary distribution system.

(i) Primary Distribution System: It is part of a.c. distribution system, which operates a voltages somewhat higher than general utilization and handles large blocks of electrical energy than the average low-voltage consumer uses.

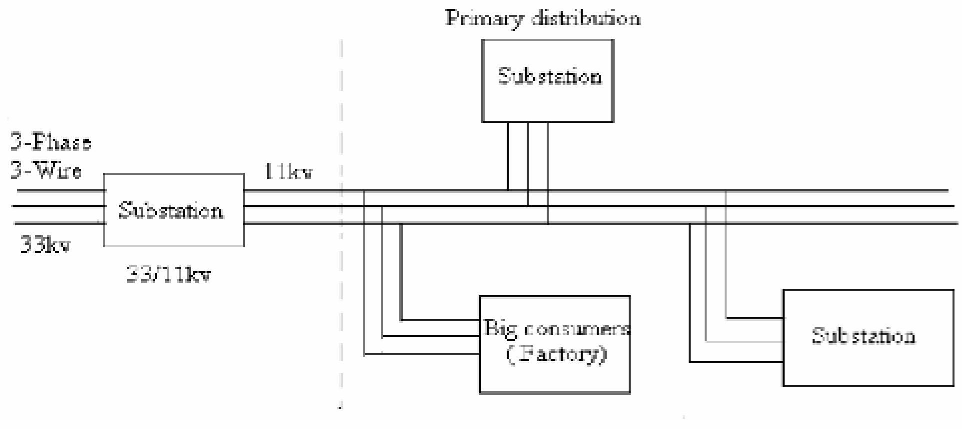


Figure 2.2 Primary Distribution Systems.

The voltage used for primary distribution depends upon the amount of power to be conveyed and the distance of the sub-station required to be fed. The most commonly used primary distribution voltages are 22 kV, 6.6 kV and 2.2 kV. Due to economic considerations, primary distribution is carried out by 3-phase, 3-wire system. Figure 2.2 shows a typical primary distribution system. Electric power from the generating station is transmitted at high voltage to the sub-station located in or near the city. At this sub-station, voltage is stepped down to 11kV with the help of step-down transformer. Power is supplied to various sub-stations for distribution or to big consumers at this voltage. This forms the high voltage distribution or primary distribution.

(ii) Secondary Distribution System: It is that part of a.c. distribution system that includes the range of voltages at which the ultimate consumer utilizes the electrical energy delivered to him. The secondary distribution employs 400/230 V, 3-phase, 4-wire system. Figure 2.3 shows a typical secondary distribution system.

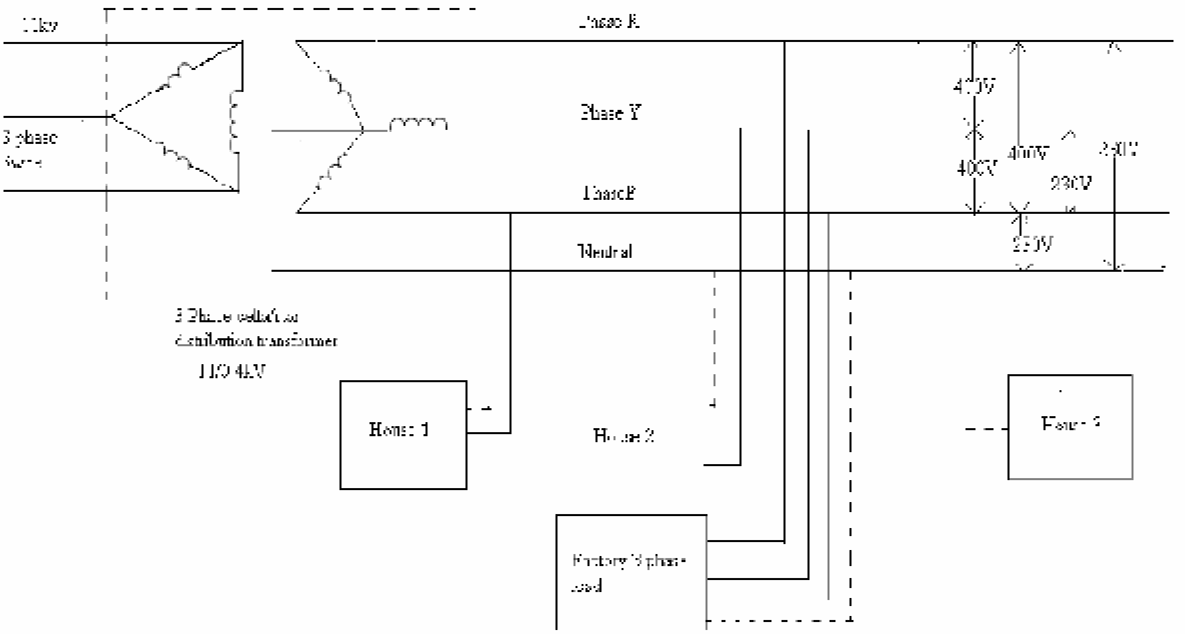


Figure 2.3 Secondary Distribution Systems.

The primary distribution circuit delivers power to various sub-stations, called distribution sub-stations. The sub-stations are situated near the consumer's localities and contain step-down transformers. At each distribution sub-station, the voltage is stepped down to 400 V and power is delivered by 3-phase, 4-wire a.c. system. The voltage between any two phases in 400 V and between any phase and neutral is 230. The single phase domestic loads are connected between any one phase and the neutral whereas 3-phase 400 V motor loads are connected across 3-phase lines directly.

2.9 Direct Current System

Direct current systems usually consist of two or three wires. Although such distribution systems are no longer employed, except in very special instances, older ones now exist and will continue to exist for some time. Direct current systems are essentially the same as single- phase ac systems of two or three wires; the same discussion for those systems also applies to dc systems.

2.10 Over Head versus Underground System

The distribution system can be overhead or underground. Overhead lines are generally mounted on wooden, concrete or steel poles which are arranged to carry distribution transformers in addition to the conductors. The choice between overhead and underground system depends upon a number of widely differing factors.

1. Public Safety:- The underground system is more safe than overhead system because all distribution wiring is placed underground and there are little chances of any hazard.

2. Initial Cost:- The underground system is more expensive due to the high cost of trenching, conduits, cables, manholes, and other special equipments. The initial cost of an underground system may be five to ten times than that of an overhead system.

3. Flexibility:- The overhead system is much more flexible than the underground system. In the latter case, manholes, duct lines etc., are permanently placed once installed and the load expansion can only be met by laying new lines. However on an overhead system, poles, wires, transformer etc., can be easily shifted to meet the change in load conditions.

4. Faults:- The chances of fault in underground system are very rare as the cables are laid underground and are generally provided with better insulation.

5. Appearance:- The general appearance of an underground system is better as all the distribution lines are visible. This factor is exerting considerable public pressure on electric supply companies to switch over to underground system.

6. Fault location and repairs:- In general, there are little chances of fault in an underground system. However, if a fault does occur, it is difficult to locate and repair the system. On an overhead system, the conductors are visible and easily accessible so that fault locations and repairs can easily be made.

7. Current carrying capacity and voltage drop:- An overhead distribution conductor has a considerably higher current carrying capacity than an underground cable conductor of the same material and cross-section. On the other hand, underground cable conductor has much lower inductive reactance than that of an overhead conductor because of closer spacing of conductor.

8. Useful Life:- The useful life of underground system is much longer than that of an overhead system. An overhead system may have a useful life of 25 years, whereas an underground system may have a useful life of more than 50 years.

9. Maintenance cost:- The maintenance cost of underground system is very low as compared with that of overhead system because of less chances of fault and service interruptions from wind, ice, lightning as well as from traffic hazards.

10. Interference with communication circuits:- An overhead system causes electromagnetic interference with telephone lines. The power line currents are superimposed on speech currents, resulting in the potential of the communication channel being raised to an undesirable level. However, there is no such interference with the underground system.

2.11 Connection Scheme of Distribution System

All distribution of electrical energy is done by constant voltage system. In practice, the following distribution circuits are generally used. According to connection scheme the distribution system has three types as given below:

(i) Radial System.

(ii) Ring Main System.

(iii)Interconnected system.

2.12 Radial Distribution System

A radial system has only one power source for a group of customers. A power failure, short-circuit, or a downed power line would interrupt power in the entire line which must be fixed before power can be restored. The figure of Radial Distribution System is shown as :-

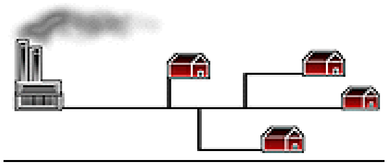


Figure 2.4 Radial Distribution System

In this system, separate feeders radiate from a single sub-station and feed the distributors at one end only. Figure 2.5 (a) shows a single line diagram of a radial system for d.c. Distribution where a feeder OC supplies a distributor AB at point A. Obviously, the distributors are fed at one point only i.e. point A in this case. Figure 2.5 (b) shows a single line diagram of radial system for a.c. distribution. The radial system is employed only when power is generated at low voltage and the sub-station is located at the centre of load. This is the simplest distribution circuit and has the lowest initial cost.

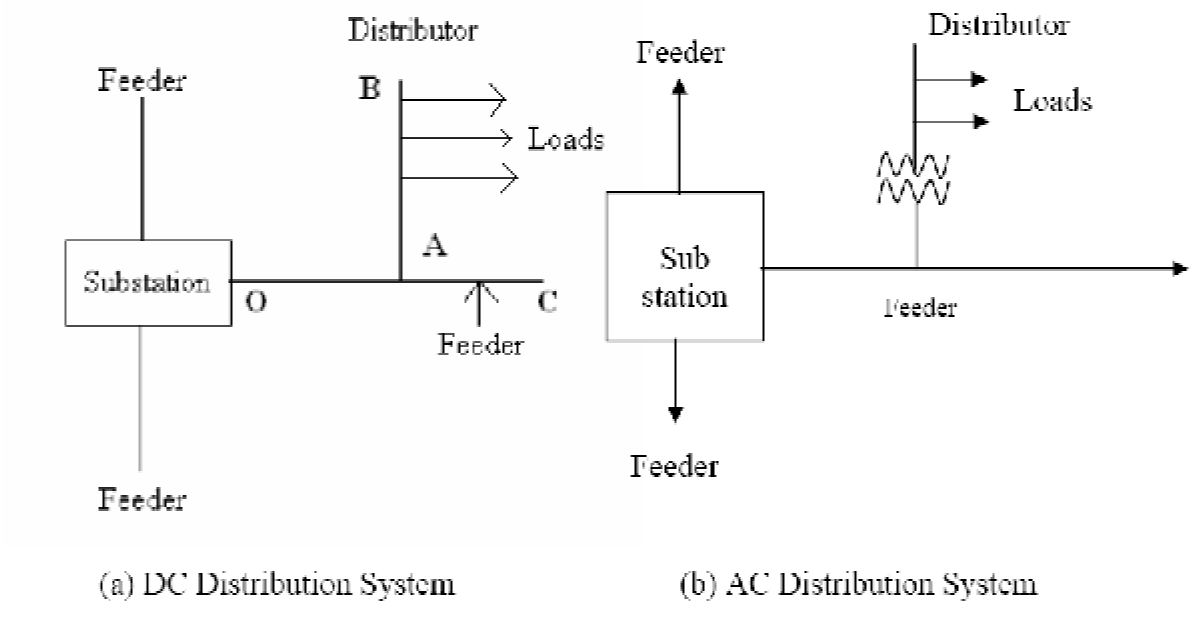


Figure 2.5 Single Line Diagram of Radial Distribution System

29−Node Radial Distribution Network:-

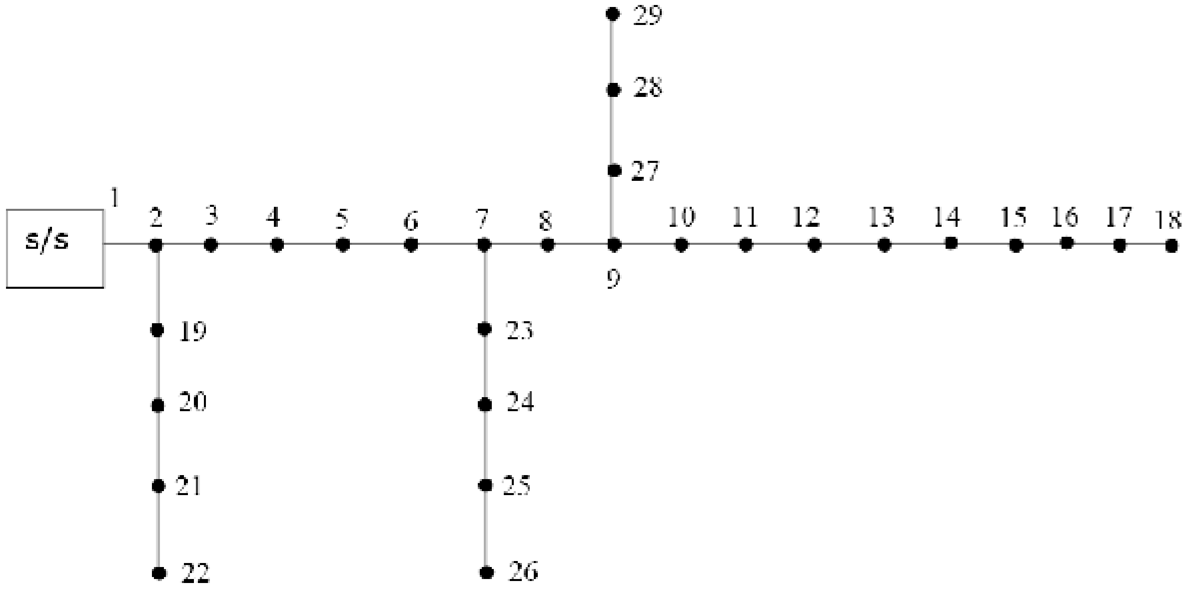


Figure 2.6 29-Node Radial Distribution System.

2.12.1 Objectives of Radial Distribution System:-

1. Planning, modernization and automation.
2. To provide service connection to various urban, rural and industrial consumer in the allocated area.
3. Maximum security of supply and minimum duration of interruption.
4. Safety of consumers, utility personnel.
5. To provide electricity of accepted quality in terms of :-
    (a) Balanced three phase supply.
    (b) Good power factor.
    (c) Voltage flicker within permissible limits.
    (d) Less voltage dips.
    (e) Minimum interruption in power supply.

2.12.2 Advantages of Radial Distribution System:-

(a) Radial distribution system is easiest and cheapest to build.

(b) The maintenance is easy.

(c) It is widely used in sparsely populated areas.

2.12.3 Drawback of Radial Distribution System:-

(a) The end of the distributor nearest to the feeding point will be heavily loaded.

(b) The consumers are dependent on a single feeder and single distributor. Therefore, any fault on the feeder or distributor cuts off supply to the consumers who are on the side of the fault away from the sub-station.

(c) The consumers at the distant end of the distributor would be subjected to serious voltage fluctuations when the load on the distributor changes.

2.13 Ring Main System:

In this system, the primaries of distribution transformers are from a loop. The loop circuit starts from the sub-station bus bars, makes a loop through the area to be served, and returns to the substation.

Figure 2.7 shows the single line diagram of ring main system for a.c. Distribution where sub-station supplies to the closed feeder LMNOPQRS and Q of the feeder through distribution transformers.

The ring main system has the following advantages:

(a) There are less voltage fluctuations at consumer's terminals

(b) The system is very reliable as each distributor is fed via two feeders. In the event of fault on any section of the feeder, the continuity of supply is maintained. For example, suppose that fault occurs at any point F of section SLM of the feeder. Then section SLM of the feeder can be isolated for repairs and at the same time continuity of supply is maintained to all the consumers via the feeder SRQPONM.

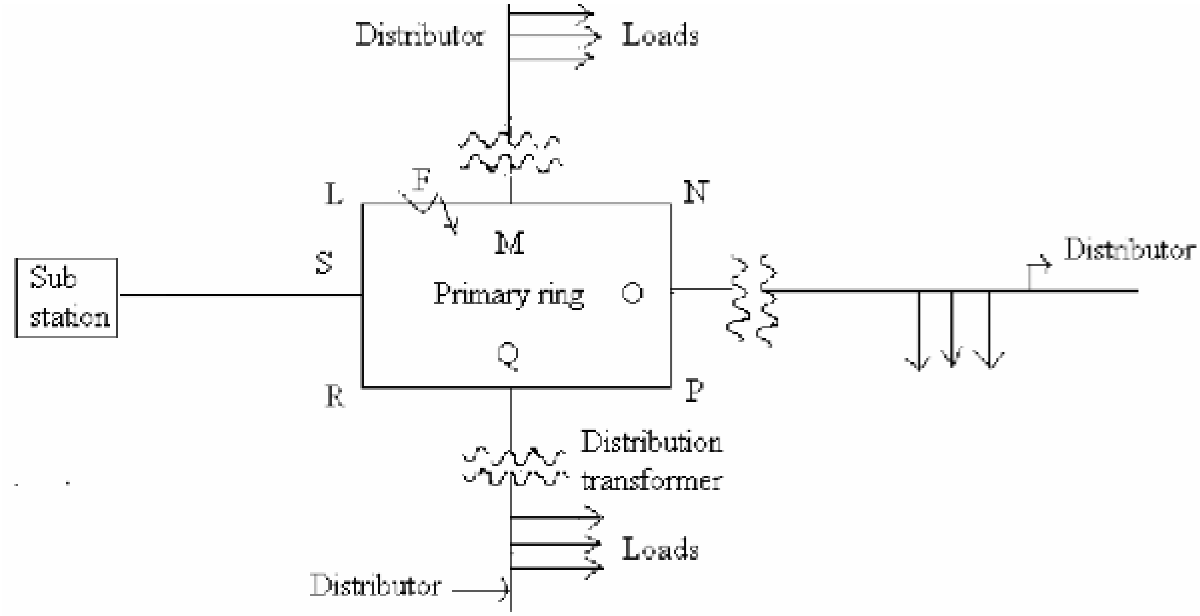


Figure 2.7 Ring Main System.

2.14 Interconnected System:

When the feeder ring is energized by two or more than two generating stations or sub stations, it is called interconnected system. Figure 2.8 shows the single line diagram of interconnected system where the closed feeder ring ABCD is supplied by two sub-stations S1 and S2 at points D and C respectively. Distributors are connected to points O, P, Q and R of the feeder ring through distribution transformers.

The interconnected system has the following advantages:

(a) It increases the service reliability.

(b) Any area fed from one generating station during peak load hours can be fed from the other generating station. This reduces reserve power capacity and increases efficiency of the system.

The figure for the interconnected distribution system is given following as 2.8

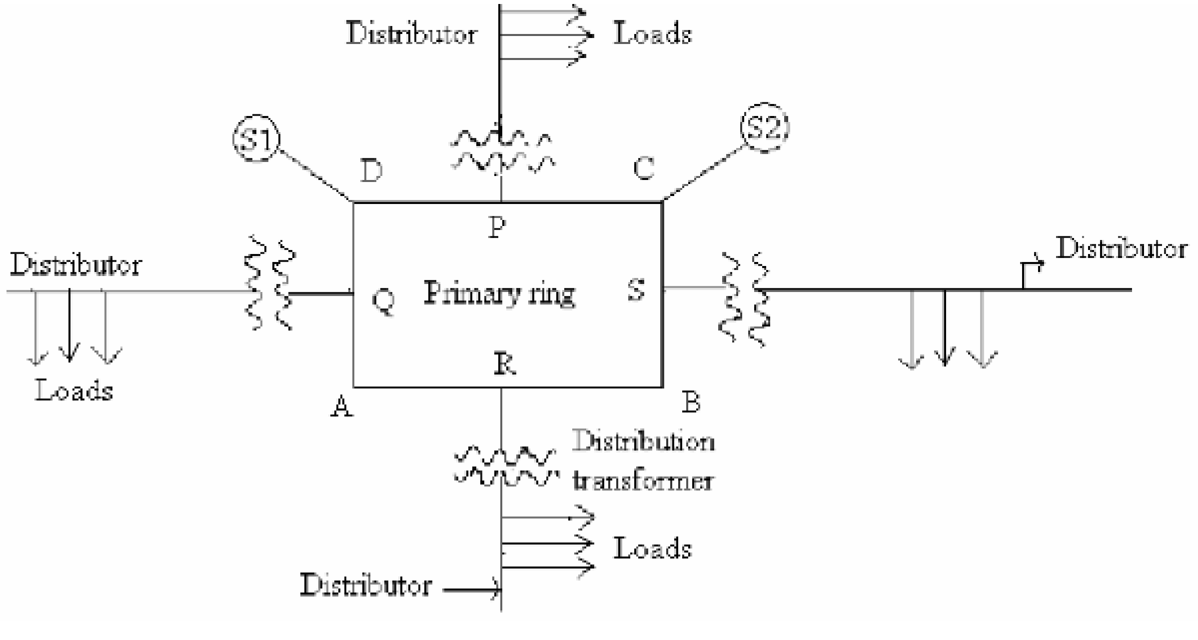


Figure 2.8 Interconnected System.

CHAPTER-3

LOAD FLOW

3.1 Power Flow Analysis

The electric power system is one of the tools for converting and transporting energy, which is playing an important role in meeting the challenges of modern life.

Planning the operation, looking out for a scope of expansion in future, all require a proper load flow study of the system, transient behavior of the system as well as correct analysis of fault and methods to mitigate the effects of the same.

Load flow analysis aims at determination of system parameters like voltage, current, power factor power (real and reactive) flow at various points in the electric system under existing conditions of normal operation. This analysis helps in determining the scope of future expansion of the system.

In power system powers are known rather than currents. Thus the resulting equations in terms of power, known as *power flow equation*, become non linear and must be solved by iterative techniques. Power flows studies, commonly referred to as *load flow*, are the backbone of power system analysis and design. They are necessary for planning, operation, economic scheduling and exchange of power between utilities. In addition, power flow analysis is required for many other analyses such as transient stability and contingency studies.

The two primary considerations in the development of an effective engineering computer program are:

(1) The formulation of a mathematical description of the problem; and

(2) The application of a numerical method for a solution.

The analysis of the problem must also consider the interrelation between these two factors. The mathematical formulation of the problem results in a system of algebraic nonlinear equations.

The load flow problem consists of calculation of power flow and voltages of a network for specified terminal or bus conditions. A single phase representation is adequate since power systems are usually balanced. First the power and load shared by each of the generators is calculated during the course of normal operation. Then the effect on bus system on changing the load requirement will be seen.

The power flow analysis is a very important and fundamental tool in power system analysis. Power flow analysis plays the major role during the operational stages of any system for its control and economic schedule, as well as during expansion and design stages. The purpose of any load flow analysis is to compute precise steady-state voltages and voltage angles of all buses in the network, the real and reactive power flows into every line and transformer, under the assumption of known generation and load.

Successful operation of electrical systems requires that :-

a. Generation must supply the demand (load) plus the losses.

b. Bus voltage magnitudes must remain close to rated values.

c. Generators must operate within specified real and reactive power limits.

d. Transmission lines and transformers should not be overloaded for long periods.

The voltages and power flows in an electrical system can be determined for a given set of loading and operating conditions. This is known as the *power flow* problem. Power flow analysis is used extensively in the planning, design and operation of electrical systems.

In power flow analysis, it is normal to assume that the system is balanced and that the network is composed of constant, linear, lumped-parameter branches. (In the most basic form of the power flow, transformer taps are assumed to be fixed. This assumption is relaxed in commercial power flows though.). Therefore nodal analysis is generally used to describe the network. However, because the injection/demand at bus-bars is generally specified in terms of real and reactive power, the overall problem is nonlinear. Accordingly, the power flow problem is a set of simultaneous nonlinear algebraic equations. Numerical techniques are required to solve this set of equations.

3.2 Need of Load Flow Study

Load flow study in power system is the steady state solution of power system network .The power system is modeled by an electric network and solve for steady state power and voltage at various buses .The direct analysis of circuits is not possible as the loads are given in terms of complex powers rather than impedances and the generators behaves more like power source than voltage source.

3.3 Significance of Load Flow Study

1. Determination of current, voltage, active power, reactive power etc. at various buses in power system operating under normal steady state or static condition.
2. To plan best operation and control of existing system.
3. To plan future expansion to keep pace with load growth.
4. Help in ascertaining the effect of new load, new generating stations, new lines and new interconnections before they are installed.
5. Due to this information system losses are minimized and also check is provided on system stability.
6. Provides the proper prefault power system analysis to avoid system outage due to fault.

3.4 Information Obtained from Load flow Studies

1. Magnitude of voltages (Vi) .
2. Phase angle of voltages (δi) .
3. Active power (Pi) .
4. Reactive power (Qi)

3.5 Methods Used to Solve Static Load Flow Equations

It is important to note that the voltages and power flows in an electrical system can be determined for a given set of loading and operating conditions. This is known as the ***power flow*** problem. Power flow analysis is used extensively in the planning, design and operation of ,electrical systems.

The solution of static load flow equation is difficult because of non linear characteristics of equations as bus voltages are involved in product form and sine, cosine terms are present. Hence solutions are possible through only iterative numerical techniques.

Following methods are used to solve static load flow equation:

1. GAUSS-SEIDEL METHOD.

2. NEWTON RAPHSON METHOD.

3. FAST DECOUPLE METHOD.

3.5.1 The Advantages of These Methods used in Distribution System are

a) They should have high speed and low storage requirements, especially for real-time large system applications, as well as multiple case and interactive applications.
b) They should be highly reliable, especially for ill-conditioned problems, outage studies, and real-time applications.
c) They should have acceptable versatility and simplicity.

3.6 Constraints at Nodes

Four variables are associated with each node:-

a. Bus voltage magnitude (V).
b. Voltage angle (θ).
c. Real power (P).
d. Reactive power (Q).

Each node introduces two equations, namely the real and reactive power balance equations. To obtain (isolated) solutions for a set of simultaneous equations, it is necessary to have the same number of equations as unknowns. Therefore two of the variables associated with each bus must be specified, i.e., given fixed values. The other two variables are free to vary during the solution process.

The traditional way of specifying bus-bar quantities allows buses to be identified as follows:-

3.6.1 *PQ* Bus-bar:- At which the net active and reactive powers are specified. The net power entering a bus-bar is the power supplied to the system from a generating source minus the power consumed by a load at that bus-bar.

3.6.2 *PV* Bus-bar:- At which the net active power is specified, and the voltage magnitude is specified.

The net reactive power is an unknown which is determined as part of the power flow solution. This type of bus-bar typically represents a node in the system at which a synchronous source (generator or compensator) is connected, where the source's reactive power output is varied to control the voltage magnitude to a scheduled value.

3.6.3 Slack or Swing Bus-bar:- Where the voltage magnitude and angle are specified.

Generally the angle is set to zero. Unlike the other two bus types, which represent physical system conditions, this bus-bar type is more a mathematical requirement. It is needed to provide a 'reference' angle to which all other angles are referred. Also, this bus absorbs any real power mismatch across the system. (Note that it is not possible to specify the net active power at all buses in the system, because transmission losses are unknown until the power flow solution is completed.) Normally there can only be one slack bus-bar in the system. It is generally chosen from among the voltage controlled bus-bars.

3.7 Choice of Variables

Basically load-flow analysis deals with known real and reactive power flows at each bus, and those voltage magnitudes that are explicitly known, and from this information calculating the remaining voltage magnitudes and all the voltage angles. We are familiar with the notion of organizing the descriptive variables of the circuit into categories of "knowns" and "unknowns," whose relationships can subsequently be expressed in terms of multiple equations.

For AC circuits, because we have introduced the dimension of time: unlike in DC, where everything is essentially static (except for the instant at which a switch is thrown), with AC we are describing an ongoing oscillation or movement. Thus each of the two main variables, voltage and current, in an AC circuit really has two numerical components: a magnitude component and a time component. By convention, AC voltage and current magnitude are described in terms of root-mean-squared (r.m.s.) values and their timing in terms of a phase angle, which represents the shift of the wave with respect to a reference point in time . To fully describe the voltage at any given node in an AC circuit, we must, therefore, specify two numbers: a voltage magnitude and a voltage angle. Accordingly, when we solve for the currents in each branch, we will again obtain two numbers: a current magnitude and a current angle.

When we consider the amount of power transferred at any point of an AC circuit, we again have two numbers: a real and a reactive component. An AC circuit thus requires exactly two pieces of information per node in order to be completely determined. More than two, and they are either redundant or contradictory; fewer than two and possibilities are left open so that the system cannot be solved. Owing to the nonlinear nature of the load-flow problem, it may be impossible to find one unique solution because more than one answer is mathematically consistent with the given configuration. However, it is usually straightforward in such cases to identify the “true” solution among the mathematical possibilities based on physical plausibility and common sense. Conversely, there may be no solution at all because the given information was hypothetical and does not correspond to any situation that is physically possible. Still, it is true in principle—and most important for a general conceptual understanding that two variables per node are needed to determine everything that is happening in the system. In practice, current is not known at all; the currents through the various circuit branches turn out to be the last thing that we calculate once we have completed the load-flow analysis. Voltage, as we will see, is known explicitly for some buses but not for others. More typically, what is known is the amount of power going into or out of a bus.

Load-flow analysis consists of taking all the known real and reactive power flows at each bus, and those voltage magnitudes that are explicitly known, and from this information calculating the remaining voltage magnitudes and all the voltage angles. This is the hard part. The easy part, finally, is to calculate the current magnitudes and angles from the voltages. We know how to calculate real and reactive power from voltage and current: power is basically the product of voltage and current, and the relative phase angle between voltage and current determines the respective contributions of real and reactive power. Conversely, one can deduce voltage or current magnitude and angle if real and reactive power are given, but it is far more difficult to work out mathematically in this direction. This is because each value of real and reactive power would be consistent with many different possible combinations of voltages and currents. In order to choose the correct ones, we have to check each node in relation to its neighboring nodes in the circuit and find a set of voltages and currents that are consistent all the way around the system.

3.8 Summary of Variables in Load Flow Analysis

To summarize, our three types of buses in load flow analysis are PQ (load bus), PV (generator bus), and θ V (slack bus). Given these two input variables per bus, and knowing all the fixed properties of the system (i.e., the impedances of all the transmission links, as well as the AC frequency), we now have all the information required to completely and unambiguously determine the operating state of the system. This means that we can find values for all the variables that were not originally specified for each bus: θ and V for all the PQ buses; θ and Q for the PV buses; and P and Q for the slack bus. The known and unknown variables for each type of bus are shown in table 3.1

Table 3.1: Variables in Power Flow Analysis

Types of Bus	Variables Given (Knowns)	Variables Found (Unknowns)
Genrator	Real Power (P) Voltage magnitude (V)	Voltage angle (θ) Reactive Power (Q)
Load or Genrator	Real Power (P) Reactive power (P)	Voltage angle (θ) Voltage magnitude (V)
Slack	Voltage angle (θ) Voltage magnitude (V)	Real power (P) Reactive power (Q)

Once we know θ and V, the voltage angle and magnitude, at every bus, we can very easily find the current through every transmission link; it becomes a simple matter of applying Ohm’s law to each individual link. (In fact, these currents have to be found simultaneously in order to compute the line losses, so that by the time the program announces θ’ s and V’s, all the hard work is done.) Depending on how the output of a load-flow program is formatted, it may state only the basic output variables, as in it may explicitly state the currents for all trans-mission links in amperes; or it may express the flow on each transmission link in terms of an amount of real and reactive power owing, in megawatts (MW) and (MVAr).

3.9 Power Flow Solution

Power flow studies ,commonly known as load flow ,form an important part of power system analysis .They are necessary for planning ,economic rescheduling ,and control of existing system as well as planning its future expansion .The problem consists of determining the magnitudes and phase angle of voltages at each bus and active and reactive power flow in each line .

In solving a power flow problem, the system is assumed to be operating under balanced conditions and a single phase model is used .Four quantities are associated with each bus.

These are voltage magnitude $|V|$, phase angle δ, real power P, and reactive power Q. The system buses are generally classified into three types.

Slack bus one bus, known as slack or swing bus, is taken as reference where the magnitude and phase angle of the voltage are specified. This bus makes up the difference between the scheduled loads and the generated power that are caused by losses in the network.

Load buses at these buses the active and reactive powers are specified. The magnitude and phase angle of the bus voltages are unknown. These buses are called P-Q buses.

Regulated buses these buses are the generator buses. They are also known as voltage-controlled buses. At these buses, the real power and voltage magnitude are specified. The phase angles of the voltage and reactive power are to be determined. The limits on the value of reactive power are also specified. These buses are called P-V buses.

CHAPTER-4

ROLE OF POWER FLOW IN DISTRIBUTION SYSTEM

4.1 Introduction

Load flow analysis forms an essential prerequisite for power system studies. Considerable research has already been carried out in the development of computer programs for load flow analysis of large power systems. However, these general purpose programs may encounter convergence difficulties when a radial distribution system with a large number of buses is to be solved and, hence, development of a special program for radial distribution studies becomes necessary.

There are many solution techniques for load flow analysis. The solution procedures and formulations can be precise or approximate, with values adjusted or unadjusted, intended for either on-line or off-line application, and designed for either single-case or multiple-case applications.

Power flow method is a fundamental tool in application software for distribution management system. In the past decades, a mass of methods to solve the distribution power flow problem have been developed and well documented. These methods can be roughly categorized as node based methods and branch based methods.

The first category used node voltages or currents injection as state variables to solve power flow problem. In this category, the most notable methods include network equivalence method, Z-bus method, Newton–Raphson's algorithm, Fast Decoupled algorithm. The second category adopted branch currents or branch powers as state variables to solve power flow problem. The backward/forward sweep based methods and loop impedance methods can be categorized in this group.

We are discussing here the Newton Raphson's method and the Fast Decoupled Load Flow method for the distribution system. The Fast Decoupled method is the modified version of Newton Raphson's method.

4.2 General Purpose Newton Raphson's Method of Power flow Analysis

In solving a power flow problem, system is assumed to be operating under balanced conditions and a single phase model is used. Four quantities are associated with each bus. These are voltage magnitude |V|, phase angle δ, real power P, and reactive power Q.

The system buses are generally classified into three types:

Newton Raphson method is used for solving non linear algebraic equations. This method is successive approximation procedure based on initial estimate of unknown and use of Taylor series.

4.2.1 Power flow equation

Typical bus of a power system network shown in figure 4.1 as:

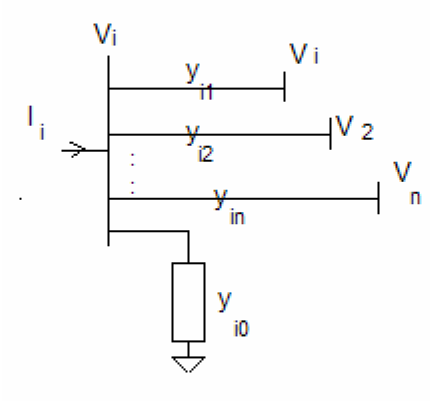


Figure 4.1 Typical bus of a power system network.

Applying kcl at this node

$$I_i = (y_{i0}+y_{i1}+y_{i2}+\dots y_{in})\ Vi-y_{i1}V_1-y_{i2}V_2-\dots -y_{in}V_{n\dots} \qquad \text{..…………...…(1)}$$

$$I_{i} = v_i \sum_{j=0}^{n} Y_{ij} - \sum_{j=0}^{n} Y_{ij} V_j \quad \text{where } j \neq I \qquad \text{……………. (2)}$$

$$P_i + JQ_i\, I_i = V_i\, I_i^*$$

Subsituting Ii from above equation into 2

$$(P_i - JQ_i)/V_i^* = V_i \sum_{j=0}^{n} Y_{ij} - \sum_{j=0}^{n} Y_{ij}\ V_j \quad \text{where } j \neq i \qquad \ldots\ldots\ldots\ldots\ldots(3)$$

Equqtion 2 can be written as below

$$I_i = \sum Y_{ij}\, V_j$$

Above equqtion in polar form

$$I_i = \sum |Y_{ij}||V_j| \angle\ \Theta_{ij} + \delta_{ij}$$

The complex power at bus i is

$$P_i - jQ_i = V_i^*\ I_i$$

Subsituting value of Ii in above equation is

$$P_i - jQ_i = |V_i| \angle -\ \delta_i \sum |Y_{ij}| \angle\ \Theta_{ij} + \delta_{ij}$$

Separating real and imaginary parts

$$P_i = \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \cos(\Theta_{ij} - \delta_i + \delta_j) \qquad \ldots\ldots\ldots\ldots\ldots (4)$$

$$Q_i = -\sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \sin(\Theta_{ij} - \delta_i + \delta_j) \qquad \ldots\ldots\ldots\ldots\ldots(5)$$

Above two equations constitute a set of non linear algebraic equations in terms of independent variables, voltage magnitude in per unit, and phase angle in radians. Expanding above two equations in Taylor series about initial estimate and neglecting all higher order terms results inset of equations of short form is given as follows:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix}$$

The diagonal and off diagonal elements of J1 are

$$\frac{\partial P_i}{\partial \delta_i} = \sum_{j \neq j}^{n} |V_i||V_j||Y_{ij}| \sin(\Theta_{ij} - \delta_i + \delta_j) \qquad \ldots\ldots\ldots\ldots\ldots (6)$$

$$\frac{\partial P_i}{\partial \delta_j} = -|V_i||V_j||Y_{ij}| \sin(\Theta_{ij} - \delta_i + \delta_j) \quad j \neq I \qquad \ldots\ldots\ldots\ldots\ldots (7)$$

The diagonal and off diagonal of J4 are

$$\frac{\partial Q_i}{\partial |V_i|} = -2\ |V_i||Y_{ii}|\sin\Theta_{ii} - \sum_{j\neq i}|V_i||Y_{ij}|\sin(\Theta_{ij} - \delta_i + \delta_j) \qquad \ldots\ldots\ldots\ldots\ldots(8)$$

$$\frac{\partial Q_i}{\partial |V_j|} = -\ |V_i||Y_{ii}|\ \sin(\Theta_{ij} - \delta_i + \delta_j) \qquad \ldots\ldots\ldots\ldots\ldots(9)$$

The terms $\Delta Pi^{(k)}$ and $\Delta Qi^{(k)}$ are the differences between the scheduled and calculated values,termed as power residuals, given by

$$\Delta Pi^{(k)} = Pi^{(sch)} -- Pi^{(k)} \qquad \ldots\ldots\ldots\ldots\ldots(10)$$

$$\Delta Qi^{(k)} = Qi^{(sch)} - Qi^{(k)} \qquad \ldots\ldots\ldots\ldots\ldots(11)$$

The new estimates for bus voltages are

$$\delta i^{(k+1)} = \delta i^{(k)} + \Delta\delta i^{(k)} \qquad \ldots\ldots\ldots\ldots\ldots(12)$$

$$|Vi^{(k+1)}| = |Vi^{(k)}| + \Delta|Vi^{(k)}| \qquad \ldots\ldots\ldots\ldots\ldots(13)$$

4.2.2 Algorithm for Newton Raphson method of Load Flow Analysis

The procedure for power flow solution by the Newton-Raphson method is as follows:

1. For load buses , where $Pi^{(sch)}$ and $Qi^{(sch)}$ are specified, voltage magnitudes and phase angles are set equal to the slack bus values , or 1.0 and 0.0, i.e., $|Vi^{(0)}| = 1.0$ and $\delta i^{(0)} = 0.0$. For voltage-regulated buses, where |Vi| and $Pi^{(sch)}$ are specified, phase angles are set equal to the slack bus angle, or 0, i.e., $\delta i^{(0)} = 0$.

2. For load buses, $P_i^{(k)}$ and $Q_i^{(k)}$ are calculated from (4)and (5)and $\Delta P_i^{(k)}$ and $\Delta Q_i^{(k)}$ are calculated (10) and (11).

3. For voltage-controlled buses, $P_i^{(k)}$ and $\Delta P_i^{(k)}$ are calculated from (4) and (10), respectively.

4. The elements of the Jacobian matrix (J_1,J_2,J_3 and J_4) are calculated from (6)- (8).

5. The linear simultaneous equation is solved directly by optimally ordered triangular factorization and Gaussian elimination.

6. The new voltage magnitudes and phase angles are computed from (12) and (13).

7. The process is continued until the residuals $\Delta P_i^{(k)}$ and $\Delta Q_i^{(k)}$ are less than the specified accuracy i.e.,

$$| \Delta Pi^{(k)|} <= \varepsilon$$

$$| \Delta Qi^{(k)}| <= \varepsilon$$

4.2.3 Flow Chart for Newton-Raphson's Method

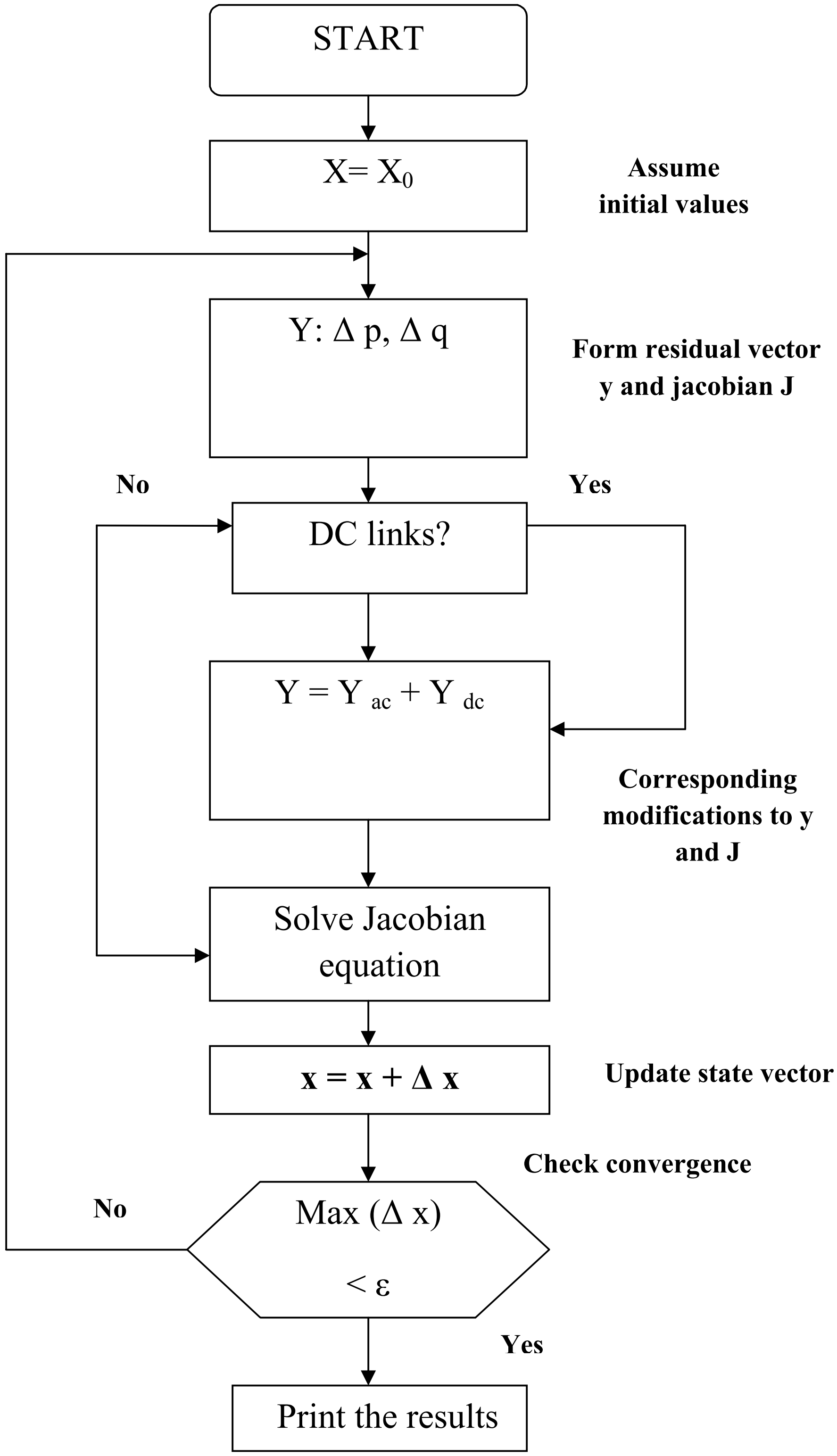


Figure 4.2 Flow Chart for NR Method

4.3 General purpose Fast Decoupled Power Flow Method

Probably almost all the relevant known numerical methods used for solving the nonlinear equations have been applied in developing power flow models. Among various methods, ***power*** flow models based on the Newton- Raphson (NR) method have been found to be most reliable. Many decoupled polar versions of the NR method have been attempted for reducing the memory requirement and computation time involved for power flow solution. Among decoupled versions, the fast decoupled load flow (FDLF) model developed by Stott and Alsac is possibly the most popular of those frequently used by the power utilities.

The basic equations used in FDLF methods are given below:-

$$\left[\frac{\Delta P}{V}\right] = [B'][\Delta\theta] \qquad \text{.....................(14)}$$

And

$$\left[\frac{\Delta Q}{V}\right] = [B''][\Delta V] \qquad \text{.....................(15)}$$

Where ***[B]*** = -ve imaginary elements of Ybus matrix.

While forming the above model, certain additional assumptions have been made to improve the convergence property of the FDLF model, they are:-

a) While forming ***[B']***, parameters such as shunt reactance and off-nominal in-phase transformer taps are omitted.
b) Line series resistances are neglected while forming ***[B'].***

These additional assumptions have a significant effect on the convergence property of the FDLF model.

In view of the above, another motivating factor is to develop an efficient but simple compensation technique to handle the problems of Q-limit enforcements at **PV** buses associated with bus-type switching. Therefore, in the proposed work, attention is focused on two aspects:-

a) To develop a **FDPF** model which exhibits stable convergence behavior for both normal and ill-conditioned situations and to compare its performance with that of the Stott **FDLF** model.

b) To develop an efficient compensation technique for Q-limit enforcement problems at **PV** buses to contain the number of iterations taken so that they are comparable with the number of iterations taken for the unadjusted solution case.

4.3.1 Mathematical Model of Fast Decoupled Power Flow Method

In a power system network, the net injected active and reactive powers at an *i*th bus are given by:-

$$P_i = \sum_{l=1}^{NB} V_i V_j \left(G_{ij} \cos\theta_{ij} - B_{ij} \sin\theta_{ij} \right) \qquad \text{…………………(16)}$$

And

$$Q_i = \sum_{J=1}^{NB} V_i V_j \left(G_{ij} \cos\theta_{ij} + B_{ij} \cos\theta_{ij} \right) \qquad \text{............................(17).}$$

where **V*i*** and **V*j*** , voltage magnitudes at the *i*th and jth buses, respectively; ***Gij*** + jBij is the ijth element of the Y-bus; and ***NB,*** total number of buses. The linearised power flow eqns. 16 and 17 are expressed in compact form as:-

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J1 & J2 \\ J3 & J4 \end{bmatrix} \begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix} \qquad \text{..............................(18)}$$

In eqn. 18, the sub matrices ***J1*** and ***J4*** have dissimilar dimensions due to the absence of the Q-V equations of **PV** buses. The following assumptions are made in shaping the **FDPF** model from eqn. 18:-

(i) The sub matrices ***J2*** and ***J3*** are ignored.

(ii) All network shunt reactance such as line charging reactance, external reactance located at buses and shunts formed due to representation of off-nominal in-phase transformers are lumped at each bus and are treated as constant impedance loads. Hence, the Y-bus elements (diagonals) are devoid of these shunts. By involving the second assumption, the number of parameters involved will be reduced while forming ***[B']*** and ***[B"]*** matrices and attention can be focused on line series resistances to study their effect on the convergence behavior of the **FDPF** model. The effect of phase shifters is not studied in the present model. All buses are assumed to be of the **PQ** type while forming the Jacobean-like matrices ***[B']*** and ***[B"]*** with a flat voltage start of 1.0 p.u. After incorporating the above assumptions, the resulting **FDPF** equations are:-

$$\left[\frac{\Delta P'}{V}\right] = [B'][\Delta\theta] \qquad \text{.........................(19)}$$

And

$$\left[\frac{\Delta Q'}{V}\right] = [B''][\Delta V] \qquad \text{.....................(20)}$$

Where

$$\Delta P_i^{'} = P_{scheduled,t} - P_{caloulated,1} - P_{shunts,1}$$

$$\Delta Q_i^{'} = Q_{scheduled,f} - Q_{calculated,t} = Q_{shunts,i} \qquad \text{.....................(21)}$$

The suffix ***i*** stands for the ***i***th bus. $\mathbf{P}_{\text{shunts},i}$; $\mathbf{Q}_{\text{shunts},i}$ are the real and reactive powers, respectively, due to lumped shunts at the ***i***th bus. It should be. noted that the dimensions of the Jacobians ***[B']*** and ***[B'']*** are the same, ***(NB*** - 1) by ***(NB*** - 1) in eqns. **(19)** and **(20)** whereas that of ***[B"]*** in eqn. 15 is ***(NB* - *MB*** - 1) by ***(NB* - *MB*** - 1) where, ***MB*** is the number of voltage controlled buses. When both ***[B']*** and ***[B"]*** are of the same order of ***(NB*** - 1). These matrices are real, sparse and only contain network elements. These matrices are only factorised once, then stored and are held constant throughout the solution process. The solution of eqns. 22 and 23 are given by:-

$$[\Delta\theta] = [B']^{-1}\left[\frac{\Delta P'}{V}\right] \qquad \text{.....................(22)}$$

And

$$[\Delta V] = [B'']^{-1}\left[\frac{\Delta Q'}{V}\right] \qquad \text{.....................(23)}$$

Therefore by using simplified Fast Decoupled Load Flow method, the voltage magnitude and change in angle can be calculated.

4.3.2 Fast Decoupled Power Flow for Radial Distribution System

In Radial Distribution System, the large R/X ratio causes problems in convergence of conventional load flow algorithm. Therefore for the better convergence some modified load flow methods are used.

For the purposes of power flow studies, we model a radial distribution system as a network of buses connected by distribution lines, switches, or transformers to a voltage specified source bus. Each bus may also have a corresponding load, shunt capacitor, and/or co-generator connected to it. The model can be represented by a radial interconnection of copies of the basic building block shown in Figure 4.2 the dotted lines from the co-generator, shunt capacitor, and load to ground are to indicate that these elements may be connected in an ungrounded delta-configuration. Since a given branch may be single-phase, two-phase, or three-phase. The basic building block of radial distribution system [1] is shown on the next page as:-

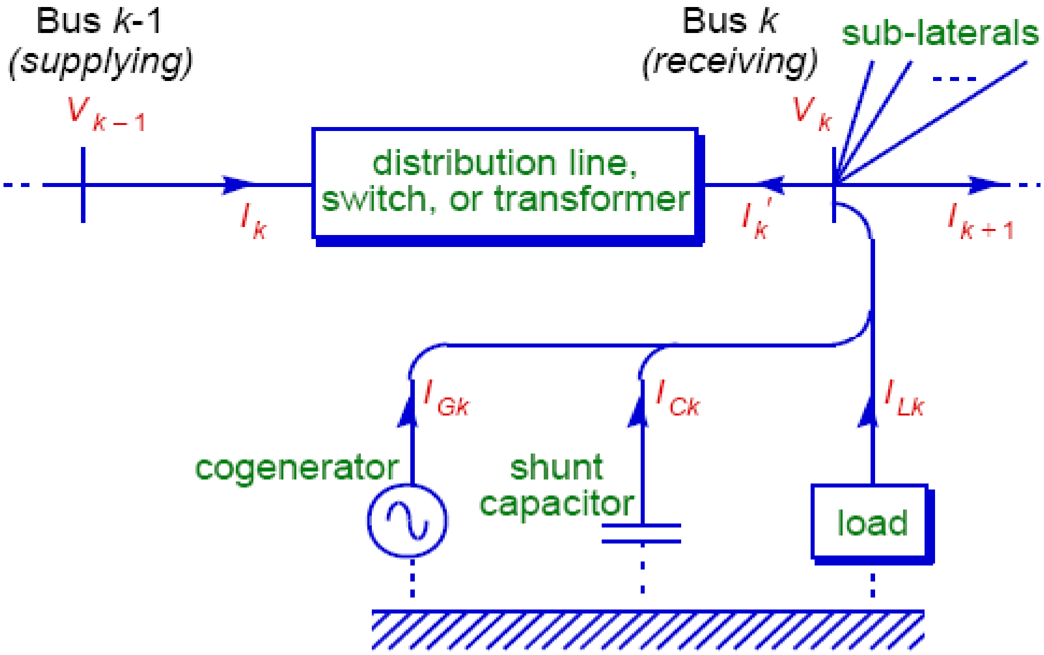


Figure 4.3 The Basic Building Block of Radial Distribution System.

One of the key concepts behind our formulation is that the voltage and current at one bus can be expressed as a function of the voltage and current at the next bus. If we let the equations [1] as

$$W_k = \begin{bmatrix} V_k \\ I_{k+1} \end{bmatrix} \qquad \text{..........................(24).}$$

The branch update function [1] is given below as:

$$W_{k-1} = g_k(w_k) \qquad \text{…......................(25).}$$

Where $\boldsymbol{W_k}$ is a vector containing the real and imaginary parts of the voltages and currents at bus $\boldsymbol{k}$**.** The function $\boldsymbol{g_k}$ is determined by the sub-laterals attached at bus $\boldsymbol{k}$ as well as the models for distribution lines, switches, transformers, loads, shunt capacitors, and co-generators. From $\boldsymbol{V_k}$ we can compute the currents injected by the loads, shunt capacitors, and co-generators. Given $\boldsymbol{I_k + 1}$ and the currents $\boldsymbol{I_j}$ injected into sub-laterals branching off from bus $\boldsymbol{k}$, we apply KCL at bus $\boldsymbol{k}$ to caculate current [1] given as:-

$$I_k' = I_{GK} + I_{CK} + I_{LK} - I_{k+1} - \sum_{J \in A_K} I_j \qquad \text{……….............(26).}$$

Where $\boldsymbol{A_k}$ is the set of buses adjacent to bus k on sub-laterals.

From the following equation (28), we can solve for the voltage and current at the primary given the voltage and current at the secondary [1] as:-

$$\begin{bmatrix} I_K \\ I_K' \end{bmatrix} = \begin{bmatrix} Y_k^{pp} & Y_k^{ps} \\ Y_k^{sp} & Y_k^{ss} \end{bmatrix} \begin{bmatrix} V_{k-1} \\ V_k \end{bmatrix} \qquad \text{…………………(27).}$$

Therefore by solving equation (27) , we get

$$V_{k-1} = \left(Y_k^{sp}\right)^{-1}\left(I_k' - Y_k^{ss} V_k\right) \qquad \text{..........................(28).}$$

And

$$I_k = Y_k^{pp} V_{k-1} + Y_k^{ps} V_k \qquad \text{..........................(29).}$$

So that by using this method we get the converged value easily and fast than the other ordinary methods.

4.4 Algorithm for Fast Decoupled Power Flow Method

The stepwise algorithm to solve the power flow problem by using Fast Decoupled Power Flow Method is given below as:-

Step 1: Creation of the bus admittance Y_{bus} according to the lines data given by the IEEE standard bus test systems.

Step 2: Detection of all kinds and numbers of buses according to the bus data given by the IEEE standard bus test systems, setting all bus voltages to an initial value of 1 pu, all voltage angles to 0, and the iteration counter ***iteration*** to 0.

Step 3: Creation of the matrices B' and B" according to equations (30) and (31) as given below:-

$$\frac{\Delta P}{|Vi|} = -B'\Delta\delta \qquad \text{..........................(30).}$$

And

$$\frac{\Delta Q}{|Vi|} = -B''\Delta|V| \qquad \text{..........................(31).}$$

Where **B'** and **B"** are the imaginary part of the bus admittance matrix $\mathbf{Y_{bus}}$, such that **B'** contains all buses admittances except those related to the slack bus, and **B"** is B' deprived from all voltage-controlled buses related admittances.

Step 4: Calculate the value of $\boldsymbol{\Delta P}$ and $\boldsymbol{\Delta Q}$ by using the following equations as

$$[\Delta P] = [H][\Delta\delta] \qquad \text{.......................(32).}$$

And

$$[\Delta Q] = [L][\Delta V] \qquad \text{........................(33).}$$

Step 5: Check the convergence as

Now if **max(ΔP, ΔQ) ≤ accuracy**

then Go to Step 6.

Else

(a). Calculation of the **H** and **L** elements from the following equqtions as given:-

$$H_{ii} = -|V_i|B_{ii} \qquad \text{.............................(34).}$$

And

$$H_{ij} = -|V_i|B_{ij} \qquad \text{.............................(35).}$$

Similarly, the diagonal elements of the L matrix can be written as:-

$$L_{ii} = -|V_i|B_{ii} \qquad \text{.............................(36).}$$

And

$$L_{ij} = -|V_i|B_{ij} \qquad \text{.............................(37).}$$

(b). Calculation of the real and reactive power at each bus, and checking if Mvar of generator buses are within the limits, otherwise update the voltage magnitude at these buses by ±2 %.

(c). Calculation of the power residuals, ΔP and ΔQ.

(d). Calculation of the bus voltage and voltage angle updated $\Delta\delta$ *and* ΔV according to equations given below:-

$$\Delta\delta = -[B']^{-1}\frac{\Delta P}{|V|} \qquad \text{......................(38).}$$

And

$$\Delta V = -[B'']^{-1}\frac{\Delta Q}{|V|} \qquad \text{.......................(39).}$$

(e). Update of the voltage magnitude ***V*** and the voltage angle ***δ*** at each bus .

(f). The current can be calculated from the calculated Ybus and the calculated voltage as given in the following equation as:-

$$\begin{bmatrix} I_k \\ I_k' \end{bmatrix} = \begin{bmatrix} Y_k^{pp} & Y_k^{ps} \\ Y_k^{sp} & Y_k^{ss} \end{bmatrix} \begin{bmatrix} V_{k-1} \\ V_k \end{bmatrix} \qquad \text{……..........(40).}$$

(g). Increment of the iteration counter iter = iter + 1.

Step 6: *if* iter ≤ maximum number of iteration

Then Go to Step 4

Else Print out ‘Solution did not converge’ and go to Step 6.

Step 7: Print out of the power flow solution, computation and display of the line flow, current and losses.

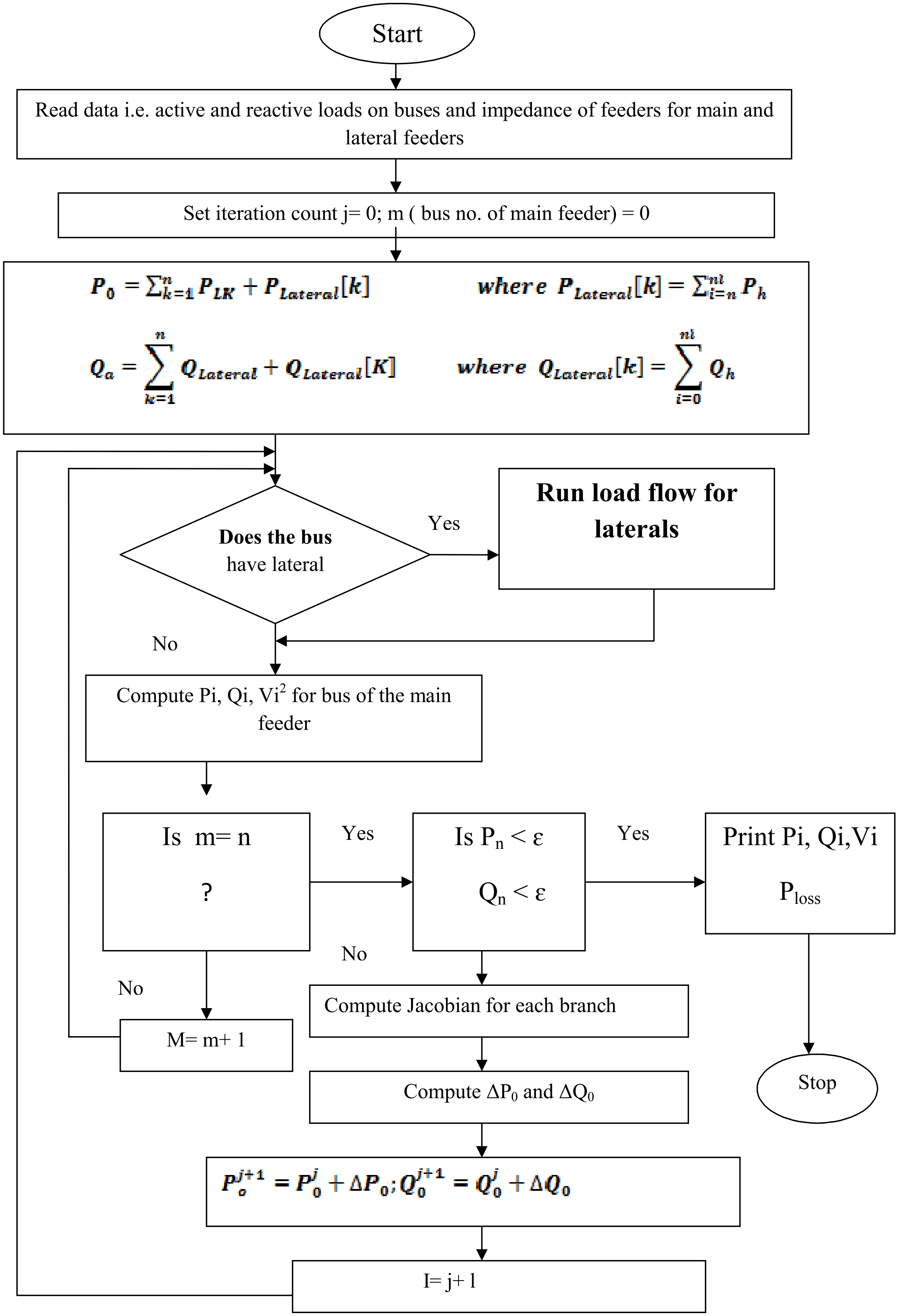
4.5 Advantages of Fast Decoupled Method:-

1. The memory requirement is very less than the other ordinary used method like as Newton’s method, Gauss-Seidel method etc.

2. This method is less complicated than the other methods, therefore it is more easy method to calculate the power flow.

3. The number of iteration and size of equations used is less.

4. The convergence is fast than the other method.


Start
Read data i.e. active and reactive loads on buses and impedance of feeders for main and lateral feeders
Set iteration count j= 0; m (bus no. of main feeder) = 0
$P_0 = \sum_{k=1}^{n} P_{LK} + P_{Lateral}[k]$
$where\ P_{Lateral}[k] = \sum_{i=n}^{nl} P_h$
$Q_a = \sum_{k=1}^{n} Q_{Lateral} + Q_{Lateral}[K]$
$where\ Q_{Lateral}[k] = \sum_{i=0}^{nl} Q_h$
Does the bus have lateral
Yes
Run load flow for laterals
No
Compute Pi, Qi, Vi^2 for bus of the main feeder
Is m= n ?
Yes
Is $P_n < \varepsilon$ $Q_n < \varepsilon$
Yes
Print Pi, Qi,Vi P_{loss}
No
No
M= m+ 1
Compute Jacobian for each branch
Compute ΔP_0 and ΔQ_0
$P_o^{j+1} = P_0^j + \Delta P_0; Q_0^{j+1} = Q_0^j + \Delta Q_0$
I= j+ 1
Stop

CHAPTER-5

RESULTS AND DISCUSSION

5.1 Discussion

Load flow is very important and fundamental tool for the analysis of any power system and used in the operational as well as planning stages. Certain application, particularly in distribution automation and optimization of power system requires repeated load flow solution. In these applications it is very important to solve the load flow problem as efficiently as possible.

So that there are different type of methods are used to solve the load flow problem. A new method of power flow analysis for solving balanced and unbalanced radial distribution systems has been developed and successfully implemented. First, the radial distribution system is properly modeled and a set of power flow equations is derived. After that, the solution method is developed for solving the power flow study. The validity of the results of radial distribution flow has also been verified by comparing them with the existing methods of power flow analysis. The proposed method offers a very attractive combination of advantages over the existing methods including the Newton Raphson's method and the Fast-Decoupled method in terms of convergent characteristic, computation time, simplicity and memory storage requirements. These methods are explained above. In addition, its performance was also found to be better than the other recent methods of power flow analysis developed for distribution systems. A more accurate prediction of the power system performance can also be obtained with the incorporation of static load models in the power flow study. The constant-power load model gave the most conservative results, with the lowest voltage profile and the highest load demand as opposed to the constant-impedance load model. Hence, it can be seen that accurate modeling of the load is necessary for a good distribution system design. The convergence analysis on this power flow method shows that its convergence property is neither affected by the number of buses nor the R/X ratio of the distribution system. However, the method would take longer to converge for very heavily loaded systems as well as for systems whereby there are more than 5 levels of laterals. In addition, using different load models also affect the convergence of the method. The more sensitive the load models are to the bus voltage, the slower the rate of convergence.

Here we used Newton Raphson's and Fast Decoupled Power Flow Methods to solve the power flow problem for the given distribution system. The Newton Raphson's and Fast Decoupled power flow solution techniques and host of their derivatives have efficiently solved "well behaved" power systems. By using these methods we are able to calculate the active power (P), reactive power (Q), path-loss and voltage (V) for 10 bus system data and for 33 bus system data.

5.2 Results

The results by using the methods explained above for the distribution system are given in the following tables as:-

Table 5.1 Results for 10 Bus Systems without Load Flow Solution

Bus No.	Active Power	Reactive Power	Path loss	Voltage
1	3.170300	1.163396	0.010894	1.000000
2	2.724629	0.928449	0.000923	0.993463
3	2.489705	0.807121	0.041338	0.988780
4	2.021367	0.633850	0.024990	0.966335
5	1.615377	0.171734	0.045392	0.952326
6	1.185985	-0.011342	0.011806	0.923624
7	0.987878	-0.047832	0.019017	0.914543
8	0.694861	-0.072903	0.022967	0.897525
9	0.437895	-0.116926	0.011449	0.870152
10	0.035446	-0.171110	0.000000	0.000000

Total Active Power = 15.3677

Total Reactive Power = 3.1951

Total Path loss = 0.1888

Here these results are calculated without using any load flow technique.

The result for the same 10 bus distribution system by using load flow technique is given below, the load flow technique used here is the Newton Raphson and Fast Decoupled Power flow method.

Table 5.2 Results for 10 Bus Systems by using Load Flow Solution

Bus No.	Active Power	Reactive Power	Path loss	Voltage
1	3.041737	1.100350	0.012223	1.000000
2	2.501890	0.857576	0.001012	0.993922
3	2.267112	0.742530	0.044540	0.989593
4	1.805824	0.580647	0.027473	0.969082
5	0.985779	0.123218	0.044030	0.955930
6	0.985779	-0.049784	0.010444	0.931436
7	0.791439	-0.082991	0.015659	0.924219
8	0.505384	-0.104119	0.015789	0.911170
9	0.259230	-0.142011	0.006009	0.892752
10	-0.136396	-0.192331	0.000000	0.000000

Total Active Power = 13.3342

Total Reactive Power = 2.7309

Total Path loss = 0.1364

The same techniques as explained above can also be used for the 33 bus distribution system. Here also we show the results for 33 bus system without any load flow techniques and with load flow techniques. Therefore the results without load flow techniques are given as:-

Table 5.3 Results for 33 Bus Systems without Load Flow Solution

Bus No.	Active Power	Reactive Power	Path Loss	Voltage
1	0.365649	0.251579	0.001090	1.000000
2	0.319410	0.200005	0.004399	0.997215
3	0.213011	0.165243	0.001711	0.984202
4	0.199300	0.159207	0.001624	0.976480
5	0.191676	0.151781	0.003249	0.969651
6	0.105427	0.090438	0.00249	0.952647
7	0.085179	0.079127	0.000253	0.947693
8	0.064926	0.063717	0.000602	0.939762
9	0.048323	0.052224	0.000379	0.932188
10	0.041944	0.045935	0.000055	0.926226
11	0.037388	0.042936	0.000089	0.925465
12	0.031300	0.033957	0.000229	0.924163
13	0.025071	0.024167	0.000049	0.918412
14	0.013023	0.018113	0.000022	0.916318
15	0.007001	0.011884	0.000011	0.915146
16	0.000990	0.002406	0.000001	0.914348
17	-0.005011	-0.006955	0.000004	0.913978
18	-0.014015	-0.010668	1.011000	0.914501
1	0.036078	0.031653	0.000024	0.997215
2	0.026976	0.021857	0.000114	0.996537
3	0.017862	0.010765	0.000011	0.992139
4	0.008851	0.004172	0.000004	0.991357
5	-0.000153	-0.000144	0.001210	0.990716
1	0.093823	0.025625	0.000270	0.984202
2	0.083730	0.017076	0.000425	0.981050
3	0.041305	0.006211	0.000102	0.975505
4	-0.000797	-0.000599	0.000024	0.972861

Bus No.	Active Power	Reactive Power	Path loss	Voltage
1	0.079049	0.049827	0.000127	0.952647
2	0.070887	0.047232	0.000148	0.951264
3	0.064754	0.039455	0.000436	0.949498
4	0.058363	0.029469	0.000245	0.942567
5	0.046143	0.022438	0.000095	0.938092
6	0.045057	0.015074	0.000155	0.936247
7	0.029918	0.005847	0.000020	0.932254
8	0.008900	0.001746	0.000002	0.931490
9	-0.001102	-0.000867	0.000256	0.931224

Total Active Power = 2.4291

Total Reactive Power = 1.6974

Total Path loss = 0.0161

Here the power is distributed as from bus number 1-18, 1-5, 1-4 and from 1-9 by using the distribution system.

Table 5.4 Results for 33 bus system by using load flow techniques are given as

Bus No.	Active Power	Reactive Power	Path loss	Voltage
1	10.518657	5.550569	0.101456	1.000000
2	9.209444	2.637625	0.010492	0.980900
3	8.964952	2.100510	0.533791	0.968041
4	8.004162	1.131802	0.449411	0.895906
5	7.173750	0.301195	1.136312	0.841283
6	5.653438	-0.837834	0.461245	0.712067
7	5.005894	-1.266013	0.980040	0.665094
8	3.751854	-1.835428	2.041124	0.569145
9	1.476729	-3.023783	2.165726	0.469736
10	1.079997	-4.298044	0.000000	0.601050
11	1.027264	-4.475270	0.005980	0.622751
12	0.582284	-4.844129	0.325793	0.656977
13	0.022887	-5.450928	0.313005	0.723883
14	0.717118	-5.830173	0.909303	0.761072
15	0.593185	-7.083504	0.487651	0.861326
16	0.278466	-7.651796	1.151400	0.909909
17	1.059234	-8.330173	2.714102	0.992246
18	1.929167	-9.883589	3.069534	1.182474
19	1.365367	-11.647924	0.071023	1.370562
20	0.903344	-11.934320	0.088023	1.397348
21	0.595274	-12.284987	0.432832	1.438107
22	0.023442	-13.093120	0.411262	1.516891
23	0.621819	-13.532684	1.177840	1.559054
24	0.983021	-14.671304	0.550194	1.677413
25	0.051827	-15.589803	1.321855	1.729065
26	1.654028	-16.481829	3.147915	1.817563
27	1.680187	-18.292955	3.521232	2.011023

Bus No.	Active Power	Reactive Power	Path loss	Voltage
28	2.115045	-20.301507	0.599838	2.230037
29	1.281207	-21.104086	1.364194	2.308275
30	0.473987	-22.954771	3.194340	2.500890
31	2.994353	-24.983443	3.569614	2.735867
32	0.809261	-25.793499	3.215165	2.801830
33	2.796905	-27.664257	0.000000	0.000000

Total Active Power = 2.0135

Total Reactive Power = 1.396

Total Path loss = 0.0136

By comparing table 5.3 and table 5.4 it is clear that total path loss value is lower in table 5.4 which is obtained from results for 33 bus system by using load flow technique. Also, active power is increased and reactive power is decreased by using load flow techniques which when compared to results for 33 bus system without load flow solution.

CHAPTER-6

CONCLUSION AND FUTURE SCOPE

6.1 Conclusion

In this a new method of power flow analysis for solving unbalanced radial distribution systems has been developed and successfully implemented. In this we have exploited the radial structure (physical property) and the decoupling numerical property of a distribution system to develop a fast decoupled Newton method for solving unbalanced distribution load flow. It involves a reduced set of equations and unknowns proportional to the number of laterals in the network as opposed to the number of buses. Due to the reduced number of equations and the fact that the Jacobian is approximated by a constant triangular matrix, it is significantly faster than the implicit $\mathbf{Z_{bus}}$ Gauss method or the traditional Newton method based on $\boldsymbol{Y_{bus}}$. Since each function evaluation involves updating each bus voltage and current and the Jacobian is triangular the computation in each iteration is proportional to **n,** making it suitable for very large radial systems. It is also shown to be more efficient than the backward/forward sweep method of due to the savings during the update of the end voltages. The load flow method proposed in this paper could possibly be improved further in several ways. As described here, it is limited to radial systems with one voltage-regulated bus treated as the source. Therefore considerable saving in the execution time has been achieved. The proposed model exhibits very reliable convergence even for high degree of ill-conditioning, where traditional Newton's method failed to converge. The model will be very useful for reactive power planning and management studies on all sizes of system with any degree of ill-conditioning. Effectiveness of the proposed method has been tested by two examples 10-node and 33- node radial distribution networks. The voltage convergence has assured the satisfactory convergence in all these cases. The superiority of the proposed method in terms of speed has been checked by comparing with the other existing methods. The proposed method consumes less amount of memory compared to other load flow techniques.

The network is then solved using a radial load flow algorithm along with corrections to the breakpoint currents or powers. These approaches also allow for PV buses, treated as artificial breakpoints, making them suitable for weakly-meshed transmission systems.

6.2 Future Scope

(i) Due to some distinct characteristics of distribution system, conventional load flow algorithm may fail to converse in solving to distribution network. Therefore various sweep based methods can be used to study the power flow of distribution network. Backward/forward sweep algorithm for three phase load flow analysis of radial distribution can be used.

(ii) The Jacobian matrix used to solve the load flow problem is a time consuming system and the memory requirement is more. The Fast Decoupled Power Flow has less memory requirement and it is easy to operate. So that in future the use of Fast Decoupled Power Flow method to solve the power flow in distribution and transmission system is best.

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APPENDIX A

TABLE A 1 DATA FOR 10 BUS DISTRIBUTION NETWORK

Bus No.	PL kw	QL kvar	From Bus	To Bus	R ohms	X ohms
1	0	0	0	1	0.0007	0.0036
2	0.439	0.109	1	2	0.0001	0.0048
3	0.234	0.0812	2	3	0.0059	0.00953
4	0.427	0.10653	3	4	0.0052	0.00481
5	0.381	0.439	4	5	0.0156	0.01367
6	0.384	0.1433	5	6	0.00716	0.00624
7	0.1863	0.0262	6	7	0.01626	0.00921
8	0.274	0.0143	7	8	0.0379	0.02149
9	0.234	0.031	8	9	0.0422	0.0239
10	0.391	0.0477	9	10		

APPENDIX B

TABLE B 1 DATA FOR 33 BUS DISTRIBUTION SYSTEM

Bus No.	PL kw	QL kvar	R ohms	X ohms
0	0.000	0.0000	0.0058	0.0029
1	0.001	0.01318	0.0308	0.0157
2	0.009	0.0075	0.0228	0.0166
3	0.012	0.00479	0.0238	0.0121
4	0.006	0.0066	0.0511	0.0441
5	0.02	0.0063	0.0117	0.0386
6	0.02	0.01049	0.0168	0.0771
7	0.016	0.01425	0.0643	0.0462
8	0.006	0.01106	0.0651	0.0462
9	0.0045	0.00602	0.0123	0.0041
10	0.006	0.00298	0.0234	0.0077
11	0.006	0.00895	0.0916	0.0721
12	0.012	0.00961	0.0338	0.0445
13	0.006	0.00599	0.0369	0.0328
14	0.006	0.00621	0.0488	0.034
15	0.006	0.00947	0.0804	0.1074
16	0.009	0.00936	0.0457	0.0358
17	0.000	0.00371	0.0102	0.0098
18	0.009	0.000	0.0939	0.0846
19	0.009	0.0097	0.0255	0.0298
20	0.009	0.01099	0.0442	0.0585
21	0.000	0.00658	0.0282	0.0192
22	0.009	0.00431	0.056	0.0442

Bus No.	PL kw	QL kvar	R ohms	X ohms
23	0.042	0.000	0.0559	0.0437
24	0.042	0.00776	0.0559	0.0065
25	0.000	0.01053	0.0127	0.009
26	0.006	0.00673	0.0177	0.0583
27	0.006	0.000	0.0661	0.0437
28	0.006	0.00495	0.0502	0.0161
29	0.012	0.00772	0.0317	0.0601
30	0.001	0.00963	0.0608	0.0226
31	0.015	0.00680	0.0194	0.0331
32	0.021	0.00732	0.0213	0.0226
33	0.001	0.00909	0.0317	0.0583

Base MVA =100;
Base KV =12.66;