VOLTAGE STABILITY ANALYSIS IN DISTRIBUTION SYSTEM FOR REALISTIC LOADS

A DISSERTATION

Submitted in partial fulfilment of the requirements for the award of the degree

of

MASTER OF ENGINEERING

in

ELECTRICAL ENGINEERING

(With Specialization in Power System Engineering)

By

LALIT PRASAD

DEPARTMENT OF ELECTRICAL ENGINEERING
UNIVERSITY OF ROORKEE
ROORKEE–247 667 (INDIA)

MARCH, 2000

CANDIDATE'S DECLARATION

I here by declare that the work is being presented in this dissertation entitled "VOLTAGE STABILITY ANALYSIS IN DISTRIBUTION SYSTEM FOR REALISTIC LOADS" in the partial fulfillment of the requirement for the award of the Degree of **Master of Engineering in Electrical Engineering** with specialization in **Power System Engineering** submitted in the Department of Electrical Engineering, University of Roorkee, Roorkee, is an authentic record of my own work carried out with effect from August 1999 to March 2000, under the kind guidance of **Dr. B. Das** and **Dr. N.P.padhy**, Department of Electrical Engineering, University of Roorkee, Roorkee.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

L. Prasad

DATE : 24|3|2000 **(LALIT PRASAD)**

This is to certify that the above statement made by the candidate is correct is to the best of our knowledge and belief.

Biswarup Das 24.3.2000

(Dr. B. Das)

N. P. Padhy 28/04/2000

(Dr. N. P. Padhy)

Department of Electrical Engineering

University Of Roorkee

Roorkee --247667 (U.P.)

(INDIA)

ACKNOWLEDGMENT

It is my pleasure to express my deep sense of gratitude of thanks to my guides Dr.B. Das and Dr. N.P. Padhy, Lecturers, Electrical Engineering Department, University of Roorkee for helping me in guidance and towards constant support, whenever I faced problems during this course of my dissertation inspite of his busy academic schedule.

I thank to the Mr. Bharat Gupt O.C., Power system simulation Lab, Electrical Engineering Department, University of Roorkee for providing computer facilities for simulation of this dissertation work.

I also thank the Almighty, faculties of power system group and friends for being with me whenever I was in need.

DATED : 24|3|2000
PLACE : Roorkee

L. Prasad.
(LALIT PRASAD)

ABSTRACT

In this thesis, attempts have been made to analysis and understand the voltage stability or instability problem in a radial power distribution system. Although a lot of research work has been made and being carried out to understand the voltage instability problem in a transmission network, not significant amount of work has been carried out in this direction for power distribution system. Moreover, only constant load model has been used to analysis the voltage instability problem for power distribution system in the literature. However, in a power distribution system the power demand for almost all the loads which are connected, such as television, refrigerator etc. are voltage dependent in nature. Hence, for analyzing the voltage stability/instability problem in a radial power distribution system, it is more proper to take into account the voltage dependent characteristics of the loads instead of the constant power characteristics of the loads.

CONTENTS

CHAPTER-1

INTRODUCTION

To meet the ever-increasing demand for electrical energy, it is necessary to augment the generation, transmission and distribution systems appropriately. While in the last few decades significant enhancement of total generation of electricity has taken place, matching augmentations have not taken place in the transmission and distribution sector due to the problem of the right-of-way, environmental regulations, financial bottlenecks etc. Consequently, more and more power is being pushed over the existing transmission and distribution circuits. It is a well known fact that as a transmission/distribution system carries more and more power, there is more threat to the stability of the system. Hence, before pushing more power over any transmission/distribution system, it is very important to determine the stability limit (maximum power which can be carried without any loss of stability) of that system.

Different kinds of stability (or instability) problems occur in a system when the system is being increasingly loaded, such as transient stability, dynamic stability, voltage stability etc. Among the above three stability problems, the first two problems, namely transient stability and dynamic stability problem are manifested primarily in a high-voltage transmission system but not in a low-voltage distribution system. This is so because in a transmission system the influence of the dynamics of the synchronous generators are very important, whereas in a distribution system synchronous generator dynamic plays a very insignificant role. On the other hand, voltage-instability is essentially a load-driven instability problem and hence it is manifested both in the transmission as well as distribution systems.

As the transmission system carries bulk amount of power, any instability in the transmission system causes a major loss of electric supply and the revenue loss due to this disturbance of supply is also very high. Hence, it is extremely important to understand, predict and possibly arrest any kind of instability in the transmission system. Consequently, a phenomenal amount of research work have been carried out to solve various instability problems in the transmission system and a lot more amount of research work are also being actively pursued presently in this direction. On the other hand, as the importance of the distribution

CHAPTER-1

INTRODUCTION

To meet the ever-increasing demand for electrical energy, it is necessary to augment the generation, transmission and distribution systems appropriately. While in the last few decades significant enhancement of total generation of electricity has taken place, matching augmentations have not taken place in the transmission and distribution sector due to the problem of the right-of-way, environmental regulations, financial bottlenecks etc. Consequently, more and more power is being pushed over the existing transmission and distribution circuits. It is a well known fact that as a transmission/distribution system carries more and more power, there is more threat to the stability of the system. Hence, before pushing more power over any transmission/distribution system, it is very important to determine the stability limit (maximum power which can be carried without any loss of stability) of that system.

Different kinds of stability (or instability) problems occur in a system when the system is being increasingly loaded, such as transient stability, dynamic stability, voltage stability etc. Among the above three stability problems, the first two problems, namely transient stability and dynamic stability problem are manifested primarily in a high-voltage transmission system but not in a low-voltage distribution system. This is so because in a transmission system the influence of the dynamics of the synchronous generators are very important, whereas in a distribution system synchronous generator dynamic plays a very insignificant role. On the other hand, voltage-instability is essentially a load-driven instability problem and hence it is manifested both in the transmission as well as distribution systems.

As the transmission system carries bulk amount of power, any instability in the transmission system causes a major loss of electric supply and the revenue loss due to this disturbance of supply is also very high. Hence, it is extremely important to understand, predict and possibly arrest any kind of instability in the transmission system. Consequently, a phenomenal amount of research work have been carried out to solve various instability problems in the transmission system and a lot more amount of research work are also being actively pursued presently in this direction. On the other hand, as the importance of the distribution network was perceived to be much less than that of a transmission network, not much research work has been carried out to prevent instability (i.e. voltage instability) in a distribution system.

However, with the rise in demand of electricity, the amount of power carried by a distribution system has also increased significantly over time. As a result, the instability problem (i.e. voltage instability) of the distribution system has also become more acute. Essentially, a voltage instability phenomenon can be described as follows:

When the load demand (active or reactive) in a system increases, the voltages in the different buses in the system decrease. If the load demand in the system increases progressively, the bus voltages also decrease progressively, until a sharp accelerated decrease in the magnitude of the bus voltages take place. When this happens, the overall voltage in the system becomes very low and hence, the voltage in the system is said to have "collapsed" or voltage in the system is said to be "unstable". Clearly, this low voltage in the system is an infeasible operating point.

As the voltage instability problem is essentially load driven, the nature of the problem depends upon the nature of the load. If the loads in the system are considered to be static (i.e. constant power load), then the instability in the system is considered to be static voltage instability problem. Traditionally, the static instability problem has been solved through repeated load flow study of the system. On the other hand, if the loads in the system are considered to be dynamic loads, such as induction motor loads, then the voltage instability problem is said to be a dynamic problem. This kind of problem is generally investigated by solving the associated differential equations in the system.

In recent years the voltage instability problem in a distribution system has been studied as a static problem. In [1] and [2], the uniqueness of the load flow solution for a radial power distribution network has been studied in detail. It has been proved in [1] and [2] that the feasible operating point in a radial distribution system is unique. Voltage stability limit of radial distribution system has been investigated in detail in [3] and [4]. In these two papers, simple algebraic criteria for determining very quickly whether a system is voltage stable or not based on its present loading condition has been developed. However, in all the above works constant power loads in the system have been assumed for investigation. However, in a power distribution system, the real and reactive power consumed by the connected loads such as television, refrigerator, air-conditioners, heaters, fluorescent tube light, pump, motors etc. have a voltage dependent characteristic, i.e. as the voltage across these loads varies, power consumption by the loads also varies. Traditionally, the voltage dependent characteristic of the loads in a distribution system is given by the following two relations [5] :

$$P = P_0 |V|^a \qquad \text{----------(1.1)}$$

$$Q = Q_0 |V|^b \qquad \text{----------(1.2)}$$

Where P and Q are the real and reactive power consumed by the loads, 'a' and 'b' are the exponents. V is the voltage magnitude of the bus at which the load is connected, P_0 and Q_0 are the real and reactive power drawn by the load at the initial operating condition. The values of the exponents 'a' and 'b' for different type of loads are given in [5]. Obviously, it would be appropriate to considered the voltage dependency characteristics of the loads while doing a voltage stability analysis of a distribution system.

In this thesis, an attempt has been made to determine the effect of the voltage dependent characteristics of the connected load on the voltage stability margin of a radial power distribution system. In Chapter 2, for constant power loads, a simple algebraic criterion for determining whether a distribution system is voltage stable or not at its present operating condition is derived. Based on the criterion, a simple computer algorithm to determine the voltage stability limit of a radial power distribution system is described. These are essentially the repetition of the work reported in [1-4]. Suitable modifications of this algorithm for considering the voltage dependent characteristic of the loads are also proposed in this chapter. A comparative analysis of the results regarding the voltage stability limits for constant power loads and voltage dependent loads is given in Chapter 3. Chapter 4 gives the main conclusions of this work.

CHAPTER-2

VOLTAGE STABILITY ANALYSIS OF A DISTRIBUTION SYSTEM

Introduction

A distribution system is different from the transmission system in both structure and the characteristics. In most cases, the distribution system draws power from a single source (substation) and transmits it over a radial type structure. Consequently, the technique for analyzing the voltage stability problem in a distribution system is different from that used in the transmission system. It is possible to reduce a radial power distribution system to an equivalent two-bus system and subsequently predict the voltage stability limit of the original system from the voltage stability property of the equivalent two-bus system. In the next section, voltage stability criterion for a two-bus system is derived. In the subsequent sections, the algorithms for deriving an equivalent two-bus system from a radial distribution system for constant power loads and voltage dependent loads are described.

2.1 Voltage stability criterion for a two-bus system

Let us consider a two-bus system shown in Fig. 2.1. Bus 1 is the swing (substation) bus and the voltage of bus 2 is expressed as $e_2 + jf_2$. The power demand at bus 2 is $P_2 + jQ_2$.

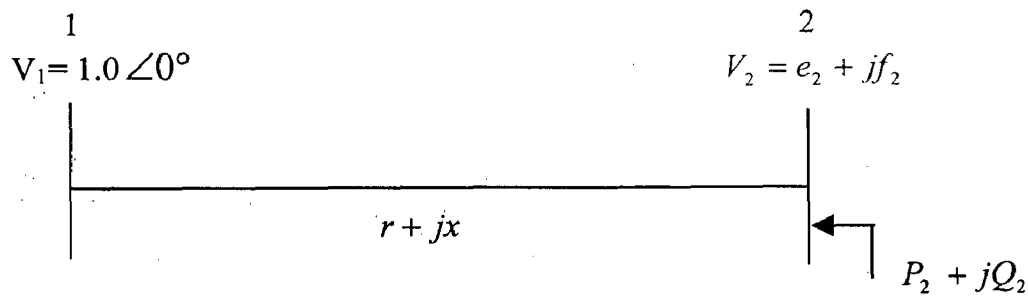

Figure 2.1 : The two-bus system.

The power flow equation in the rectangular form are expressed as:

$$P_2 = G_{22}\left(e_2^2 + f_2^2\right) + e_2\left(e_1 G_{21} + f_1 B_{21}\right) + f_2\left(f_1 G_{21} - e_1 B_{21}\right) \qquad \text{----------(2.1)}$$

$$Q_2 = B_{22}\left(e_2^2 + f_2^2\right) - e_2\left(f_1 G_{21} - e_1 B_{21}\right) + f_2\left(e_1 G_{21} - f_1 B_{21}\right) \quad \text{----------(2.2)}$$

where $y_{ij} = G_{ij} - jB_{ij}$ and

$$G_{ij} - jB_{ij} = \begin{cases} -\dfrac{1}{r + jx} & i \neq j \\ \dfrac{1}{r + jx} & i = j \end{cases} \quad \text{----------(2.3)}$$

From equations (2.1) and (2.2) and noting that $e_1 + jf_1 = 1.0 + j0$, we have,

$$\left(e_2 + \frac{G_{21}}{2G_{22}}\right)^2 + \left(f_2 - \frac{B_{21}}{2G_{22}}\right)^2 = \frac{G_{21}^2 + B_{21}^2}{4G_{22}^2} + \frac{P_2}{G_{22}} \quad \text{----------(2.4)}$$

$$\left(e_2 + \frac{B_{21}}{2B_{22}}\right)^2 + \left(f_2 - \frac{G_{21}}{2B_{22}}\right)^2 = \frac{G_{21}^2 + B_{21}^2}{4B_{22}^2} + \frac{Q_2}{B_{22}} \quad \text{----------(2.5)}$$

Using equation (2.3), equations (2.4) and (2.5) can be re-written as,

$$\left(e_2 - \frac{1}{2}\right)^2 + \left(f_2 + \frac{x}{2r}\right)^2 = (r^2 + x^2)\left(\frac{1 + 4rP_2}{4r^2}\right) \quad \text{----------(2.6)}$$

$$\left(e_2 - \frac{1}{2}\right)^2 + \left(f_2 - \frac{r}{2x}\right)^2 = (r^2 + x^2)\left(\frac{1 + 4xQ_2}{4x^2}\right) \quad \text{----------(2.7)}$$

Equations (2.6) and (2.7) define two circles on the $e_2 - f_2$ plane, with centers at $(1/2, -x/2r)$ and $(1/2, r/2x)$ respectively and radii of $\left[(r^2 + x^2)\left(\frac{1 + 4rP_2}{4r^2}\right) \right]^{1/2}$ and $\left[(r^2 + x^2)\left(\frac{1 + 4xQ_2}{4x^2}\right) \right]^{1/2}$ respectively. The intersection points of these two circles represent the solution points of e_2 & f_2. If the solutions for e_2 and f_2 exist, then these two circles must intersect each other. Thus, the condition for existence of the solution is,

$$\left[(r^2 + x^2)\left(\frac{1 + 4rP_2}{4r^2}\right) \right]^{1/2} + \left[(r^2 + x^2)\left(\frac{1 + 4xQ_2}{4x^2}\right) \right]^{1/2} \geq \left(\frac{r^2 + x^2}{2xr}\right) \quad \text{----------(2.8)}$$

Simplifying equation (2.8) we get,

$$\left(\frac{1+4rP_2}{r^2}\right)\left(\frac{1+4xQ_2}{x^2}\right)\geq 4\left(\frac{P_2}{r}+\frac{Q_2}{x}\right)^2$$

or,

$$(1+4rP_2)(1+4xQ_2)\geq 4(P_2x+Q_2r)^2$$

or,

$$4(xP_2-rQ_2)^2-4(rP_2+xQ_2)\leq 1 \qquad \text{----------(2.9)}$$

Equation (2.9) is the condition for voltage stability in the two-bus system.

2.2 Reduction of radial distribution system to an equivalent two bus network

To use the condition for voltage stability of a two-bus system for predicting the voltage stability property of a general radial distribution system, it is necessary to find an equivalent two-bus system of a given radial power distribution network. Essentially, the DIST-FLOW technique proposed by Baran and Wu [6] is used to derive such an equivalent network. The technique is described briefly as follows. For presentational convenience, we first consider a special case where there is only one main feeder. The general case for any distribution system comprising one main feeder and a number of lateral feeders is considered next.

2.2.1 Special case – Main feeder

Consider that a distribution system consists of only a radial main feeder as shown in Fig. 2.2. In this figure, V_1 represents the substation bus voltage magnitude and is assumed to be constant. The distribution lines are modeled as series impedance $z_i = r_i + jx_i$. Load demand at bus i is modeled as constant power sink, $S_{li} = P_{li} + jQ_{li}$.

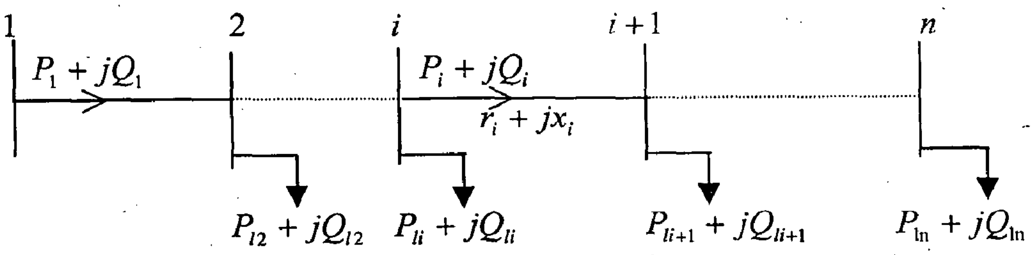

Figure 2.2 : A radial distribution system comprising of one main feeder

The real and reactive power flows on the line from bus i to $i+1$ and the voltages on the buses can be derived with the following iterative formulas [6] :

$$P_{i+1} = P_i - P_{lsi} - P_{li+1} \quad \text{----------(2.10)}$$

$$Q_{i+1} = Q_i - Q_{lsi} - Q_{li+1} \quad \text{----------(2.11)}$$

$$V_{i+1}^2 = V_i^2 - 2(r_i P_i + x_i Q_i) + (r_i^2 + x_i^2)\frac{P_i^2 + Q_i^2}{V_i^2} \quad \text{----------(2.12)}$$

$$P_{lsi} = r_i \frac{(P_i^2 + Q_i^2)}{V_i^2} \quad \text{----------(2.13)}$$

$$Q_{lsi} = x_i \frac{(P_i^2 + Q_i^2)}{V_i^2} \quad \text{----------(2.14)}$$

Where P_{lsi} & Q_{lsi} are real and reactive power losses in the branch emanating from bus i and P_{li} & Q_{li} are the real and reactive power demand. Derivation of equations (2.12) – (2.14) are given in Appendix A.

Algorithm for equivalent two bus system :

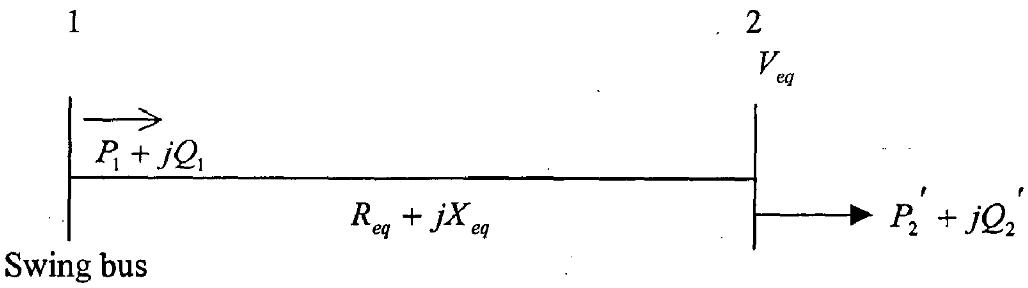

Figure 2.3 : The two-bus equivalent network.

Using equations (2.10) – (2.14), an equivalent two-bus network can be derived from Fig. 2.2 as shown in Fig. 2.3. The equivalent resistance and reactance can be computed by the algorithm described as follows :

Step 1: Sum all the load demands on each bus in Fig. 2.2. Let this term be the initial power injection $(P_1 + jQ_1)$ for the swing bus in Fig. 2.2 as well as the load demand $(P_2' + jQ_2')$ in Fig. 2.3.

Step 2: Starting from the substation bus, calculate the successive $P_{i+1}, Q_{i+1}, V_{i+1}$ and the power losses, P_{lsi}, Q_{lsi} in Fig. 2.2 using equations (2.10) – (2.14).

Step 3: Sum all these power losses and compute the equivalent impedance ($R_{eq} + jX_{eq}$).

$$R_{eq} = \frac{\sum P_{lsi}}{(P_1^2 + Q_1^2)} \qquad \text{----------(2.15)}$$

$$X_{eq} = \frac{\sum Q_{lsi}}{(P_1^2 + Q_1^2)} \qquad \text{----------(2.16)}$$

Step 4: Calculate the new power injection of the equivalent 2-bus network by using equations,

$$P_1^{new} = \frac{1}{2(R_{eq}^2 + X_{eq}^2)}[(2P_2'X_{eq}^2 - 2R_{eq}X_{eq}Q_2' + R_{eq}) - \{(2P_2'X_{eq}^2 - 2R_{eq}X_{eq}Q_2' + R_{eq})^2 - 4(R_{eq}^2 + X_{eq}^2)$$
$$\left(X_{eq}^2 P_2'^2 + R_{eq}^2 Q_2'^2 - 2R_{eq}X_{eq}Q_2'P_2' + R_{eq}P_2'\right)\}^{1/2}] \qquad \text{----------(2.17)}$$

$$Q_1^{new} = \frac{1}{2(R_{eq}^2 + X_{eq}^2)}[(2Q_2'R_{eq}^2 - 2R_{eq}X_{eq}P_2' + X_{eq}) - \{(2Q_2'R_{eq}^2 - 2R_{eq}X_{eq}P_2' + X_{eq})^2 - 4(R_{eq}^2 + X_{eq}^2)$$
$$\left(X_{eq}^2 P_2'^2 + R_{eq}^2 Q_2'^2 - 2R_{eq}X_{eq}Q_2'P_2' + X_{eq}Q_2'\right)\}^{1/2}] \qquad \text{----------(2.18)}$$

The derivations of the equations (2.17) and (2.18) are given in Appendix A.

Step 5: Compare P_1^{new} & P_1 which was obtained from Step 1, if ($P_1^{new} - P_1$) < tolerance, then stop. Otherwise, Set P_1 to P_1^{new} and Q_1 to Q_1^{new} and return to Step 2.

2.2.2 General case - Lateral feeder.

The algorithm described in previous sub-section can be generalized to include laterals. Consider a main feeder with a lateral branching out from the main feeder as shown in Fig. 2.4. A node k is referred as branching node indicating that there is a lateral branching out from that node. The same process for finding the equivalent network applied to the main feeder can be applied to the lateral branching out of node k also. The only difference is that the voltage magnitude at the branching node V_k is not a constant, while voltage magnitude at the substation bus is a constant. Steps of the algorithm to consider lateral branches are as follows :

Step 1: Sum all the load demands on each bus in Fig. 2.4. Let this term be the initial power injection $(P_1 + jQ_1)$ for the swing bus in Fig. 2.4 as well as the load demand $(P_2' + jQ_2')$ in Fig. 2.3.

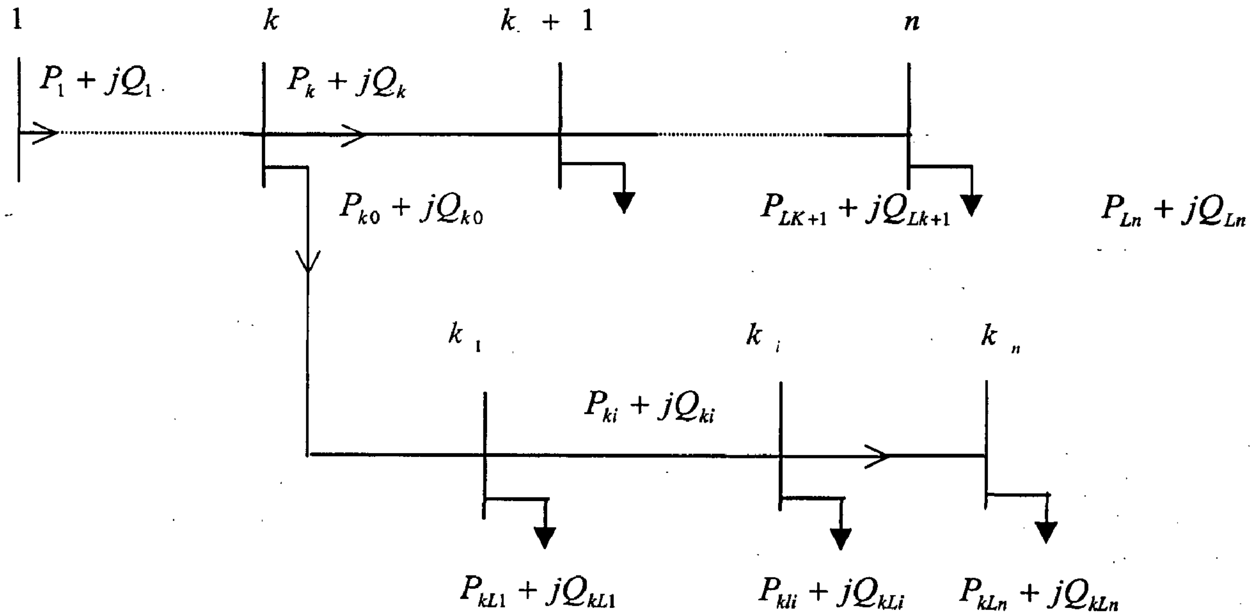

Figure 2.4 : A radial distribution system with laterals

Step 2: Starting from the substation bus, calculate the successive V_{i+1} and check whether any lateral exists at each bus i. If there is a lateral at that bus then go to step 3, otherwise go to step 4.

Step 3.: Let there be a lateral at bus k. Sum all the real and reactive loads on the lateral at bus k. Let this term be denoted as $P_{k0} + jQ_{k0}$: With the knowledge of the voltage on bus k which has already been calculated from step 2, it is possible to calculate power flows, losses and the bus voltages on the subsequent sections and buses on that lateral. Sum up the losses on all the sections on that lateral. Add this loss term to $P_{k0} + jQ_{k0}$. Let the resultant term be denoted as $P_{kr} + jQ_{kr}$. The original lateral would be replaced by a constant power load and the value of the load is $P_{kr} + jQ_{kr}$.

Step 4: Calculate the successive P_{i+1}, Q_{i+1} and V_{i+1} and the power losses, P_{lsi}, Q_{lsi} on the main feeder in Fig. 2.4 from equations (2.10) - (2.14).

Step 5: Sum all these power losses and compute the equivalent impedance $(R_{eq} + jX_{eq})$ using equations (2.15) and (2.16).

Step 6: By using equations (2.17) & (2.18), calculate the new power injection of the equivalent 2-bus network

Step 7: Compare P_1^{new} & P_1 which was obtained from Step 1. If $(P_1^{new} - P_1)$ < tolerance, then stop. Otherwise, Set P_1 to P_1^{new} and Q_1 to Q_1^{new} and return to Step 2.

2.3 Algorithm to derive two-bus equivalent for voltage dependent loads.

From the discussion of Section 2.2, it is obvious that the algorithm described is suitable only for constant power loads. However, as discussed earlier in Chapter 1, in a practical distribution system the connected loads are often not of constant power type. Rather, they are essentially voltage dependent loads and expressed by the following equations:

$$P = P_0 |V|^a \qquad \text{----------(2.19)}$$

$$Q = Q_0 |V|^b \qquad \text{----------(2.20)}$$

Where P & Q are real and reactive parts of the loads at a voltage magnitude V. P_0 & Q_0 are the loads at the initial operating condition. 'a' & 'b' are the suitable exponents. The typical values of 'a' & 'b' for different loads are shown in Table 2.1 [5].

Table 2.1

Equipment	Value of co-efficient 'a'	Value of co-efficient 'b'
Refrigerator	0.77	2.5
Television	0.76	7.4
Tube-light	2.00	5.1

To derive an equivalent two-bus system of a radial distribution system with voltage dependent loads, the algorithm described in Section 2.2 is slightly changed. In the next two subsections, the details of the proposed algorithms are described.

2.3.1 Algorithm for a radial system with only one main feeder

When the distribution system comprises only one main feeder, the algorithm described in the Subsection 2.2.1 needs to be slightly modified. The detail algorithm is as follows :

Step 1: Assume flat voltage profile in the system initially. As the exponents 'a' and 'b' and the values of P_0 and Q_0 are specified at each load bus, the effective real and reactive load demand at each bus can be calculated. Sum the load demands on each bus. Let this term be the initial power injection $(P_1 + jQ_1)$ for the swing bus in Fig. 2.2 as well as the load demand ($P_2^{'} + jQ_2^{'}$) in Fig. 2.3.

Step 2: Starting from the substation bus, calculate the voltage at the next bus by using equation (2.12). After the voltage is calculated, the effective real and reactive power at that bus is calculated using equations (2.19) and (2.20). Once these load demands are calculated, the power flows and the losses over the next feeder section can be calculated.

Step 3: Repeat step 2 for all the subsequent buses and the feeder sections. Once the new load demands at all the buses are calculated, add these new load demands and set the result equal to load demand ($P_2^{'} + jQ_2^{'}$) in Fig. 2.3.

Step 4: Sum all the losses and calculate the equivalent impedance ($R_{eq} + jX_{eq}$).

Step 5: Calculate new power injections P_1^{new} & Q_1^{new}.

Step 6: Compare P_1^{new} & P_1 which was obtained from Step 1. If ($P_1^{new} - P_1$) < tolerance, then stop. Otherwise, Set P_1 to P_1^{new} and Q_1 to Q_1^{new} and return to Step 2.

2.3.2 Algorithm for a radial system involving laterals

With a little modification of the algorithm described in Subsection 2.2.2, it is possible to derive a two-bus equivalent for a radial system having several laterals. The algorithm is described as follows :

Step 1: Assume flat voltage profile in the system initially. As the exponents 'a' and 'b' and the values of P_0 and Q_0 are specified at each load bus, the effective real and reactive load demand at each bus can be calculated. Sum the load demands on each bus. Let this term be the initial power injection $(P_1 + jQ_1)$ for the swing bus in Fig. 2.4 as well as the load demand $(P_2^{'} + jQ_2^{'})$ in Fig. 2.3.

Step 2: Starting from the substation bus, calculate the voltage at the next bus by using equation (2.12). Check whether any lateral exists at that bus. If there is a lateral at that bus then go to step 3, otherwise go to step 4.

Step 3 : Let there be a lateral at bus k. Sum all the real and reactive loads on the lateral at bus k. Let this term be denoted as $P_{k0} + jQ_{k0}$. With the knowledge of the voltage on bus k which has already been calculated from step 2, it is possible to calculate bus voltage, effective load at a bus, feeder section power flow and feeder section loss in that order on the subsequent buses and sections on that lateral. Sum up the losses on all the sections on that lateral. Add this loss term to $P_{k0} + jQ_{k0}$. Let the resultant term be denoted as $P_{kr} + jQ_{kr}$. The original lateral would be replaced by a constant power load and the value of the load is $P_{kr} + jQ_{kr}$. The original lateral, having voltage dependent loads on it, is replaced by a constant load as there is no easy method to compute aggregate or equivalent 'a' and 'b' coefficients for that lateral.

Step 4: Calculate the successive bus voltage, effective load at a bus, feeder section power flow and feeder section loss in that order for the subsequent buses and feeder sections on the main feeder in Fig. 2.4. Once the new load demands at all the buses are calculated, add these new load demands and set the result equal to load demand $(P_2^{'} + jQ_2^{'})$ in Fig. 2.3.

Step 5: Sum all these power losses and compute the equivalent impedance $(R_{eq} + jX_{eq})$.

Step 6: Calculate the new power injection of the equivalent 2-bus network

Step 7: Compare P_1^{new} & P_1 which was obtained from Step 1. If $(P_1^{new} - P_1)$ < tolerance, then stop. Otherwise, Set P_1 to P_1^{new} and Q_1 to Q_1^{new} and return to Step 2.

It is to be noted that while calculating the new power injections or replacing a lateral with an aggregate load power demand for the case with voltage dependent loads, no attempt was made to find equivalent or aggregate values of the exponents 'a' and 'b'. In other words, constant power load demand has been assumed while finding the new power injection or replacing the lateral with an equivalent load demand. Apparently, this seems to be quite contradictory, as it appears to be more appropriate that the voltage dependent nature of the loads should be maintained always while doing the analysis with voltage dependent loads. However, a justification for this simplification is attempted in the next chapter.

2.4 Conclusion

In this chapter, a simple criterion for determining the voltage stability property of a radial distribution system based on an equivalent two-bus system has been described. Algorithm for deriving the equivalent two-bus network for a distribution system involving laterals and having constant power loads has also been described. Suitable modifications of this algorithm have been suggested to include the effect of voltage dependent loads in the system.

RESULTS AND DISCUSSION

To investigate the effects of the voltage dependent loads on the voltage stability of a radial distribution system, detail studies have been carried out on two different study systems. To gain an insight regarding the effects of the voltage dependent loads, voltage stability limits for these two systems have been found out for both the constant power and voltage dependent loads and subsequently, some interesting conclusions have been drawn from the comparison of these results. In the following sections, the main results of this work are presented in detail.

3.1 Radial distribution system with only one main feeder

The first test system which has been undertaken for study is a 10-bus system taken from [7]. The one-line diagram of this system is shown in Fig. 3.1. The load data and the feeder data of this system are given in Tables B.1 and B.2 in Appendix B.

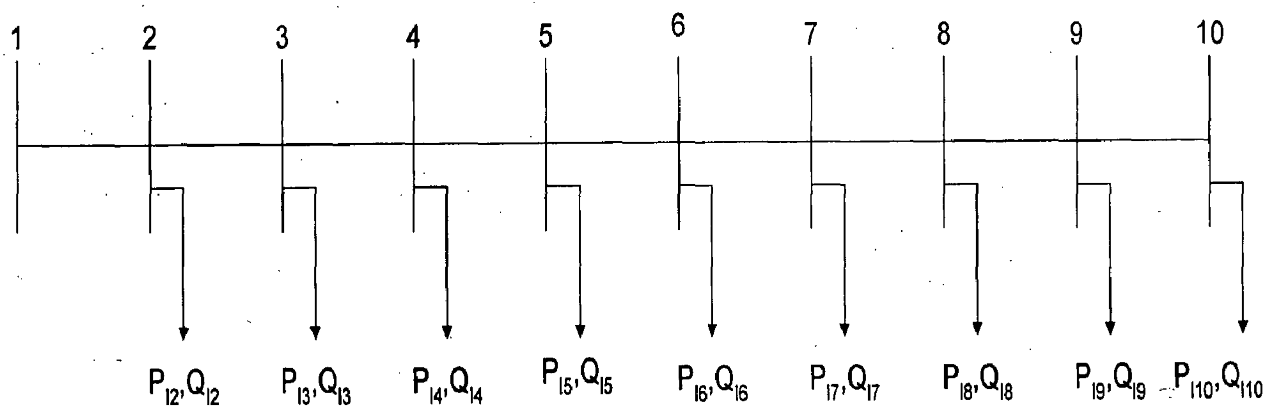

Figure 3.1 : Radial distribution system with one main feeder

It has been already discussed in Chapter 1 that as the loading (real or reactive) in an system increases, the voltages at the buses in the system decrease. After the loading is increased beyond a particular maximum level (value), the voltages in the system collapse. This maximum level is called the voltage stability limit of the system. It is obvious that the stability limit of a system is always expressed in terms of the maximum loadability of the system. Consequently, if the real or reactive power loading at any bus of a distribution system is increased progressively, after a certain limit, the voltages at all the buses of the system would collapse. This maximum value of the load would be known as the stability limit of the system at that particular bus or the "bus stability limit". Similarly it is possible to determine the "bus stability limits" at all the buses of the system. As there are always two types of loads in any system (e.g. real and reactive), the "bus stability limits" would also be either of real power type or of reactive power type.

An attempt has been made to determine the "bus stability limits" (both real and reactive power type) of the system shown in Fig. 3.1. To find out the limit at any particular bus (say bus no. 2), the real or reactive power load at that bus is gradually increased till the voltages in the system collapse. The step-by-step algorithm for determining the "bus stability limits" is given below. Let this algorithm be denoted as **algorithm 1**.

Step 1 : For the base loading condition given in Table B.1, determine the equivalent two-bus network following the algorithm described in Subsection 2.2.1.

Step 2 : Check whether the system is voltage stable or not using equation (2.9). If the system is voltage stable, go to step 3. Otherwise go to step 9.

Step 3 : Choose any bus i of the system.

Step 4 : Set $P_i = P_{Bi}$, where P_i is the present real power loading at bus i and P_{Bi} is the base real power loading at that bus given in Table B.1. Increase the real power loading at bus i by an amount ΔP. Keep the loading at all the other buses constant at the level of the base loading condition. Hence $P_i = P_{Bi} + \Delta P$.

Step 5 : Determine the two-bus equivalent of the system at this new loading condition. After the two bus equivalent system is obtained, check for voltage stability using equation (2.9). If the system is stable, go to step 6. Else, go to step 7.

Step 6 : Set $P_i = P_i + \Delta P$ and go back to step 5.

Step 7 : The "bus stability limit" at bus i is given by P_i. Set $P_i = P_{Bi}$.

Step 8 : Repeat steps 3, 4, 5, 6 and 7 for the remaining buses of the system.

Step 9 : Stop.

In the above algorithm, real power "bus stability limits" have been found out. Similarly, the reactive power "bus stability limits" can also be found out very easily.

By following the above algorithm, both the real power and reactive power "bus stability limits" of the system in Fig. 3.1 have been found out. The results are tabulated in Table 3.1. To determine these limits, the increments ΔP (ΔQ) have been taken as 0.01 p.u.

TABLE 3.1 : Bus stability limits for 10-Bus system with constant power loads

Load bus number	Maximum value of load P_{max}(p.u)	Maximum value of load Q_{max}(p.u)
2	34.639614	31.70997
3	20.234 56	16.88125
4	11.927630	10.40655
5	8.8817470	8.539557
6	8.2846110	5.443332
7	8.7863320	4.726276
8	9.8747260	3.914331
9	12.134130	2.631056
10	14.291800	2.247780

To present the results in Table 3.1 in a more compact form, the "bus stability limits" (both real and reactive) are plotted with respect to the "electrical distance" of the buses from the substation as shown in Figs. 3.2 and 3.3. The "electrical distance" of any bus from the substation is simply the modulus of the sum total of the impedances of the intermediate feeder sections which need to be traversed to reach that particular bus from the substation. For example, from Fig. 3.1 and Table B.2, the electrical distance of bus 4 from the substation is 0.018928 p.u. This value is calculated by first adding the impedances of the feeder sections 1-2, 2-3 and 3-4 and subsequently by computing the modulus of the resultant term. Similarly, the "electrical distances" for all the other buses from the substation can easily be computed.

It is observed from Figs. 3.2 and 3.3 that the reactive power "bus stability limits" progressively decrease as the "electrical distance' increase. Hence, the further a load point from the substation is, lesser would be its reactive power stability limit. On the other hand, the real power limits decrease up to a certain distance and beyond that these limits again increase. Also, from Table 3.1 it can be easily seen that the reactive power limits are always less than the real power limits. This seems to be appropriate as it is known that the voltages in any system is more sensitive to the reactive power demand in that system and voltage stability phenomenon is essentially a manifestation of the reactive power deficiencies in the system.

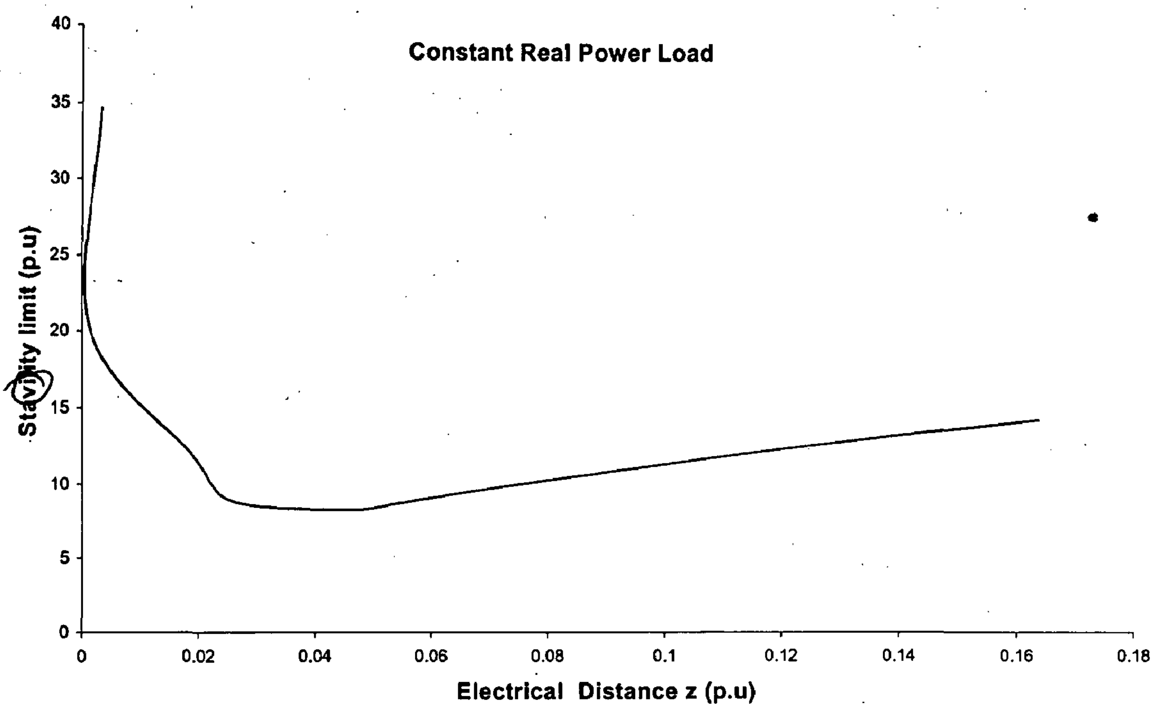

Figure 3.2 : Real power "bus stability limits" for 10 bus system

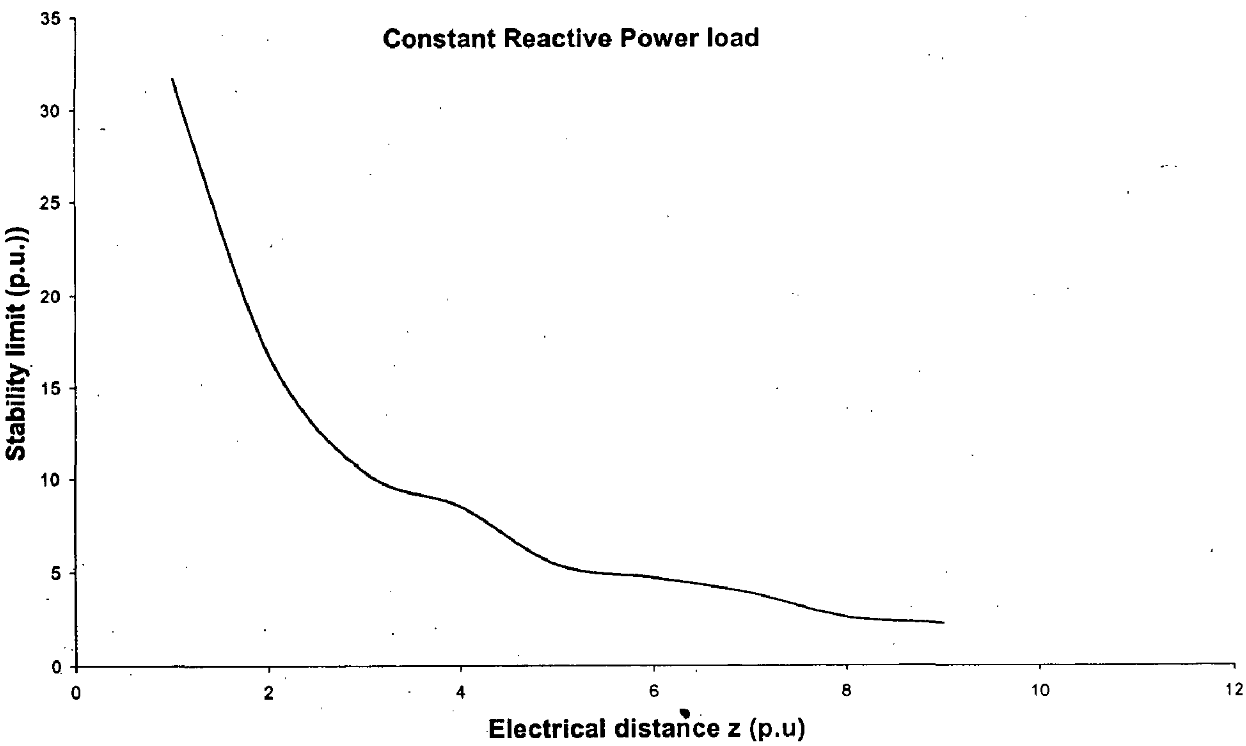

Figure 3.3 : Reactive power "bus stability limits" for 10 bus system

To determine the voltage stability limits for any distribution system involving voltage dependent loads, it is first necessary to determine the condition for voltage stability for a simple two-bus network as has been done for the case with constant power loads. Towards this objective, the simple two-bus network in Fig. 2.3 is again considered. However, in this case, the real load demand is assumed to be $P_2' = P_0|V|^a$ and the reactive load demand is assumed to be $Q_2' = Q_0|V|^b$. The equations involving the real and imaginary parts of the voltage of bus 2 are highly non-linear involving the exponents 'a' and 'b'. The detail derivation of these non-linear equations is given in Appendix C (equations (C.7) and (C.8)). Hence, no easy, analytical solution of these two equations (which gives the voltage magnitude of bus 2) exists and consequently, any simple condition for checking the voltage stability as in equation (2.9) is very difficult to obtain. On the other hand, the voltage of bus 2 can be obtained by solving the equations (C.7) and (C.8) through numerical techniques. The solution for the voltage of bus 2 has been obtained for different values of 'a' and 'b'. The results are tabulated in Table 3.2.

Table 3.2

Coefficient 'a'	Coefficient 'b'	Real part of voltage 'e'	Imaginary part of voltage 'f'
0.0	0.0	0.990163	-0.0000481
0.76	7.4	0.984400	0.001301
0.77	2.5	0.983078	-0.037791
2.0	5.1	0.984956	-0.000353
1.0	3.5	0.987656	-0.000481

From the above table it is observed that the voltage of bus 2 does not change appreciably when different types of loads (constant power load having zero 'a' and 'b' coefficients or different voltage dependent loads) are connected at that bus. Hence, for the two-bus system, the stability condition given in equation (2.9) can be used as an approximate condition for voltage dependent loads. As the variation of the voltage of bus 2 is not very high (from constant power load to different voltage dependent loads), it is expected that the error accrued by using equation (2.9) as an approximate stability condition for voltage dependent loads would be within acceptable limits. By the same reasoning, in Section 2.3, constant power loads (most recent estimate of the loads based on the most recent information of various bus voltages) have been assumed while calculating the new power injections in the equivalent two-bus system or replacing a lateral with an aggregate load power demand. It is again expected, that the errors incurred by this "engineering" simplification would be within acceptable limits.

To find out the "bus stability limits" with voltage dependent loads for the 10-bus system, three types of voltage dependent loads as given in Table 2.1 are considered. It has been assumed, rather arbitrarily, the following combinations of 'a' and 'b' coefficients for different buses as given in Table 3.3. The initial real and reactive power loading at the buses (P_0 & Q_0) are taken to be the same as the loading at each bus given in Table B.1.

Table 3.3 : 'a' and 'b' coefficients at different buses (Case I)

Buses at which this type of load is connected	Value of co-efficient 'a'	Value of co-efficient 'b'
7, 8, 9	0.77	2.5
4, 5, 10	0.76	7.4
2, 3, 6	2.00	5.1

The step-by-step algorithm for determining the "bus stability limits" with voltage dependent loads is given below. Let this algorithm be denoted as **algorithm 2.**

Step 1 : For the base loading condition described above, determine the equivalent two-bus network following the algorithm described in Subsection 2.2.2.

Step 2 : Check whether the system is voltage stable or not using equation (2.9). If the system is voltage stable, go to step 3. Otherwise go to step 9.

Step 3 : Choose any bus i of the system.

Step 4 : Set $P_{i0} = P_{Bi0}$, where P_{i0} is the present initial real power loading at bus i and P_{Bi0} is the base initial loading at that bus given in Table B.1. Increase the initial real power loading at bus i by an amount ΔP. Keep the initial loadings at all the other buses constant at the level of the base initial loading condition. Hence P_{i0} = P_{Bi0} + ΔP.

Step 5 : Determine the two-bus equivalent of the system at this new loading condition. After the two bus equivalent system is obtained, check for voltage stability using equation (2.9). If the system is stable, go to step 6. Else, go to step 7.

Step 6 : Set $P_{i0} = P_{i0} + \Delta P$ and go back to step 5.

Step 7 : The "bus stability limit" at bus i is given by P_{i0}. Set $P_{i0} = P_{Bi0}$.

Step 8 : Repeat steps 3, 4, 5, 6 and 7 for the remaining buses of the system.

Step 9 : Stop.

Although in the above algorithm, real power "bus stability limits" have been found out, reactive power "bus stability limits" can also be found out very easily.

The results regarding the "bus stability limits" for various voltage dependent loads in the 10-bus system as described in Table 3.3 are tabulated in Table 3.4. Comparison of tables 3.4 and 3.1 reveals that the stability limits of the system are lower for voltage dependent loads than the stability limits for constant loads.

TABLE 3.4 : Stability limits with voltage dependent loads in 10-Bus system (Case I)

Load bus number	Maximum value of load P_{max} (p.u)	Maximum value of load Q_{max} (p.u)
2	17.13960	6.509886
3	12.03412	3.781222
4	4.527614	1.909654
5	2.581749	2.339560
6	3.084614	1.643335
7	2.586335	1.826278
8	1.674725	1.574333
9	1.834114	1.531056
10	1.691782	1.547777

To investigate more elaborately the effects of voltage dependent loads on the "bus stability limits" of the system, two more combinations (sets) of 'a' and 'b' coefficients at different buses have been assumed and the corresponding stability limits have been found out. It is to be noted that the choice of various 'a' and 'b' coefficients at different buses have been made arbitrarily. The two sets of 'a' and 'b' coefficients are tabulated in Tables 3.5 and 3.6 respectively.

Table 3.5 : 'a' and 'b' coefficients at different buses (Case II)

Buses at which this type of load is connected	Value of co-efficient 'a'	Value of co-efficient 'b'
2, 4, 6, 9	0.77	2.5
7, 10	0.76	7.4
3, 5, 8	2.00	5.1

Table 3.6 : 'a' and 'b' coefficients at different buses (Case III)

Buses at which this type of load is connected	Value of co-efficient 'a'	Value of co-efficient 'b'
2, 4, 9	0.77	2.5
3, 5, 7	0.76	7.4
6, 8, 10	2.00	5.1

The results of "bus stability limits" for case II and case III are shown in Tables 3.7 and 3.8 respectively.

TABLE 3.7 : Stability limits with voltage dependent loads in 10-Bus system (Case II)

ad bus number	Maximum value of load P_{max} (p.u)	Maximum value of load Q_{max} (p.u)
2	17.439568	6.809886
3	7.534109	3.281221
4	4.627614	2.706546
5	2.581748	2.439560
6	2.884615	2.243335
7	2.586335	1.526278
8	1.674725	1.414333
9	1.834114	1.531056
10	1.691782	1.647778

TABLE 3.8 : Stability limits with voltage dependent loads in 10-Bus system (Case III)

Load bus number	Maximum value of load P_{max}(p.u)	Maximum value of load Q_{max}(p.u)
2	16.539572	6.309888
3	11.734109	2.781222
4	4.327614	2.706546
5	3.381748	2.039560
6	2.084615	1.743335
7	2.674735	1.426278
8	2.374725	1.414333
9	1.834114	1.431056
10	1.591782	1.447778

From the results of Tables 3.7 and 3.8 it is again observed that the stability limits with the voltage dependent loads are less than the stability limits with constant loads. To present the results in a more compact form, the stability limits with constant power loads and with voltage dependent loads (for cases I, II and III) are plotted with respect to the "electrical distance" in Figs. 3.4 and 3.5 respectively. Fig. 3.4 shows the real power stability limits and Fig. 3.5 shows the reactive power stability limits. From the comparison of Figs. 3.2, 3.3, 3.4 and 3.5 it is obvious that the stability limits with voltage dependent loads are definitely lower than the limits with constant power loads.

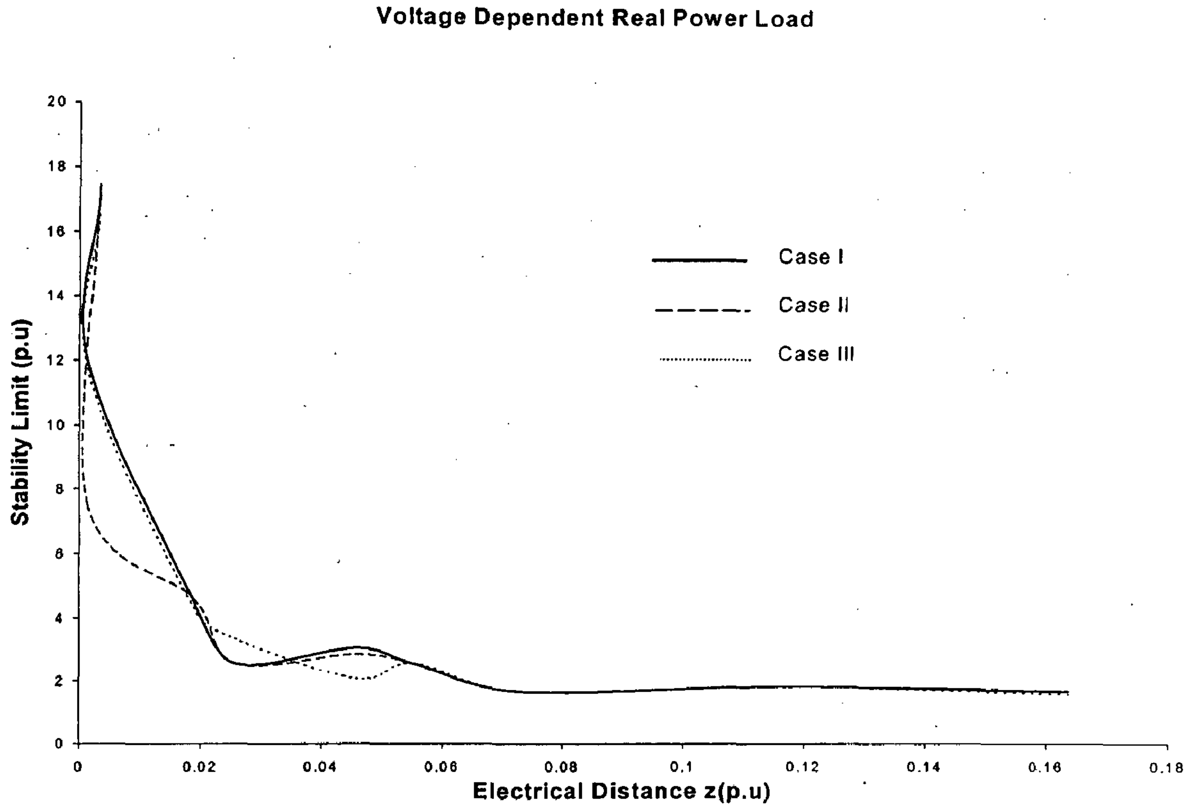

Figure 3.4 : Real Power "Stability limit" for 10-bus system

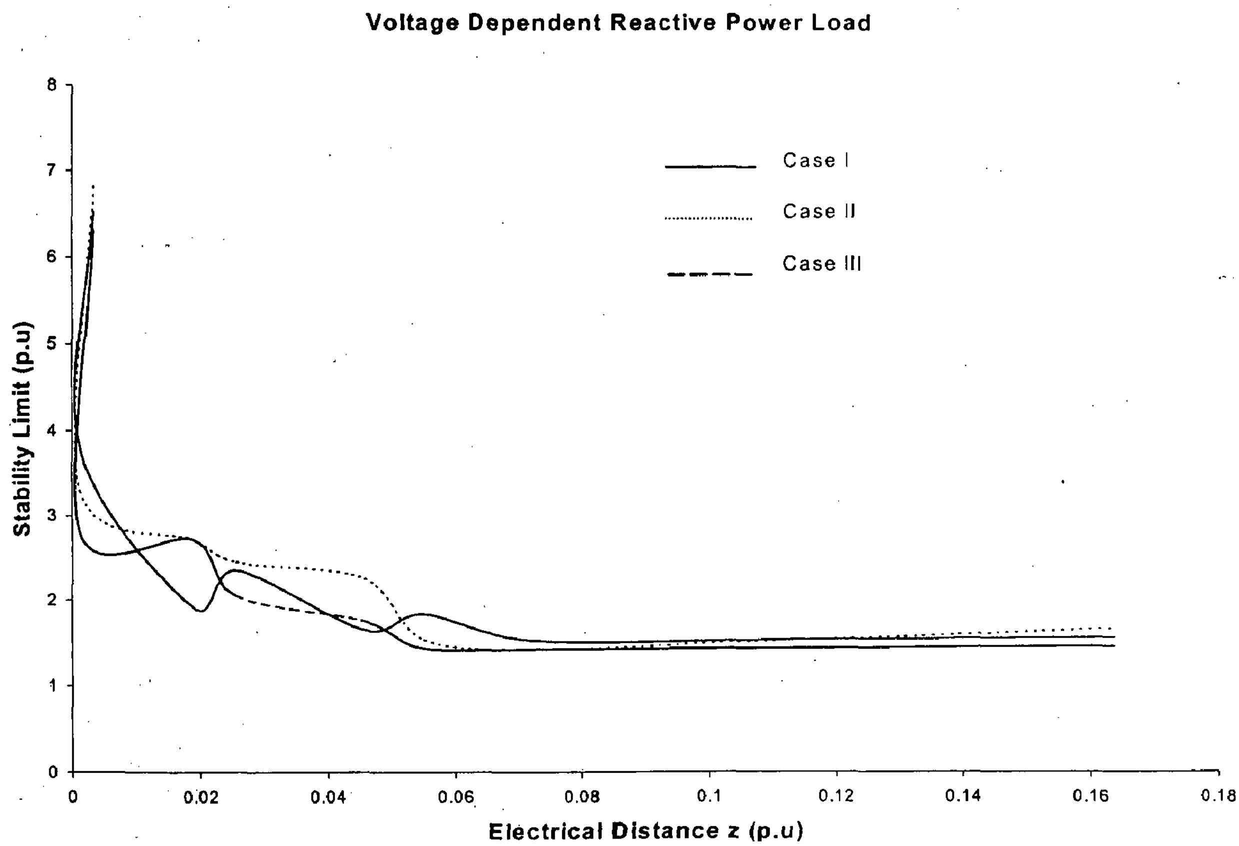

Figure 3.5 : Reactive Power "stability limit" for 10-bus system

3.2 Radial distribution system with laterals

The second test system which has been considered for study is a 31-bus system taken from [8]. The one line diagram of this system is shown in Fig. 3.6. The load data and feeder data of this system are given in Tables B.3 and B.4 in Appendix B respectively.

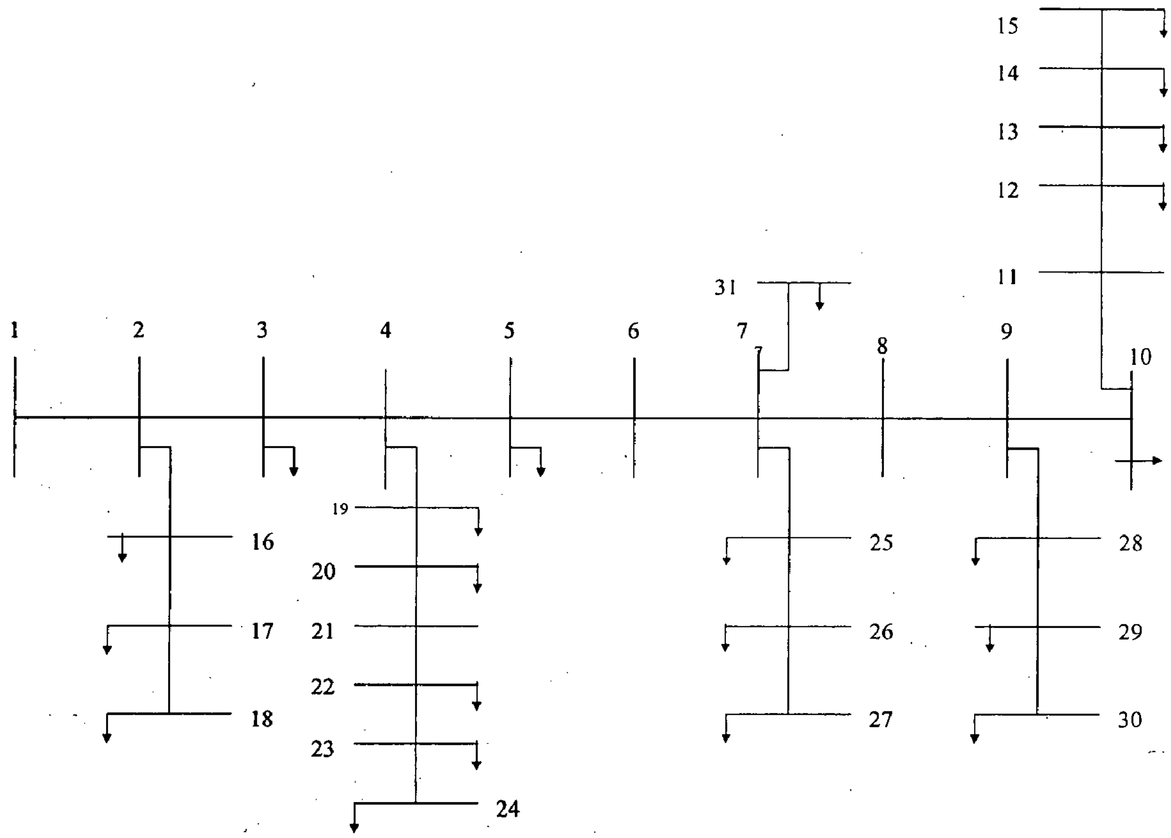

Fig. 3.6 : Radial distribution system with laterals.

The same studies as carried out for the 10-bus system have also been undertaken for this system. Initially, the "bus stability limits" (both real and reactive) have been found out for constant power loading. Algorithm 1, as described in the previous section, has been followed for this study with the difference that in this case, to determine the equivalent two-bus network, the algorithm described in Subsection 2.3.1 has been used instead of the algorithm described in Subsection 2.2.1. The results regarding the stability limits for constant power loads are tabulated in Table 3.9.

TABLE 3.9 : Bus stability limits for 31-Bus system with constant power loads

Load bus number	Maximum value of load P_{max} (p.u)	Maximum value of load Q_{max} (p.u)
3	3.284797	4.761614
5	1.942800	2.314518
10	0.512600	1.014199
12	0.422400	0.937499
13	0.543800	0.924599
14	0.552200	0.987399
15	0.548600	1.016199
16	0.378800	0.949599
17	0.358800	1.079599
18	0.358800	1.019599
19	0.313800	0.884599
20	0.427800	0.942599
22	0.374400	1.004799
23	0.336600	1.012199
24	0.322800	1.017599
25	0.299800	0.779900
26	0.314800	0.824899
27	0.314800	1.014899
28	0.308600	0.936199
29	0.296600	0.932199
30	0.192000	0.672200
31	0.823000	1.010999

The stability limits (both real and reactive) are plotted again with respect to the "electrical distance". These curves are shown in Figs. 3.7 and 3.8 respectively. From these two curves it is observed that with the increase in the electrical distance, both the real and reactive power stability limits generally decrease. However, the limits do not vary in a smooth fashion as in the case of the first system with only one main feeder. Moreover, the reactive power stability limits also do not decrease monotonically as in the case of first test system.

The stability limits correspond to voltage dependent loads have also been found out for three different sets of 'a' and 'b' coefficients. These three different sets of coefficients are tabulated in Tables 3.10, 3.11 and 3.12. The stability limits for these three cases are tabulated in Tables 3.13, 3.14 and 3.15 respectively. The real power stability limits for these three cases are plotted in Fig. 3.9 and the reactive power limits for these same three cases are plotted in Fig. 3.10.

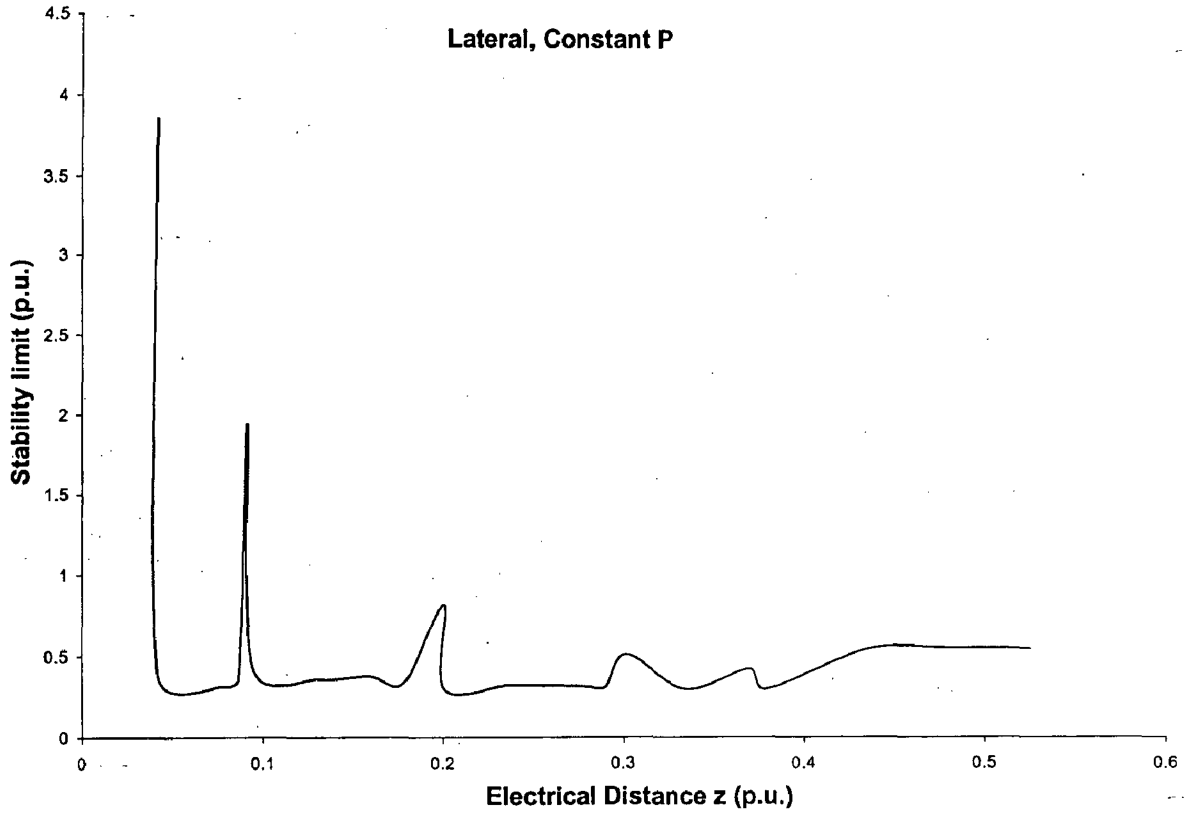

Figure 3.7 : Real Power "Stability limit" For 31-bus system

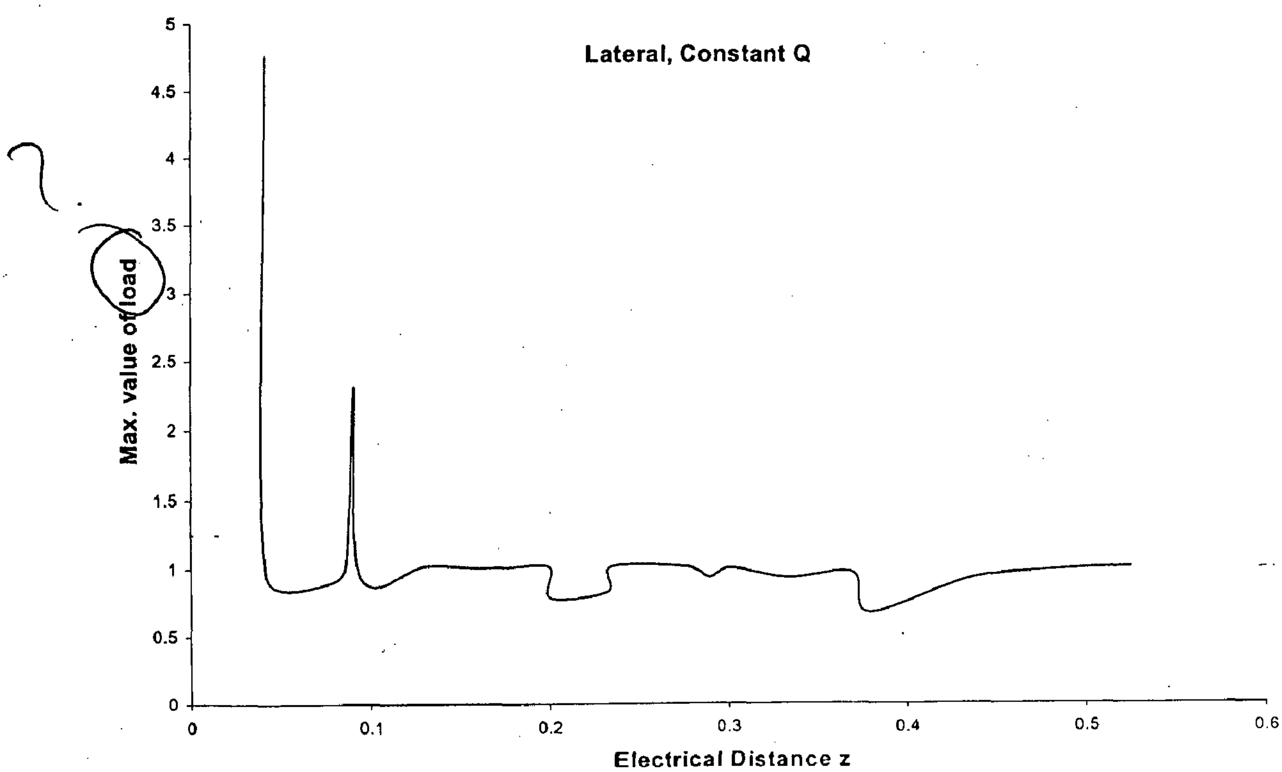

Figure 3.8 : Reactive Power "Stability limit" for 31-bus system

Table 3.10 : 'a' and 'b' coefficients at different buses (Case I)

Buses at which this type of load is connected	Value of co-efficient 'a'	Value of co-efficient 'b'
13,14,17, 21, 26,27	0.77	2.5
3,12,19,20,22,30,31	0.76	7.4
5,10,15,16,18,23,25, 28,29	2.00	5.1

Table 3.11 : 'a' and 'b' coefficients at different buses (Case II)

Buses at which this type of load is connected	Value of co-efficient 'a'	Value of co-efficient 'b'
12,14,19,20,23,25, 30	0.77	2.5
3,13,16,17,18,27,29, 31	0.76	7.4
5,10,15,22,24,26,28	2.00	5.1

Table 3.12 : 'a' and 'b' coefficients at different buses (Case III)

Buses at which this type of load is connected	Value of co-efficient 'a'	Value of co-efficient 'b'
12,13,14,16,23,25, 27	0.77	2.5
5,10,17,19,20,24,30 31	0.76	7.4
3,15,18,22,26,28,29	2.00	5.1

TABLE 3.13 : Stability limits with voltage dependent loads in 31-Bus system (Case I)

Load bus number	Maximum value of load P_{max}	Maximum value of load Q_{max}
3	3.754799	4.761614
5	1.752799	2.154198
10	0.522600	1.054199
12	0.422400	0.947499
13	0.493800	0.964599
14	0.492200	1.037399
15	0.498600	1.026199
16	0.358800	1.149599
17	0.348800	1.089599
18	0.358800	1.029599
19	0.263800	1.064599
20	0.367800	0.992599
22	0.304400	1.084799
23	0.266600	1.042199
24	0.292800	1.027599
25	0.272800	1.139899
26	0.292800	1.024899
27	0.284600	1.024899
28	0.286600	1.336199
29	0.286600	1.052199
30	0.186600	1.022199
31	0.803000	1.140999

TABLE 3.14 : Stability limits with voltage dependent loads in 31-Bus system (Case II)

Load bus number	Maximum value of load P_{max}	Maximum value of load Q_{max}
3	3.764799	4.621611
5	1.712799	2.154198
10	0.542600	1.034199
12	0.482400	0.907499
13	0.493800	0.954599
14	0.522200	0.987399
15	0.488600	1.076199
16	0.368800	1.049599
17	0.358800	0.989599
18	0.368800	0.989599
19	0.314800	1.074599
20	0.347800	1.032599
22	0.304400	1.034799
23	0.286600	1.032199
24	0.282800	1.077599
25	0.298800	1.049899
26	0.264600	1.074899
27	0.314800	1.074899
28	0.286600	1.056199
29	0.283600	1.072199
30	0.190600	1.072199
31	0.873000	1.140999

TABLE 3.15 : Stability limits with voltage dependent loads in 31-Bus system (Case III)

Load bus number	Maximum value of load P_{max}	Maximum value of load Q_{max}
3	3.954799	4.981611
5	2.152800	2.354198
10	0.582600	1.174199
12	0.512400	0.967499
13	0.482400	0.887599
14	0.502200	0.947399
15	0.478600	1.026199
16	0.388800	1.149599
17	0.388800	0.979599
18	0.368800	1.029599
19	0.294800	0.994599
20	0.367800	1.062599
22	0.304400	1.164799
23	0.286600	0.992199
24	0.291800	1.027599
25	0.299800	1.119899
26	0.294600	0.964899
27	0.282800	1.074899
28	0.298600	1.166199
29	0.266600	1.022199
30	0.206600	1.022199
31	0.843000	1.110999

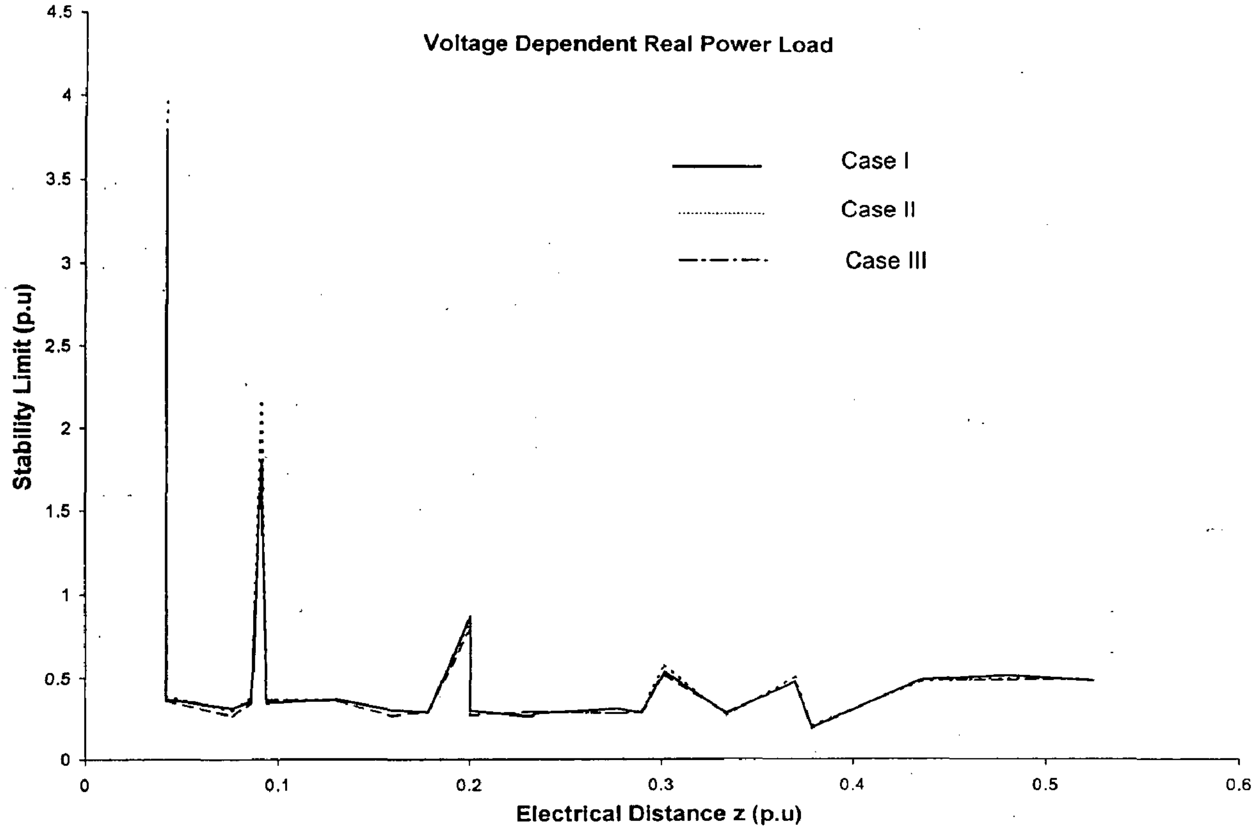

Fig. 3.9 : Real power " bus stability limit" for 31-bus system

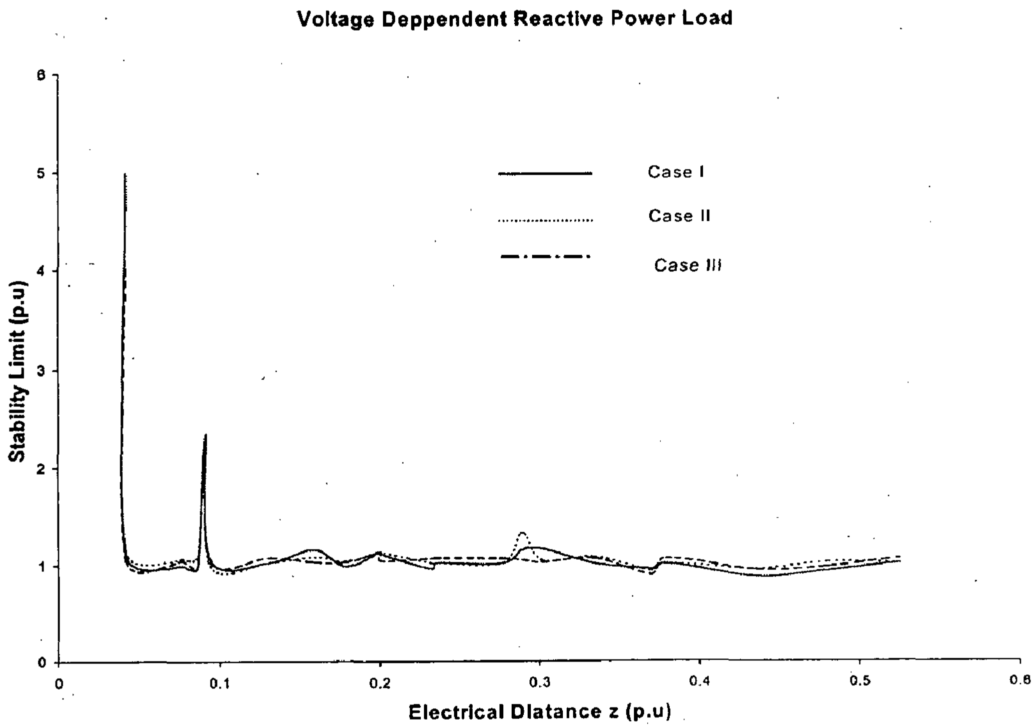

Fig. 3.10 : Reactive power "Stability limit" for 31-bus system

From the above results, it is observed that for the radial distribution system involving laterals, there is no particular pattern regarding the dependence of the stability limits on the type of loads (e.g. on 'a' and 'b' coefficients). From comparison of Tables 3.9, 3.13, 3.14 and 3.15 it is found that at some buses the real power stability limits have decreased for voltage dependent loads, whereas on the other buses, these limits have increased. On the other hand, the reactive power stability limits have increased for voltage dependent loads as compared to the limits for constant power loads. However, in all the three cases, it has been found that the stability limits (both real and reactive) generally decrease with the increase in electrical distance. Essentially, this means that the further a load point from the substation is, the lower would be its stability limits (apart from some exceptions). These variations in the stability limits with the electrical distance would be very heavily dependent upon the topology of the system. Hence, before coming to any definite conclusion, it would be necessary to investigate the stability limits with voltage dependent loads in a large number of different distribution systems.

CONCLUSIONS

In this thesis, a detail investigation about the voltage stability limits in two different radial power distribution systems has been made. Two different types of loads, e.g. constant power loads and voltage dependent loads have been considered in both the systems. The main conclusions of this work are :

- With the increase of distance of a load bus from the substation bus, the stability (both real and reactive) limits at that bus generally decrease.
- For a radial distribution system with only a main feeder, the reduction in the stability limits with distance is monotonic in nature.
- For radial distribution system with laterals present in the system, the reduction in the stability limits with distance is not monotonic in nature. But generally, the limits decrease with the increase in distance. Also the variation in the stability limits with distance is heavily dependent upon the particular system topology. However, for distribution systems with laterals, lot of studies involving large number of different distribution systems are required before reaching at a definite conclusion.

SCOPE FOR FUTURE WORK

- In this thesis, no analytical expression for voltage stability condition has been derived with voltage dependent loads. This expression needs to be derived, as it would obviate the need of making "engineering approximations" as done in this thesis.
- A technique for determining the equivalent 'a' and 'b' coefficients for a number of voltage dependent loads needs to be worked out. If such a technique exists, then in the equivalent two-bus system involving voltage dependent loads, equivalent values of 'a' and 'b' coefficients can be used.
- In this work, different sets of 'a' and 'b' coefficients have been chosen and allocated to different buses randomly. However, for a practical power system, these coefficients should be chosen and allocated from detail load forecasting studies.

REFERENCE

1. H. D. CHIANG and M.E. BARAN, "On the Existence and Uniqueness of Load Flow Solution for Radial Distribution Power Networks", IEEE Transaction on Circuit and System, Vol. 37, No. 3, pp : 410-416, March 1990.
2. G. B. Jasmon and L. H. C. C. Lee, "Stability of Load Flow Techniques for Distribution System Voltage Stability Analysis", IEE Proceeding, Part C, pp : 479-484, 138 (1991).
3. J. F. Chen and W. M. Wang, "Steady-State Stability Criteria and Uniqueness of Load Flow Solutions For Radial Distribution Systems", Electric Power System Research, Vol. 28, pp : 81-87, 1993.
4. J. F. Chen and W. M. Wang, "Stability Limit and Uniqueness of Voltage Solutions for Radial Power Networks", Electric Machine and Power Systems, Vol. 25, pp : 247-261, 1997.
5. P. Kundur, "Power System Stability and Control", Mcgraw-Hill, 1993.
6. Baren, M. E. And Wu. F. F, "Optimal Capacitor Placement on Radial Distribution System", IEEE Transaction on Power Delivery, Vol. 4, No. 1, pp : 725-734, 1989.
7. C. J. Tavora and O. J. M. Smith, "Equilibrium Analysis of Power System", IEEE Transaction on Power Apparatus and System, Vol. PAS-91, pp : 1131-1137, May 1972.
8. GOSWAMI S. K. and Prof. BASU S. K., "Direct Solution of Distribution Systems", IEE Proceedings, Part C, Vol. 138, No. 1, pp : 78-88, January 1991.

APPENDIX A

A.1 Derivation of the iterative equations (2.12) – (2.14)

Consider the feeder section between the buses i and $(i+1)$ in the distribution system shown in Fig. 2.2. The voltage of the $(i+1)^{th}$ bus, V_{i+1}, can be expressed as,

$$V_{i+1} = V_i - I_i z_i \qquad \text{----------(A.1)}$$

Where, V_i is the voltage of bus i, $z_i = r_i + jx_i$ is the impedance of the feeder section between the buses i and $(i+1)$ and I_i is the current over the feeder. Equation (A.1) can be written as,

$$V_{i+1} = V_i - (r_i + jx_i)(\frac{P_i + jQ_i}{V_i})^* \qquad \text{----------(A.2)}$$

Or,

$$|V_{i+1}|\angle\theta_{i+1} = |V_i|\angle\theta_i - (r_i + jx_i)(\frac{P_i + jQ_i}{V_i})^*$$

Or,

$$|V_{i+1}|(\cos\theta_{i+1} + j\sin\theta_{i+1}) = |V_i|(\cos\theta_i + j\sin\theta_i) - (r_i + jx_i)(\frac{P_i + jQ_i}{|V_i|(\cos\theta_i + j\sin\theta_i)})^*$$

Or,

$$|V_{i+1}|(\cos\theta_{i+1} + j\sin\theta_{i+1}) = |V_i|(\cos\theta_i + j\sin\theta_i) - \frac{(r_i + jx_i)}{|V_i|}\{(P_i\cos\theta_i + Q_i\sin\theta_i) - j(Q_i\cos\theta_i - P_i\sin\theta_i)\}$$

$$\text{----------(A.3)}$$

Simplifying equation (A.3) we get,

$$|V_{i+1}|(\cos\theta_{i+1} + j\sin\theta_{i+1}) = |V_i|\cos\theta_i - \frac{(r_iP_i\cos\theta_i + r_iQ_i\sin\theta_i + x_iQ_i\cos\theta_i - x_iP_i\sin\theta_i)}{|V_i|}$$
$$+ j\{ |V_i|\sin\theta_i - \frac{(x_iP_i\cos\theta_i + r_iP_i\sin\theta_i - r_iQ_i\cos\theta_i + x_iQ_i\sin\theta_i)}{|V_i|} \} \text{----(A.4)}$$

Taking the modulus of equation (A.4) on both sides and simplifying we get,

$$|V_{i+1}|^2 = |V_i|^2 + \frac{(x_iQ_i + r_iP_i)^2 + (r_iQ_i - x_iP_i)^2}{|V_i|} - 2(x_iQ_i + r_iP_i)$$

or,

$$|V_{i+1}|^2 = |V_i|^2 + \frac{(r_i^2 + x_i^2)(P_i^2 + Q_i^2)}{|V_i|^2} - 2(x_i Q_i + r_i P_i) \qquad \text{----------(A.5)}$$

Equation (A.5) is the same as that given in equation (2.12).

The real and reactive power losses on that feeder, S_{loss}, can be derived as :

$$S_{loss} = zI_i^2$$

Or,

$$S_{loss} = (r_i + jx_i)\left\{ \left[\frac{P_i + jQ_i}{V_i \angle \theta_i} \right]^* \right\}^2$$

Or,

$$S_{loss} = \frac{(r_i + jx_i)}{V_i^2}\left[(P_i \cos\theta_i + Q_i \sin\theta_i)^2 + (Q_i \cos\theta_i - P_i \sin\theta_i)^2 \right]$$

Or,

$$S_{loss} = \frac{(r_i + jx_i)}{V_i^2}\left[(P_i^2 + Q_i^2) \right] \qquad \text{----------(A.6)}$$

Separating the real and imaginary terms from equation (A.6),

$$P_{loss} = \frac{r_i}{V_i^2}\left[(P_i^2 + Q_i^2) \right] \qquad \text{----------(A.7)}$$

$$Q_{loss} = \frac{x_i}{V_i^2}\left[(P_i^2 + Q_i^2) \right] \qquad \text{----------(A.8)}$$

Equations (A.7) and (A.8) correspond to the equations (2.13) and (2.14) respectively.

A.2 Derivation of the equations (2.17) and (2.18)

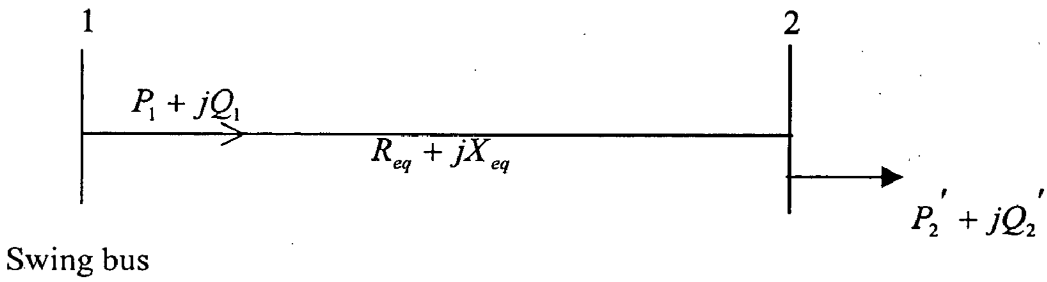

Fig. A.1 : A simple two bus network

Consider a simple two-bus network shown in Fig. A.1. Let the voltage of the swing bus V_1 be assumed to be equal to $1.0\angle 0°$. For this two bus system the load flow equations are :

$$P_2' = P_1 - R_{eq}\frac{(P_1^2 + Q_1^2)}{V_1^2} \qquad \text{----------(A.9)}$$

$$Q_2' = Q_1 - X_{eq}\frac{(P_1^2 + Q_1^2)}{V_1^2} \qquad \text{--------(A.10)}$$

From equation (A.9),

$$\frac{(P_1^2 + Q_1^2)}{V_1^2} = \frac{(P_1 - P_2')}{R_{eq}} \qquad \text{-------(A.11)}$$

Substituting equation (A.11) into equation (A.10) we get,

$$Q_1 = Q_2' + \frac{X_{eq}}{R_{eq}}(P_1 - P_2') \qquad \text{---------(A.12)}$$

Substituting equation (A.12) into equation (A.9) and noting $V_1 = 1.0\angle 0°$, we get,

$$P_2' = P_1 - R_{eq}[P_1^2 + \{ \frac{X_{eq}}{R_{eq}}(P_1 - P_2') + Q_2' \}^2]$$

Or,

$$(R_{eq}^2 + X_{eq}^2)P_1^2 - 2P_1P_2'X_{eq}^2 + X_{eq}^2P_2^{2'} + Q_2^{2'}R_{eq}^2 + 2R_{eq}X_{eq}Q_2'P_1 - 2R_{eq}X_{eq}Q_2'P_2' - P_1R_{eq} + P_2'R_{eq} = 0$$

Or,

$$(R_{eq}^2 + X_{eq}^2)P_1^2 - (2P_2'X_{eq}^2 - 2R_{eq}X_{eq}Q_2' + R_{eq})P_1 + (X_{eq}^2P_2^{2'} + Q_2^{2'}R_{eq}^2 - 2R_{eq}X_{eq}Q_2'P_2' R_{eq}P_2') = 0$$

----------(A.13)

Equation (A.13) is the quadratic equation involving P_1. The solution of equation (A.13) is:

$$P_1 = \frac{1}{2(R_{eq}^2 + X_{eq}^2)}[\left(2P_2'X_{eq}^2 - 2R_{eq}X_{eq}Q_2' + R_{eq}\right) - \{(2P_2'X_{eq}^2 - 2R_{eq}X_{eq}Q_2' + R_{eq})^2 - 4(R_{eq}^2 + X_{eq}^2)(X_{eq}^2P_2^{2'} + R_{eq}^2Q_2^{2'} - 2R_{eq}X_{eq}Q_2'P_2' + R_{eq}P_2')\}^{1/2}]$$

----------(A.14)

Equation (A.14) corresponds to equation no. (2.17).

Similarly, proceeding as before as in equations (A.9) – (A.12) we get,

$$Q_2' = Q_1 - X_{eq}[Q_1^2 + \{ \frac{X_{eq}}{R_{eq}}(Q_1 - Q_2') + P_2' \}^2] \qquad \text{-----------(A.15)}$$

Or,

$$(R_{eq}^2 + X_{eq}^2)Q_1^2 - 2Q_1Q_2^{'}R_{eq}^2 + X_{eq}^2P_2^{2'} + Q_2^{2'}R_{eq}^2 + 2R_{eq}X_{eq}P_2^{'}Q_1 - 2R_{eq}X_{eq}Q_2^{'}P_2^{'}$$
$$- Q_1X_{eq} + Q_2^{'}X_{eq} = 0$$

Or,

$$(R_{eq}^2 + X_{eq}^2)Q_1^2 - (2Q_2^{'}R_{eq}^2 - 2R_{eq}X_{eq}P_2^{'} - X_{eq})Q_1 + (X_{eq}^2P_2^{2'} + Q_2^{2'}R_{eq}^2 - 2R_{eq}X_{eq}Q_2^{'}P_2^{'}$$
$$+ Q_2^{'}X_{eq}) = 0$$

----------(A.16)

Equation (A.16) is the quadratic equation involving Q_1. The solution of equation (A.16) is:

$$Q_1 = \frac{1}{2(R_{eq}^2 + X_{eq}^2)}[(2Q_2^{'}R_{eq}^2 - 2R_{eq}X_{eq}P_2^{'} + X_{eq}) - \{(2Q_2^{'}R_{eq}^2 - 2R_{eq}X_{eq}P_2^{'} + X_{eq})^2$$
$$- 4(R_{eq}^2 + X_{eq}^2)(Q_2^{2'}R_{eq}^2 + X_{eq}^2P_2^{2'} - 2R_{eq}X_{eq}P_2^{'}Q_2^{'} + X_{eq}Q_2^{'})\}^{1/2}]$$

----------(A.17)

Equation (A.17) corresponds to equation number (2.18).

APPENDIX B

TABLE B.1 : Load data of the 10-bus test system.

Load bus number	Real power (p.u)	Reactive power (p.u)
2	0.439568	0.109896
3	0.2234114	0.081223
4	0.427616	0.106546
5	0.381749	0.439560
6	0.384615	0.143335
7	0.186335	0.026278
8	0.274725	0.014333
9	0.234114	0.031056
10	0.391782	0.047778

TABLE B.2 : Line data for the 10-bus system

From bus	To bus	Resistance (p.u)	Reactance (p.u)
1	2	0.000976	0.003266
2	3	0.000111	0.004788
3	4	0.005906	0.009535
4	5	0.005527	0.004814
5	6	0.015693	0.013671
6	7	0.007164	0.006240
7	8	0.016263	0.009211
8	9	0.037947	0.021492
9	10	0.023949	0.023949

Base KV = 23.

Base KVA = 4186.

TABLE B.3 : Load data for 31-bus test system

Load bus no.	Real power (p.u)	Reactive power (p.u)
3	0.0348	0 .0116
5	0.0428	0.0142
10	0.0126	0.0042
12	0.0224	0.0075
13	0.0438	0.0146
14	0.0522	0.0174
15	0.0486	0.0162
16	0.0588	0.0196
17	0.0588	0.0196
18	0.0588	0.0196
19	0.0138	0.0046
20	0.1278	0.0426
22	0.0744	0.0248
23	0.0366	0.0122
24	0.0528	0.0176
25	0.0298	0.0099
26	0.0448	0.0149
27	0.0448	0.0149
28	0.0486	0.0162
29	0.0366	0.0122
30	0.0522	0.0174
31	0.0330	0.0110

TABLE B.4 : Line data of 31-bus test system.

From bus	To bus	Resistance (p.u)	Reactance (p.u)
1	2	0.02733	0.02169
2	3	0.00791	0.00042
3	4	0.01258	0.01244
4	5	0.02449	0.02129
5	6	0.02449	0.02129
6	7	0.03896	0.02194
7	8	0.03896	0.02194
8	9	0.03896	0.02194
9	10	0.03896	0.02194
10	11	0.03896	0.02194
11	12	0.03896	0.02194
12	13	0.03896	0.02194
13	14	0.03896	0.02194
14	15	0.03896	0.02194
2	16	0.00791	0.00042
16	17	0.03896	0.02194
17	18	0.03896	0.02194
4	19	0.01258	0.01244
19	20	0.01258	0.01244
20	21	0.02449	0.02129
21	22	0.02449	0.02129
22	23	0.02449	0.02129
23	24	0.03896	0.02194
7	25	0.02449	0.02129
25	26	0.02449	0.02129
26	27	0.03896	0.02194
9	28	0.02449	0.02194
28	29	0.03896	0.02194
29	30	0.03896	0.02194
7	31	0.02449	0.02129

Base KV = 23

Base MVA = 15

APPENDIX C

Two Bus network with voltage dependent load

Consider a two-bus system as shown in Fig. C.1. In this system, the loads at bus 2 are assumed to be voltage dependent loads as given in equations (1.1) and (1.2).

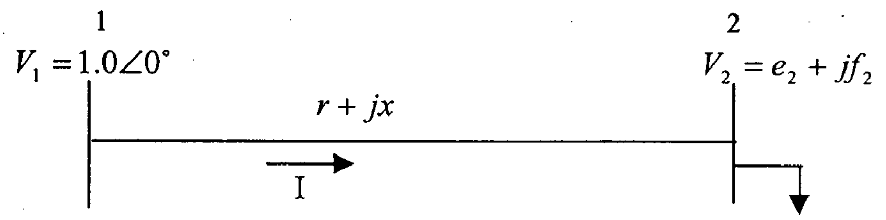

Figure C.1 : Equivalent two bus network

The current in the network is given by,

$$I = \frac{V_1 - V_2}{r + jx} \qquad \text{-----------(C.1)}$$

Noting that $V_1 = e_1 + jf_1 = 1.0 + j0$ and that $V_2 = e_2 + jf_2$, equation (C.1) reduces to

$$I = \frac{[(1-e_2)r - f_2 x] - j[(1-e_2)x + f_2 r]}{r^2 + jx^2} \qquad \text{----------(C.2)}$$

As $P + jQ = V_2 I^*$, we have,

$$P + jQ = (e_2 + jf_2)\frac{[(1-e_2)r - f_2 x] + j[(1-e_2)x + f_2 r]}{r^2 + x^2}$$

Separating the real and imaginary terms and after simplification we get,

$$P = \frac{(1-e_2)re_2 - xf_2 - f_2^2 r}{r^2 + x^2} \qquad \text{---------(C.3)}$$

$$Q = \frac{(1-e_2)xe_2 + rf_2 - f_2^2 x}{r^2 + x^2} \qquad \text{----------(C.4)}$$

Now for voltage dependent loads, $P = P_0|V|^a$ and $Q = Q_0|V|^b$. Hence from equation (C.3) we have,

$$P_0(e_2^2 + f_2^2)^{a/2} = \frac{(1-e_2)re_2 - xf_2 - f_2^2 r}{r^2 + x^2} \qquad \text{--------(C.5)}$$

Taking logarithm at both sides of equation (C.5) we have,

$$\log P_0 + \frac{a}{2}\log(e_2^2 + f_2^2) = \log[(1-e_2)e_2 r\{1 - \frac{xf_2 + f_2^2 r}{e_2 r - e_2^2 r}\}] - \log(r^2 + x^2)$$

Let constant $k_1 = \log P_0$ and $k_2 = \log(r^2 + x^2)$ and $k = k_1 + k_2$. Then from the above equation,

$$k + (a-1)\log(1 + (e_2 - 1)) + \frac{a}{2}\log(1 + \frac{f_2^2}{e_2^2}) = \log(1 - e_2) + \log\{1 - \frac{xf_2 + f_2^2 r}{e_2 r - e_2^2 r}\} + \log r \quad \text{---------(C.6)}$$

Now applying the logarithmic series to equation (C.6) and considering only first two terms, we get,

$$k' + (a-1)[(e_2 - 1) - \frac{(e_2-1)^2}{2}] + \frac{a}{2}[\frac{f_2^2}{e_2^2} - \frac{f_2^4}{2e_2^4}) = [-e_2 - \frac{e_2^2}{2}] + [\frac{xf_2 + f_2^2 r}{e_2 r - e_2^2 r} - \frac{(xf_2 + f_2^2 r)^2}{(e_2 r - e_2^2 r)^2}]$$

Where $k' = k - \log r$

Simplifying the above equation, we get,

$$\begin{aligned} e_2^8(-2ar^2 + 4r^2) + e_2^7(12ar^2 - 12r^2) + e_2^6(-24ar^2 + 18r^2 + 4k'r^2) + e_2^5(20ar^2 - 16r^2 - 8k'r^2) \\ + e_2^4(6ar^2 + 16r^2 + 4k'r^2 + 2f_2^2 ar^2 - 4fxr - 4f_2^2 r^2) + e_2^3(4f_2^2 ar^2 + 4fxr + 4f_2^2 r^2) \\ + e_2^2(2f_2^2 ar^2 - f_2^4 ar^2 + 2f_2^2 x^2 + 2f_2^4 r^2 + 4f_2^3 rx) + 2ef_2^4 ar^2 - f_2^4 ar^2) = 0 \end{aligned}$$

----------(C.7)

Similarly, for the reactive power load, we have,

$$Q = Q_0 |V|^b$$

Then, from equation (C.4) we have,

$$Q_0(e_2^2 + f_2^2)^{b/2} = \frac{(1-e_2)xe_2 + rf_2 - f_2^2 x}{r^2 + x^2}$$

Taking the logarithm at both sides of the above equation we have,

$$\log Q_0 + \frac{b}{2}\log(e_2^2 + f_2^2) = \log[(1-e_2)e_2 x\{1 + \frac{rf_2 - f_2^2 x}{e_2 x - e_2^2 x}\}] - \log(r^2 + x^2)$$

Let constant k = k_3+ k_4, where $k_3 = \log Q_0$ and $k_4 = \log(r^2 + x^2)$. Then from the above equation,

$$k + (b-1)\log(1 + (e_2 - 1)) + \frac{b}{2}\log(1 + \frac{f_2^2}{e_2^2}) = \log(1 - e_2) + \log\{1 - \frac{rf_2 - f_2^2 x}{e_2 x - e_2^2 x}\} + \log r$$

Now applying the logarithmic series to above equation and considering only first two terms, we get,

$$k' + (b-1)[(e_2 - 1) - \frac{(e_2 - 1)^2}{2}] + \frac{b}{2}[\frac{f_2^2}{e_2^2} - \frac{f_2^4}{2e_2^4}) = [-e_2 - \frac{e_2^2}{2}] + [\frac{rf_2 - f_2^2 x}{e_2 x - e_2^2 x} - \frac{(rf_2 - f_2^2 x)^2}{(e_2 x - e_2^2 x)^2}]$$

Where $k' = k - \log r$

Simplifying the above equation, we get

$$\begin{aligned} e_2^8(-2bx^2 + 4x^2) + e_2^7(12bx^2 - 12x^2) + e_2^6(-24bx^2 + 18x^2 + 4k'x^2) + e_2^5(20bx^2 - 16x^2 - 8k'x^2) \\ + e_2^4(-6bx^2 + 16x^2 + 4k'x^2 + 2f_2^2br^2 - 4fxr - 4f_2^2x^2) + e_2^3(-4f_2^2bx^2 + 4fxr + 4f_2^2x^2) \\ + e_2^2(2f_2^2bx^2 - f_2^4xr^2 + 2f_2^2r^2 + 2f_2^4x^2 + 4f_2^3rx) + 2ef_2^4bx^2 - f_2^4bx^2) = 0 \end{aligned}$$

----------(C.8)

APENDIX-D

Software for 10-bus constant loads

```
#include<stdio.h>
#include<math.h>
#define x 50
#define y 50
#define itmax 500
#define EPS 0.00001
#define BKVA 4186
#define BKV 23

void main()
{
FILE*fp,*fs,*fq;
int ii;
int i,j,k, A[x][y],nbus,n,nlbus,m;
float
P[x],Q[x],p[x],q[x],V[x],R[x],X[x],a,b,c,P2,Q2,z,z1,z2,z3,z4,z5,z6,z7,z8;
float t1,t2,t3,Pls[x],Qls[x],G[x],H[x],Req,Xeq,Pl[x],Ql[x],pls,qls;
float oo;
for(i=1;i<=x;i++)
 {
   P[i]=Q[i]=R[i]=X[i]=V[i]=Pls[i]=Qls[i]=pls=qls=t1=t2=t3=0.0;
   z=z1=z2=z3=z4=z5=z6=z7=z8=Pl[x]=Ql[x]=G[x]=H[x]=0.0;
 }
fp=fopen("b5.dat","r");
fs=fopen("b6.dat","r");
fq=fopen("r.res","w");
clrscr();


            /* CHECKING THE CONNECTIVITY OF BUSES*/

fscanf(fp,"%d",&nbus);
for(i=1;i<=nbus;i++)
 {
   for(j=1;j<=nbus;j++)
    {
      A[i][j]=0;
    }
 }
for(i=1;i<=nbus;i++)
 {
   A[i][i]=1;
       /* printf("A[%d][%d]=%d\n",i,i,A[i][i]);*/
 }

for(i=1;i<=nbus;i++)
 {
   for(; ;)
    {
      fscanf(fp,"%d",&n);
      if(n==999)
      break;
      A[i][n]=1;
```

```
            /* printf("A[%d][%d]=%d\n",i,n,A[i][n]);*/
    }
 }

            /*SUMMATION OF ALL THE LOADS*/

fscanf(fp,"%d",&nlbus);
for(i=1;i<=nlbus;i++)
fscanf(fp,"%d%f%f",&m,&Pl[i],&Ql[i]);
for(ii=1;ii<=10000;ii++)/*my loop start*/
{
fprintf(fq,"\nload iteration no.-----[%d]",ii);
V[1]=1.0;
Ql[10]=Ql[10]+0.1;
P[1]=0.0;
Q[1]=0.0;
for(i=1;i<=nlbus;i++)
{
   P[1]=P[1]+Pl[i];
   Q[1]=Q[1]+Ql[i];
}
fclose(fp);

/*fprintf(fq,"\n%f %f\n",P[1],Q[1]);*/
   G[1]=P[1];
   H[1]=Q[1];
   /*fprintf(fq,"\n%f %f",G[1],H[1]);*/

      for(k=1;k<=itmax;k++)     /* start of the main iterative loop */
       {
/*fprintf(fq,"\n\nSTART OF ITERATION NO.....[%d]",k);*/
       R[x]=X[x]=V[x]=Pls[x]=Qls[x]=pls=qls=t1=t2=t3=0.0;
       z=z1=z2=z3=z4=z5=z6=0.0;
       V[1]=1.0;
       for(i=1;i<=nbus;i++)
        {
         for(n=i+1;n<=nbus;n++)
          {
           if (A[i][n]==1)
            {
            /*fscanf(fp,"%d %f %f",&m &Pl[n],&Ql[n]);*/
            fscanf(fs,"%f %f",&R[n],&X[n]);
            P[n]=P[i]-(R[n])*(P[i]*P[i]+Q[i]*Q[i])/(V[i]*V[i])-Pl[n];
            Q[n]=Q[i]-(X[n])*(P[i]*P[i]+Q[i]*Q[i])/(V[i]*V[i])-Ql[n];
            t1=2*(R[n]*P[i]+X[n]*Q[i]);
            t2=(R[n]*R[n]+X[n]*X[n])*(P[i]*P[i]+Q[i]*Q[i]);
            t3=V[i]*V[i];
            c=(t3-t1+(t2/t3));
            V[n]=sqrt(c);
            Pls[i]=R[n]*(P[i]*P[i]+Q[i]*Q[i])/(V[i]*V[i])  ;
            Qls[i]=X[n]*(P[i]*P[i]+Q[i]*Q[i])/(V[i]*V[i])  ;
            }
          }
        }
       pls=qls=0.0;
       for(i=1;i<=nbus;i++)
        {
```

```
            pls=pls+Pls[i];
            qls=qls+Qls[i];
          }
        Req=(pls)/(P[1]*P[1]+Q[1]*Q[1]);
        Xeq=(qls)/(P[1]*P[1]+Q[1]*Q[1]);
        z=Req*Req+Xeq*Xeq;
        z1=2*Xeq*Xeq*G[1]-2*Req*Xeq*H[1]+Req;
        z2=Xeq*Xeq*G[1]*G[1]+Req*Req*H[1]*H[1]-2*Req*Xeq*G[1]*H[1]+Req*G[1];
        z3=sqrt(fabs(z1*z1-4*z*z2));
        z4=2*Req*Req*H[1]-2*Req*Xeq*G[1]+Xeq;
        z5=Req*Req*H[1]*H[1]+Xeq*Xeq*G[1]*G[1]-2*Req*Xeq*G[1]*H[1]+Xeq*H[1];
        z6=sqrt(fabs(z4*z4-4*z*z5));
        p[1]=(z1-z3)/(2*z);
        q[1]=(z4-z6)/(2*z);
        if ((fabs(p[1]-P[1]))<EPS)
        break;
        else
         {
            P[1]=p[1];
            Q[1]=q[1];
         }
        rewind(fs);
            /*SUUPER LOOP END*/
        }                       /* end of main loop */
         z7=4*(Xeq*p[1]-Req*q[1])*(Xeq*p[1]-Req*q[1]);
         z8=4*(Req*p[1]+Xeq*q[1]);
         if((z7-z8)<=1)
          {
          }
         else
          {
goto out;
          }
}/*my loop end*/
out:
printf("");
printf("\nSystem is not stable");
printf("\nQl[10] == %f\n",Ql[10]);
getch();
}         /* end of main */
```

Software for 10-bus voltage dependent loads

```
#include<stdio.h>
#include<math.h>
#define x 50
#define y 50
#define itmax 500
#define EPS 0.00001
#define BKVA 4186
#define BKV 23

void main()
{
FILE*fp,*fs,*fq;
int ii,count,count1;
int i,j,k, A[x][y],nbus,n,nlbus,m;
float
P[x],Q[x],p[x],q[x],V[x],R[x],X[x],a,b,c,d,P2,Q2,z,z1,z2,z3,z4,z5,z6,z7,z8;
float t1,t2,t3,Pls[x],Qls[x],G[x],H[x],Req,Xeq,Pl[x],Ql[x],pls,qls;
float oo,Pll[x],Qll[x],w1[x],w2[x];
clrscr();
for(count=2;count<=10;count++)
{
for(i=1;i<=x;i++)
 {
   P[i]=Q[i]=R[i]=X[i]=V[i]=Pls[i]=Qls[i]=pls=qls=t1=t2=t3=0.0;
   z=z1=z2=z3=z4=z5=z6=z7=z8=Pl[x]=Ql[x]=G[x]=H[x]=Pll[x]=Qll[x]=0.0;
   w1[x]=w2[x]=0.0;
 }
fp=fopen("b5.dat","r");
fs=fopen("b7.dat","r");
fq=fopen("r.res","w");
//clrscr();


            /* CHECKING THE CONNECTIVITY OF BUSES*/

fscanf(fp,"%d",&nbus);
for(i=1;i<=nbus;i++)
 {
   for(j=1;j<=nbus;j++)
    {
      A[i][j]=0;
    }
 }
for(i=1;i<=nbus;i++)
 {
   A[i][i]=1;

 }

for(i=1;i<=nbus;i++)
 {
   for(; ;)
    {
      fscanf(fp,"%d",&n);
      if(n==999)
```

```
       break;
       A[i][n]=1;
          }
     }
 }


            /*SUMMATION OF ALL THE LOADS*/


fscanf(fp,"%d",&nlbus);
for(i=1;i<=nlbus;i++)
{
fscanf(fp,"%d%f%f",&m,&Pl[i],&Ql[i]);
//Pl[m]=b;
//Ql[m]=d;
}

for(ii=1;ii<=1000;ii++)/*my loop start*/
{
V[1]=1.0;
Ql[count]=Ql[count]+0.1;
P[1]=0.0;
Q[1]=0.0;
for(i=1;i<=nlbus;i++)
{
   P[1]=P[1]+Pl[i];
   Q[1]=Q[1]+Ql[i];
}
fclose(fp);

   G[1]=P[1];
   H[1]=Q[1];

      for(k=1;k<=itmax;k++)     /* start of the main iterative loop */
       {
       R[x]=X[x]=V[x]=Pls[x]=Qls[x]=pls=qls=t1=t2=t3=0.0;
       z=z1=z2=z3=z4=z5=z6=0.0;
       V[1]=1.0;
       for(i=1;i<=nbus;i++)
        {
         for(n=i+1;n<=nbus;n++)
          {
           if (A[i][n]==1)
            {
            fscanf(fs,"%f%f%f%f",&R[n],&X[n],&w1[n],&w2[n]);

            t1=2*(R[n]*P[i]+X[n]*Q[i]);
            t2=(R[n]*R[n]+X[n]*X[n])*(P[i]*P[i]+Q[i]*Q[i]);
            t3=V[i]*V[i];
            c=(t3-t1+(t2/t3));
            V[n]=sqrt(c);
            Pll[n]=Pl[n]*(pow(V[n],w1[n]));
            Qll[n]=Ql[n]*(pow(V[n],w2[n]));
            P[n]=P[i]-(R[n])*(P[i]*P[i]+Q[i]*Q[i])/(V[i]*V[i])-Pll[n];
            Q[n]=Q[i]-(X[n])*(P[i]*P[i]+Q[i]*Q[i])/(V[i]*V[i])-Qll[n];
            Pls[i]=R[n]*(P[i]*P[i]+Q[i]*Q[i])/(V[i]*V[i])  ;
```

```
                Qls[i]=X[n]*(P[i]*P[i]+Q[i]*Q[i])/(V[i]*V[i]) ;
                }
             }
          }
        pls=qls=0.0;
        for(i=1;i<=nbus;i++)
          {
            pls=pls+Pls[i];
            qls=qls+Qls[i];

        Req=(pls)/(P[1]*P[1]+Q[1]*Q[1]);
        Xeq=(qls)/(P[1]*P[1]+Q[1]*Q[1]);
        z=Req*Req+Xeq*Xeq;
        z1=2*Xeq*Xeq*G[1]-2*Req*Xeq*H[1]+Req;
        z2=Xeq*Xeq*G[1]*G[1]+Req*Req*H[1]*H[1]-2*Req*Xeq*G[1]*H[1]+Req*G[1];
        z3=sqrt(fabs(z1*z1-4*z*z2));
/*      fprintf(fq,"\n%f %f %f %f",z,z1,z2,z3);*/
        z4=2*Req*Req*H[1]-2*Req*Xeq*G[1]+Xeq;
        z5=Req*Req*H[1]*H[1]+Xeq*Xeq*G[1]*G[1]-2*Req*Xeq*G[1]*H[1]+Xeq*H[1];
        z6=sqrt(fabs(z4*z4-4*z*z5));
        p[1]=(z1-z3)/(2*z);
        q[1]=(z4-z6)/(2*z);
        if ((fabs(p[1]-P[1]))<EPS)
        break;
        else
          {
            P[1]=p[1];
            Q[1]=q[1];
          }
        fclose(fs);
            /*SUUPER LOOP END*/
}                      /* end of main loop */
          z7=4*(Xeq*p[1]-Req*q[1])*(Xeq*p[1]-Req*q[1]);
          z8=4*(Req*p[1]+Xeq*q[1]);
          /*oo=z7-z8;
          f1=Xeq*G[1]-Req*H[1];
          e1=(1-sqrt(fabs(1-oo)))/2;
          e2=(1+sqrt(fabs(1-oo)))/2;
                if((z7-z8)<=1)
          {
fprintf(fq,"\nsystem is voltage stable");
          }
          else
          {
//fprintf(fq,"\nSystem is not stable");
//fprintf(fq,"\nPl[2] == %f\n",Pl[2]);
goto out;
          }
      //fprintf(fq,"Pl[2] = %f, V[2] = %f\n",Pl[2],V[2]);
      }/*my loop end*/
out:
printf("");
//printf("\nSystem is not stable");
printf("\n%f\n",Ql[count]);

  }
}          /* end of main */
```

G10,067

Software for 31-bus with lateral constant loads

```
#include<stdio.h>
#include<math.h>
#define x 35
#define y 35
#define itmax 100
#define EPS 0.00001
#define BSMVA 15
#define BSKV 23
void main()
{
FILE *fp,*fs,*fq,*fr,*fr1,*fr2;
int ii,count,tt,var1,aa[x],m1;
int i,j,J,k,l, A[x][y],nbus,nlbus,m,n,nn,a[x],var,num;
float P[x],Q[x],V[x],G[x],H[x],GG[x],HH[x],R[x],X[x],c,cc,PP[x],QQ[x];
float
t1,t2,t3,t4,t5,t6,z,z1,z2,z3,z4,z5,z6,RR,XX,Ploss,Qloss,VV[x],r[x],x1[x];
float pl[x],ql[x],Pl[x],Ql[x],b,d,zz,zz1,zz2,zz3,zz4,zz5,zz6,pp[x],qq[x];
float
PLS,QLS,pls[x],qls[x],Pls[x],Qls[x],Req,Xeq,req,xeq,PPl[x],QQl[x],p[x],q[x];
float iii,e,f,Pl1[x],Ql1[x],z7,z8,temp,bb,dd;
float zzz,zzz1,zzz2,zzz3,zzz4,zzz5,zzz6,Psload,Qsload,VS[x];
float ppp[x],qqq[x],Res,Xes,reqs,xeqs,PPPl[x],QQQl[x];
for(i=1;i<=x;i++)
 {
   P[i]=Q[i]=V[i]=R[i]=X[i]=Pl[i]=Ql[i]=PP[i]=QQ[i]=t1=t2=t3=G[i]=H[i]=0.0;
   VV[i]=t4=t5=t6=z=z1=z2=z3=z4=z5=z6=z7=z8=zz=zz1=zz2=zz3=zz4=zz5=zz6=0.0;
   Pls[i]=Qls[i]=pls[i]=qls[i]=req=xeq=Req=Xeq=pl[i]=ql[i]=Ploss=Qloss=0.0;
   r[i]=x1[i]=PPl[i]=QQl[i]=Pl1[i]=Ql1[x]=PPPl[i]=QQQl[i]=0.0;
   //Res=Xes=Psload=Qsload=reqs=xeqs=VS[x]=0.0;
   }
   for(i=1;i<=x;i++)
 {
   a[i]=aa[i]=0;
     }
fp=fopen("newc1.dat","r");
fs=fopen("newc2.dat","r");
fr=fopen("newc3.dat","r");
fr2=fopen("cc.dat","r");
fq=fopen("newr.res","w");
clrscr();

            /* CHECKING THE CONNECTIVITY OF BUSES*/

fscanf(fp,"%d",&nbus);
for(i=1;i<=nbus;i++)
 {
   for(j=1;j<=nbus;j++)
    {
      A[i][j]=0;
    }
 }
for(i=1;i<=nbus;i++)
 {
   A[i][i]=1;
```

```
 }

for(i=1;i<=nbus;i++)
 {
     for(; ;)
     {
       fscanf(fp,"%d",&n);
       if(n==999)
       break;
       A[i][n]=1;
             /* printf("A[%d][%d]=%d\n",i,n,A[i][n]);*/
     }
 }
                     /*SUMITION OF ALL THE LOADS*/

V[1]=1.0;
fscanf(fp,"%d",&var);
for(i=1;i<=var;i++)
fscanf(fp,"%d",&a[i]);
fscanf(fp,"%d",&var1);
for(i=1;i<=var1;i++)
fscanf(fp,"%d",&aa[i]);
fscanf(fp,"%d",&nlbus);
for(i=1;i<=nlbus;i++)
   fscanf(fp,"%d %f %f",&m,&Pl[i],&Ql[i]);
    //printf("**%f",Pl[31]);
   count=3;
   for(ii=1;ii<=1000;ii++)
   {
Pl[count]=Pl[count]+0.01;
      P[1]=0.0;
      Q[1]=0.0;
      for(i=1;i<=nlbus;i++)
      {
       P[1]=P[1]+Pl[i];
       Q[1]=Q[1]+Ql[i];
      }
 fclose(fp);

G[1]=P[1];
   H[1]=Q[1];

for(k=1;k<=itmax;k++)        //chota loop
{
 for(l=1;l<=nbus;l++)
  {
    for(n=l+1;n<=nbus;n++)
    {
      if(A[l][n]==1)
      {
       fscanf(fs,"%f %f",&R[n],&X[n]);

       t1=2*(R[n]*P[l]+X[n]*Q[l]);
       t2=(R[n]*R[n]+X[n]*X[n])*(P[l]*P[l]+Q[l]*Q[l]);
       t3=(V[l]*V[l]);
       c=(t3-t1+(t2/t3));
       V[n]=sqrt(c);
```

```
if(a[n]==1)
 {    /*start of lateral loop */
fscanf(fr,"%d",&nn);

for(i=1;i<=nn;i++)
{
   pl[i]=ql[i]=0.0;
  fscanf(fr,"%d",&num);
  //printf("&&%f\n",Pl[17]);
     pl[i]=Pl[num];
     ql[i]=Ql[num];

     }
  PP[1]=0.0;
  QQ[1]=0.0;
  for(i=1;i<=nn;i++)
  {
  PP[1]=PP[1]+pl[i];
  QQ[1]=QQ[1]+pl[i];
}
GG[1]=PP[1];
 HH[1]=QQ[1];
 VV[1]=V[n];

 for(j=1;j<=nn;j++)
 {
fscanf(fr,"%f%f",&r[j],&x1[j]);
 t4=2*(r[j]*PP[j]+x1[j]*QQ[j]);
 t5=(r[j]*r[j]+x1[j]*x1[j])*(PP[j]*PP[j]+QQ[j]*QQ[j]);
 t6=(VV[j]*VV[j]);
 cc=(t6-t4+(t5/t6));
 J=j+1;
 VV[J]=sqrt(cc);
 PP[J]=PP[j]-r[j]*(PP[j]*PP[j]+QQ[j]*QQ[j])/(VV[j]*VV[j])-pl[j];
 QQ[J]=QQ[j]-x1[j]*(QQ[j]*QQ[j]+PP[j]*PP[j])/(VV[j]*VV[j])-ql[j];
 pls[j]=r[j]*(PP[j]*PP[j]+QQ[j]*QQ[j])/(VV[j]*VV[j]);
 qls[j]=x1[j]*(QQ[j]*QQ[j]+PP[j]*PP[j])/(VV[j]*VV[j]);
}
PLS=QLS=0.0;
 for(i=1;i<=nn;i++)
 {
PLS=PLS+pls[i];
QLS=QLS+qls[i];
}
req=PLS/(PP[1]*PP[1]+QQ[1]*QQ[1]);
xeq=QLS/(PP[1]*PP[1]+QQ[1]*QQ[1]);
zz=req*req+xeq*xeq;
zz1=2*xeq*xeq*GG[1]-2*req*xeq*HH[1]+req*VV[1]*VV[1];
zz2=xeq*xeq*GG[1]*GG[1]+req*req*HH[1]*HH[1]-
2*req*xeq*GG[1]*HH[1]+req*GG[1]*VV[1]*VV[1];
zz3=sqrt(fabs(zz1*zz1-4*zz*zz2));

zz4=2*req*req*HH[1]-2*xeq*req*GG[1]+xeq*VV[1]*VV[1];
zz5=req*req*HH[1]*HH[1]+xeq*xeq*GG[1]*GG[1]-
2*req*xeq*GG[1]*HH[1]+xeq*HH[1]*VV[1]*VV[1];
zz6=sqrt(fabs(zz4*zz4-4*zz*zz5));
pp[1]=(zz1-zz3)/(2*zz);
```

```
qq[1]=(zz4-zz6)/(2*zz);

  PPl[n]=pp[1];
  QQl[n]=qq[1];
  }                     //end of lateral loop

 if(aa[n]==1)
{
  fscanf(fr2,"%d%f%f",&m1,&Res,&Xes);
  Psload=Pl[m1];
  Qsload=Ql[m1];
  //printf("*%f %f\n",Psload,Qsload);
 VS[1]=V[n];
  /*t7=2*(Res*Psload+Xes*Qsload);
  t8=(Res*Res+Xes*Xes*(Psload*Psload+Qsload*Qsload);
  t9=(Vs[1]*Vs[1]);
  ccc=(t9-t7+(t8/t9));
  Vs[2]=sqrt(ccc);    */
  reqs=Res/(VS[1]*VS[1]);
  xeqs=Xes/(VS[1]*VS[1]);
 zzz=reqs*reqs+xeqs*xeqs;
 zzz1=2*xeqs*xeqs*Psload-2*reqs*xeqs*Qsload+reqs*VS[1]*VS[1];
 zzz2=xeqs*xeqs*Psload*Psload+reqs*reqs*Qsload*Qsload-
 2*reqs*xeqs*Psload*Qsload+reqs*Psload*VS[1]*VS[1];
 zz3=sqrt(fabs(zz1*zz1-4*zz*zz2));
 zzz3=sqrt(fabs(zzz1*zzz1-4*zzz*zzz2));
 zzz4=2*reqs*reqs*Qsload-2*xeqs*reqs*Psload+xeqs*VS[1]*VS[1];
 zzz5=reqs*reqs*Qsload*Qsload+xeqs*xeqs*Psload*Psload-
 2*reqs*xeqs*Psload*Qsload+xeqs*Qsload*VS[1]*VS[1];
 zzz6=sqrt(fabs(zzz4*zzz4-4*zzz*zzz5));
 ppp[1]=(zzz1-zzz3)/(2*zzz);
 qqq[1]=(zzz4-zzz6)/(2*zzz);
 PPPl[n]=ppp[1];
 QQQl[n]=qqq[1];
 }

Pl1[n]=Pl[n]+PPl[n]+PPPl[n];
Ql1[n]=Ql[n]+QQl[n]+QQQl[n];
P[n]=P[1]-(R[n])*(P[1]*P[1]+Q[1]*Q[1])/(V[1]*V[1])-Pl1[n];
Q[n]=Q[1]-(X[n])*(P[1]*P[1]+Q[1]*Q[1])/(V[1]*V[1])-Ql1[n];
Pls[1]=R[n]*(P[1]*P[1]+Q[1]*Q[1])/(V[1]*V[1]) ;
Qls[1]=X[n]*(P[1]*P[1]+Q[1]*Q[1])/(V[1]*V[1]) ;
   }
 }
}
  Ploss=Qloss=0.0;
 for(i=1;i<=nbus;i++)
 {
  Ploss=Ploss+Pls[i];
  Qloss=Qloss+Qls[i];
  }
 Req=Ploss/(P[1]*P[1]+Q[1]*Q[1]);
 Xeq=Qloss/(P[1]*P[1]+Q[1]*Q[1]);
 z=Req*Req+Xeq*Xeq;
 z1=2*Xeq*Xeq*G[1]-2*Req*Xeq*H[1]+Req;
 z2=Xeq*Xeq*G[1]*G[1]+Req*Req*H[1]*H[1]-2*Req*Xeq*G[1]*H[1]+Req*G[1];
 z3=sqrt(fabs(z1*z1-4*z*z2));
```

```
      z4=2*Req*Req*H[1]-2*Req*Xeq*G[1]+Xeq;
      z5=Req*Req*H[1]*H[1]+Xeq*Xeq*G[1]*G[1]-2*Req*Xeq*G[1]*H[1]+Xeq*H[1];
      z6=sqrt(fabs(z4*z4-4*z*z5));
      p[1]=(z1-z3)/(2*z);
      q[1]=(z4-z6)/(2*z);
      if(fabs(p[1]-P[1])<EPS)
      break;
      else
      {
       P[1]=p[1];
       Q[1]=q[1];
       }
       rewind(fs);
       rewind(fr);
       rewind(fr2);
     }                                          /*end of chota loop*/
      z7=4*pow((Xeq*p[1]-Req*q[1]),2);
      z8=4*(Req*p[1]+Xeq*q[1]);
      if((z7-z8)<=1)
      {
     fprintf(fq,"SYSTEM IS VOLTAGE STABLE");
      }
      else
      {
     fprintf(fq,"SYSTEM IS NOT VOLTAGE STABLE");
     goto out;
     }
 ///printf("%f\n",Ql[3]);
  //printf("Ql[%d]= %f\n",ii,Pl[count]);
} //my loop end
out:
printf("");
printf("Ql=%f\n",Pl[count]);
getch();
}
```

Software for 31-bus with lateral voltage dependent loads

```
#include<stdio.h>
#include<math.h>
#define x 50
#define y 50
#define itmax 10
#define EPS 0.00001
#define BSMVA 15
#define BSKV 23
void main()
{
FILE*fp,*fs,*fq,*fr,*fr1,*fr2;
int ii,count,tt,var1,aa[x],m1;
int i,j,J,k,l, A[x][y],nbus,nlbus,m,n,nn,a[x],var,num;
float P[x],Q[x],V[x],G[x],H[x],GG[x],HH[x],R[x],X[x],c,cc,PP[x],QQ[x];
float
t1,t2,t3,t4,t5,t6,z,z1,z2,z3,z4,z5,z6,RR,XX,Ploss,Qloss,VV[x],r[x],x1[x];
float pl[x],ql[x],Pl[x],Ql[x],b,d,zz,zz1,zz2,zz3,zz4,zz5,zz6,pp[x],qq[x];
float
PLS,QLS,pls[x],qls[x],Pls[x],Qls[x],Req,Xeq,req,xeq,PPl[x],QQl[x],p[x],q[x];
float iii,e,f,Pl1[x],Ql1[x],z7,z8,temp,bb,dd;
float zzz,zzz1,zzz2,zzz3,zzz4,zzz5,zzz6,Psload,Qsload,VS[x];
float ppp[x],qqq[x],Res,Xes,reqs,xeqs,PPPl[x],QQQl[x],w1[x],w2[x];
float Pln[x],Qln[x],w3[x],w4[x];
for(i=1;i<=x;i++)
 {
   P[i]=Q[i]=V[i]=R[i]=X[i]=Pl[i]=Ql[i]=PP[i]=QQ[i]=t1=t2=t3=G[i]=H[i]=0.0;
   VV[i]=t4=t5=t6=z=z1=z2=z3=z4=z5=z6=z7=z8=zz=zz1=zz2=zz3=zz4=zz5=zz6=0.0;
   Pls[i]=Qls[i]=pls[i]=qls[i]=req=xeq=Req=Xeq=pl[i]=ql[i]=Ploss=Qloss=0.0;
   r[i]=x1[i]=PPl[i]=QQl[i]=Pl1[i]=Ql1[x]=PPPl[i]=QQQl[i]=0.0;
   //Res=Xes=Psload=Qsload=reqs=xeqs=VS[x]=0.0;
   }
   for(i=1;i<=x;i++)
 {
   a[i]=aa[i]=0;
      }

fp=fopen("newc1.dat","r");
fs=fopen("newc5.dat","r");
fr=fopen("newc4.dat","r");
//fr1=fopen("clo.dat","r");
fr2=fopen("cc.dat","r");
fq=fopen("newr.res","w");
clrscr();

            /* CHECKING THE CONNECTIVITY OF BUSES*/

fscanf(fp,"%d",&nbus);
for(i=1;i<=nbus;i++)
 {
   for(j=1;j<=nbus;j++)
    {
      A[i][j]=0;
    }
 }
for(i=1;i<=nbus;i++)
 {
```

```
    A[i][i]=1;
         /* printf("A[%d][%d]=%d\n",i,i,A[i][i]);*/
  }

 for(i=1;i<=nbus;i++)
  {
     for(; ;)
     {
       fscanf(fp,"%d",&n);
       if(n==999)
       break;
       A[i][n]=1;
            /* printf("A[%d][%d]=%d\n",i,n,A[i][n]);*/
     }
  }

         /*Sum all the loads*/

 V[1]=1.0;
 fscanf(fp,"%d",&var);
 for(i=1;i<=var;i++)
 fscanf(fp,"%d",&a[i]);
 fscanf(fp,"%d",&var1);
 for(i=1;i<=var1;i++)
 fscanf(fp,"%d",&aa[i]);
 fscanf(fp,"%d",&nlbus);
 for(i=1;i<=nlbus;i++)
    fscanf(fp,"%d %f %f",&m, &Pl[i],&Ql[i]);
    count=31;
    for(ii=1;ii<=1000;ii++)
    {
    fprintf(fq,"iteration[%d]\n",ii);
     Ql[count]=Ql[count]+0.01;
       P[1]=0.0;
       Q[1]=0.0;

       for(i=1;i<=nlbus;i++)
       {
        P[1]=P[1]+Pl[i];
        Q[1]=Q[1]+Ql[i];
       }
  fclose(fp);
 G[1]=P[1];
    H[1]=Q[1];

 for(k=1;k<=itmax;k++)        //chota loop
 {
  for(l=1;l<=nbus;l++)
   {
     for(n=l+1;n<=nbus;n++)
     {
       if(A[l][n]==1)
       {
        fscanf(fs,"%f%f%f%f",&R[n],&X[n],&w3[n],&w4[n]);
       t1=2*(R[n]*P[l]+X[n]*Q[l]);
        t2=(R[n]*R[n]+X[n]*X[n])*(P[l]*P[l]+Q[l]*Q[l]);
        t3=(V[l]*V[l]);
```

```
        c=(t3-t1+(t2/t3));
        V[n]=sqrt(c);
if(a[n]==1)
        {   //printf("%f\n",Pl[31]);        /*start of lateral loop */
       fscanf(fr,"%d",&nn);
       for(i=1;i<=nn;i++)
       {
           pl[i]=ql[i]=0.0;
         fscanf(fr,"%d",&num);
         //printf("%d\n",num);getch();
            pl[i]=Pl[num];
            ql[i]=Ql[num];
                  }
         PP[1]=0.0;
         QQ[1]=0.0;
         for(i=1;i<=nn;i++)
         {
         PP[1]=PP[1]+pl[i];
         QQ[1]=QQ[1]+pl[i];
       }
GG[1]=PP[1];
        HH[1]=QQ[1];
        VV[1]=V[n];
for(j=1;j<=nn;j++)
        {
       fscanf(fr,"%f%f%f%f",&r[j],&x1[j],&w1[j],&w2[j]);
        t4=2*(r[j]*PP[j]+x1[j]*QQ[j]);
        t5=(r[j]*r[j]+x1[j]*x1[j])*(PP[j]*PP[j]+QQ[j]*QQ[j]);
        t6=(VV[j]*VV[j]);
        cc=(t6-t4+(t5/t6));
        J=j+1;
        VV[J]=sqrt(cc);
        pl[j]=pl[j]*(pow(VV[J],w1[j]));
        ql[j]=ql[j]*(pow(VV[J],w2[j]));
        PP[J]=PP[j]-r[j]*(PP[j]*PP[j]+QQ[j]*QQ[j])/(VV[j]*VV[j])-pl[j];
        QQ[J]=QQ[j]-x1[j]*(QQ[j]*QQ[j]+PP[j]*PP[j])/(VV[j]*VV[j])-ql[j];
        pls[j]=r[j]*(PP[j]*PP[j]+QQ[j]*QQ[j])/(VV[j]*VV[j]);
        qls[j]=x1[j]*(QQ[j]*QQ[j]+PP[j]*PP[j])/(VV[j]*VV[j]);
       }
       PLS=QLS=0.0;
        for(i=1;i<=nn;i++)
        {
       PLS=PLS+pls[i];
       QLS=QLS+qls[i];
       }
       req=PLS/(PP[1]*PP[1]+QQ[1]*QQ[1]);
       xeq=QLS/(PP[1]*PP[1]+QQ[1]*QQ[1]);

       zz=req*req+xeq*xeq;
       zz1=2*xeq*xeq*GG[1]-2*req*xeq*HH[1]+req*VV[1]*VV[1];
       zz2=xeq*xeq*GG[1]*GG[1]+req*req*HH[1]*HH[1]-
       2*req*xeq*GG[1]*HH[1]+req*GG[1]*VV[1]*VV[1];
       zz3=sqrt(fabs(zz1*zz1-4*zz*zz2));
       zz4=2*req*req*HH[1]-2*xeq*req*GG[1]+xeq*VV[1]*VV[1];
       zz5=req*req*HH[1]*HH[1]+xeq*xeq*GG[1]*GG[1]-
       2*req*xeq*GG[1]*HH[1]+xeq*HH[1]*VV[1]*VV[1];
       zz6=sqrt(fabs(zz4*zz4-4*zz*zz5));
```

```
      pp[1]=(zz1-zz3)/(2*zz);
      qq[1]=(zz4-zz6)/(2*zz);

       PPl[n]=pp[1];
       QQl[n]=qq[1];
       }                        //end of lateral loop

     if(aa[n]==1)
     {
       fscanf(fr2,"%d%f%f",&m1,&Res,&Xes);
       Psload=Pl[m1];
       Qsload=Ql[m1];
       //printf("*%f %f\n",Psload,Qsload);
      VS[1]=V[n];
       /*t7=2*(Res*Psload+Xes*Qsload);
       t8=(Res*Res+Xes*Xes*(Psload*Psload+Qsload*Qsload);
       t9=(Vs[1]*Vs[1]);
       ccc=(t9-t7+(t8/t9));
       Vs[2]=sqrt(ccc);    */
       reqs=Res/(VS[1]*VS[1]);
       xeqs=Xes/(VS[1]*VS[1]);
      zzz=reqs*reqs+xeqs*xeqs;
      zzz1=2*xeqs*xeqs*Psload-2*reqs*xeqs*Qsload+reqs*VS[1]*VS[1];
      zzz2=xeqs*xeqs*Psload*Psload+reqs*reqs*Qsload*Qsload-
      2*reqs*xeqs*Psload*Qsload+reqs*Psload*VS[1]*VS[1];
      zzz3=sqrt(fabs(zzz1*zzz1-4*zzz*zzz2));
      zzz4=2*reqs*reqs*Qsload-2*xeqs*reqs*Psload+xeqs*VS[1]*VS[1];
      zzz5=reqs*reqs*Qsload*Qsload+xeqs*xeqs*Psload*Psload-
      2*reqs*xeqs*Psload*Qsload+xeqs*Qsload*VS[1]*VS[1];
      zzz6=sqrt(fabs(zzz4*zzz4-4*zzz*zzz5));
      ppp[1]=(zzz1-zzz3)/(2*zzz);
      qqq[1]=(zzz4-zzz6)/(2*zzz);
      //printf("**%f %f\n",ppp[1],qqq[1]);
      PPPl[n]=ppp[1];
      QQQl[n]=qqq[1];
      //printf("%f %f\n",PPPl[n],QQQl[n]);
      }
     Pl1[n]=Pl[n]+PPl[n]+PPPl[n];
     Ql1[n]=Ql[n]+QQl[n]+QQQl[n];
     Pln[n]=Pl1[n]*(pow(V[n],w3[n]));
     Qln[n]=Ql1[n]*(pow(V[n],w4[n]));
     P[n]=P[1]-(R[n])*(P[1]*P[1]+Q[1]*Q[1])/(V[1]*V[1])-Pl1[n];
     Q[n]=Q[1]-(X[n])*(P[1]*P[1]+Q[1]*Q[1])/(V[1]*V[1])-Ql1[n];
     Pls[1]=R[n]*(P[1]*P[1]+Q[1]*Q[1])/(V[1]*V[1])  ;
     Qls[1]=X[n]*(P[1]*P[1]+Q[1]*Q[1])/(V[1]*V[1])  ;
       }
      }
    }
       Ploss=Qloss=0.0;
      for(i=1;i<=nbus;i++)
      {
       Ploss=Ploss+Pls[i];
       Qloss=Qloss+Qls[i];
       }
//fprintf(fq,"%f %f\n",Ploss,Qloss);
      Req=Ploss/(P[1]*P[1]+Q[1]*Q[1]);
      Xeq=Qloss/(P[1]*P[1]+Q[1]*Q[1]);
```

```
        z=Req*Req+Xeq*Xeq;
        z1=2*Xeq*Xeq*G[1]-2*Req*Xeq*H[1]+Req;
        z2=Xeq*Xeq*G[1]*G[1]+Req*Req*H[1]*H[1]-2*Req*Xeq*G[1]*H[1]+Req*G[1];
        z3=sqrt(fabs(z1*z1-4*z*z2));
//fprintf(fq,"\n%f %f %f %f",z,z1,z2,z3);
        z4=2*Req*Req*H[1]-2*Req*Xeq*G[1]+Xeq;
        z5=Req*Req*H[1]*H[1]+Xeq*Xeq*G[1]*G[1]-2*Req*Xeq*G[1]*H[1]+Xeq*H[1];
        z6=sqrt(fabs(z4*z4-4*z*z5));
        p[1]=(z1-z3)/(2*z);
        q[1]=(z4-z6)/(2*z);
fprintf(fq,"\np[1]=%f q[1]=%f\tReq=%f Xeq=%f\n",p[1],q[1],Req,Xeq);
        if(fabs(p[1]-P[1])<EPS)
        break;
        else
        {
         P[1]=p[1];
         Q[1]=q[1];
         }
         rewind(fs);
         rewind(fr);
         rewind(fr2);
       }                                  /*end of chota loop*/
fprintf(fq,"\np[1]=%f q[1]=%f\tReq=%f Xeq=%f\n",p[1],q[1],Req,Xeq);
        z7=4*pow((Xeq*p[1]-Req*q[1]),2);
        z8=4*(Req*p[1]+Xeq*q[1]);
        if((z7-z8)<=1)
        {
       //fprintf(fq,"SYSTEM IS VOLTAGE STABLE");
        }
        else
        {
       //fprintf(fq,"SYSTEM IS NOT VOLTAGE STABLE");
       goto out;
       }
       printf("Ql[%d] =%f\n",ii,Ql[count]);
   } //my loop end
out:
printf("");
printf("Pl[%d] =%f\n",count,Ql[count]);
getch();
 }
```

Software for Solving nonlinear equation of voltage dependent loads

```
#include<stdio.h>
#include<math.h>
#include<conio.h>
#define x 2
#define y 2
#define itmax 100

void main()
{
FILE *fp;
int  i,j,k;
float R,X,s,m,a[2][2],z,z1,t1,t2,t3,t4,t5,t6,t7,t8,t9,t10,t11,F1,e;
float z2,z3,y1,y2,y3,y4,y5,y6,y7,y8,y9,y10,y11,F2,f1;
float A,B,C,D,E,F,Temp,Temp1,Temp2;
float e1,f,P,Q;
clrscr();
fp=fopen("nl.res","w");
e=0.5;
f=0.5;
for(k=1;k<=itmax;k++)
  {          //iteration loop start
    P=Q=0.0;
    R=X=s=m=z=z1=t1=t2=t3=t4=t5=t6=t7=t8=t9=t10=t11=0.0;
    z2=z3=y1=y2=y3=y4=y5=y6=y7=y8=y9=y10=y11=F1=F2=0.0;
    A=B=C=D=E=F=Temp=Temp1=Temp2=e1=f1=0.0;
    a[1][1]=a[1][2]=a[2][1]=a[2][2]=0.0;
    P=2.954610;
    Q=1.000000;
    R=0.017992;
    X=0.022725;
    s=0;
    m=0;
  fprintf(fp,"\n\nno. of iteration[%d]",k);
   z1=P*(R*R+X*X);
   z=log(z1/R);
   t1=2*R*R*(2-s);
   t2=12*R*R*(s-1);
   t3=2*R*R*(2*z+9-12*s);
   t4=4*R*R*(5*s-4-2*z);
   t5=(6*R*R-6*s*R*R+4*z*R*R);
   t6=(2*f*f*s*R*R-4*f*X*R-4*f*f*R*R);
   t7=(4*f*X*R-4*R*R*s*f*f+4*f*f*R*R);
   t8=(2*R*R*s*f*f-R*R*s*f*f*f*f+2*f*f*X*X+2*f*f*f*f*R*R+4*f*f*f*R*X);
   t9=R*R*s*f*f*f*f;
   t10=2*R*R*e*e-s*R*R*e*e+2*R*R*s*e-s*R*R;
   t11=e*e*(s*R*R*e*e-2*R*R*e*e-2*R*R*s*e+2*R*R*e+R*R*s*e*e+X*X*e*e);
   z2=Q*(R*R+X*X);
   z3=log(z2/X);
   y1=2*X*X*(2-m);
   y2=12*X*X*(m-1);
   y3=2*X*X*(2*z3+9-12*m);
   y4=4*X*X*(5*m-4-2*z3);
   y5=2*X*X*(2*z3+3-3*m);
   y6=(2*m*X*X*f*f-4*f*f*X*X+4*f*R*X);
```

```
    y7=4*f*X*(f*R-m*X*f-R);
    y8=f*f*(2*X*X*m-f*f*X*X*m+2*R*R+2*f*f*X*X-4*f*R*X);
    y9=X*X*m*f*f*f*f;
    y10=2*X*X*e*e-m*X*X*e*e+2*m*X*X*e-m*X*X;
    y11=e*e*(e*e*m*X*X-2*X*X*e*e+2*X*R*e-2*m*X*X*e+X*X*m-R*R);
    /*printf("*%f",f);*/

F1=t1*pow(e,8)+t2*pow(e,7)+t3*pow(e,6)+t4*pow(e,5)+t5*pow(e,4)+t6*pow(e,4)+t7*
pow(e,3)+t8*pow(e,2)+t9*(2*e-1);

F2=y1*pow(e,8)+y2*pow(e,7)+y3*pow(e,6)+y4*pow(e,5)+y5*pow(e,4)+y6*pow(e,4)+y7*
pow(e,3)+y8*pow(e,2)+y9*(2*e-1);
/*    printf("**%f",f);*/
    //fprintf(fp,"\n%f %f",F1,F2);

A=a[1][1]=8*t1*pow(e,7)+7*t2*pow(e,6)+6*t3*pow(e,5)+5*t4*pow(e,4)+4*t5*pow(e,3
)+4*t6*pow(e,3)+3*t7*pow(e,2)+2*t8*e+2*t9;
    B=a[1][2]=4*f*f*f*t10+12*f*f*R*X*e*e+4*f*t11+4*X*R*e*e*e*(1-e);

C=a[2][1]=8*y1*pow(e,7)+7*y2*pow(e,6)+6*y3*pow(e,5)+5*y4*pow(e,4)+4*y5*pow(e,3
)+4*y6*pow(e,3)+3*y7*pow(e,2)+2*y8*e+2*y9;
    D=a[2][2]=4*f*f*f*y10-12*f*f*R*X*e*e+4*f*y11+4*X*R*e*e*e*(1-e);
//fprintf(fp,"\n%f %f %f %f",a[1][1],a[1][2],a[2][1],a[2][2]);
       E=-1*F1;
       F=-1*F2;
       //fprintf(fp,"\n%f %f",E,F);
       Temp=A*D-B*C;
       //fprintf(fp,"\nTemp=%f",Temp);
       Temp1=D*E-B*F;
       Temp2=A*F-C*E;
       //fprintf(fp,"\nTemp1=%f Temp2=%f",Temp1,Temp2);
       e1=Temp1/Temp;
       f1=Temp2/Temp;
       //fprintf(fp,"\ne1=%f f1=%f",e1,f1);
       if(fabs(F1)<=0.000001 && fabs(F2)<=0.000001)
       break;
       else
       {
       e=(e+e1);
       f=(f+f1);
       }
       fprintf(fp,"\n\ne=%f f=%f",e,f);
  }  //iteration loop end
 fprintf(fp,"\nFINAL VALUE %f %f",e,f);
 }
```