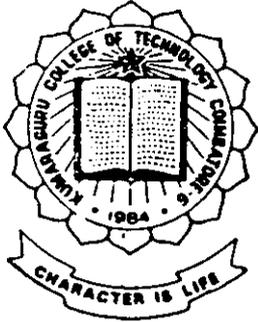# COMPUTER AIDED ANALYSIS OF

COMPENSATED EHV LINES

PROJECT REPORT

submitted by

A RICHARD
PRASHANTH CHANDRAN
V ASHOK KUMAR

1995-96

under the guidance of

Mr V SIVAKUMAR, B.E.

In partial fulfilment of the requirements
for the award of the degree of

BACHELOR OF ENGINEERING

In ELECTRICAL AND ELECTRONICS ENGINEERING

of the Bharathiar University, Coimbatore

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING
KUMARAGURU COLLEGE OF TECHNOLOGY
Coimbatore 641 006

CERTIFICATE

Department of Electrical and Electronics Engineering

Kumaraguru College of Technology
Coimbatore - 641 006

Certificate

Name _A. RICHARD, PRASHANTH CHANDRAN, V. ASHOK KUMAR_

University Register No. _____

This is to certify that the Project work

"COMPUTER AIDED ANALYSIS OF COMPENSATED EHV LINES"

is a bonafide work carried out by

Mr. _____

In partial fulfilment of the requirements for the award of the degree of Bachelor of Engineering in Electrical and Electronics Engineering Branch of the Bharathiar University, Coimbatore during the academic year 1995-1996

Station : Coimbatore

Date : 9/4/96

_____
Guide

_____
PROFESSOR & HEAD
Dept. of Electrical & Electronics Engg.
Kumaraguru College of Tech., Coimbatore-

Submitted for the University Examination held on _____

_____
Internal Examinar

_____
External Examinar

BANGALORE
29 MARCH 1996

CERTIFICATE

This is to certifiy that the following final year B.E. ELECTRICAL & ELECTRONICS ENGINEERING students of KUMARAGURU COLLEGE OF TECHNOLOGY, COIMBATORE have under taken a project under the title:

"COMPUTER AIDED ANALYSIS OF COMPENSATED EHV LINES"

in Power System division department of the Central Power Research Institute, Bangalore during the period September 1995 to March 1996.

1. A. RICHARD

2. V.ASHOK KUMAR

3. PRASHANTH CHANDRAN

The above students have taken great interest and have shown immence potential in the field of study. Their conduct and character have been good and have completed the project sucessfully.

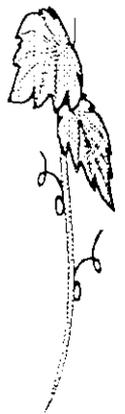Yours,

P.V.BALASUBRAMANYAM, M.Tech
ENGINEERING OFFICER GR.IV

DEDICATED
TO OUR
BELOVED PARENTS

ACKNOWLEDGEMENT

ACKNOWLEDGEMENT

We record our sincere thanks and profound gratitude to our beloved lecturer **Mr V SIVAKUMAR, B.E.,** for his valuble guidance and immense help at all stages of this project work.

We are elated to record our heartiest indebtness to our beloved **Professor and Head Of The Department of Electrical And Electronics Engineering, Dr K A PALANISWAMY, M.Sc.(Engg.), Ph.D., M.I.S.T.E., C.Engg.(I), F.I.E.,** for inspiring us to do this project. We are indebted to him for his valuable ideas which helped us in the successful completion of the project.

Our thanks are due, to our principal, **Dr S SUBRAMANIAN,B.E., M.Sc.(Engg.), Ph.D., S.M.IEEE., M.I.S.T.E.,** for providing us all the facilities to carry out this project work.

We whole-heartedly express our gratitude and sincere thanks to **Mr P V BALASUBRAMANYAM, E.O.IV, Power System Division, CENTRAL POWER RESEARCH INSTITUTE (C.P.R.I.),** for his valuable ideas which helped us in the successful completion of our project.

We also wish to acknowledge our sincere thanks to our beloved parents, friends and all the faculty members who stood by our side in pain and pleasure during this project work.

SYNOPSIS

SYNOPSIS

The growing demand of electricity and the economics associated with its supply at low rates to consumers has resulted in the construction of large capacity generating station at suitable locations. Large load centres are often located at great distances from such generating stations. Bulk power is carried from these stations to load centres over Extra High Voltage transmission lines for which voltages upto 400 Kilo Volt have been used. Use of series capacitors to compensate line parameters has led to an economical and efficient method of improving stability and system performance.

The present work deals with the analysis of series capacitor compensated Extra High Voltage (E.H.V) lines. Further, the problems arising in the series capacitor compensation and their remedies have been mentioned.

A software in Fortran 77 has been developed to analyse the compensated line.

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CONTENTS

INTRODUCTION

CHAPTER 1

INTRODUCTION

1.1. STRUCTURE OF POWER SYSTEM

The major parts of a power system are

      1.1.1. Generating System.

      1.1.2. Transmission Lines.

      1.1.3. Distribution Systems.

These are schematically represented in fig (1.01).

1.1.1. GENERATING SYSTEM

This forms the head of the frame. Energy is generated by using the earth's natural resources to the fullest extent.The different types of generating plants are,

      1.1.1.1. Diesel power plant.

      1.1.1.2. Hydro-electric power plant.

      1.1.1.3. Thermal power plant.

      1.1.1.4. Nuclear power plant.

Voltages like 6.6, 11, 13.8 KV are generated.

1.1.2. TRANSMISSION LINES

Transmission lines and distribution systems are the connecting link between the generating station and lead to other power systems over interconnections.

The generated voltage is stepped up to transmission levels in the range of 115 to 765 KV.

They can be categorised as High Voltage (HV) and Extra High Voltage (EHV) at 330 KV. The above fall under EHV category.

In INDIA, 400 KV A.C. transmission system are in service. The behavior of these EHV lines are in many respect similar to the 220 KV lines.

Transmission of large blocks of power over long distance can be done most economically only by using EHV lines. Normally EHV A.C. lines are preferred.

Underground transmission cables are mostly used in heavily populated areas. Research is still being carried out on an ultra high voltage transmission in the range of 1000 KV to 1500 KV.

1.1.3. DISTRIBUTION SYSTEM

A distribution system connects all the individual loads to the transmission lines at sub stations, which perform voltage transformation and switching action.

1.2. LONG DISTANCE POWER TRANSMISSION

Long distance, bulk power transmission from remote generating stations to concentrated load centers is one of the most important needs of the power industry.

Now a days much progress in transmission engineering has been achieved. The most important of these developments are:

    i. Increasing the voltage levels of the transmission

    ii. The use of various methods of improving the stability limits

There are many problems associated with higher transmission voltages such as switching surges, insulation of systems etc.,

There are mainly two alternatives to utilise the existing line capacity fully and improve stability limits. They are:

    i. Series and shunt compensation of lines

    ii. H.V.D.C. transmission

The H.V.D.C. transmission though has advantages, suffers the disadvantages of the impossibility of exchange of reactive power and high cost of the terminal equipments.

The compensation of transmission line inductance and capacitance by series capacitor and shunt reactor is considered as a powerful tool for the improvement of power system performance.

The series capacitors, by artificially reducing net amount of reactance presented by the line, to a degree depending on the percentage of compensation used, permits an increase of the permissible loading of the line.

The present work deals with compensation and analysis of transmission line with **SERIES CAPACITOR.**

GENERATING SYSTEM

TRANSMISSION SYSTEM

DISTRIBUTION SYSTEM
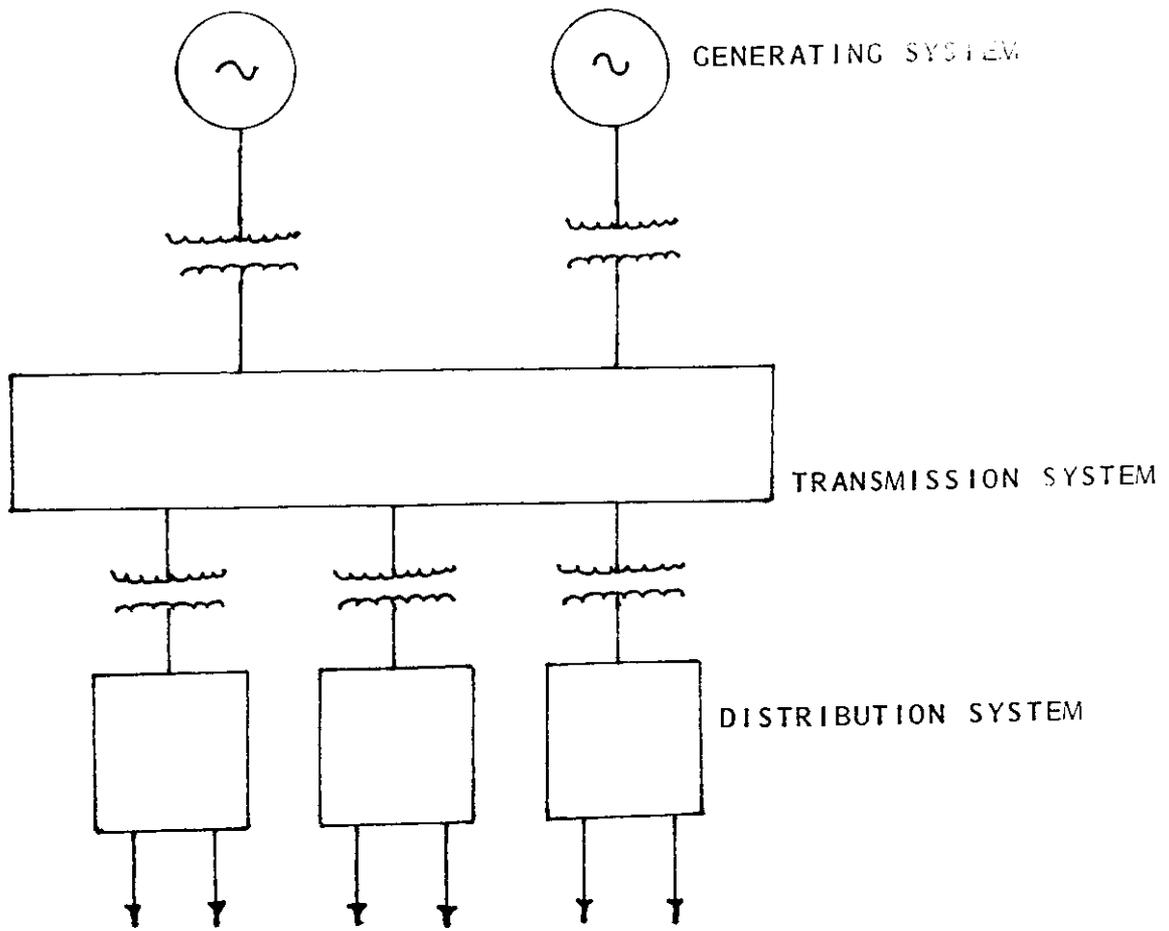
STRUCTURE OF POWER SYSTEM

FIG. 1.01

TRANSMISSION LINE MODELLING
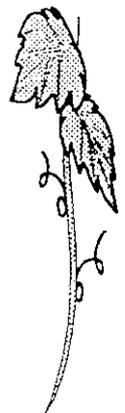
CHAPTER 2

TRANSMISSION LINE MODELING

This part primarily deals with the characteristics and performance of transmission lines. Normally, transmission lines are operated with three phase balanced loads. Hence the analysis can proceed on a per phase basis.

2.1. TWO PORT REPRESENTATION

A transmission line may be regarded as a two port network where the sending end quantities are related to the receiving end quantities, through ABCD parameters. This is shown in figure (2.01).

Let V_S be the sending end voltage. V_R be the receiving end voltage. I_S be the sending end current. I_R be the receiving end current. then

$$V_S = A{\cdot}V_R + B{\cdot}I_R \qquad\qquad (2.01)$$
$$I_S = C{\cdot}V_R + D{\cdot}I_R \qquad\qquad (2.02)$$

Equations (2.01) and (2.02) can be represented in matrix form as

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \cdot \begin{bmatrix} V_R \\ I_R \end{bmatrix} \qquad\qquad (2.03)$$

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The ABCD constants of any transmission lines may be determined easily by making suitable assumptions.

2.2. CLASSIFICATION OF TRANSMISSION LINES

Transmission lines are classified into three types depending on their length.

     1. SHORT LINES   Line length 100 Km (or less).

     2. MEDIUM LINES   Line length 100 Km to 250 Km.

     3. LONG LINES   Line length over 250 Km.

2.3. DERIVATION OF ABCD CONSTANTS FOR DIFFERENT TYPES OF TRANSMISSION LINES

2.3.1. SHORT LINES

The admittance of short lines is neglected. Thus the equivalent of short lines is as shown in fig. (2.02).

R is the resistance of the line and X is the impedance of the line.

The relationship between sending end and receiving end voltages and current are

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$$V_S = V_R + (R+jX) \cdot I_R$$

$$V_S = V_R + Z \cdot I_R \qquad (2.04)$$

where $Z = R + jX$

$$I_S = I_R$$

$$I_S = 0 \cdot V_R + I_R \qquad (2.05)$$

Equations (4) and (5) can be represented as

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \cdot \begin{bmatrix} V_R \\ I_R \end{bmatrix} \qquad (2.06)$$

Comparing equations (2.03) and (2.06)

The ABCD constants are $A = 1$; $B = Z$;

$\qquad\qquad\qquad\qquad\qquad\qquad C = 0$; $D = 1$.

2.3.2. MEDIUM LINES

The shunt admittance cannot be neglected for medium lines. They are lumped at one or two places.

If the shunt admittance placed in the middle of the line, then the circuit is called as the NOMINAL "T" NETWORK and if it is placed at the two ends of the line the circuit is called as the NOMINAL "π" NETWORK

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2.3.2.1. ABCD CONSTANTS FOR NOMINAL T NETWORK

The impedance z is derived into two (each $Z/2$) and the admittance (Y) is lumped at the centre, as shown in figure (2.03)

Let V_Y be the voltage across the shunt admittance. Then,

$$V_C = V_R + I_R \cdot (Z/2)$$

$$I_S = I_R + V_C \cdot Y$$

substituting the value of V_C in I_S, we get.

$$I_S = I_R + Y \cdot V_R + I_R \cdot (Z/2) \cdot Y$$

$$I_S = Y \cdot V_R + (1 + YZ/2) \cdot I_R \tag{2.07}$$

$$V_S = V_C + I_S \cdot (Z/2)$$

$$V_S = V_R + I_R \cdot (Z/2) + I_S \cdot (Z/2)$$

$$V_S = V_R + I_R \cdot (Z/2) + (Y \cdot V_R + (1 + YZ/2) \cdot I_R) \cdot (Z/2)$$

$$V_S = V_R (1 + YZ/2) + I_R \cdot Z (1 + YZ/4) \tag{2.08}$$

Equations (2.07) and (2.08) can be represented as

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} (1+YZ/2) & Z(1+YZ/4) \\ Y & (1+YZ/2) \end{bmatrix} \cdot \begin{bmatrix} V_R \\ I_R \end{bmatrix} \tag{2.09}$$

Comparing equations (2.08) and (2.09), we get

$$A = 1+YZ/2 \quad ; \quad B = Z(1+YZ/4)$$

$$C = Y \quad ; \quad D = (1+YZ/2)$$

2.3.2.2. ABCD CONSTANTS FOR NOMINAL - π NETWORK

The admittance (Y) is divided into 2 (ie., each is Y/2) and placed at the end of the π network, with impedance Z in the middle, as shown in the figure (2.04).

The relationship between sending end and receiving end voltages and currents are,

$$V_S = V_R + (I_R + V_R \cdot Y/2)\, Z$$

$$V_S = (1 + YZ/2) \cdot V_R + Z \cdot I_R \tag{2.10}$$

$$I_S = I_R + V_R \cdot Y/2 + V_S \cdot Y/2$$

$$I_S = I_R + V_R \cdot Y/2 + (1 + YZ/2 + I_R \cdot Z)\, Y/2$$

$$I_S = Y\,(1 + YZ/4) \cdot V_R + (1 + YZ/2) \cdot I_R \tag{2.11}$$

Equations (10) and (11) can be represented as,

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} (1+YZ/2) & Z \\ Y(1+YZ/4) & (1+YZ/2) \end{bmatrix} \cdot \begin{bmatrix} V_R \\ I_R \end{bmatrix} \tag{2.12}$$

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Comparing equations (2.03)and (2.12), we get,

$$A = 1+YZ/2 \quad : \quad B = Z :$$

$$C = Y(1+YZ/4) \quad : \quad D = (1+YZ/2).$$

2.3.3. DERIVATION OF ABCD PARAMETERS FOR LONG TRANSMISSION LINE

For long transmission lines, the impedances are distributed uniformly all along the line. Figure (2.05) shows **'SINGLE PHASE EQUIVALENT CIRCUIT'** of a long transmission line.

Consider a small elemental length 'dx' of the line at a distance 'x' from the receiving end. let 'L' be the total length of the line measured from receiving end. Let 'Z' be the impedance of the line per phase per unit length of line in ohms.

Let `Y` be the susceptance per phase per unit length of line in mhos,

From figure (2.05) we have,

$$dv = IZdx$$

or

$$dv/dx = IZ \qquad\qquad (2.13)$$

$$dl/dx = VY \qquad\qquad (2.14)$$

Differentiating equation (2.13) w.r.t. x, we get,

$$\frac{d^2V}{dx^2} = \frac{dI}{dx} \cdot z$$

substituting the value of dI/dx from equation (2.14),

$$\frac{d^2V}{dx^2} = YZV \tag{2.15}$$

This is a linear differential equation whose solution can be written as,

$$V = K_1 \cdot e^{\sqrt{(YZ)}x} + K_2 \cdot e^{-\sqrt{(YZ)}x}$$
$$V = K_1 \cdot e^{\gamma X} + K_2 \cdot e^{-\gamma X} \tag{2.16}$$

where,

$$\gamma = \sqrt{(YZ)}$$

K_1, K_2 are arbitrary constants to be evaluated.
Differentiating equation (2.16) w.r.t. x,

$$\frac{dV}{dX} = K_1 \cdot \gamma \cdot e^{\gamma x} - K_2 \cdot \gamma \cdot e^{-\gamma x}$$

Substituting the value of dV/dX from eq.(2.13),

$$IZ = \gamma (K_1 \cdot e^{\gamma x} - K_2 \cdot e^{-\gamma x}) \tag{2.17}$$

Substituting the value of γ,

$$IZ = \sqrt{(YZ)} [K_1 \cdot e^{\gamma x} - K_2 \cdot e^{-\gamma x}]$$
$$I = \sqrt{(Y/Z)} [K_1 \cdot e^{\gamma x} - K_2 \cdot e^{-\gamma x}]$$

Let $Z_o = \sqrt{(Y/Z)}$, then
$$I = 1/Z_o \cdot (K_1 \cdot e^{\gamma x} - K_2 \cdot e^{-\gamma x}) \tag{2.18}$$

The constants K_1 & K_2 can be evaluated by using end conditions.

When $X = 0$; $V = V_R$ and $I = I_R$

substituting these values in eq.(2.16) and (2.18), we get,

$$V_R = K_1 + K_2$$
$$I_R = 1/Z_o \cdot (K_1 - K_2)$$

Which on solving yields,

$$K_1 = 1/2 (V_R + Z_o \cdot I_R)$$
$$K_2 = 1/2 (V_R - Z_o \cdot I_R)$$

Substituting the values of K_1 and K_2 in equations (2.16) and (2.18), we get,

$$V = \frac{(V_R + I_R \cdot Z_o) \cdot e^{\gamma X}}{2} + \frac{(V_R - I_R \cdot Z_o) \cdot e^{\gamma X}}{2} \qquad (2.19)$$

$$I = \frac{(V_R + I_R \cdot Z_o) \cdot e^{\gamma X}}{2 \cdot Z_o} - \frac{(V_R - I_R \cdot Z_o) \cdot e^{\gamma X}}{2 \cdot Z_o} \qquad (2.20)$$

Rearranging equations (2.19) and (2.20) we get,

$$V = V_R \cdot \frac{(e^{\gamma X} + e^{\gamma X})}{2} + I_R \cdot Z_o \cdot \frac{(e^{\gamma X} - e^{\gamma X})}{2}$$

$$I = \frac{V_R}{Z_o} \cdot \frac{(e^{\gamma X} - e^{\gamma X})}{2} + I_R \cdot \frac{(e^{\gamma X} + e^{\gamma X})}{2}$$

The above equations can be written as,

$$V = V_R \cdot COSH(\gamma X) + I_R \cdot Z_o \cdot SINH(\gamma X)$$
$$I = (V_R/Z_o) \cdot SINH(\gamma X) + I_R \cdot COSH(\gamma X)$$

When $X = L$: $V = V_s$ and $I = I_s$

$$\therefore \quad V_s = V_R \cdot COSH(\gamma X) + I_R \cdot Z_o \cdot SINH(\gamma L) \qquad (2.21)$$

$$\therefore \quad I_s = (V_R/Z_o) \cdot SINH(\gamma L) + I_R \cdot SINH(\gamma L) \qquad (2.22)$$

But we know that,

$$V_s = A.V_R + B.I_R \qquad (2.23)$$

$$I_s = C.V_R + D.I_R \qquad (2.24)$$

Comparing equations (2.21) and (2.23), equations (2.22) and (2.24), we get,

$$A = COSH(\gamma L) \qquad B = Z_o \cdot SINH(\gamma L)$$

$$C = (1/Z_o) \cdot SINH(\gamma L) \qquad D = COSH(\gamma L)$$

Where

Z_o is called the 'CHARACTERISTIC IMPEDANCE' and

γ is called the 'PROPAGATION CONSTANT'

2. 4 ABCD CONSTANTS FOR SERIES CAPACITOR COMPENSATING NETWORK

The series capacitor compensating network is shown in fig.(2.06).

We know that

$$V_s = A \cdot V_R + B \cdot I_R \qquad (2.25)$$

$$I_s = C \cdot V_R + D \cdot I_R \qquad (2.26)$$

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From the above network, we have,

$$V_R = V_S - I_R(-jX_C)$$
$$= V_S + I_R \cdot jX_C$$
$$\therefore \quad V_S = V_R - (jX_C) \cdot I_R \qquad\qquad (2.27)$$
$$I_S = O \cdot V_R + I_R \qquad\qquad (2.28)$$

Comparing equations (2.25) and (2.27), equations (2.26) and (2.28) we get,

$$A_C = 1 \qquad B_C = -jX_C$$
$$C_C = O \qquad D_C = 1$$

2.5 ABCD CONSTANTS FOR A NETWORK CONNECTED IN SERIES

Whenever a power system consists of a series combination of networks, whose ABCD constants are known, the overall ABCD constants for the system may be determined as follows.

Consider two series networks of ABCD constants $A_{S1}, B_{S1}, C_{S1}, D_{S1}$ and $A_{S2}, B_{S2}, C_{S2}, D_{S2}$ as shown in fig. (2.07)

The two networks can be reduced to a single equivalent network as follows.

For the first network we have,

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A_{S1} & B_{S1} \\ C_{S1} & D_{S1} \end{bmatrix} \cdot \begin{bmatrix} V_x \\ I_x \end{bmatrix} \qquad\qquad (2.29)$$

For the second network we have,

$$\begin{bmatrix} V_x \\ I_x \end{bmatrix} = \begin{bmatrix} A_{S2} & B_{S2} \\ C_{S2} & D_{S2} \end{bmatrix} \cdot \begin{bmatrix} V_R \\ I_R \end{bmatrix} \qquad\qquad (2.30)$$

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From equations (2.29) and (2.30), we get,

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A_{S1} & B_{S1} \\ C_{S1} & D_{S1} \end{bmatrix} \cdot \begin{bmatrix} A_{S2} & B_{S2} \\ C_{S2} & D_{S2} \end{bmatrix} \cdot \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

On simplification we get,

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A_0 & B_0 \\ C_0 & D_0 \end{bmatrix} \cdot \begin{bmatrix} V_R \\ I_R \end{bmatrix}$$

Thus the overall ABCD constants of the network is equal to the product of the ABCD matrix of the networks.

$$\begin{bmatrix} A_0 & B_0 \\ C_0 & D_0 \end{bmatrix} = \begin{bmatrix} A_{S1} & B_{S1} \\ C_{S1} & D_{S1} \end{bmatrix} \cdot \begin{bmatrix} A_{S2} & B_{S2} \\ C_{S2} & D_{S2} \end{bmatrix}$$

2.6 POWER FLOW THROUGH A TRANSMISSION LINE

The sending end and receiving endvoltages and currents of a transmission line are related by,

$$V_S = A_0 \cdot V_R + B_0 \cdot I_R \qquad (2.31)$$

$$I_S = C_0 \cdot V_R + D_0 \cdot I_R \qquad (2.32)$$

Let $V_R = V_R \lfloor 0$ and $V_S = V_S \lfloor \delta$

where δ is called the Torque or the p[ower angle.

Let $A_0.B_0.C_0.D_0$ be the net transmission line constants.

Then $A_0 = A_0 \lfloor \alpha \qquad B_0 = B_0 \lfloor \beta$

$\qquad C_0 = C_0 \lfloor \Delta \qquad D_0 = D_0 \lfloor \delta$

From eq.(2.31) we have,

$$I_R = (1/B_0) \cdot V_S - (A_0/B_0) \cdot V_R \qquad (2.33)$$

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Substituting the value of I_R from equations (2.33) in (2.32) we get.

$$I_s = C_o \cdot V_R + \left[\frac{V_s}{B_o} - \frac{A_o}{B_o} \cdot V_R \right] \cdot D_o$$

$$I_s = \frac{D_o}{B_o} \cdot V_s + \left[C_o - \frac{(A_o \cdot D_o)}{B_o} \right] \cdot V_R$$

$$I_s = \frac{D_o}{B_o} \cdot V_s - (A_o \cdot D_o - C_o \cdot B_o) \cdot \frac{V_R}{B_o}$$

$$\therefore \quad I_s = \frac{D_o}{B_o} \cdot V_s - \frac{V_R}{B_o} \qquad (2.34)$$

Therefore equations (2.33) and (2.34) can be written as,

$$I_R = (1/B_o) \cdot |V_s| \underline{|\delta\text{-}\beta} - (A_o/B_o) \cdot |V_R| \underline{|\alpha\text{-}\beta}$$

$$I_s = (D_o/B_o) \cdot |V_s| \underline{|\delta\text{+}\alpha\text{-}\beta} - (1/B_o) \cdot |V_R| \underline{|\Delta\text{-}\beta}$$

The complex power at the sending and receiving end are,

$$S_R = P_R + jQ_R = V_R \, I_R^* \qquad (2.35)$$

$$S_s = P_s + jQ_s = V_s \, I_s^* \qquad (2.36)$$

* represents conjugate.

Substituting the value of I_R from eq.(2.33) into (2.35) we get.

$$S_R = |V_R| \underline{|0} \cdot \left[\frac{1}{|B_o|} \cdot |V_s| \underline{|\beta-\delta} - \frac{|A_o|}{|B_o|} \cdot |V_R| \underline{|\beta-\alpha} \quad \right]$$

$$\therefore \quad S_R = \frac{|V_s||V_R|}{|B_o|} \cdot \underline{|\beta-\delta} - \frac{|A_o|}{|B_o|} \cdot |V_R|^2 \cdot \underline{|\beta-\alpha} \qquad (2.37)$$

Substituting the value of I_S from equation (2.32) into (2.36) we get

$$S_S = \frac{|A_0|}{|B_0|} |V_S|^2 \underline{|\beta - \alpha|} - \frac{|V_R||V_R|}{|B_0|} \underline{|\beta + \alpha|} \tag{2.38}$$

If equations (2.37) and (2.38) are expressed as real and imaginary parts, then real power at receiving end is given by,

$$P_R = \frac{|V_S||V_R|}{|B_0|} \cos(\beta - \delta) - \frac{|A_0||V_R|^2}{|B_0|} \cos(\beta - \alpha) \tag{2.39}$$

and real power at sending end is,

$$P_S = \frac{|D_0||V_S|^2}{|B_0|} \cos(\beta - \alpha) - \frac{|V_S||V_R|}{|B_0|} \cos(\beta + \delta) \tag{2.40}$$

Reactive power at receiving end is.

$$Q_R = \frac{|V_S||V_R|}{|B_0|} \sin(\beta - \delta) - \frac{|A_0||V_R|^2}{|B_0|} \sin(\beta - \alpha) \tag{2.41}$$

Reactive power at sending end is.

$$Q_S = \frac{|D_0||V_S|^2}{|B_0|} \sin(\beta - \alpha) - \frac{|V_S||V_R|}{|B_0|} \sin(\beta + \delta) \tag{2.42}$$

It is seen from equation (2.39) that the receiving end power (P_R) is maximum at $\delta = \beta$

$$P_{R\,MAX} = \frac{|V_S||V_R|}{|B_0|} - \frac{|A_0||V_R|^2}{|B_0|} \cos(\beta - \alpha) \tag{2.43}$$

Let R be the ratio of sending end voltage (V_S) and receiving end voltage (V_R).

$$R = \frac{V_S}{V_R}$$

From this,

$$V_R = \frac{V_S}{R}$$

Substituting the value of V_R in equations (2.39), (2.40), (2.41), (2.42) and (2.43) we get.

$$P_R = \frac{|V_s|^2}{R|B_o|} \cos(\beta - \delta) - \frac{|V_s|^2 |A_o|}{R^2|B_o|} \cos(\beta - \alpha) \qquad (2.44)$$

$$P_S = \frac{|V_s|^2 |D_o|}{|B_o|} \cos(\beta - \alpha) - \frac{|V_s|^2}{R|B_o|} \cos(\beta + \delta) \qquad (2.45)$$

$$Q_R = \frac{|V_s|^2}{R|B_o|} \sin(\beta - \delta) - \frac{|V_s|^2 |A_o|}{R^2|B_o|} \sin(\beta - \alpha) \qquad (2.46)$$

$$Q_S = \frac{|V_s|^2 |D_o|}{|B_o|} \sin(\beta - \alpha) - \frac{|V_s|^2}{R|B_o|} \sin(\beta + \delta) \qquad (2.47)$$

$$P_{R\,MAX} = \frac{|V_s|^2}{R|B_o|} - \frac{|V_s|^2 |A_o|}{R^2|B_o|} \cos(\beta - \alpha) \qquad (2.48)$$

2.7 DERIVATION FOR LOAD ANGLE (δ)

For a power factor equal to cos ϕ, the ratio of real to reactive power is given by,

$$\frac{P_R}{Q_R} = \frac{\cos\phi}{\sin\phi} = \frac{\dfrac{E_s^2}{RB}\cos(\beta - \delta) - \dfrac{E_s^2}{R^2 B} A \cos(\beta - \alpha)}{\dfrac{E_s^2}{RB}\sin(\beta - \delta) - \dfrac{E_s^2}{R^2 B} A \sin(\beta - \alpha)}$$

$$= \frac{\cos(\beta - \delta) - \dfrac{A}{R}\cos(\beta - \alpha)}{\sin(\beta - \delta) - \dfrac{A}{R}\sin(\beta - \alpha)}$$

$$\Rightarrow \frac{COS\phi}{SIN\phi} = \frac{R\,COS(\beta-\delta) - A\,COS(\beta-\alpha)}{R\,SIN(\beta-\delta) - A\,SIN(\beta-\alpha)}$$

$R\,COS\phi\,SIN(\beta-\delta) - A\,COS\phi\,SIN(\beta-\delta) = R\,SIN\phi\,COS(\beta-\delta) - A\,SIN\phi\,COS(\beta-\alpha)$

$R\,[COS\phi\,SIN(\beta-\delta) - SIN\phi\,COS(\beta-\delta)] = A\,[COS\phi\,SIN(\beta-\alpha) - SIN\phi\,COS(\beta-\alpha)]$

$-R\,[SIN(\phi-\beta+\delta)] = -A\,[SIN(\phi-\beta+\alpha)]$

$$SIN(\phi-\beta+\delta) = \frac{A}{R}\,SIN(\phi-\beta+\alpha)$$

$$\phi-\beta+\delta = SIN^{-1}\left[\frac{A}{R}\,SIN(\phi-\beta+\alpha)\right]$$

$$\therefore \quad \delta = \phi-\beta+SIN^{-1}\left[\frac{A}{R}\,SIN(\phi-\beta+\alpha)\right] \tag{2.49}$$

2.8 EFFICIENCY

The efficiency of the system is given by

$$\text{Efficiency } (\eta) = (PR/PS) \cdot 100 \tag{2.50}$$

2.9 DERIVATION OF CRITICAL VOLTAGE ($V_{R\,CRIT}$) AND CRITICAL LOAD ANGLE (δ_{CRIT})

We know that.

$$P_R = \frac{V_S \cdot V_R}{B}\,COS(\beta-\delta) - \frac{A\,V_R^{\,2}}{B}\,COS(\beta-\alpha) \tag{2.51}$$

$$Q_R = \frac{V_S \cdot V_R}{B}\,SIN(\beta-\delta) - \frac{A\,V_R^{\,2}}{B}\,SIN(\beta-\alpha) \tag{2.52}$$

Where,

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} |A|\underline{\alpha} & |B|\underline{\beta} \\ |c|\underline{\gamma} & |d|\underline{\Delta} \end{bmatrix}$$

are the ABCD constants of transmision line.

The two equations can be written as a function of $V_S.V_R.\delta$ and are given by

$$F_1 = P_R - \frac{V_S.V_R}{B} COS(\beta - \delta) + \frac{A.V_R^2}{B} COS(\beta - \alpha) \qquad (2.53)$$

$$F_2 = Q_R - \frac{V_S.V_R}{B} SIN(\beta - \delta) + \frac{A.V_R^2}{B} SIN(\beta - \alpha) \qquad (2.54)$$

Where F_1 and F_2 are dependant on $V_S.V_R.\delta$

Assuming V_S is fixed at 1P.U. F_1 and F_2 depends on V_R and δ

From equations (2.53) and (2.54), small variations of F_1 and F_2 in V_R and δ can be obtained and are,

$$\Delta F_1 = \frac{\partial F_1}{\partial \delta} \Delta \delta + \frac{\partial F_1}{\partial V_R} \Delta V_R \qquad (2.55)$$

$$\Delta F_2 = \frac{\partial F_2}{\partial \delta} \Delta \delta + \frac{\partial F_2}{\partial V_R} \Delta V_R \qquad (2.56)$$

putting it in matrix form we get,

$$\begin{bmatrix} \Delta F_1 \\ \Delta F_2 \end{bmatrix} = \begin{bmatrix} \partial F_1/\partial \delta & \partial F_1/\partial V_R \\ \partial F_2/\partial \delta & \partial F_2/\partial V_R \end{bmatrix} \cdot \begin{bmatrix} \Delta \delta \\ \Delta V_R \end{bmatrix} \qquad (2.57)$$

The maximum power transfer criterion is determined by considering the singularity of equation (2.57)

$$\frac{\partial F_1}{\partial \delta} \cdot \frac{\partial F_2}{\partial V_R} \cdot \frac{\partial F_2}{\partial \delta} = 0 \qquad (2.58)$$

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From equations (2.53) and 2.54) we get.

$$\frac{\partial F_1}{\partial \delta} = 0 - \frac{V_s \cdot V_R}{B} \left[-Sin(\beta - \delta)(-1) \right]$$

$$\frac{\partial F_1}{\partial \delta} = - \frac{V_s \cdot V_R}{B} \left[Sin(\beta - \delta) \right] \tag{2.59}$$

$$\frac{\partial F_1}{\partial V_R} = \frac{-V_s}{B} Cos(\beta - \delta) + 2\frac{A}{B} V_R Cos(\beta - \alpha) \tag{2.60}$$

$$\frac{\partial F_2}{\partial \delta} = \frac{-V_s \cdot V_R}{B} \left[Cos(\beta - \delta)(-1) \right]$$

$$\frac{\partial F_2}{\partial \delta} = \frac{V_s \cdot V_R}{B} Cos(\beta - \delta) \tag{2.61}$$

$$\frac{\partial F_2}{\partial V_R} = \frac{-V_s}{B} SIN(\beta - \delta) + 2\frac{A}{B} V_R SIN(\beta - \alpha) \tag{2.62}$$

Substituting equations (2.59), (2.60), (2.61) and (2.62) in equation (2.58) we get.

$$\left[\frac{-V_s V_R}{B} SIN(\beta - \delta) \right] \left[\frac{-V_s}{B} SIN(\beta - \delta) + 2\frac{A}{B} V_R SIN(\beta - \alpha) \right] -$$

$$\left[\frac{-V_s}{B} COS(\beta - \delta) + 2\frac{A}{B} V_R COS(\beta - \alpha) \right] \left[\frac{V_s V_R}{B} COS(\beta - \delta) \right]$$

$$\Rightarrow \frac{V_s^2 V_R}{B_2} SIN^2(\beta - \delta) - 2\frac{A}{B_2} V_s V_R^2 SIN(\beta - \delta) - SIN(\beta - \alpha) +$$

$$\frac{V_s^2 V_R}{B_2} COS^2(\beta - \delta) - 2\frac{A}{B_2} V_s V_R^2 COS(\beta - \alpha) COS(\beta - \delta) = 0$$

$$\frac{V_s \cdot V_R}{B_2} \left[V_s - SIN^2(\beta - \delta) + V_s COS^2(\beta - \delta) - 2A V_R SIN(\beta - \delta) SIN(\beta - \alpha) \right.$$

$$\left. -2A V_R COS(\beta - \delta) COS(\beta - \alpha) \right] = 0$$

$$V_s \left[SIN^2(\beta-\delta)+COS^2(\beta-\delta) \right] - 2AV_R \left[SIN(\beta-\delta)SIN(\beta-\alpha)+COS(\beta-\delta)COS(\beta-\alpha) \right] = 0$$

$$V_s - 2AV_R COS(\beta) = 0$$

$$V_s = 2AV_R COS(\alpha-\delta)$$

$$V_R = \frac{V_s}{2A COS(\alpha-\delta)}$$

Wherer V_R is the critical voltage.

$$\therefore V_{R\ CRIT} = \frac{V_s}{2A.COS(\alpha-\delta)} \qquad (2.63)$$

To find the critical load angle .
we know that .

$$Q_R = P_R\ TAN\ \phi$$

$$Q_R = P_R\ \frac{SIN\ \phi}{COS\ \phi}$$

Where $COS\ \phi$ is the load power factor

Then $TAN\ \phi = Q_R / P_R$

Substituting.

$$TAN\,\phi = \frac{\dfrac{V_s V_R}{B} SIN(\beta-\delta) - \dfrac{A}{B}V_R^2\ SIN(\beta-\alpha)}{\dfrac{V_s V_R}{B} COS(\beta-\delta) - \dfrac{A}{B}V_R^2\ COS(\beta-\alpha)}$$

Substituting the value of $V_{R\,CRIT}$ from equation (2.63) we get.

$$TAN\,\phi = \frac{\dfrac{V_s^2\,SIN(\beta-\delta)}{2AB\,COS(\alpha-\delta)} - \dfrac{A\,V_s^2\,SIN(\beta-\alpha)}{4A^2B\,COS^2(\alpha-\delta)}}{\dfrac{V_s^2\,COS(\beta-\delta)}{2AB\,COS(\alpha-\delta)} - \dfrac{A\,V_s^2\,COS(\beta-\alpha)}{4A^2B\,COS^2(\alpha-\delta)}}$$

$$= \frac{SIN(\beta-\delta)\,COS(\alpha-\delta) - SIN(\beta-\alpha)}{2\,COS(\beta-\delta)\,COS(\alpha-\delta) - COS(\beta-\alpha)}$$

$$= \frac{SIN(\beta+\alpha-2\delta) + SIN(\beta-\delta-\alpha-\delta) - SIN(\beta-\alpha)}{COS(\beta-\delta+\alpha-\delta) + COS(\beta-\delta-\alpha+\delta) - COS(\beta-\alpha)}$$

$$= \frac{SIN(\beta+\alpha-2\delta) + SIN(\beta-\alpha) - SIN(\beta-\alpha)}{COS(\beta+\alpha-2\delta) + COS(\beta-\alpha) - COS(\beta-\alpha)}$$

$\therefore \quad TAN\,\phi = TAN(\beta+\alpha-2\delta)$

$\Rightarrow \quad \phi = \beta+\alpha-2\delta$

$\therefore \quad \delta = \dfrac{\alpha+\beta-\phi}{2}$

where δ is the critical load angle.

$$\therefore \quad \delta_{CRIT} = \frac{\alpha+\beta-\phi}{2} \tag{2.64}$$

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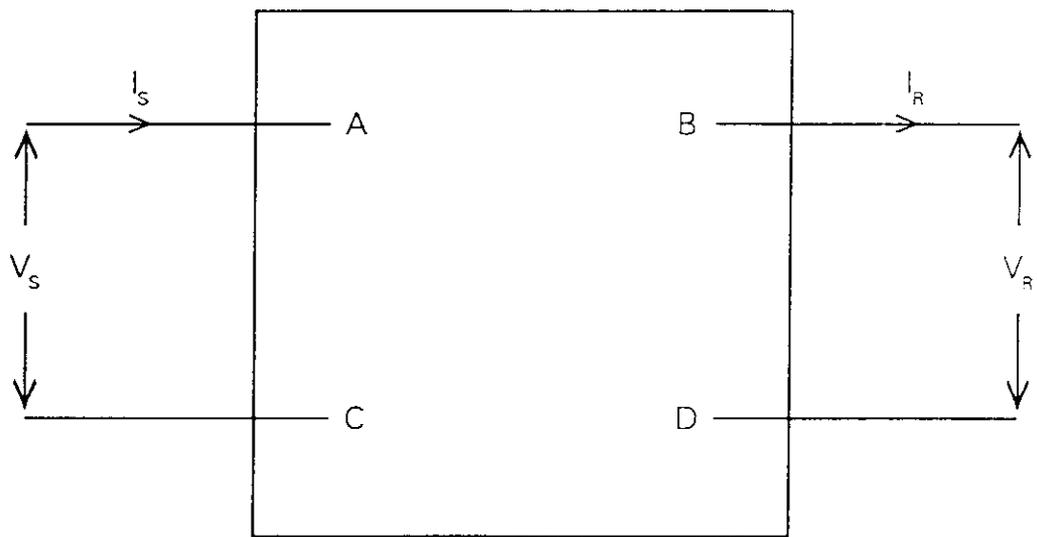
Fig 2.01

TWO PORT REPRESENTATION
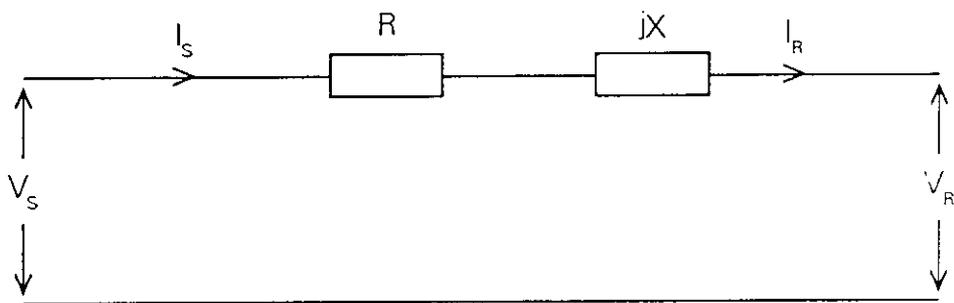
Fig 2.02

EQUIVALENT CIRCUIT OF SHORT LINE
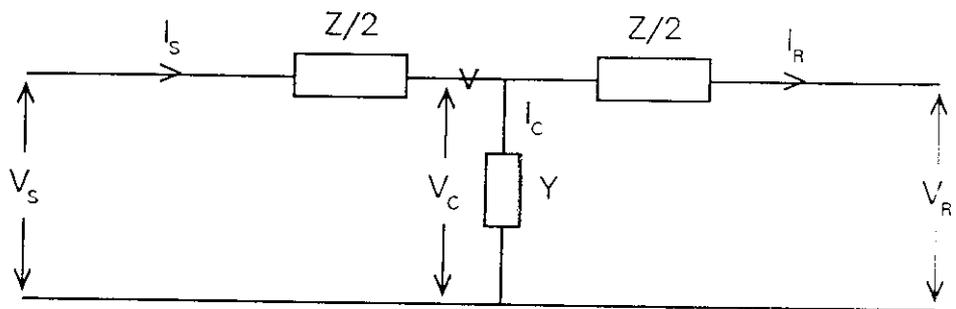
Fig 2.03

EQUIVALENT CIRCUIT OF MEDIUM LINE
NOMINAL - T NETWORK
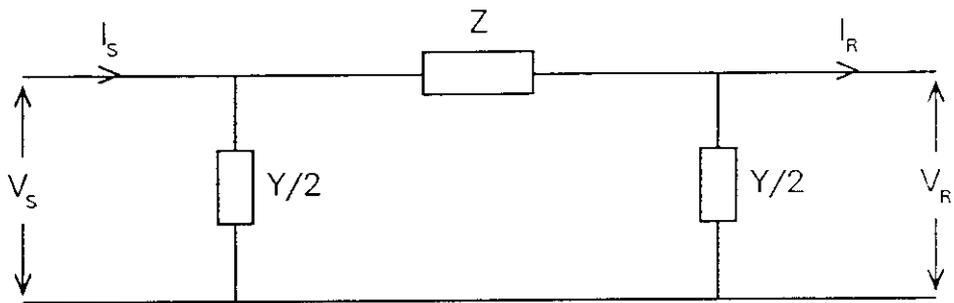
Fig 2.04

EQUIVALENT CIRCUIT OF MEDIUM LINE

NOMINAL - π NETWORK
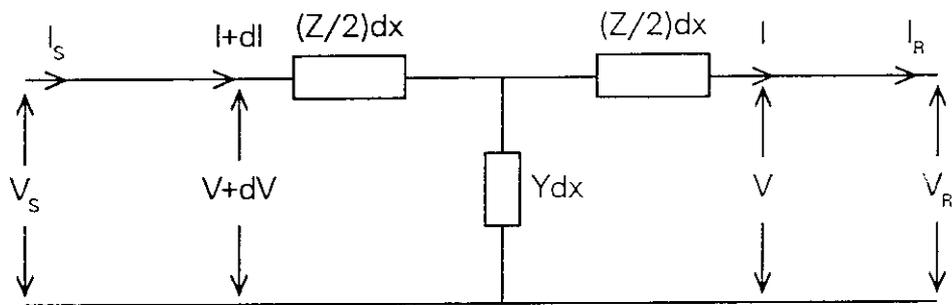
Fig 2.05

EQUIVALENT CIRCUIT OF LONG TRANSMISSION LINE
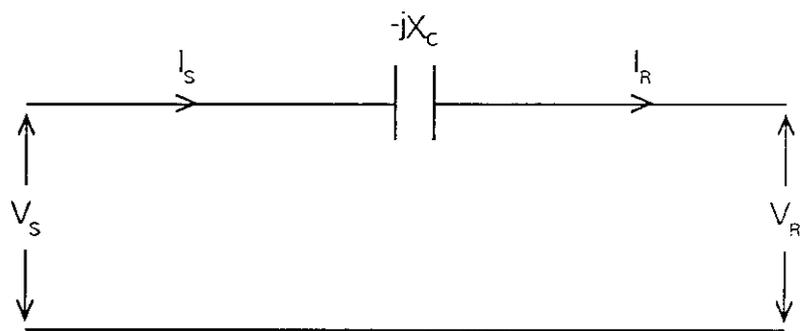
Fig 2.06

SERIES CAPACITOR NETWORK

I_S

A_{S1} B_{S1} I_X A_{S2} B_{S2} I_R

V_S V_X V_R

C_{S1} D_{S1} C_{S2} D_{S2}
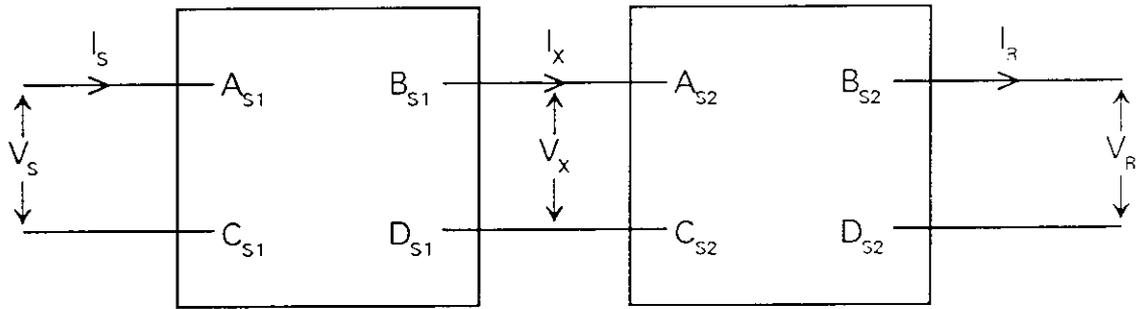
Fig 2.07

TWO PORT NETWORK CONNECTED IN SERIES

SERIES CAPACITOR COMPENSATION

CHAPTER 3

SERIES COMPENSATION

The stability requirement limits the permissible power on E.H.V. lines, which decreases with increase in the line length.

The implementation of series capacitor in long distance lines offer an effective and economical means of improving stability limits and permits the line to carry more power.

3.1. SERIES COMPENSATION FACTOR

The series compensation factor is defined as the ratio of the capacitive reactance of the series capacitor to the total inductive reactance of the line.

If X_c is the reactance of the capacitor and X_L is the total reactance of the transmission line, then

$$\text{Series compensation factor} = \frac{X_c}{X_L}$$

3.2. PRINCIPAL OF SERIES COMPENSATION

3.2.1. POWER TRANSFERABILITY OF AN UN-COMPENSATED E.H.V - A.C TRANSMISSION SYSTEM

Consider an E.H.V transmission line as shown in the figure (3.01).

Let $V_s \lfloor \delta$ be the sending end voltage and $V_R \lfloor 0$ be the receiving end voltage and δ be the load angle or transmission angle.

Let X_L be the series reactance of the transmission line (all values in P.U.)

Power transferability of the a.c transmission system is given by the equation

$$Pac = \frac{V_s \cdot V_R}{X_L} \cdot SIN\ \delta$$

For analysis purpose, let V_s and V_R be kept at 1 p.u. and the value of the load angle δ be take as 90 degrees. Then the equation reduces to

$$Pac \propto \frac{1}{X_L}$$

Hence the series reactance X_L is inversely proportional to the power transferability and directly proportional to the length of the line. Now it becomes essential to reduce X_L. for which we go for series compensation.

3.2.2. POWER TRANSFERABILITY OF SERIES COMPENSATED E.H.V - A.C TRANSMISSION SYSTEM

The power transferability can be increased by reducing the equivalent series reactance X_L of the line by installing the series capacitors having reactance X_C.

Consider a series capacitor bank installed on the E.H.V. transmission line as shown in the figure (3.02).

By introducing series capacitor banks in series with the A.C. lines, the effective series reactance X_L of the A.C. line is reduced to

$$X_L' = X_L - X_C$$

Where X_L' is the equivalent series reactance of the line, after installing series capacitors.

X_L is the series inductive reactance of the line, without series capacitive reactance X_C.

X_C is the series capacitive reactance of the capacitor bank.

Hence the power transferability equation reduces to

$$Pac \propto \frac{1}{X_L'}$$

$$\text{ie.... } Pac \propto \frac{1}{X_L - X_C}$$

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Now by increasing the value of the series capacitive reactance (X_c), the net equivalent reactance of the line ie., $(X_L - X_c)$ can be reduced and the power transferability can be increased.

Hence power flow is given by,

$$Pac = \frac{V_S \cdot V_R}{X_L - X_c} \cdot SIN\ \delta$$

By choosing series compensation factor as K, then $\dfrac{X_c}{X_L} = K$

$$\therefore \quad X_c = K \cdot X_L$$

Substituting in equation

$$Pac = \frac{V_S \cdot V_R}{X_L - X_L \cdot K} \cdot SIN\ \delta$$

ie., $$Pac = \frac{V_S \cdot V_R}{(1-K) \cdot X_L} \cdot SIN\ \delta$$

Usually 40% to 60% of the X_L is compensated by the series capacitor.

For 50% compensation, the value of K = 0.5

Then

$$Pac = \frac{V_S \cdot V_R}{0.5 \cdot X_L} \cdot SIN\ \delta$$

$$\therefore Pac = \frac{2\ V_S \cdot V_R}{X_L} \cdot SIN\ \delta$$

Power flow is doubled by 50% compensation of the series reactance.

3.3. COMPENSATION SCHEMES

Two types of compensation schemes are implemented. They are

    3.3.1. Single capacitor compensation

    3.3.2. Twin capacitor compensation

In single capacitor compensation scheme the capacitor is located at

    3.3.1.1. sending end

    3.3.1.2. receiving end

    3.3.1.3. centre

and the performance of the line was studied.

In twin capacitor compensation scheme the capacitor was located at

    3.3.2.1. Capacitor at both ends.

    3.3.2.2. Capacitor at one-third end locations.

and the performance of the line was studied.

3.4. ANALYSIS OF SERIES COMPENSATED TRANSMISSION SYSTEMS

For analysis the total compensation line was divided into a number of sections and ABCD line constants of the individual sections was determined . The total ABCD constants of the line was obtained by connecting all the sections in series as explained in section (2.5).

3.5. EVALUATION OF ABCD CONSTANTS OF COMPENSATED LINE

The circuit configuration and process followed to determine the total ABCD constants of the transmission line for the different compensating schemes are as given below.

3.5.1. SINGLE CAPACITOR CONFIGURATION

3.5.1.1. Capacitor Located At Sending End

The ABCD constants of the compensating capacitor is $A_x.B_x.C_x.D_x$ and that of the transmission line is $A_1.B_1.C_1.D_1$. The total ABCD constants of the compensated line ie., $A_0.B_0.C_0.D_0$. is obtained by multiplying the ABCD constants $(A_x.B_x.C_x.D_x)$ of the compensating network with the ABCD constants $(A_1.B_1.C_1.D_1)$ of the transmission line.

The net ABCD constants $A_0.B_0.C_0.D_0$. of all the above compensating network schemes have been calculated referring to section (2.5).

3.5.1.2. Capacitor At Receiving End

The total ABCD constants of the compensated line is obtained by the product of the ABCD constants of the line $(A_1.B_1.C_1.D_1)$ and the ABCD constants of the compensating network $(A_x.B_x.C_x.D_x)$.

3.5.1.3. Capacitor At Centre

The total ABCD constants of the compensated line $(A_0.B_0.C_0.D_0)$ is obtained by the triple product of the ABCD constants of the half-line ,the ABCD Constants of the compensating network and the ABCD constants of the other half of the line.

3.5.2. TWIN CAPACITOR COMPENSATION

3.5.2.1. Capacitor Located At Both The Ends

The total ABCD constants of the compensated line $(A_0.B_0.C_0.D_0)$ is obtained as follows.

The ABCD constants of the compensating network $(A_0.B_0.C_0.D_0)$ is multiplied with that of the transmission line $(A_x.B_x.C_x.D_x)$ .This value is again multiplied with the ABCD constants of the compensation network $(A_x.B_x.C_x.D_x)$.

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3.5.2.2. Capacitor at one third location

The total ABCD constants of the compensated line $(A_o.B_o.C_o.D_o)$ is obtained by the product of ABCD constant of line $(A_1.B_1.C_1.D_1)$ with ABCD constants of the compensation network $(A_x.B_x.C_x.D_x)$, this is now multiplied with the ABCD constants of the line $(A_1.B_1.C_1.D_1)$ and the whole is now multiplied with the ABCD constant of the compensation network $(A_x.B_x.C_x.D_x)$. The whole expression is now multiplied with the ABCD constants of the line $(A_1.B_1.C_1.D_1)$.
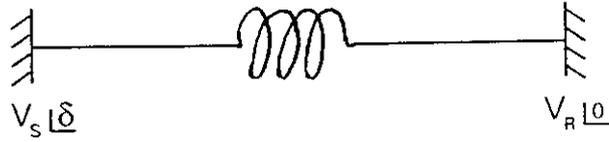
Fig 3.01

UN-COMPENSATED TRANSMISSION LINE
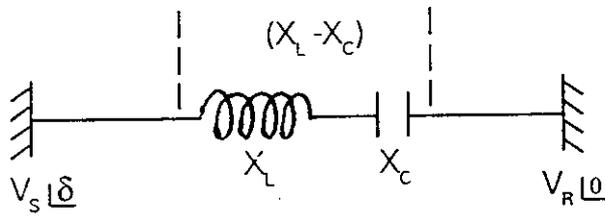
Fig 3.02

SERIES CAPACITOR COMPENSATED TRANSMISSION LINE

40
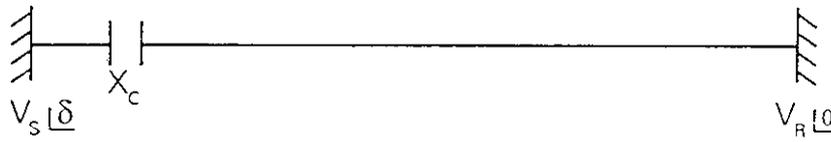
Fig 3.03

SERIES CAPACITOR LOCATED AT SENDING END

Fig 3.04

SERIES CAPACITOR LOCATED AT RECEIVING END
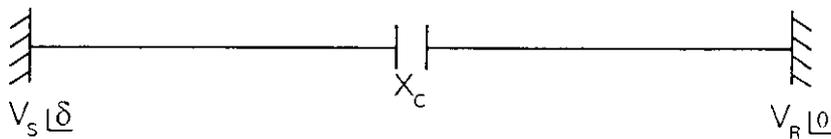
Fig 3.05

SERIES CAPACITOR LOCATED AT CENTRE

41
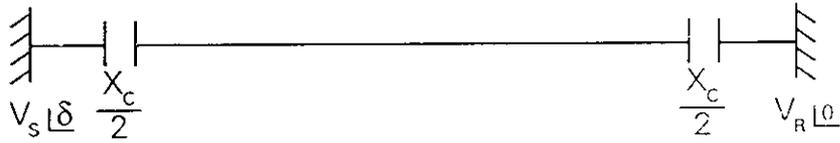
Fig 3.06

SERIES CAPACITORS LOCATED AT BOTH ENDS

Fig 3.07

SERIES CAPACITORS LOCATED AT ONE - THIRD DISTANCE FROM BOTH ENDS

EVALUATION OF PARAMETERS

CHAPTER 4

EVALUATION OF VARIOUS PARAMETERS

For each compensating network scheme, the value of compensating factor is varied from 10% to 60% to determine the line performance.

4.1. LINE CONSTANTS AND THEIR ASSUMPTIONS

For analysis the system having following constants was considered,

a. Line length (D_L)   = 400 KM

b. Operating voltage   = 400 KV

c. Resistance of the line (R)   = 0.274E-01

d. Reactance of the line (X_L)   = 0.332

e. Susceptance of the line (BB)   = 3.47E-06

f. Conductance of the line (GG) = 0.0

g. Base voltage   = 400 KV

h. Base MVA   = 100

4.2. ASSUMPTION MADE IN THE ANALYSIS

Since the analysis is mainly for determining the effect and influence of series compensation on the line performance the terminal equipments with power

factors 0.8, 0.9 and 1.0 are only considered.

The terminal loading limits of the transmission line are not considered.

Under normal operating condition with the sending end voltage (V_S) taken as constant at 1 p.u. the value of R= V_S/V_R was varied from 1.1 to 2.0 with incremental value of 0.1.

4.3.   PARAMETERS CONSIDERED FOR ANALYSIS

4.3.1.   POWER AT RECEIVING END (P_R)

The receiving end power of the transmission line was determined by using the equation (2.44) for various power factors 0.8, 0.9 and 1.0.

4.3.2.   MAXIMUM POWER AT THE RECEIVING END ($P_{R\ MAX}$)

The maximum receiving end power of the transmission line was determined by using the equation (2.48) of section 2.6.

4.3.3.   EFFICIENCY OF THE SYSTEM

The efficiency of a system is an important factor for optimal operation of a system. The efficiencies of various compensation network locations was

calculated using the equation (2.50) in section 2.8.

4.3.4. CALCULATION OF B_0

From the expression of $P_{R\ MAX}$, it is seen that the value of $P_{R\ MAX}$ depends on V_S, V_R and B_0, but in the system considered V_S and V_R are fixed. Hence the only variable which has any effect on the value $P_{R\ MAX}$ is B_0. Therefore the value of B_0 was determined for various compensation schemes.

4.3.5. CALCULATION OF $V_{R\ CRIT}$ AND δ_{CRIT}

The critical receiving end voltage ($V_{R\ CRIT}$) is the value below which the value of the receiving end power (P_R) decreases. Hence it is calculated using the equation (2.63) for various compensation schemes. The value of the critical load angle (δ_{CRIT}) is the value above which the value of the receiving end power (P_R) decreases and stability problems arise. Hence it is calculated using the equation (2.64) for various compensation schemes.

4.3.6. POWER ANGLE CHARACTERISTICS

The power angle characteristics of any electrical systems are useful for stability studies. Hence the power angle calculations are done by varying the value of delta (δ) from $10°$ to $90°$ for various compensation schemes.

RESULTS AND COMPARATIVE STUDY

CHAPTER 5

TABULATION OF RESULTS AND COMPARATIVE STUDY

With the procedure described, the results obtained have been tabulated for the compensation network at various locations as from the point of view of,

5.1. P_R vs Compensation factor for power factors 0.8, 0.9 and 1.0.

5.2. $P_{R\,MAX}$ vs Compensation factor.

5.3. Efficiency vs Compensation factor.

5.4. $|B_0|$ vs Compensation factor.

5.5. P_R vs δ

5.6. Effect of $V_{R\,CRIT}$ and δ_{CRIT} on P_R and $P_{R\,MAX}$.

5.1. VARIATIONS OF RECEIVING END POWER (P_R)

From the table no. (5.03) to (5.05) it is seen that, for each location the power transfer increases with the compensating factor. At low compensation, it has been seen that the value of P_R is practically independent of the type of the location of the series capacitor and at higher degree of compensation, it is also seen that the value of P_R is maximum when the series capacitor is located at the receiving end .It has been seen that the value of P_R is almost same when the capacitors are located at the centre. one third and both ends.

The value of P_R is lowest when the capacitor is located at sending end.

5.2. VARIATIONS OF $P_{R\ MAX}$

From the table no. (5.01) and the graph no. (5.01)the following conclusions can be drawn.

The value of $P_{R\ MAX}$ increases with the compensation factor for various positions of the series capacitor. At low compensating factor, the values of $P_{R\ MAX}$ is almost same for all the positions of the series capacitors. As the compensating factor increases the location of series capacitor will be an important factor and should be taken into consideration. It is seen that the value of $P_{R\ MAX}$ obtained is maximum when the series capacitor is located at one-third distance from both the ends. The value of $P_{R\ MAX}$ at the center is slightly lower than that for the series capacitors located at one third distance from both ends and so for all practical purposes, it can be taken as the same. The value of $P_{R\ MAX}$ for the sending end and the receiving end is the lowest and almost the same. when the capacitor is located at both ends. the values of $P_{R\ MAX}$ is higher than that for the sending end or the receiving end but lower than that for the centre.

5.3. VARIATIONS OF THE EFFICIENCY

The table no. (5.06) to (5.08) and the graph no. (5.06) to (5.08) shows the variations of the efficiency with the compensation factor for the various positions of the series capacitor.

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The efficiency is found to be decreasing with the increase in the series compensation factor. At lower degree of compensation factors, the value of the efficiency is the same irrespective of the type of location of the series capacitor. When the compensation factor is increased to higher degrees of compensation, it is seen that the maximum efficiency is got when a single series capacitor is located at the sending end of the transmission line. The efficiency is marginally lower when the capacitor is located at the centre, one third or at both ends of the transmission line. The least efficiency is got when the capacitor is located at the receiving end of the transmission line.

5.4. VARIATION OF B_0

The table no. (5.02) and the graph no. (5.02) shows the variations of $|B_0|$ with the compensation factors for various positions of the capacitor, which determines the power transfer capability of the line.

It is seen that the value of $|B_0|$ is inversely proportional to the compensation factor.

The transfer impedance $|B_0|$ is minimum, when the series capacitor is located at one -third distances from both the ends of the line. it is also seen that the value of $|B_0|$ is exactly the same for a given value of the compensation factor when the capacitor is located either at the receiving end or at the sending end.

It can also be seen that the value of $|B_0|$, when the capacitor is located at the centre is only slightly higher than that for the capacitor located at one third

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distance and so it can be taken as the same.

The value of $|B_0|$ when twin capacitors are located at both ends of the transmission line is lower than that for the receiving end (or) sending end but higher than that of the centre.

5.5. VARIATIONS OF P_R WITH δ

The table nos. 5.09 to 5.13 shows the variation of P_R with δ. It is seen that the value of the receiving end power (P_R) increases with increase in the value of δ upto a certain value and thereafter it decreases. Also for the same value of δ, the value of P_R increases with increase in the compensation factor.

5.6. EFFECT OF V_RCRIT AND DELCRIT ON P_R AND $P_{R\,MAX}$

From the table nos. (5.14) & (5.15) it is seen that the critical values of $V_{R\,CRIT}$ and δ_{CRIT} determine the maximum real power transfer limit of the transmission line. As the value of receiving end voltage (V_R) decreases below it's critical value the value of load angle d exceeds it's critical value. Therefore, the value of P_R & $P_{R\,MAX}$ starts decreasing.

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		TABULATION OF PRMAX			
COMP FACTOR	SENDING END	RECEIVING END	CENTRE	BOTH ENDS	ONE-THIRD DISTANCE
Ø.1	10.529	10.545	10.591	10.542	10.587
Ø.2	11.6Ø4	11.643	11.757	11.648	11.75
Ø.3	12.917	12.992	13.2Ø4	13.Ø21	13.199
Ø.4	14.553	14.684	15.Ø46	14.769	15.Ø49
Ø.5	16.637	16.864	17.458	17.Ø58	17.485
Ø.6	19.359	19.758	2Ø.725	2Ø.158	2Ø.8Ø4

TABLE NO. 5.01

	TABULATION OF BM				
COMP FACTOR	SENDING END	RECEIVING END	CENTRE	BOTH ENDS	ONE-THIRD DISTANCE
Ø.1	.Ø73232	.Ø73232	.Ø72855	.Ø73196	.Ø72885
Ø.2	.Ø65725	.Ø65725	.Ø64969	.Ø65578	.Ø65ØØ5
Ø.3	.Ø58228	.Ø58228	.Ø57Ø95	.Ø57896	.Ø57111
Ø.4	.Ø5Ø745	.Ø5Ø745	.Ø49236	.Ø5Ø158	.Ø492Ø8
Ø.5	.Ø43285	.Ø43285	.Ø414Ø1	.Ø4237Ø	.Ø413Ø6
Ø.6	.Ø35862	.Ø35862	.Ø336Ø9	.Ø34552	.Ø33423

TABLE NO. 5.02

TABULATION OF PR VS COMPENSATION FOR Ø.8 PF					
COMP FACTOR	SENDING END	RECEIVIN END	CENTRE	BOTH ENDS	ONE-THIRD DISTANCE
Ø.1	2.733	2.893	2.828	2.815	2.826
Ø.2	2.843	3.199	3.Ø57	3.Ø28	3.Ø55
Ø.3	2.974	3.578	3.342	3.296	3.34
Ø.4	3.134	4.Ø58	3.7Ø8	3.64	3.7Ø7
Ø.5	3.337	4.686	4.194	4.Ø98	4.197
Ø.6	3.6Ø3	5.54	4.87	4.737	4.885

TABLE NO. 5.03

TABULATION OF PR VS COMPENSATION
FOR Ø.9 PF

COMP FACTOR	SENDING END	RECEIVIN END	CENTRE	BOTH ENDS	ONE-THIRD DISTANCE
Ø.1	3.577	3.768	3.629	3.813	3.69
Ø.2	3.73	4.16	3.992	3.955	3.989
Ø.3	3.91	4.641	4.363	4.3Ø3	4.36
Ø.4	4.125	5.247	4.834	4.745	4.833
Ø.5	4.33	6.Ø33	5.452	5.327	5.456
Ø.6	4.724	7.Ø9	6.296	6.124	6.747

TABLE NO. 5.04

TABULATION OF PR VS COMPENSATION FOR 1.0 PF					
COMP FACTOR	SENDING END	RECEIVIN END	CENTRE	BOTH ENDS	ONE-THIRD DISTANCE
Ø.1	6.424	6.638	6.566	6.535	6.563
Ø.2	6.813	7.3Ø3	7.143	7.Ø77	7.139
Ø.3	-	8.112	7.847	7.738	7.841
Ø.4	-	9.119	8.72	8.559	8.718
Ø.5	-	1Ø.4	9.83	9.6Ø5	9.837
Ø.6	-	12.Ø79	11.277	1Ø.968	11.3Ø4

TABLE NO. 5.05

		TABULATION OF EFFICIENCY VS COMPENSATION FOR 1.0 PF			
COMP FACTOR	SENDING END	RECEIVING END	CENTRE	BOTH ENDS	ONE-THIRD DISTANCE
0.1	94.28	93.97	94.13	94.13	94.13
0.2	93.99	93.3	93.63	93.63	93.63
0.3	–	92.5	93.04	93.04	93.03
0.4	–	91.51	92.31	92.31	92.3
0.5	–	90.29	91.4	91.4	91.37
0.6	–	88.74	90.23	90.23	90.18

TABLE NO. 5.06

TABULATION OF EFFICIENCY VS COMPENSATION FACTOR FOR Ø.8 PF					
COMP FACTOR	SENDING END	RECEIVING END	CENTRE	BOTH ENDS	ONE-THIRD DISTANCE
Ø.1	96.97	96.62	96.79	96.8	96.79
Ø.2	96.88	96.11	96.49	96.49	96.49
Ø.3	96.77	95.49	96.11	96.11	96.1
Ø.4	96.63	94.71	95.61	95.62	95.61
Ø.5	96.44	93.72	94.97	94.97	94.95
Ø.6	96.19	92.39	94.Ø7	94.Ø7	94.Ø3

TABLE NO. 5.07

TABULATION OF EFFICIENCY VS COMPENSATION FOR Ø.9 PF					
COMP FACTOR	SENDING END	RECEIVING END	CENTRE	BOTH ENDS	ONE-THIRD DISTANCE
Ø.1	96.54	96.21	96.38	96.38	96.38
Ø.2	96.42	95.7	96.Ø5	96.Ø5	96.Ø5
Ø.3	96.28	95.Ø8	95.66	95.66	95.65
Ø.4	96.11	94.31	95.15	95.15	95.15
Ø.5	95.9	93.33Ø	94.5	94.5	94.48
Ø.6	95.62	92.Ø4	93.62	93.62	93.58

TABLE NO. 5.08

FOR CAPACITOR LOCATED AT SENDING END

COMP → DELTA	0.0	0.1	0.2	0.3	0.4	0.5	0.6
10	1.91	2.112	2.362	2.677	3.086	3.639	4.423
20	3.605	3.975	4.429	4.997	5.729	6.706	8.066
30	5.169	5.691	6.328	7.124	8.143	9.489	11.345
40	6.556	7.209	8.003	8.991	10.25	11.905	14.162
50	7.723	8.481	9.402	10.543	11.99	13.879	16.431
60	8.634	9.47	10.483	11.733	13.309	15.352	18.083
70	9.762	10.146	11.213	12.523	14.167	16.28	19.068
80	9.587	10.487	11.569	12.891	14.538	16.633	19.355
90	9.601	10.485	11.541	12.825	14.41	16.402	18.937

TABLE NO. 5.09

TABULATION OF PR VS DELTA							
FOR CAPACTOR LOCATD AT RECEIVING ENDDD							
COMP -> DELTA ↓	Ø.Ø	Ø.1	Ø.2	Ø.3	Ø.4	Ø.5	Ø.6
1Ø	1.91	2.128	2.4	2.751	3.218	3.866	4.822
2Ø	3.6Ø5	3.99	4.467	5.Ø71	5.861	6.933	8.465
3Ø	5.169	5.7Ø7	6.367	7.198	8.273	9.716	11.744
4Ø	6.556	7.274	8.Ø42	9.Ø65	1Ø.381	12.132	14.561
5Ø	7.723	8.497	9.441	1Ø.615	12.121	14.1Ø6	16.83
6Ø	8.634	9.486	1Ø.522	11.8Ø7	13.44	15.579	18.482
7Ø	9.762	1Ø.161	11.251	12.597	14.298	16.5Ø7	19.467
8Ø	9.587	1Ø.5Ø3	11.6Ø8	12.965	14.669	16.89	19.755
9Ø	9.5Ø1	1Ø.5	11.58	12.899	14.541	16.629	19.336

TABLE NO. 5.10

TABULATION OF PR VS DELTA

FOR CAPACITOR LOCATED AT CENTRE

COMP -> DELTA↓	Ø.Ø	Ø.1	Ø.2	Ø.3	Ø.4	Ø.5	Ø.6
1Ø	1.91	2.131	2.4Ø9	2.769	3.253	3.935	4.96
2Ø	3.6Ø5	4.ØØ3	4.5	5.135	5.976	7.136	8.832
3Ø	5.169	5.728	6.422	7.3Ø3	8.459	1Ø.Ø39	12.313
4Ø	6.556	7.254	8.116	9.2Ø7	1Ø.629	12.559	15.296
5Ø	7.723	8.533	9.531	1Ø.788	12.419	14.611	17.69
6Ø	8.634	9.527	1Ø.624	12	13.744	16.14	19.424
7Ø	9.262	1Ø.2Ø6	11.361	12.8Ø4	14.654	17.Ø98	2Ø.443
8Ø	9.587	1Ø.549	11.721	13.179	15.Ø32	17.456	2Ø.718
9Ø	9.5Ø1	1Ø.546	11.693	13.1Ø9	14.895	17.2Ø2	2Ø.24

TABLE NO. 5.11

TABULATION OF PR VS DELTA

FOR CAPACITOR LOCATED AT BOTH ENDS

COMP → DELTA ↓	0.0	0.1	0.2	0.3	0.4	0.5	0.6
10	1.91	2.121	2.387	2.731	3.193	3.845	4.824
20	3.605	3.985	4.458	5.064	5.866	6.973	8.591
30	5.169	5.702	6.362	7.702	8.304	9.809	11.976
40	6.556	7.22	8.04	9.079	10.434	12.269	14.878
50	7.723	8.493	9.442	10.639	12.191	14.276	17.207
60	8.634	9.483	10.525	11.833	13.521	15.771	18.893
70	9.262	10.158	11.256	12.627	14.385	16.707	19.884
80	9.587	10.5	11.612	12.995	14.755	17.056	20.152
90	9.501	10.49	11.584	12.927	14.621	16.808	19.686

TABLE NO. 5.12

TABULATION OF PR VS DELTA

FOR CAPAOR LOCATED AT ONE-THIRD DISTANCE FROM BOTH ENDSHE ENDS

COMP -> DELTA↓	0.0	0.1	0.2	0.3	0.4	0.5	0.6
10	1.91	2.13	2.408	2.769	3.256	3.946	4.992
20	3.605	4.002	4.498	5.134	5.979	7.153	8.883
30	5.169	5.726	6.418	7.301	8.464	10.061	12.378
40	6.556	7.751	8.111	9.704	10.634	12.582	15.372
50	7.723	8.529	9.525	10.784	12.424	14.639	17.773
60	8.634	9.523	10.617	11.995	13.779	16.17	19.509
70	9.762	10.202	11.355	12.799	14.658	17.177	20.527
80	9.587	10.545	11.714	13.172	15.035	17.483	20.796
90	9.501	10.542	11.686	13.103	14.898	17.225	20.307

TABLE NO. 5.13

	TABULATION OF VRCRIT				
COMP FACTOR	SENDING END	RECEIVING END	CENTRE	BOTH END	ONE-THIRD DISTANCE
0.0	.60	.60	.60	.60	.60
0.1	.59	.60	.60	.60	.60
0.2	.58	.60	.59	.59	.59
0.3	.56	.60	.58	.58	.58
0.4	.55	.60	.57	.57	.57
0.5	.54	.59	.56	.56	.56
0.6	.53	.59	.55	.55	.55

TABLE NO. 5.14

	TABULATION OF DELCRIT				
COMP FACTOR	SENDING END	RECEIVING END	CENTRE	BOTH ENDS	ONE-THIRD DISTANCE
0.0	24.514	24.514	24.514	24.514	24.514
0.1	24.252	24.255	24.252	24.252	24.252
0.2	23.930	23.936	23.927	23.927	23.925
0.3	23.527	23.536	23.513	23.512	23.508
0.4	23.006	23.017	22.966	22.966	22.956
0.5	22.305	22.319	22.214	22.213	22.190
0.6	21.315	21.332	21.111	21.110	21.060

TABLE NO. 5.15
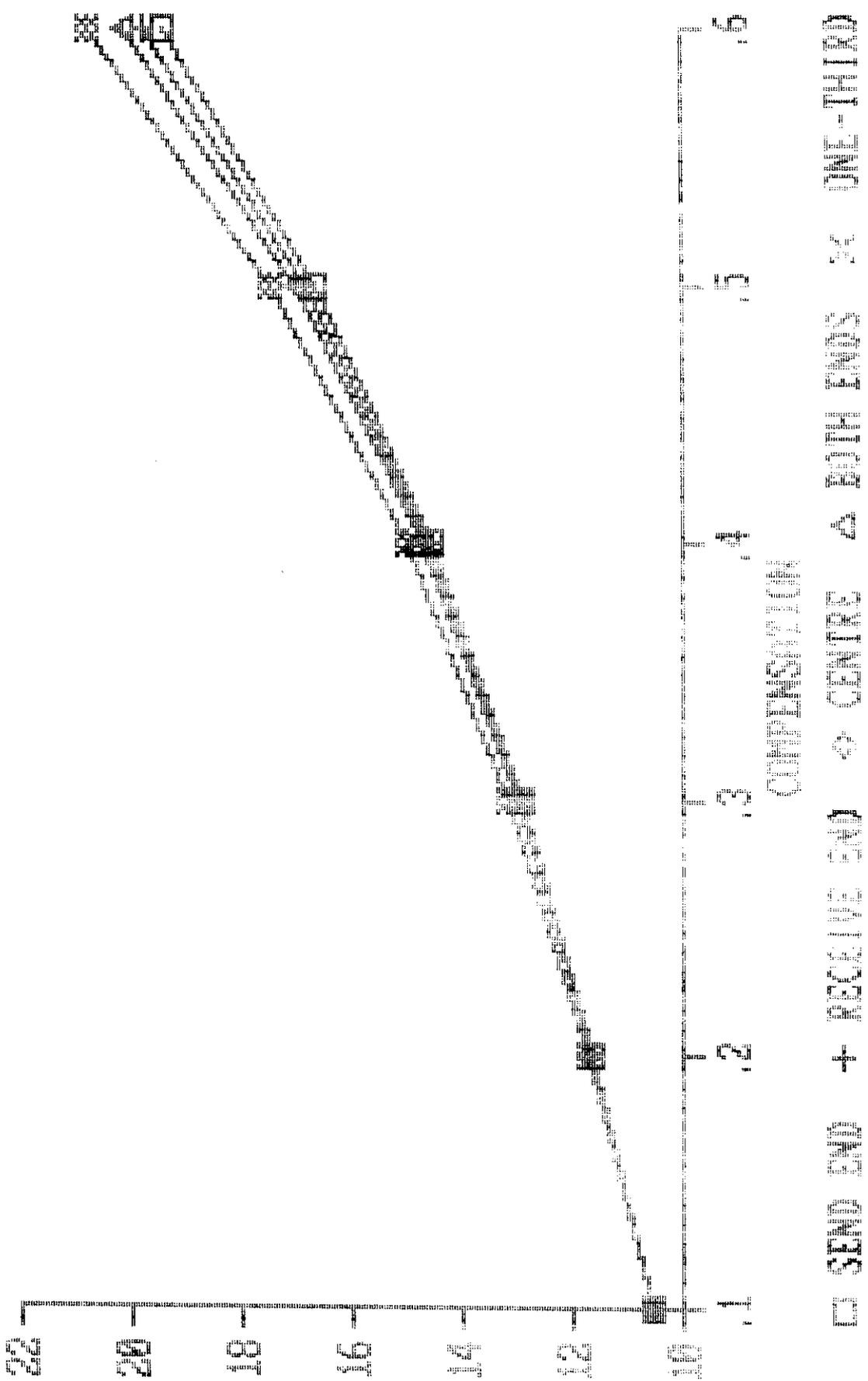
CRAPH NO. 5.01

6 5

EFF VS COMP
FOR VARIOUS POSITIONS

CONF VS COMP

GRAPH NO. 5.02

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PR VS COMP
FOR 0.9 PF

COMPENSATION

□ SEND   + RECEIVE   ⋄ CENTRE   △ BOTH THE ENDS   × ONE-THIRD

GRAPH NO. 5.03

57
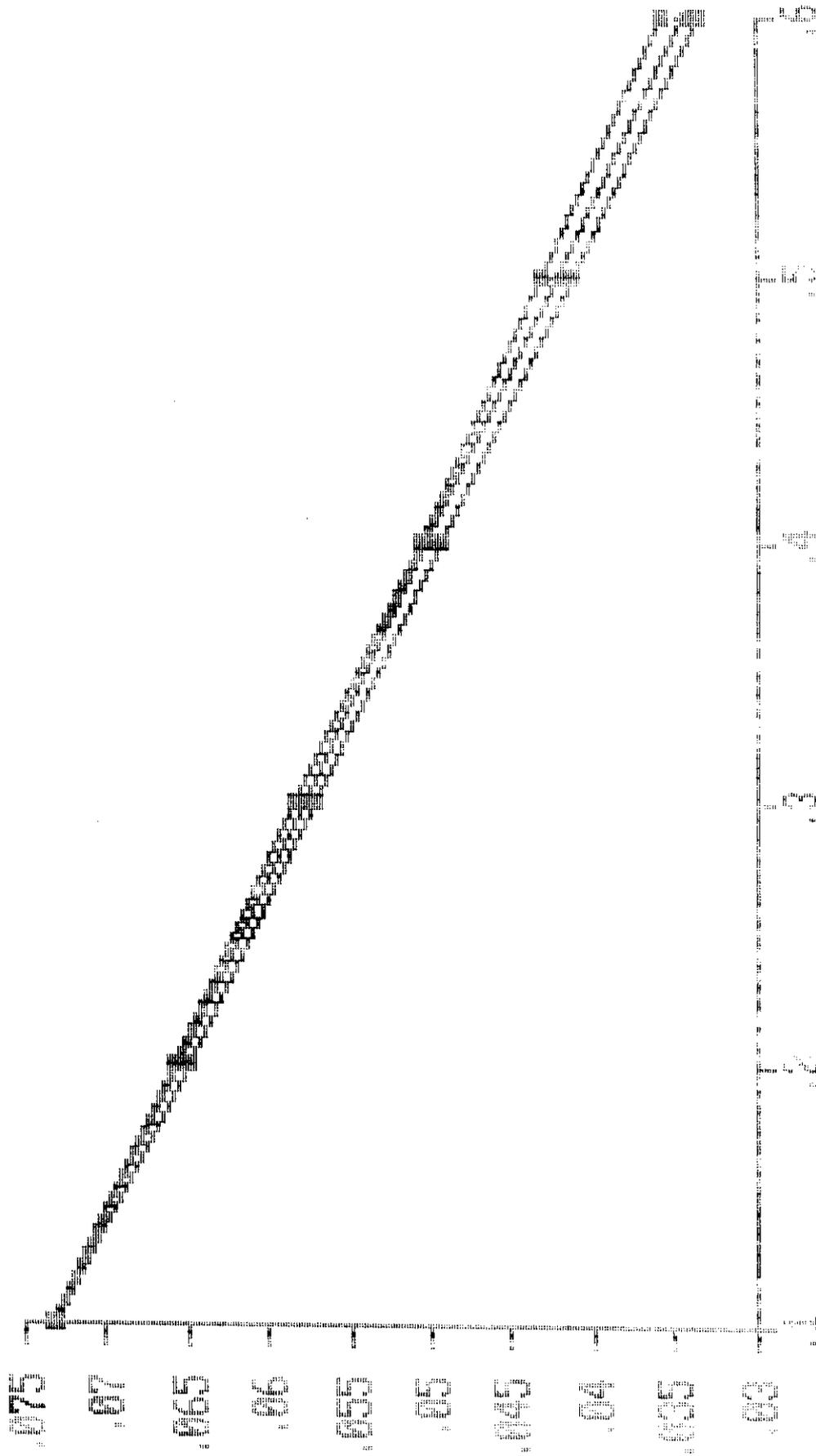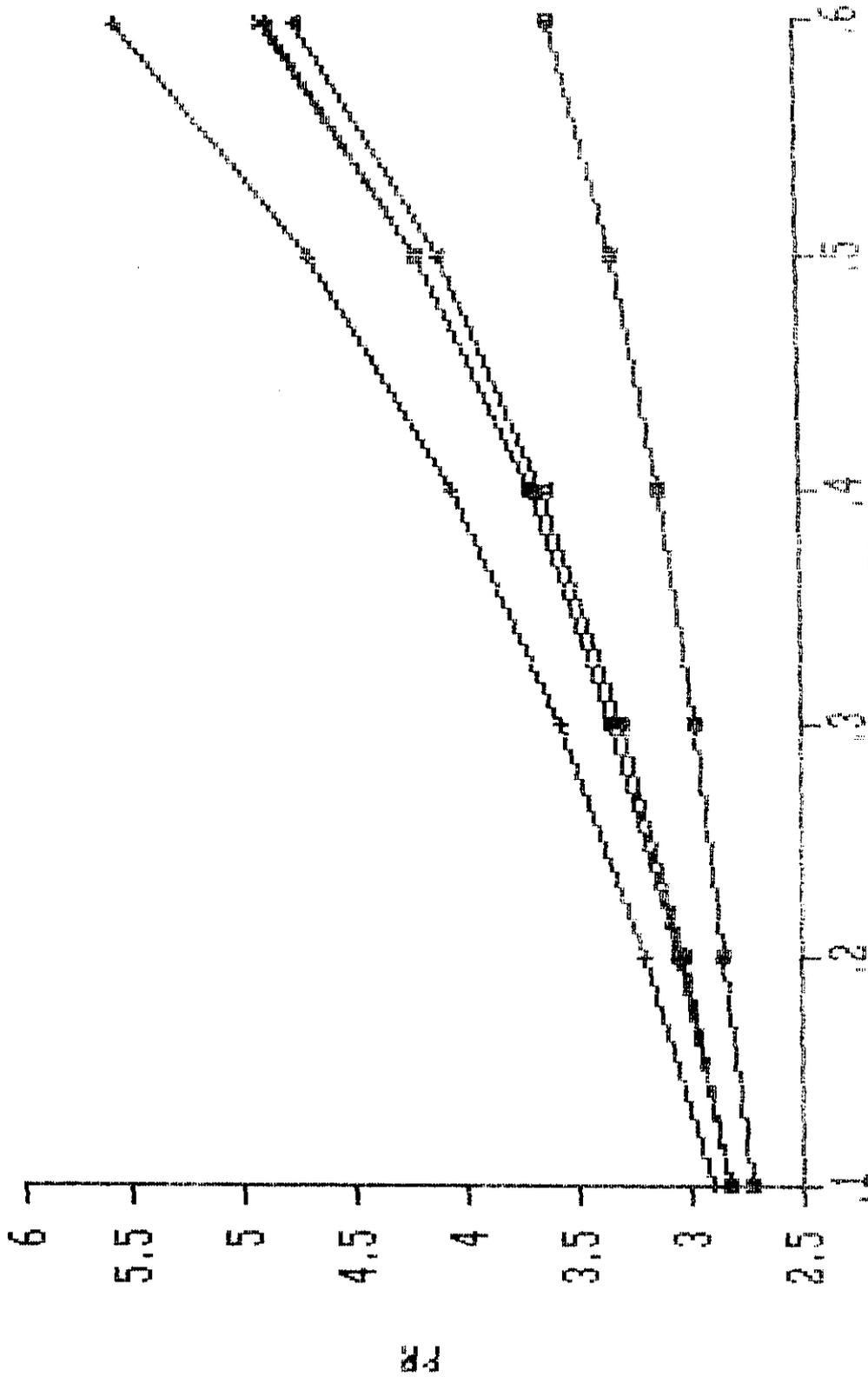
PR VS COMP
FOR 0.9 COMP

PR
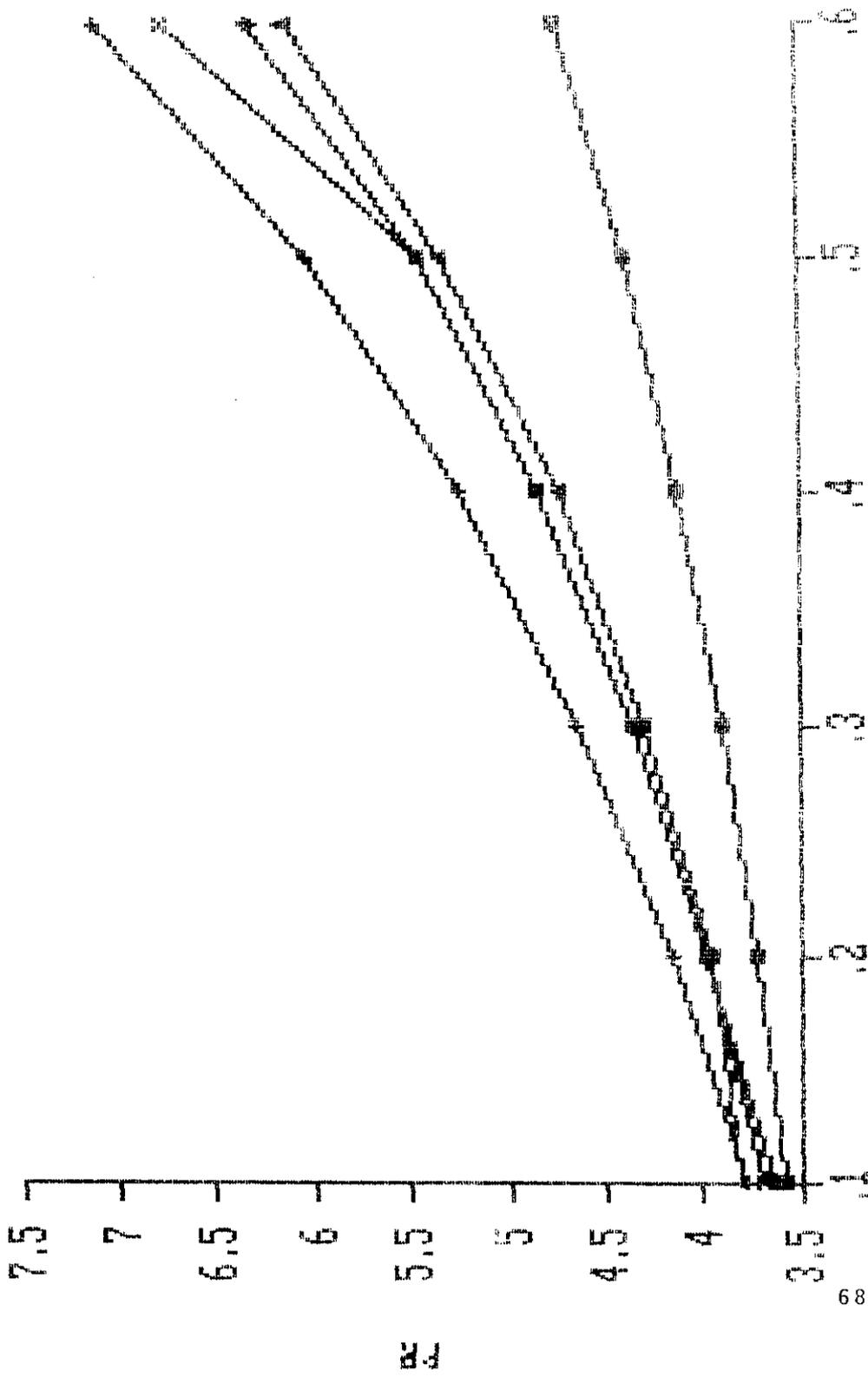
COMPENSATION

□ SEND + RECEIVE ◇ CENTRE △ BOTH THE ENDS × ONE-THIRD

GRAPH NO. 5.04

PR VS COMP
FOR 1.0 PF

PR

13
12
11
10
9
8
7
6

1   2   3   4   5   6

COMPENSATION

□ SEND   + RECEIVE   ◇ CENTRE   ▲ BOTH THE ENDS   × ONE-THIRD

GRAPH NO. 5.05

69
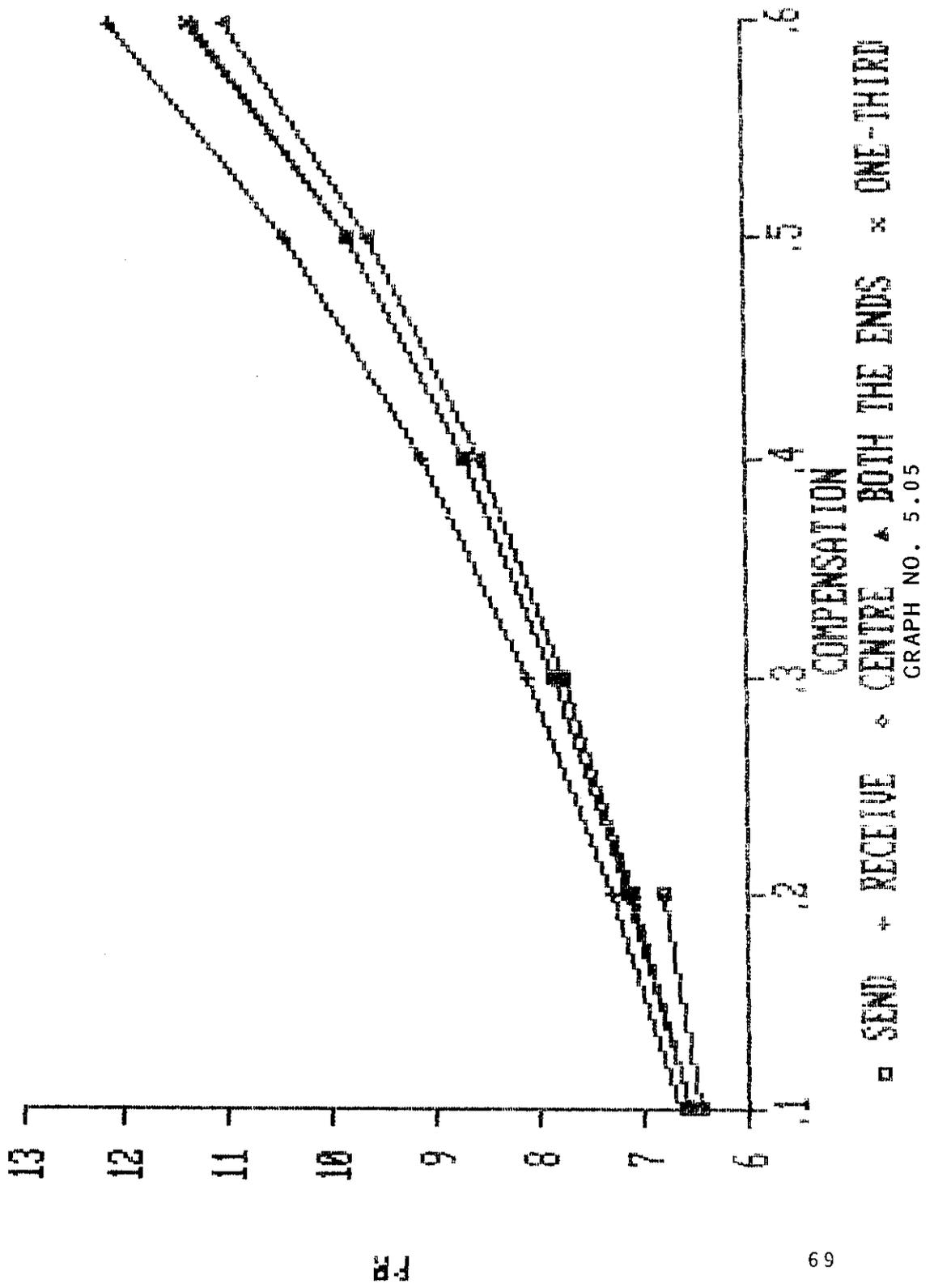
EFF VS COMP
FOR VARIOUS POSITIONS
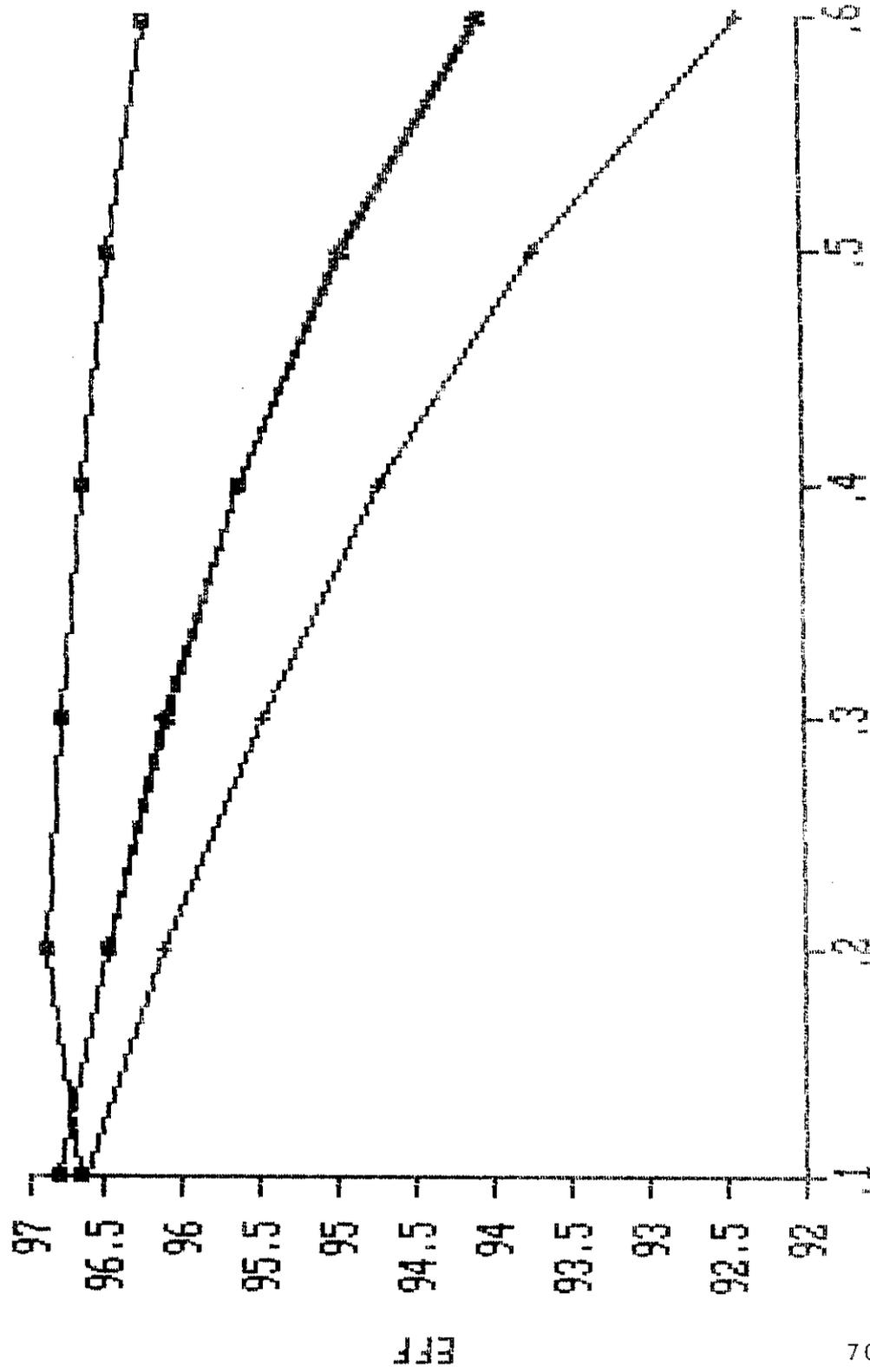
COMPENSATION

□ SENDING END   + RECEIVING END   ◇ CENTRE   △ BOTH THE ENDS   × ONE-1

GRAPH NO. 5.06

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EFF VS COMP
FOR 0.9 PF

Graph plotting EFF (y-axis, from 92 to 97) versus COMPENSATION (x-axis, from 1 to 6).

Legend:
- □ SENDING END
- + RECEIVING END
- ◇ CENTRE
- △ BOTH THE ENDS × ONE−1

GRAPH NO. 5.07

GRAPH NO. 5.08

72
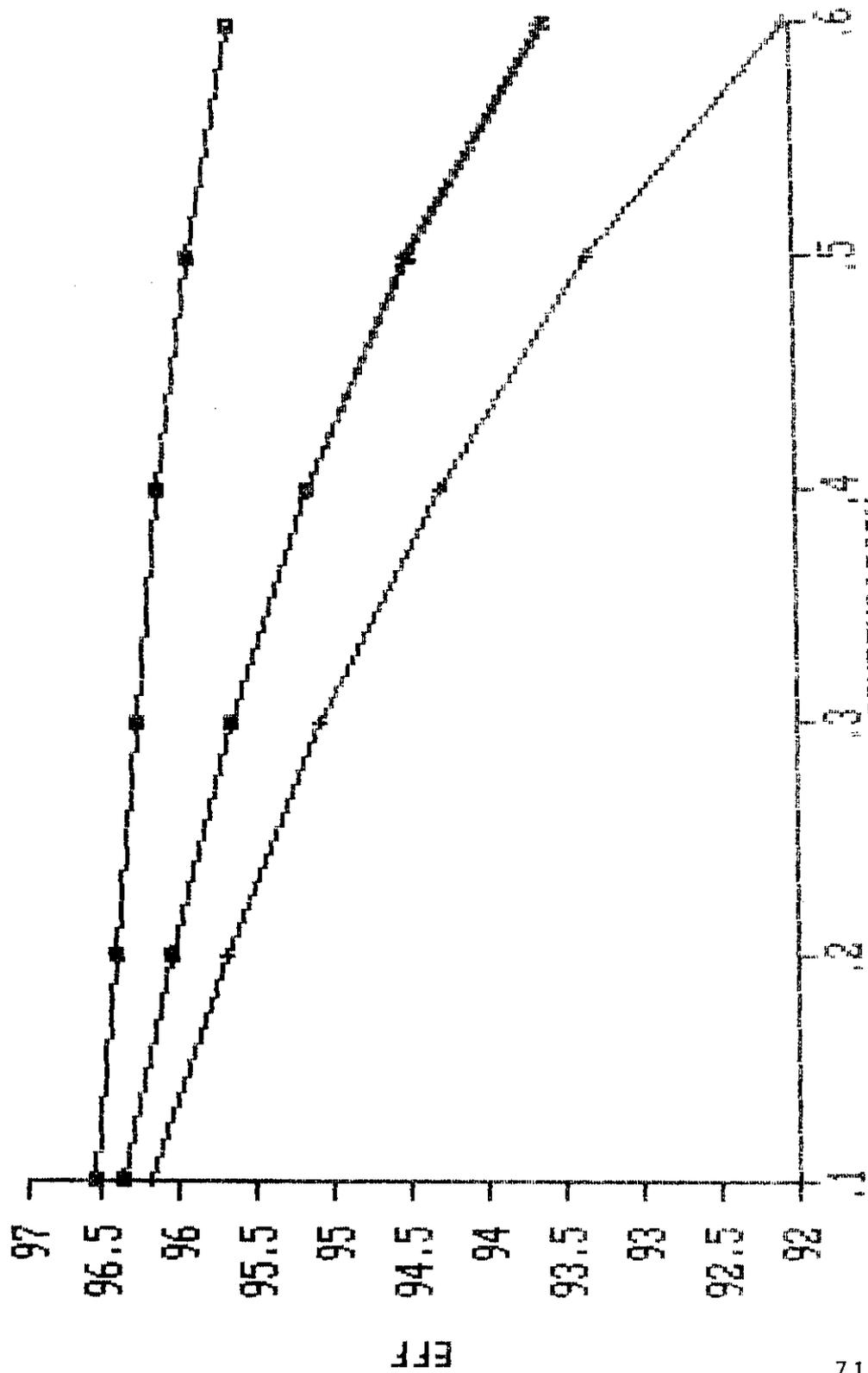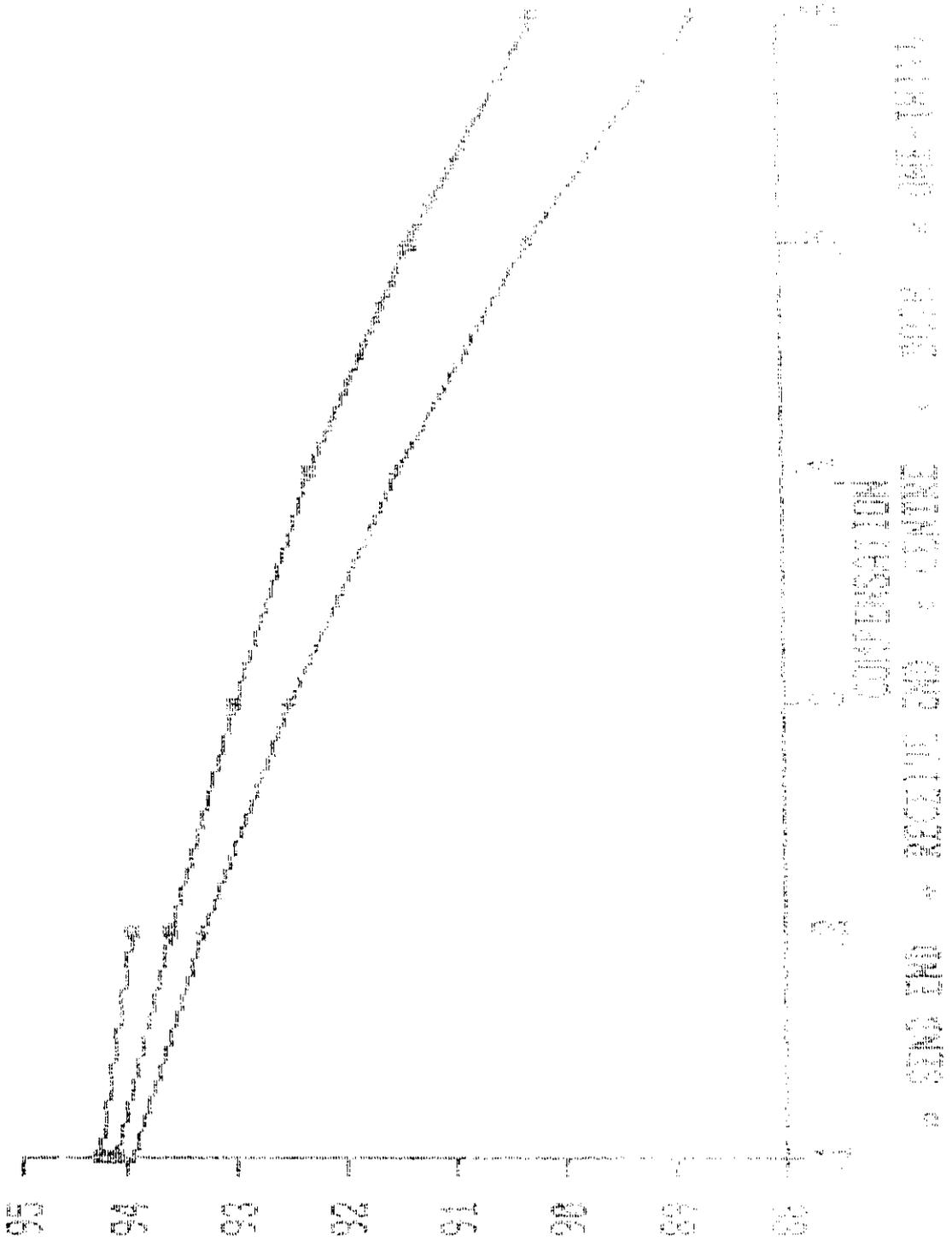
PR VS DELTA
FOR SENDING END
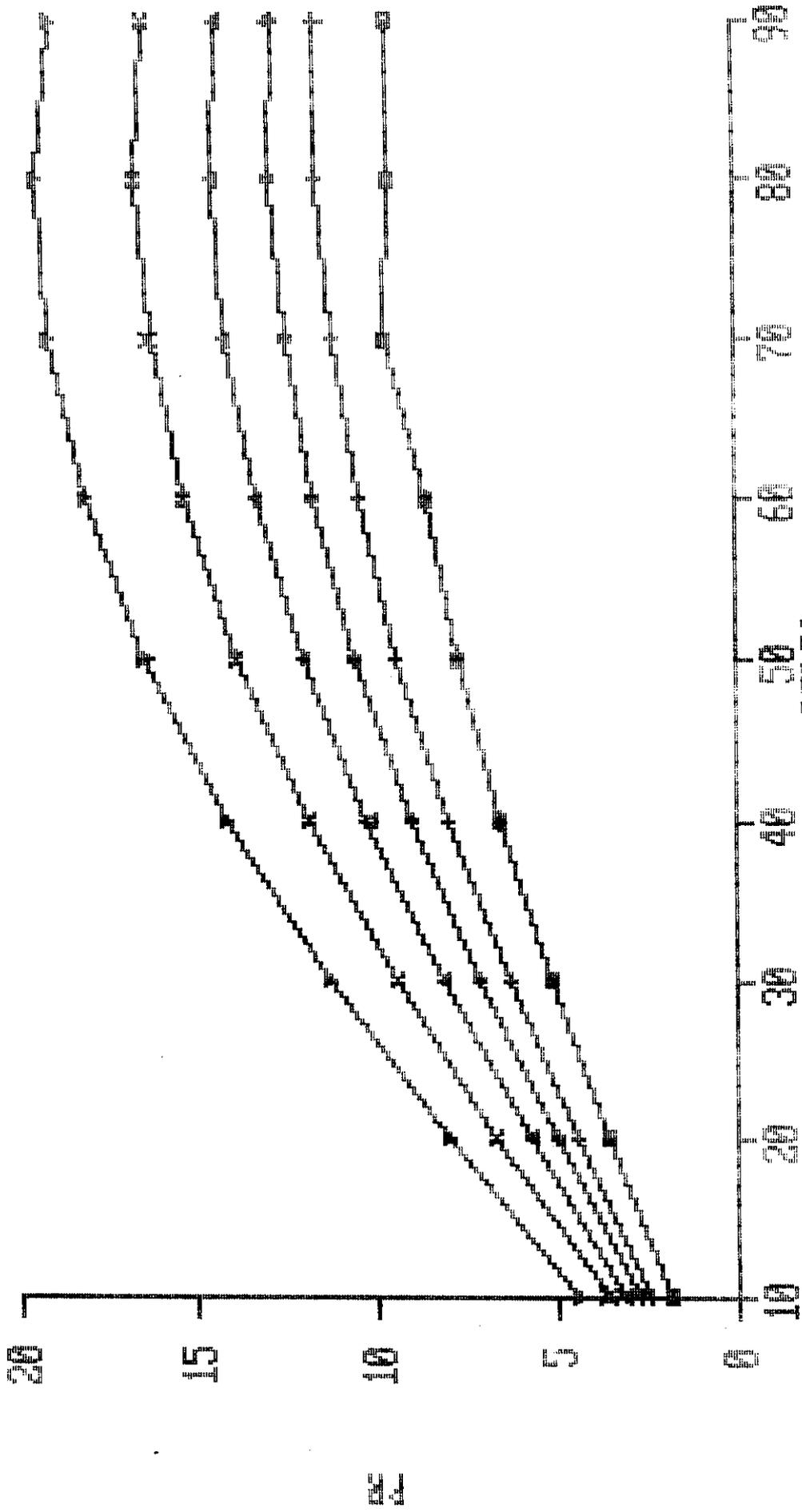
GRAPH NO. 5.09

UNCOMPENSATED + 2 COMP ◇ 3 COMP △ 3 COMP ✕ 3 COMP ✦ 3 COMP

73

GRAPH NO. 5.10

74
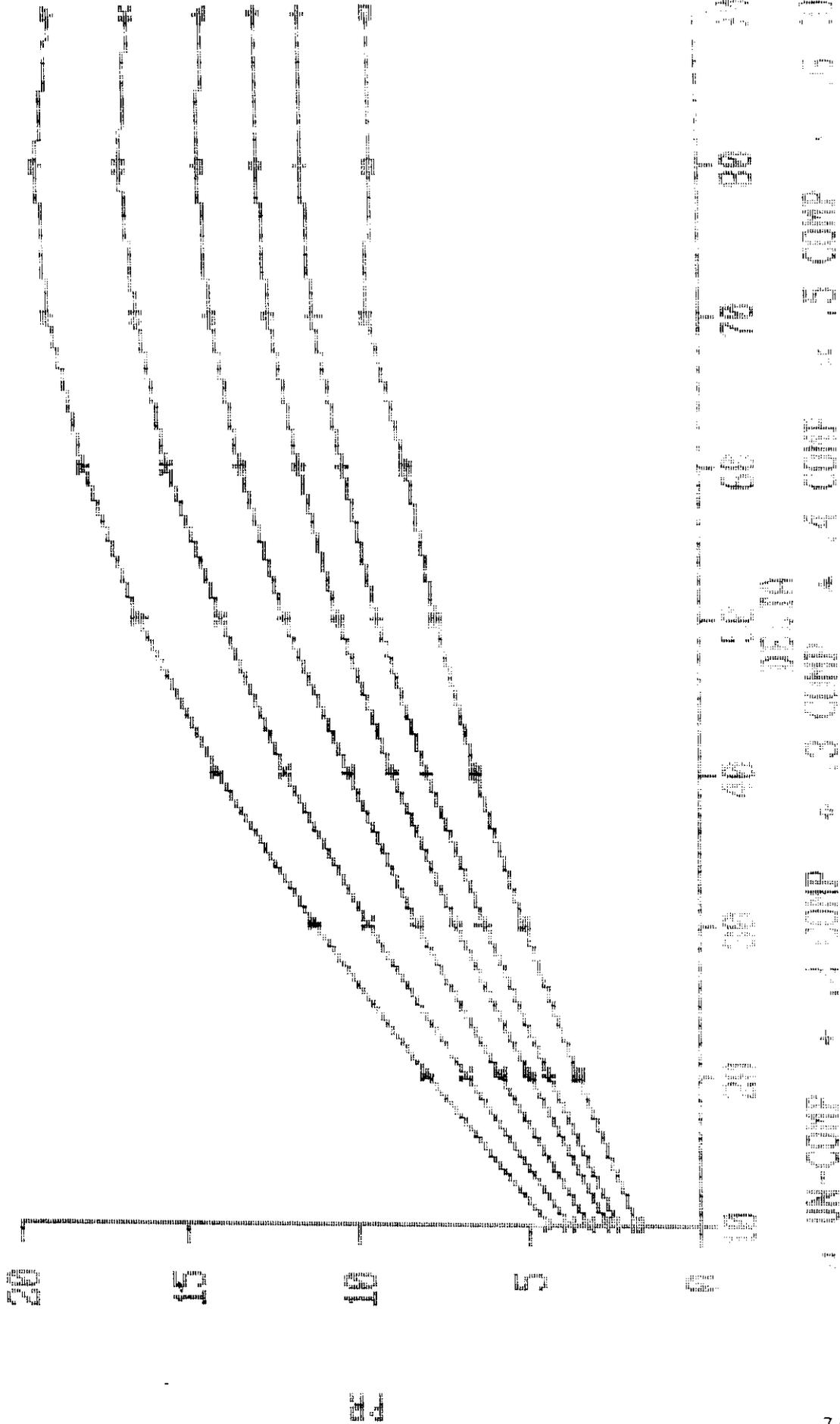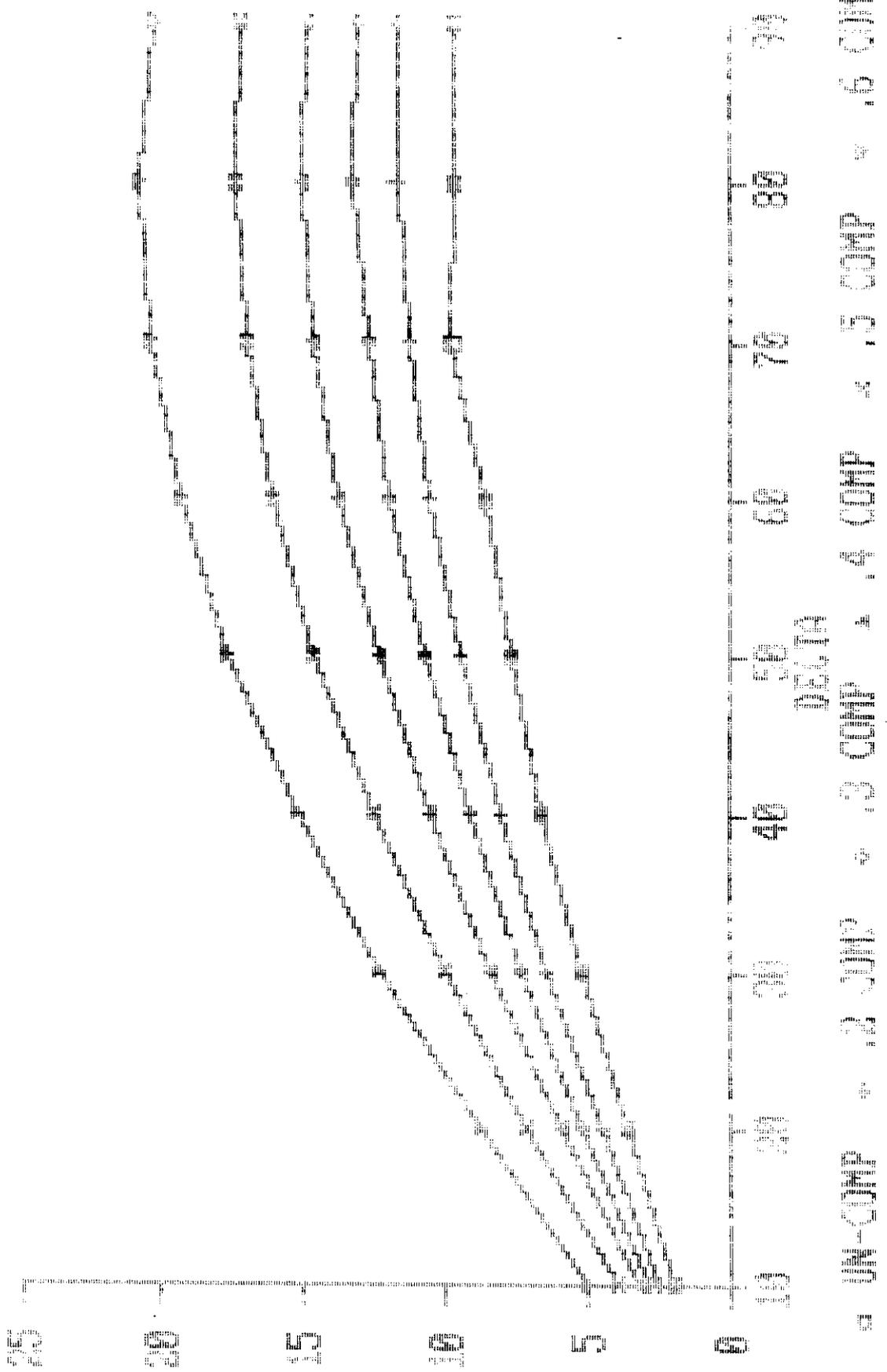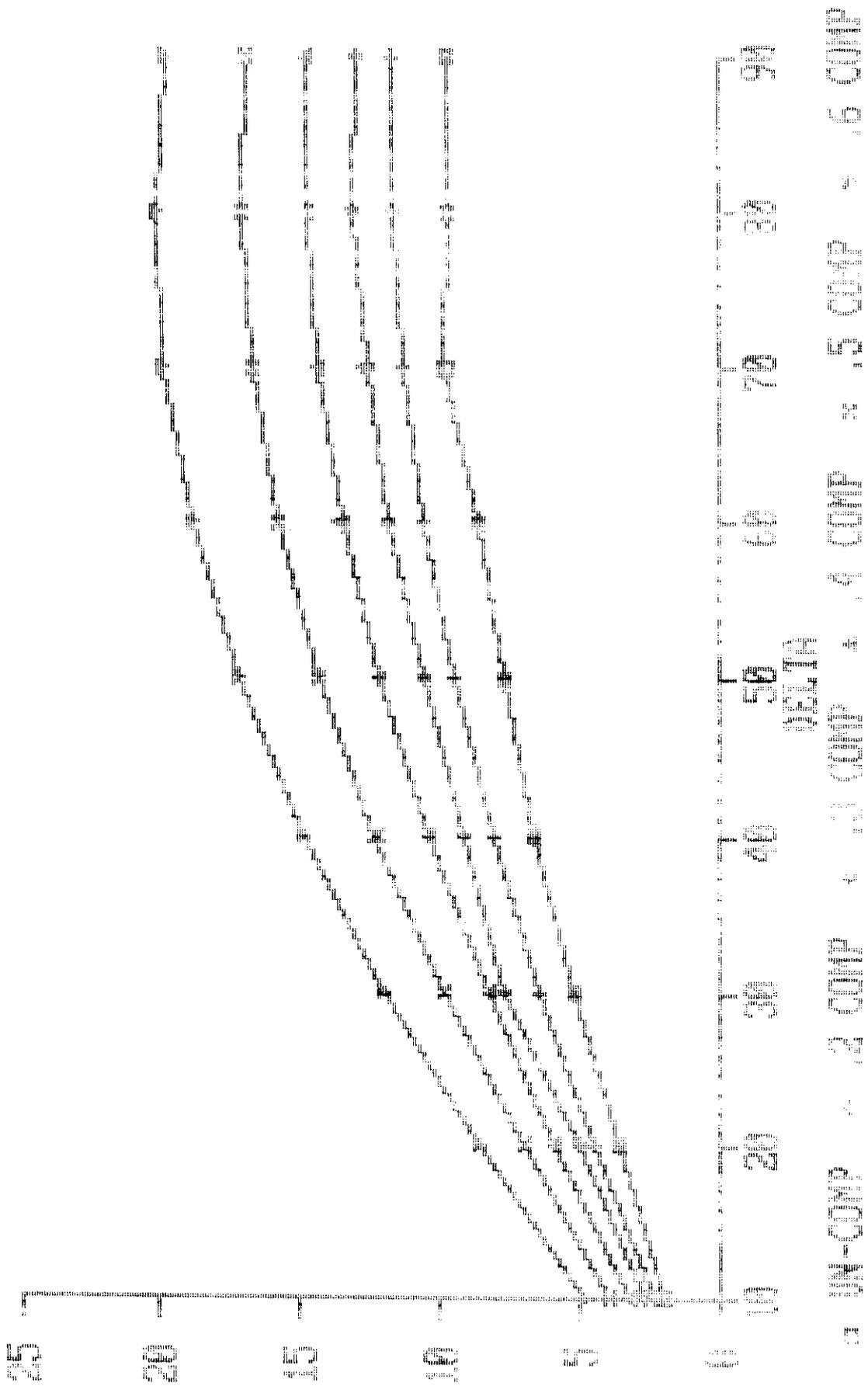
GRAPH NO. 5.11

GRAPH NO. 5.12

PR VS DELTA

FOR ONE-THIRD DISTANCE

GRAPH NO. 5.13

77
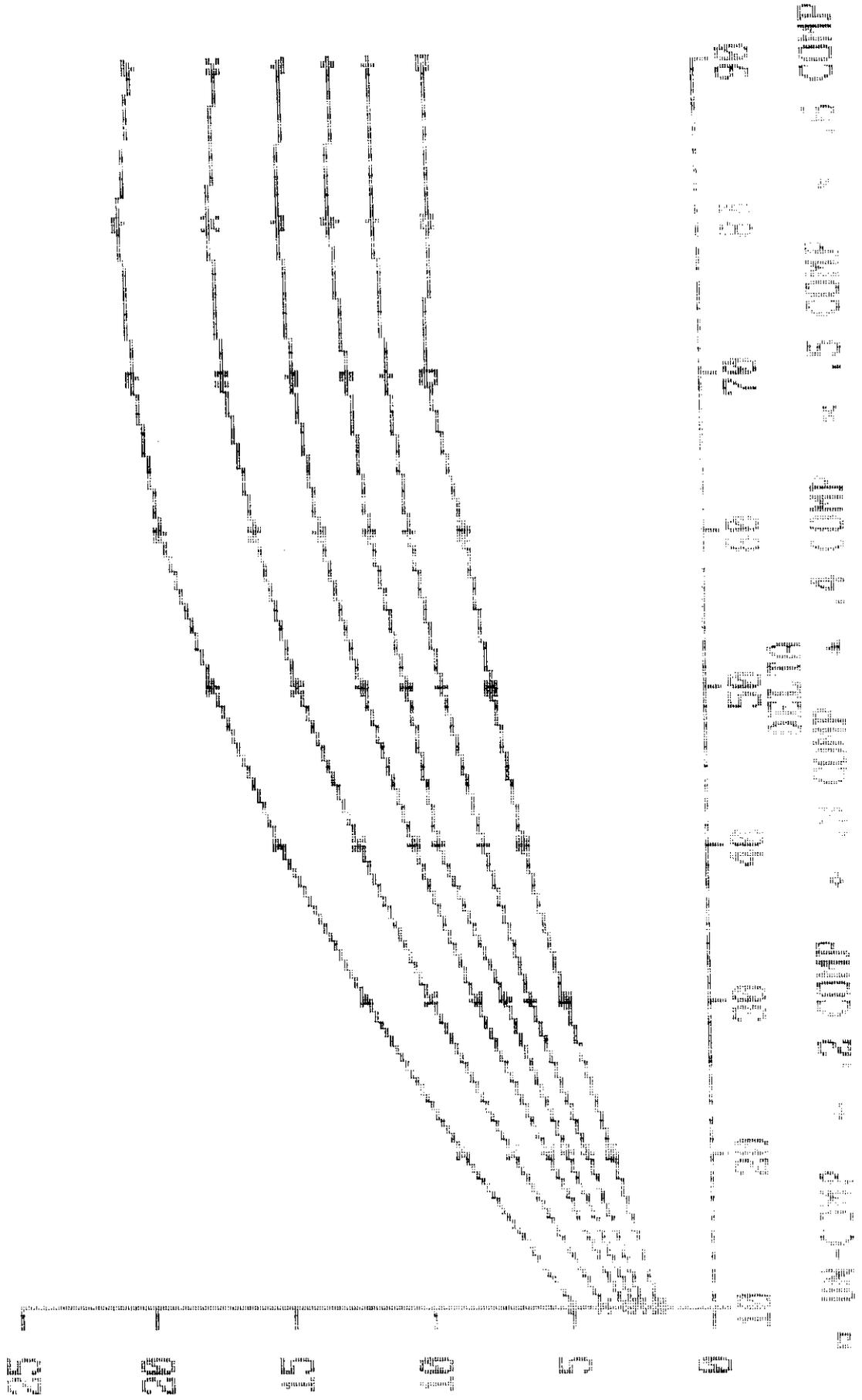
COMPARISION OF VARIOUS PARAMETERS
FOR DIFFERENT POSITIONS

	SENDING END	RECEIVING END	CENTRE	BOTH ENDS	ONE-THIRD
PRMAX	LOWEST	LOWER	HIGHEST	HIGHER	HIGHEST
PR	LOWEST	HIGHEST	HIGHER	MODERATE	HIGHER
EFFICIENCY	HIGHEST	LOWEST	MODERATE	MODERATE	MODERATE
BM	LOWEST	LOWEST	HIGHEST	HIGHER	HIGHEST

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SOFTWARE
DEVELOPMENT
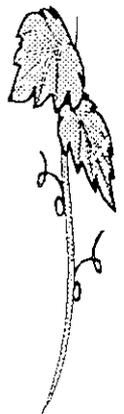
CHAPTER 6

DEVELOPMENT OF SOFTWARE

A software in FORTRAN 77 has been developed and various parameters are computed for the line datas given in the section.The software also has the option of evaluating the various parameters for any line data input.the results obtained are tabulated.

The VPP package is been used to draw the characteristic curves.

The flow chart in the section indicates the sequence of steps involved in computations.

6.1.   ALGORITHM

1.   Read the values of resistance, inductance, line length, conductance, susceptance and system voltage of the transmission line.

2.   Read the initial, increment and final values of R which is equal to V_S/V_R.

3.   Convert all line values to P.U.

4.   Compute the ABCD constants of the transmission line.

5.   Read the type of compensation required and the compensating factor.

6. Compute the ABCD constants of the compensating network for the given compensating factor.

7. Compute the net ABCD constant of the series capacitor compensated line.

8. Compute the receiving end power P_R for different power factors of 0.8, 0.9 and 1.0.

9. Compute the maximum receiving end power $P_{R\ MAX}$, efficiency, $V_{R\ CRIT}$, and δ_{CRIT}

10. Print the values of P_R, $P_{R\ MAX}$, B_0, efficiency, $V_{R\ CRIT}$ and δ_{CRIT}

6.2 FLOW CHART

```
           ┌─────────┐
          (  Start   )
           └────┬────┘
                │
                ▼
        ╱───────────────╲
       ╱ Read R,XL,GG,BB ╱
      ╱ SYSVOL,BASEMVA  ╱
     ╱ LINE LENGTH     ╱
     ╲────────┬───────╱
                │
                ▼
        ┌───────────────┐
        │ Convert all the│
        │ data values to │
        │      p.u       │
        └───────┬────────┘
                │
                ▼
        ┌───────────────┐
        │ Compute the ABCD│
        │ constants of the│
        │ transmission line│
        └───────┬────────┘
                │
                ▼
        ╱───────────────╲
       ╱ Read the type   ╱
      ╱ of compensation ╱
     ╱ required        ╱
     ╲────────┬───────╱
                │
                ▼
        ╱───────────────╲
       ╱ Read the        ╱
      ╱ compensation    ╱
     ╱ factor          ╱
     ╲────────┬───────╱
                │
                ▼
           ┌─────────┐
          (    A     )
           └─────────┘
```

```
                      ┌───┐
                      │ A │
                      └─┬─┘
                        │
                        ▼
        ┌───────────────────────────────┐
        │   Compute the ABCD            │
        │   constants of the            │
        │   compensating                │
        │   network                     │
        └───────────────┬───────────────┘
                        │
                        ▼
        ┌───────────────────────────────┐
        │   Compute the net             │
        │   ABCD constants              │
        │   of the line                 │
        └───────────────┬───────────────┘
                        │
                        ▼
        ┌───────────────────────────────┐
        │      Set p.f = 0.8            │
        └───────────────┬───────────────┘
                        │        ┌───┐
                        ◄────────┤ D │
                        │        └───┘
                        ▼
        ┌───────────────────────────────┐
        │      Set R = 1.1              │
        └───────────────┬───────────────┘
                        │        ┌───┐
                        ◄────────┤ C │
                        │        └───┘
                        ▼
        ┌───────────────────────────────┐
        │  Compute PR,PRMAX,            │
        │  PS,VR,EFF,DELTA,            │
        │  VRCRIT,DELCRIT              │
        └───────────────┬───────────────┘
                        │
                        ▼
        ╱───────────────────────────────╱
       ╱   Print R,VS,VR,              ╱
      ╱    PR,PRMAX,PS,               ╱
     ╱     EFF,DELTA                 ╱
    ╱───────────────┬───────────────╱
                    │
                    ▼
                  ┌───┐
                  │ B │
                  └───┘
```

```
                    ( B )
                      │
                      ▼
              ╱───────────────╲
             ╱     Print        ╲
            ╱    VRCRIT          ╲
            ╲    DELCRIT         ╱
             ╲─────────────────╱
                      │
                      ▼
            ┌───────────────────┐
            │                   │
            │    R = R + 0.1    │
            │                   │
            └───────────────────┘
                      │
                      ▼
                   ╱  IS  ╲
                  ╱ R > 1.4 ╲────NO────▶ ( C )
                  ╲        ╱
                   ╲      ╱
                     │ YES
                     ▼
            ┌───────────────────┐
            │                   │
            │  P.F = P.F + 0.1  │
            │                   │
            └───────────────────┘
                     │
                     ▼
                  ╱  IS  ╲
                 ╱ P.F > 1 ╲────NO────▶ ( D )
                 ╲         ╱
                  ╲       ╱
                    │ YES
                    ▼
               (  Stop  )
```

```fortran
C     *********************************************************
C
C           COMPUTER AIDED ANALYSIS OF COMPENSATED EHV LINES
C
C     *********************************************************
      CHARACTER *1,CHOICE
      INTEGER CAP
      COMPLEX CMPLX,CSQRT
      COMPLEX A,B,C,D,AS,BS,CS,DS,A0,B0,C0,D0
      COMPLEX A01,B01,C01,D01,A02,B02,C02,D02,A03,B03,C03,D03
      COMPLEX ABCD1,ZL,YL,ZC,YC,GMA
      PRINT 101
101   FORMAT(12X,'*********** TITLE OF THE PROJECT  ***********'/)
      WRITE(*,115)
      WRITE(*,102)
102   FORMAT(80('~'))
      PRINT 103
103   FORMAT(15X,'COMPUTER AIDED ANALYSIS OF COMPENSATED EHV LINES'/)
      WRITE(*,102)
      PRINT 104
104   FORMAT(30X,'carried out by')
      PRINT 105
105   FORMAT(/30X,'ASHOK KUMAR V.',
     +       /30X,'PRASHANTH CHANDRAN.',
     +       /30X,'RICHARD A.',
     +       /30X,' ',
     +       /35X,'at',
```

```
     +          /30X,' ',
     +          /15X,'CENTRAL POWER RESEARCH INSTITUTE,BANGALORE.',
     +          /30X,' ',
     +          /30X,'guided by',
     +          /30X,' ',
     +          /5X,'Guide at the Organisation',10X,'Guide at the College'
     +          /5X,'MR. P. V. BALASUBRAMANYAM',10X,'MR. SIVA KUMAR',
     +          /10X,' ',
     +          /25X,'Head Of The Dept.',
     +          /5X,'DR.K.A.PALANISWAMY, B.E., M.Sc.(Engg), Ph.D.,'
     +          ' M.I.S.T.E., C.Eng.(I), F.I.E'
     +          /10X,' ',
     +          /10X,' '/)
      READ *,
      PRINT *,'ASSUME STANDARD VALUES (Yes/No)'
      READ *,CHOICE
      IF (CHOICE .EQ. 'Y') GOTO 106
      PRINT *,'ENTER THE VALUE OF SYSTEM VOLTAGE'
      READ (*,*) SYSVOL
      VS = SYSVOL
      PRINT *,'ENTER THE TRANSMISSION LINE LENGTH'
      READ (*,*) DL
      PRINT *,'ENTER THE VALUES OF RL , XL , GG AND BB'
      READ (*,*) RL,XL,GG,BB
      PRINT *,'ENTER THE VALUE OF RINI , RINC AND RMAX'
      READ (*,*) RINI,RINC,RMAX
      PRINT *,'ENTER THE VALUES OF PFINI, PFINC AND PFMAX'
```

84

```fortran
      READ (*,*) PFINI,PFINC,PFMAX

      GOTO 107
C     STANDARD VALUES
106   SYSVOL = 400.0

      DL = 400.0

      RL = 0.0274

      XL = 0.332

      GG = 0.0

      BB = 3.47E-06

      VS = SYSVOL

      RINI = 1.1

      RINC = 0.1

      RMAX = 2.0

      PFINI = 0.8

      PFINC = 0.1

      PFMAX = 1.0

107   WRITE(*,108) SYSVOL

108   FORMAT(20X,'SYSTEM VOLTAGE (KV) = ',F10.6)

      WRITE(*,109) DL

109   FORMAT(/20X,'TOTAL LENGTH OF THE LINE =',F8.2)

      WRITE(*,110) RL,XL,GG,BB

110   FORMAT (/20X,'LINE RESISTANCE (OHMS/KM) = ',E14.7,
     +         /20X,'LINE INDUCTIVE REACTANCE (OHMS/KM) = ',E14.7,
     +         /20X,'GG = ',E14.7,/,20X,'BB = ',E14.7)

      WRITE(*,111) VS

111   FORMAT(/20X,'SENDING END VOLTAGE (KV) = ',F10.6/)

      WRITE(*,112) RINI,RINC,RMAX
```

```fortran
  112 FORMAT(/10X,'RINI = ',F10.6,5X,'RINC = ',F10.6,5X,'RMAX =',F10.6)
      WRITE(*,130) PFINI,PFINC,PFMAX
  130 FORMAT(/10X,'PFINI=',F10.6,5X,'PFINC=',F10.6,5X,'PFMAX=',F10.6)
C
      WRITE(*,116)
C
      BASMVA = 100.0
      WRITE(*,113) BASMVA
  113 FORMAT(/30X,'BASEMVA = ',F10.4)
      BASIMP = (SYSVOL*SYSVOL)/BASMVA
      RL = RL/BASIMP
      XL = XL/BASIMP
      GG = GG*BASIMP
      BB = BB*BASIMP
      VS = VS/SYSVOL
      YL = CMPLX(GG,BB)
      ZL = CMPLX(RL,XL)
      ZC = CSQRT(ZL/YL)
      GMA = CSQRT(ZL*YL)
      YC = 1.0/ZC
      ZCM = CABS(ZC)
      DL1 = DL
C
      WRITE(*,114) ZC,GMA,ZCM
  114 FORMAT(/10X,'CHARACTERISTIC IMPEDANCE =',2E14.7,
     +        /10X,'PROPOGATION CONSTANT = ',2E14.7
     +        /10X,'MAGNITUDE OF SURGE IMPEDANCE =',F10.6)
```

```
C
      WRITE(*,115)
115   FORMAT(80(' '))
      WRITE(*,116)
116   FORMAT(80('*'))
      READ *,
117   FORMAT(80('-'))
C     TYPES OF SERIES COMPENSATION
      WRITE(*,118)
118   FORMAT(/12X,'SERIES CAPACITANCE AT THE SENDING END (1)',
     +        /12X,'SERIES CAPACITANCE AT THE RECEIVING END (2)',
     +        /12X,'SERIES CAPACITANCE IN THE MIDDLE (3)',
     +        /12X,'SERIES CAPACITANCES AT BOTH THE ENDS (4)',
     +        /12X,'SERIES CAPACITANCES AT ONE-THIRD DISTANCE FROM'
     +           ' BOTH THE ENDS (5)',
     +        /12X,'UNCOMPENSATED LINE (6)')
      WRITE(*,116)
      WRITE(*,119)
119   FORMAT(/12X,'ENTER THE TYPE OF COMPENSATION REQUIRED')
      READ *,CAP
      IF (CAP .EQ. 3) DL = DL/2
      IF (CAP .EQ. 5) DL = DL/3
      YY = DL
C
C     CALCULATION OF ABCD PARAMETERS
      CALL ABCD(GMA,YY,ZC,YC,A,B,C,D)
      IF( CAP .EQ. 6) GOTO 7
```

```
C    COMPENSATION FACTOR
     WRITE(*,120)
120  FORMAT(/12X,'ENTER THE COMPENSATION FACTOR')
     READ *,COMP
     WRITE(*,117)
     AS = CMPLX (1.0,0.0)
     CS = CMPLX (0.0,0.0)
     DS = AS
     C1 = - COMP*XL*DL1
     IF (CAP .EQ. 4) C1= C1/2
     IF (CAP .EQ. 5) C1= C1/2
     BS = CMPLX (0.0,C1)
     GOTO (1,2,3,4,5),CAP
1    CALL MATMUL(AS,BS,CS,DS,A,B,C,D,A0,B0,C0,D0)
     GOTO 8
2    CALL MATMUL(A,B,C,D,AS,BS,CS,DS,A0,B0,C0,D0)
     GOTO 8
3    CALL MATMUL(A,B,C,D,AS,BS,CS,DS,A0,B0,C0,D0)
     CALL MATMUL(A0,B0,C0,D0,A,B,C,D,A01,B01,C01,D01)
     GOTO 6
4    CALL MATMUL(AS,BS,CS,DS,A,B,C,D,A0,B0,C0,D0)
     CALL MATMUL (A0,B0,C0,D0,AS,BS,CS,DS,A01,B01,C01,D01)
     GOTO 6
5    CALL MATMUL (A,B,C,D,AS,BS,CS,DS,A0,B0,C0,D0)
     CALL MATMUL (A0,B0,C0,D0,A,B,C,D,A01,B01,C01,D01)
     CALL MATMUL (A01,B01,C01,D01,AS,BS,CS,DS,A02,B02,C02,D02)
     CALL MATMUL (A02,B02,C02,D02,A,B,C,D,A03,B03,C03,D03)
```

```
        AO = AO3

        BO = BO3

        CO = CO3

        DO = DO3

        GOTO 8

6       AO = AO1

        BO = BO1

        CO = CO1

        DO = DO1

        GOTO 8

7       AO = A

        BO = B

        CO = C

        DO = D

8       CALL MAG(AO,BO,CO,DO,AM,BM,CM,DM)

        CALL ANG(AO,BO,CO,DO,AN,BN,CN,DN)

        PRINT 121

121     FORMAT(30X,'ABCD PARAMETERS OF THE TOTAL LINE (PU)')

        WRITE(*,122)A,B,C,D

122     FORMAT(/20X,'A = ',2F10.6,5X,'B = ',2F10.6/,
     +          20X,'C = ',2F10.6,5X,'D = ',2F10.6)

C

        WRITE(*,123) AM,BM,CM,DM

123     FORMAT (/20X,'AM=',F10.6,5X,'BM=',F10.6/,
     +          20X,'CM=',F10.6,5X,'DM=',F10.6)

        WRITE(*,124) AN,BN,CN,DN

124     FORMAT(/20X,'AN=',F10.6,5X,'BN=',F10.6/,
```

```
     +             20X,'CN=',F10.6,5X,'DN=',F10.6)
       ABCDL=A*D-B*C
       WRITE(*,125) ABCDL
 125   FORMAT(50X,'ABCD=',2F10.6)
       WRITE (*,117)
       READ *,
       PI = 22.0/7.0
C
C      INITIAL VALUE OF R (VS/VR RATIO)
C

       R = RINI
       PF = PFINI
C      ---------------


 131   PRINT *,'TABULATION FOR PF = ',PF
       PRINT *,' R      VS      VR      DELTA      PR      PRMAX      PS      EFF
      + VRCRIT    DELCRIT'
       THETA = ACOS(PF)
       THE = THETA-BN+AN
 126   THE1 = (AM/R)*SIN(THE)
       DELTA = BN-THETA+ASIN(THE1)
       PR = (1/(R*BM))*COS(BN-DELTA)-(AM/(BM*R*R))*COS(BN-AN)
       PS = (DM/BM)*COS(BN-AN)-(1/(R*BM))*COS(BN+DELTA)
       PRM = (1/(R*BM))-(AM/(BM*R*R))*COS(BN-AN)
       EFF = (PR/PS)*100
       VR = VS/R
       DELCRIT = ((AN+BN)-THETA)/2.0
```

```fortran
      VRCRIT = VS/(2.0*AM*COS(AN-DELCRIT))
      WRITE(*,127) R,VS,VR,DELTA*57.3,PR,PRM,PS,EFF,
     +VRCRIT,DELCRIT*57.3
127   FORMAT(1F4.2,2X,1F4.2,2X,1F4.2,2X,1F8.3,2X,1F6.3,2X,1F6.3,
     +2X,1F6.3,2X,1F5.2,2X,1F4.2,2X,1F8.3)
      R   = R +RINC
      IF (R .LE. RMAX) GOTO 126
      R = RINI
      PF = PF+PFINC
      READ *,
      IF (PF .LE. PFMAX) GOTO 131
C     VARIATION OF PR WITH DELTA
      PRINT *,'   DELTA          PR'
      DEL1 =10
      R = 1.2
345   PRDEL = (1/(R*BM))*COS(BN-DEL1/57.3)-(AM/(BM*R*R))*COS(BN-AN)
      WRITE(*,489)DEL1,PRDEL
489   FORMAT(1F10.6,5X,1F6.3)
      DEL1 = DEL1 + 10
      IF (DEL1 .LE. 90) GOTO 345
      STOP
      END
      SUBROUTINE ABCD(GMA,X,ZC,YC,A,B,C,D)
      COMPLEX A,B,C,D,ZC,YC,GX,CMPLX,GMA
      GX = GMA*X
      ALPHA = REAL(GX)
      BETA = AIMAG(GX)
```

```fortran
      C1 = EXP(ALPHA)

      C2 = 1.0/C1

      SNH = (C1-C2)*0.5

      CSH = (C1+C2)*0.5

      A1 = CSH*COS(BETA)

      A2 = SNH*SIN(BETA)

      B1 = SNH*COS(BETA)

      B2 = CSH*SIN(BETA)

      A = CMPLX(A1,A2)

      B = CMPLX(B1,B2)

      C = YC*B

      B = ZC*B

      D = A
      RETURN
      END
      SUBROUTINE MATMUL(A,B,C,D,E,F,G,H,P,Q,R,S)
      COMPLEX A,B,C,D,E,F,G,H,P,Q,R,S,PL,QL,RL,SL

      P = A*E+B*G

      Q = A*F+B*H

      R = C*E+D*G

      S = C*F+D*H
      RETURN
      END
      SUBROUTINE MAG(A0,B0,C0,D0,AM,BM,CM,DM)
      COMPLEX A0,B0,C0,D0

      AM = CABS(A0)

      BM = CABS(B0)
```
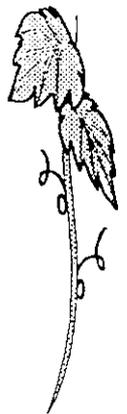
```fortran
      CM = CABS(C0)
      DM = CABS(D0)
      RETURN
      END
      SUBROUTINE ANG(A0,B0,C0,D0,AN,BN,CN,DN)
      COMPLEX A0,B0,C0,D0
      REAL REAL,AIMAG,ATAN2
      PI = 22.0/7.0
      T1 = AIMAG(A0)
      T2 = REAL(A0)
      AN = ATAN2(T1,T2)
      T1 = AIMAG(B0)
      T2 = REAL(B0)
      BN = ATAN2(T1,T2)
      T1 = AIMAG(C0)
      T2 = REAL(C0)
      CN = ATAN2(T1,T2)
      T1 = AIMAG(D0)
      T2 = REAL(D0)
      DN = ATAN2(T1,T2)
      RETURN
      END
```

PROBLEMS IN SERIES COMPENSATION

CHAPTER 7

PROBLEMS ASSOCIATED WITH SERIES COMPENSATED TRANSMISSION LINE

The application of series capacitor for the transmission line has the following advantages.

    i. Increasing the power transfer capability.

    ii. Voltage and reactive power control.

    iii. Load sharing in parallel and loss minimization.

But series compensation is also associated with certain problems like dynamic system instability, switching over voltage, sub-synchronous oscillations, etc. In this chapter, an attempt is made to explain the problems and their analysis. Some preventive methods have also been suggested.

7.1. PROBLEMS IN THE APPLICATION OF SERIES CAPACITOR

7.1.1. The voltage drops across the capacitor results in the voltage to ground at the terminals of the capacitor being different.Thus there is a possibility of an over voltage on one side of the capacitor under certain conditions. This must be examined in detail at the planning stage. The over voltage can be overcome by connecting switched shunt reactors.

7.1.2. SSR Phenomena

The basic sub-synchronous electrical oscillation phenomena may be explained as follows.

For a generator connected to an infinite bus through a series compensated line, if the speed of the generator and its angular position relative to the infinite bus are constant, then the system will have a natural resonant frequency decided by the total effective inductance and capacitance of the system. As a result of any small system disturbance, the RLC circuit will ring down at its sub-synchronous resonant frequency, causing generator armature current. But at this sub-synchronous frequency the synchronous machine behaves as an induction generator with negative slip.

Therefore energy is fed into the RLC circuit at the synchronous frequency and hence will tend to sustain or amplify the sub-synchronous currents. Under certain unfavourable conditions, this action will cause sub-synchronous currents to grow to disruptive magnitudes throughout the transmission systems. The sub-synchronous currents flowing in the armature of the synchronous machine will give rise to a component of air gap torque. Components at frequencies equal to the system frequency plus or minus the sub-synchronous frequency may be large enough, especially when the orsional resonance frequency of the system is close enough to the frequency of the torque pulsation, to damage the turbine generator shafts.

7.2. EFFECT OF SSR ON POWER SYSTEMS

Though series capacitors have added new dimensions to the solutions of large power transfer associated with E.H.V. long lines, it also causes some problems as given below.

The sub-synchronous current flowing in the armature of the synchronous machine gives rise to a pulsating air gap torque. If the frequency of this torque is nearer to the natural frequency of the mechanical system, resonance will occur causing damage to the turbine shaft. SSR has become a subject of great concern, especially after the damage to the two generator shafts at Mohava generating station in Southern Nevade, U.S.A., on,

i. December 9, 1970 and,

ii. October 26, 1971.

The sub-synchronous frequency oscillation also possess a natural danger to the system stability, because a disturbance seems to inject more energy into the system by its induction generator action. If the net resistance of the system is negative, the induction generator action is amplified, thereby causing system instability.

At sub-synchronous frequency, the increased reactance of the series capacitor causes a proportionally high voltage to appear across the capacitor bank, leading to the possible incorrect capacitor gap flash over.

7.3. VARIOUS METHODS OF ANALYSIS OF SSR

The methods available in the frequency domain to simulate and analyse the phenomena of SSR are,

  i. ROUTH HURWITH stability criteria,

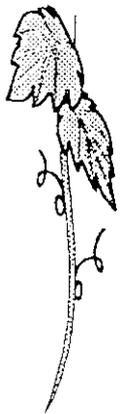 ii. Frequency scanning technique and,

  iii. Eigen value analysis.

7.4. SSR PREVENTIVE METHODS

Prevention against SSR is normally provided by one of the following methods.

  i. Filtering and damping.

  ii. Relaying and protective devices.

CONCLUSION

CHAPTER 8

CONCLUSION

In this project the various types of compensating schemes are compared from the point of view of,

    8.1. $P_{R\ MAX}$

    8.2. EFFICIENCY

    8.3. B_o

The best method of compensation and location is also suggested.

8.1. $P_{R\ MAX}$

The maximum value of $P_{R\ MAX}$ is obtained when the series capacitor is located at the centre or one-third distance from both the ends of the transmission line. Hence from the economic point of view, it is advisable and preferable to have a single capacitor located at the centre.

8.2. EFFICIENCY

It is found that the efficiency is maximum for series capacitor located at the sending end and is slightly lower for centre, one-third and both the ends. As the

value of P_R is more for the centre, it is better to select the centre location of the series capacitor, for the best efficiency.

8.3. B_O

The value of $P_{R\ MAX}$ is inversely proportional to $|B_O|$ of the line. Hence if the type of compensation to be employed from the point of view of $|B_O|$ is taken into consideration, the compensation scheme which gives maximum $P_{R\ MAX}$ is preferred. Hence the centre location is preferred as it gets the least value of $|B_O|$.

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REFERENCE

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