OPTIMISATION OF DISTRIBUTION AND SUBTRANSMISSION SYSTEMS

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By

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SUMMARY

With in the last one century tremendous technological progress has been made in the field of power generation and modern power system's complicated interconnections and the long distances of transmission of large quantum of power with too many variables and constraints the simple philosophies which were used in primitive systems do not hold good for modern system. To get power adequately, reliably and economically with declared voltage, frequency, active power (P) and reactive power (Q) at all consumers and proper distribution network planning is very important. In order to fulfil the above requirements, one has to forecast the load demand properly, to design the distribution system in an optimum manner.

A short term for five years period and long term for ten years and twenty years forecast was done in terms of East zone, West zone, East and West combined zone and political districts of Bangladesh. Linear model, non-linear and econometric models have been used for making this demand estimates. Considering all other factors the year wise demand forecasted was done which assumed a factor growth rate (16%) which is after five years 2.3 times more than the present level. Different computer programs have been developed for this forecasting purpose.

Different computer programs have also been developed for optimising the parameters of primary main circuit and distribution system. For both the cases planned system then compared with the existing one. The methods for integrating the existing system into the planned one have also been discussed so as to achieve an optimised system.

A design engineer can get detailed information regarding optimum design of a distribution system for any area A with any load density L. He can also select the number and rating of 33/11 KV and 11/.415 KV sub-station for any newly design distribution system or for extension of any existing distribution system with minimum cost.

CONTENTS

Page no.	Chapter No.	Section no.	Description
(i)			Certificate
(ii)			Acknowledgement
(iii)			Summary
(iv)			Abreviation
1	1	1	Introduction
1		1.1	The Nature of the Problem
2		1.2	Author's Line of Attack
4		1.3	Arrangement of the Thesis
6	2	2	Review of Design Techniques
6		2.1	Review of Methods use for optimum Design of Distribution system.
9		2.2	Review of Methods use for Optimum Design of Primary Main circuit.
12		2.3	Review of Methods use for Optimum Design of Sub-transmission system.
13	3	3	Load Forecasting of Bangladesh.
13			Introduction
16		3.1	Methodology & study design

ABBREVIATIONS

G.W.H	Gigawatt Hour (Million Kilowatt hour)
ILC	Intermediate load centre (33/11 KV Sub-station)
KW/KWh	Kilowatt/Kilo watt hour
MVA	Mega Volt Ampere
MW/MWh	Mega watt/Megawatt hour
NWS	Non weather sensitive
p.f.	Power Factor
WS	Weather Sensitive

Page no.	Chapter no.	Section no.	Description
18		3.2	Different techniques of forecasting
19		3.2.1	Time Series Model
20		3.2.2	Casual Model
20		3.2.3	Qualitative forecast
20		3.2.4	Separation of WS and NWS demand technique.
21		3.3	Compilation and analysis of field data.
22		3.3.1	Historical Analysis- Linear Model
22		3.3.2	Historical Analysis: Non Linear Model.
24		3.3.3	Evaluation of Regression Model.
24		3.4	Corrected load demand forecast.
29	4	4	Optimum Design of Distribution System. Introduction
31		4.1	Cost of High Voltage branch loops
34		4.2	Cost of distribution sub-stations.
35		4.3	Cost of Low Voltage Cables.
38		4.4	Optimised Design of Distribution system.
40		4.4.1	Calculation of Optimised Total Cost.
41		4.4.2	Calculation of Optimum Sub-Station Area.

Page no.	Chapter no.	Section no.	Description
56	4	4.4.3	Calculation of Optimum Sub-station Load and Cross-section of conductor.
58		4.5	Discussion of the Results of Optimised Design.
60		4.6	Interpretation of Existing System in to the Optimised System.
64	5	5	Optimum Design of Primary Main circuit.
64		5.1	Cost of 33 KV High Voltage branch loops.
66		5.2	Cost of 33/11 KV Sub-Station
67		5.3	Cost of 11 KV cables
68		5.4	Optimised Design of Primary Main
73		5.5	Integration of Existing System with the proposed system.
76	6	6	Discussion and Conclusions.
86		A	Appendix
86		A.1	Economic Back Ground and Power System of Bangladesh.
86		A.1.1	Physical features
87		A.1.2	Population
87		A.1.3	Administrative Structure.
88		A.1.4	Infrastructure
89		A.2	Present Power System of Bangladesh.
91		A.2.1	Generating Stations.

Page no.	Chapter no.	Section no.	Description
91		A.2.2	Transmission Lines.
92		A.2.3	Distribution Lines.
92		A.2.4	Central Load Dispatch and Control.
95		B.1	Computer program for calculating District-wise forecasting of Urban and Rural load demand of Bangladesh.
97		B.2	Computer program for forecasting load demand of Bangladesh.
98		B.3	Computer program for calculating of Optimum Sub-station area considering factors Dcgn.
100		B.4	Computer Program for Calculating of optimum sub-station area considering factors Dcgy. and maximum Allowable voltage drop conditions.
102			Refrences.

CHAPTER - 1

1. Introduction

1.1 The Nature of the Problem

1.2 Author's Line of Attack

1.3 Arrangement of the Thesis

1. INTRODUCTION

Electricity consumption is often used as a rough indicator of the level of technology and development of a country. Power serves as an important input in the agricultural and industrial growth process, as a basic infrastructure it plays a crucial role in determining the rate of economic and social development in any country. Historically, power supply has been a major bottleneck in the growth process of economy of many developing countries. Efforts for planned development in the past thus could not be fully fruitful because of this factor apart from many others. However, in addition to increase power generation measures are needed for improving power supply system, e.g. forecasting load demand, optimised system design.

1.1 The nature of the Problem:

The purpose of the optimum design of electric system is to supply the loads in such a way so that the system can supply load demands adequately, reliably and economically with declared voltage, frequency, active power (P) and reactive power (Q) at all the consumer's end i.e. at all the load points not only for the present but also for the future. Often, the power system is not well planned resulting in the poor performance.

To fulfil the above purpose effectively load forecasting of Bangladesh was very necessary which is an attempt to create a bridge that links data that we currently have with data that we would like to have but can't obtain directly.

After having got the proper forecast one then has to design the power system in such a way that it fulfils aim of supplying power with minimum expenditure. This necessitates the use of optimisation techniques to the measure component of power system, i.e. the generation, transmission and distribution systems.

The problem that was undertaken for this dissertation was "Optimisation [redacted] of distribution and sub-transmission system".

1.2 Author's Plan of attack:

In the light of the above discussion we have to plan our work. Depending on the availability of data, economic back ground and present power system literature was reviewed to get familiar with various techniques of optimised design of a distribution system and to be able to integrate the existing system into the optimised system. The existing system chosen to be a distribution system of Jessore Sadar distribution sub-division of Bangladesh for this purpose and because of which a knowledge about the load growth of

Bangladesh was very essential. After forecasting the load demand of Bangladesh the next important task was the optimum distribution network planing for ensuring declared distribution voltage and frequency at all load points, reliable and economic demand supply. For the above factors an optimised design of a distribution system has been developed, from which the optimum size of area of a sub-station can be calculated by knowing the factor 'b' (by which the area changes to get the optimum cost). Then the optimums sub-station load can be calculated knowing the load density. The optimum number of sub-stations and finally the optimum size of conductor can also be calculated assuming a certain (6%) maximum allowable voltage drop. With the help of this optimum design of distribution system design Engineer can also integrate the number and size of additional units of distribution sub-station required to meet the increased load demand also with the desired expansion of the area by expending minimum amount of additional cost. This is followed by the optimum design of primary main which is necessary to make the whole distribution system optimum.

The review of various techniques of optimised design of sub-transmission system was conducted but the actual optimised design could not be carried out because of lack of time.

1.3 Arrangement of the thesis:

This thesis is devided in six sections which is arranged in the order in which the work was done.

Section 1. gives the introduction which explains the nature of the problem, author's line of attack and the arrangement of this thesis.

Section 2 gives the review of the work done by other research workers in the field of my dissertation.

Section 3 gives the load fore casting of Bangladesh. Load forecasted was done for each district, for each zone and then finally for the whole country taking 1980-81 as the base year of forecasting.

Section 4 gives the detailed optimum design of distribution system. Firstly, the introduction to this field is given by defining the term. Then the factors affecting this design with the methods of design was discussed. Next part of this section gives the detailed design procedure considering and without considering the other factors. Then the results of the optimised design was discussed following the discussion of integration of existing system into the optimised system.

Section 5 gives the design procedure of primary mains with its discussion and section 6 gives the conclusions.

The numbering of the equations, the figures and the tables correspond to the number of the section/sub-section where it appears.

CHAPTER -2

2. Review of Design Techniques

2.1 Review of Methods used for optimum Design of Distribution System

2.2 Review of Methods used for optimum Design of Primary Main Circuit.

2.3 Review of Methods used for Optimum Design of Sub-transmission system.

CHAPTER-2

REVIEW OF DESIGN TECHNIQUES

The detailed review of different techniques of forecasting load demand like time series model or extrapolation technique, casual model or correlation technique, separation of WSand NWS demand technique and qualitative forecasts etc. along with data required for these techniques are given in the next chapter.

2.1 Review of Methods use for Optimum Design of Distribution Systems:

"An Interactive Procedure For Sizing and Timing Distribution Sub-stations Using Optimisation Techniques"(21) was discussed by E.Masud. In his paper he defines a mathematical model which simulates the growth of a power system and determines the least cost expansion plan for a system of distribution substations. A new approach employing linear and integer programming is used to optimise the system substation capacities subject to the constraints of cost load, voltage, and reserve requirements. The model has been successfully applied to a 1600 square mile urban area served by 70 distribution substations.

Rising growth rates, high load densities, ecological considerations, and the scarcity of available land in urban areas have thrust the problem of optimal substation placement beyond the resolving power of the unaided human mind. Economy dictates that we do more than plan adequate substation capacities for the projected system load; the added capacity must be in the proper location.

What is required for the distribution planner is to determine the load magnitude and its geographic location; then the distribution substations must be placed and sized in such a way as to serve the load at maximum cost effectiveness by minimizing feeder losses and construction costs while considering the constraint of service reliability.

The above problem was discussed by D.M. Crawford et.al. (24) in their paper, " A Mathematical Optimization Technique for Locating and Sizing Distribution Sub-stations and Deriving their Optimal service Areas".

The problem discussed in their paper is mainly the planning of distribution substation locations, sizes and service boundaries. The technique discussed used operations research methods to simultaneously optimize substation sizes and services boundaries, given alternative locations for the substations and reliability constraints. The results of the discussed techniques will lead to a configuration of substations that will minimize distribution feeder losses and substation construction cost. Adherence to the results will lower long-range distribution expenses.

A primary feeder model using small area demand locations to represent nonuniform loads, and feeder segments having variable distribution costs and limited capacities is formulated by D.L.Wall et.al.(17) in their paper - "An Optimization Model for Planning Radial Distribution Networks." The solution of problems having 1000 demand locations and 100 substations can be found in a fraction of a second by using a current fast upper bounded transshipment code. The problem of restructuring the solution to satisfy other kinds of constraints is also discussed.

In a series of papers which describe the computer programs and results produced in a cooperative generalized distribution system planning study by the Arizona Public Service Company and the General Electric Company. The first paper in the series presents the objectives and philosophy of the study and the general treatment of the programs (11). The second paper is devoted to the details of the secondary and primary lateral programs (12). The third paper describes the primary main program and the results of its use (13). The fourth paper describes the distribution program and the results of its use (14). Subsequent papers described the subtransmission system and concluded the series with a detailed discussed of the overall results of the joint study.

In these generalised approaches, the problem is stated in terms of average or general conditions which prevail. Specific details are included only in the cases that they contribute to formulating the generalisation. The generalised system constans a regular array of similar loads and equipments. The actual system which is represented usually does not have near this degree of regularity.

2.2 Review of Methods use for Optimum Design of Primary Main Circuit:-

Computer program which has been developed jointly by the Arizona Public Service Company and the General Electric Company for studying the design of primary main circuit and can be used independently or in conjunction with programs for studying distribution and sub-transmission system economics, examines each of many possible primary circuit designs, determines investment and operating costs, and compares the total cost with that of other possible designs. Use of the program at four different load levels and two primary circuit voltage levels has produced much significant data and has resulted in optimisation of conductor size and of the dimensions of the sub station load area. In addition a lower annual cost for higher primary circuit distribution voltage has been demonstrated.

There have been a number of advances in recent years in the application of mathematical programming to the solution of distribution system planning models (21-25). Each of these models makes approximation, in varying degrees of detail, to the primary feeder network. The greatest level of detail is reached in the Adams, Laughton paper (22) which represents each feeder line segment in terms of capacity and linearised cost, and also considers multiple time periods. They used the model to solve small problems (involving a single substation, 34 feeder segments, 24 demand locations).

Later other authors developed models (21,23) that achieved results which involved more realistically sized problems having 10-15 substations. However, in each of these later models the feeder network was approximated in terms of load transfer capabilities between station service areas (21) or primary feeder service areas (23). These approximations thus reduced the capability of such models to reflect the nonuniform distribution of loads within a typical system and also the capability of the models to include feeder network variable costs directly into the optimization process.

Two other models (23,24) recognised the importance of including the load points to represent non-uniform load distribution and feeder cost directly in the optimisation process. However, only the Hindi, Brameller model includes capacity limitation on feeder segments.

This model which contains all the detail of the Adams, Laughton model for a single time period except for the fixed charges on feeder segments. A highly efficient transshipment code is used to solve the model which incorporates several recent significant advances (6,7,9), thereby decreasing the time of solution of such problems.

2.3 Review of Methods use for Optimum Design of Sub-transmission System:

A computer program for studying the economics of sub-transmission system design is described, and the results of its use on a load area of the Arizona Public Service Company are summarised in their paper , "Optimised Distribution and Subtransmission Planning by Digital Computer IV-Subtransmission System Design" by M.J.Hyland et.al.(14). The program, which can be used independently or in conjunction with programs for studying secondary and primary system economics, examines each of many possible subtransmission designs, determines investment and operating costs, and compares the total cost with that of other possible designs. The use of the program with data for a specific load area for four different load levels produced cost savings on the order of 9 percent of total secondary plus primary plus subtransmission costs and established the low cost combinations of subtransmission voltage, conductor size, distribution substation rating, and bulk power station locations and capacities. Although the program can be used independently, the results are most significant when the program input data include the results obtained from the other programs which produce economic secondary, primary lateral, and primary main system designs. Such use takes into account the influence of the interrelated subsystems on the overall distribution system design.

CHAPTER-3

LOAD FORECASTING OF BANGLADESH

3 Introduction

3.1 Methodology and Study Design

3.2 Different Techniques of Forecasting.

3.2.1 Time Series Model

3.2.2 Casual Model

3.2.3 Qualitative Forecast

3.2.4 Separation of WS and NWS demand techniques.

3.3 Compilation and analysis of field data

3.3.1 Historical Analysis: Linear Model

3.3.2 Historical Analysis: Non Linear Model

3.3.3 Evaluation of Regression Model

3.4 Corrected Load demand forecast.

CHAPTER - 1

INTRODUCTION

Let me start this chapter 'Demand analysis and load forecasting' with a proverb 'A prudent man foresees the difficulties ahead and prepares for them; the simpleton goes blindly on and suffers the consequences'. Forecasting in general is nothing but preparation of a statement concerning uncertain or unknown events mostly the events lie in future. Fore casts are needed to acquire knowledge about uncertain events that are important to our present decisions. No forecast is accepted generally as final forecast, but the forecast need constant review in the light of the latest data. Of course different authors have tried to convey the idea of forecasting in a different ways.

According to Wood and Fildes 'Forecasting is an attempt to create a bridge that links data that we currently have with data that we would like to have but can't obtain directly. Again they say (8) ' Forecasting is an activity which estimates the value of unknown variables in terms of the value of variables which are currently known.' According to Mitchel Firth (2)' Planning involves making decisions which will have their effects and out comes in the future and so an estimate of future is required. This estimate is termed as forecasting'. Forecasts can be classified in many was but the most important distinction to make the basic approach to forecast is between judgement forecasts and statistical forecasts. Forecasts based on judgement, sometimes called 'predictions', include those based on expert opinions of individuals. Perhaps the greatest problem with with judgement forecast is the fact that human beings are most intensively affected by recent occurences. Judgement forecasts normally tend to over react to immediate occurrences and circumstances. The human forecaster who uses nothing but judgement can make some very serious errors, that is why we apply mathematical techniques for forecasting. The yearly forecasts are needed to establish feasible generation, transmission and distribution plan. Weekly or monthly forecasts are required for maintenance scheduling. Daily forecasts are required to schedule generating units for optimum economy. A good forecast is a key to effective system planning. For optimum design of distribution system design must be made for each area. Hence we need to break the total area into its constituent districts.

Urban and rural classification of load demands was done on the basis of simple assumption that all district and sub-division level towns belong to the urban group ~~[illegible]~~ and others to the rural group. The assumption is a little arbitrary, but none the less it was accepted by the Bangladesh Power Development Board because of its simplicity in application.

With the above assumption, I have forecasted the load-demands for each district, fore each zone and then whole country finally for~~d~~ the taking 1980-81 as the base year forecasting. We can also forecast load demand by forecasting energy which is less difficult because energy is much less erratic and is considered a better-trend growth indicator. It can be readily related to demographic and economic factors, having a look at the energy data broken into different classes of consumers. On the other hand peak demand forecast can very much erratically, but the advantage in separately forecasting the peak demand is that it is a more direct method and we can directly relate it to weather variables like temperature But it is to be emphasised whether we should forecast peak-demand using forecasted load factors or we should forecast it separately is a situation dependent.

In order to forecast load demand of Bangladesh properly it is necessary to study the historical growth rate of that country. It is also appropriate to study the historical growth rate separately through two different time series instead of one in order to make any meaningful use of the same for forecasting future load demand of Bangladesh One is upto the year 1970 and the other is 1973 onward. The intermediate two years 1971 and 1972 fall within disturbed range due to the socio-political circumstances prevailing in the country then

The trend of this second series is basically different from the earlier one. The objective situation affecting the power demand is different. For future forecasting thus the power demand from 1973-74 to 1977-78 will provide a more realistic basis to start with .

3.1 Methodology and Study Design:

Electricity consumption is often used as a rough indicator of the level of technology as well as the extent of development of a country. The growth in the industrial and agricultural sector can not be sustained without a steady supply of electric power. In Bangladesh power supply has been historically a major bottle neck in the growth process of the economy. Some of the basic problems connected with the power sector in the Bangladesh economy are as follows:-

1. The per-capita generating capacity of electricity in Bangladesh has been one of the lowest in the world In 1976-77 the per capita annual generation of the electricity in Bangladesh came to 25.80 KWh. This is a considerably low figure which comes to around a quarter of that in India.

2. The relative cost of electrical generation in Bangladesh is also high. The price charged to the

the consumers had been higher than in other countries.

3. The total installed capacity of electricity came to 767 MW in 1976-77 while the peak demand was 342 MW in the same year which shows a significant surplus generating capacity over the normal requirement of reserve capacity.

4. There are two separate power systems that have emerged in Bangladesh, the sources and coverage of electricity supply between the two zones differ between themselves, their problems are also different.

5. The problems of interruption of power supply staggering of load and high energy losses due to various technical deficiencies have considerably affected and restricted the growth of the economy.

It is not only necessary that these and other issues related to the supply of electricity be probed and examined throughly, it is also absolutely essential to remove the imbalance between the generation and distribution of electricity, and also assess the future demand pattern based on a rational policy to meet the requirements of the development activity of both the rural and urban sectors of the country's economy.

In the absence of the perspective plan of the country, it was not possible to assess the future demand pattern in terms of economic activity, their magnitude of growth and the location and area of those economic activities.

It is very difficult to prepare a detailed demand analysis in corporating a realistic load demand of different localities. In this chapter the demand projection includes (1) a short-term forecast of load demand for each area by consumption for five years period, and

(2) a long-term forecast for the next ten years and twenty years of load demand for each area by consumption.

The analysis of future (yearly) load demand of Bangladesh is made with different techniques of forecasting in terms of -

Total system load - East Zone - Total load demand
West zone - Total load demand

<u>East and West</u>
Combined zone - Total load demand
Political
districts - Total load demand.

3.2 <u>Different techniques of forecasting</u>:-

There are many types of forecasting techniques, ranging from quite simple mathematical routine to very sophisticated statistical models and subjective human judgment methods. These techniques may be further classified as deterministic, probabilistic or stochastic. The broad categories are:

3.2.1 Time series model or extrapolation technique:

Trend extrapolation is one of the best and simplest known technique of forecasting. The basic assumption, no matter how sophisticated technique we apply in extrapolation, is that pattern will reoccur over time, which is more likely to be valid in short term. Thus this technique is likely to be most appropriate in short term forecasting. When we get forecast simply by evaluating the trend curve function at the desired d future point , this is known as deterministic extrapolation, since no attempt is made to account for random errors in the data or in the analytical model. If uncertainty or extrapolated results is to be quantified using statistical entitie , variance, standard deviation etc., then the basic technique becomes probabilistic extrapolation. The use of stochastic models. (3) to generate a forecast from random inputs derived from historical data is very common now a days.

The most common curve fitting technique for finding coefficients and exponents of a function in a given forecast in the method of least squares.

3.2.2 Causal model or correlation technique:-

This technique involves an equation which expresses relationship between forecast to a number of independent variables as that of economic and demographic factors. Thus this model expresses mathematically the inherent causal relationship and thus forces the forecaster to understand clearly the inter-relationship between load growth patterns and other measurable factors. The disadvantage here is the need to forecast demographic and economic factors. Typical such factors are population, employment, building permits, appliance saturation, business indicators weather data (temperature, humidity, pressure, wind velocity etc) and the like are used in correlation technique.

3.2.3 Qualitative forecasts:-

Qualitative forecasts are made when there is little or no relevant quantitative data available on which to work. In these cases of little or no data, human judgement of various factors which might have an impact on load growth patterns, is required.

3.2.4 Comparison of MW and MWh demand Technique:

Over the past few years some well defined analytical methods are coming up. This technique of getting total forecast by adding forecasted nonweather sensitive (NWS) and weather sensitive, is the recent technique. This technique permits weather conditions to be included with ease in forecast. Basically this approach includes the following steps:-

i. Determine seasonal weather load model.
ii. Separate historical weather sensitive and non weather sensitive components of peak demand using weather load model.
iii. Forecast mean and variance of NWS components of demand.
iv. Extrapolate weather load model and forecast mean and variance of weather sensitive component.
v. Determine mean, variance and density function of total required forecast.

To use this forecasting technique a data base of at least 12 years is recommended.(5)

3.3 Compilation and analysis of field data:-

Linear, non-linear and econometric models have been used for analysing the collected data and for making demand estimates.

3.3.7 Historical Analysis: Linear Model.

The time series data on power since 1973 was analysed under the linear regression model and the resulting regression equations are as follows:-

Maximum load equations:-

(1) For Eastern Region

$$Y = 138.0883 + 30.2415X. \qquad (3.3.1)$$

(2) For Western Region

$$Y = 52.7645 + 7.7828X \qquad (3.3.2)$$

(3) For Bangladesh as a whole

$$Y = 190.8528 + 38.0243X \qquad (3.3.3)$$

where Y indicates Maximum load demand in MW and X indicates year count starting with 1973 = 1. We see that the results of extrapolating these equations upto the year 1999-2000 ~~are shown in table 3.3.~~ which follows growth in maximum load is 7.7% simple and 4.7% compound per year.

3.3.8 Historical Analysis: Non-Linear Model

(1) East Region:- Second degree least square equation fits best in case of power demand historical data for East region from 1973-74 to 1978-79. The second degree polynomical equation is -

$Y = a + b x + c x^2$

[illegible] maximum demand equation:-

$Y = 162.438614 + 11.087539\ X + 2.034045\ X^2$ (3.3.4)

(where X stands for year count starting with 1 - for 1973-74 and Y indicates maximum load demand in MW)

~~Results including forecasts by this equation are given in table 3.3.2~~

(2) West Region:-

Power historical data for west region from 1973-74 to 1978-79 do not often follow regular pattern. However in this case also the second degree curve fits fairly well. The power equation is

$Y = 52.701691 + 4.538615X + 0.717190\ X^2.$ ... (3.3.5)

~~The results obtained including the forecasts are given in table 3.3.3~~

(3) Bangladesh as a whole:

Second degree curves fit very well for the historical data on power demand for the period from 1973-74 to 1978-79. The maximum load equation for Bangladesh as whole is

$Y = 215.1403 + 15.626154X + 2.751235\underset{X}{X}.$ 3.3.6

(For the above three power equations/stands for year count starting with 1 for 1973-74 and Y indicate maximum load demand in MW)

~~The results obtained including the forecasts are given in table 3.3.4~~

3.3.3 Evaluation of Regression Models:-

The linear regression model of power demands do not fit the data for 1973-74 to 1978-79 well and thus the actual trend is not reflected by the models. This results in very low forecasts.

The non-linear trend present in the data on power demand is found to be best reflected by a non-linear model in the form of a quadratic equation.

The non-linear curve fitting analysis was done for East, West and Bangladesh total data separately. The second degree model is found to fit best in case of the East region. The West region data for the same period do not follow any definite trend and as a result the second degree model fits with a high degree of error. The total Bangladesh data being the some of the two regions, the second degree model is found to fit best as the influence of the West region data, whose absolute magnitude is much smaller compared to that of the East region, is smoothed out.

3.4 Corrected load demand forecast:-

The forecasted maximum demand beyond 1980 should be corrected by providing higher rate of growth of power demand due to the following regions:

a. From 1980 onward the rate of growth of demand has increased beyond the forecasted rate.

(based on data - 1975-80).

(b) That the forecasting Power demand by forecasting energy and Load factor donot tally with the forecasted power demand which is forecasted separately. Forecasted power demand separately gives lower value which results too high load factor. [For example the energy demand for year 1999 - 2000 is found to be 19426GWH and power 2643MW results load factor of 0.84 which is too high. The figure should be 4718MW with a load factor 0.47 which is expected].

Now the year wise forecasted load demand by adding the REB's demand forecast which is based upon the presidential directives to that of the year wise estimated growth of Bangladesh Power Development Board loads (Urban and sectoral demands included 11 percent growth for East zone and 16 percent growth for that of the West zone till 1985) are as shown in the table below:

The Year-wise Forecasted Demands

Fiscal year	Maximum Demand
1979 - 80	504
1980 - 81	559
1981 - 82	648
1982 - 83	815
1983 - 84	1115
1984 - 85	1482

Which assumed a faster growth rate i.e. 16 percent in the West zone upto 1985, because of the fact that the area suffered suppressed ~~deamdn~~ demand, for both generation shortage and inadequate system expansion facilities.

Due to resource constraint, and also to avoid over-investment an average growth rate of 16 percent upto 1985 has been considered. This has been/allow Bangladesh Power Development Board to met growing demand without risking too much financial burdan as a result of unwanted expansion of the system or due to supply gap within the resource allocated. For Bangladesh Power Development Board's own system demand, excluding Rural Electrification Board, an average growth rate of 12 percent, has been assumed. This load is after keeping in view all sectoral loads, excluding rural loads to be served by Rural Electrification Board. The rural load has been considered as per Rural Electrification Board. So, it is estimated that with the resources available for the power sector, a maximum of 1035 MW can be met at 1984-85, (at the end of second five year plan). It is estimated by Planning Commission that the zone wise share of Bangladesh Power Development Board's own peak demand will be two-third for East and one-third for west by 1985 as compared to existing share of three-fourth for East and one-quarter for West zone. Beyond 1984-85, a uniform annual growth rate of 9 percent has been assumed for Urban peak demand and 12 percent average growth rate for the whole system peak demand and projected upto 1980-90. The details of year wise Bangladesh Power Development Board, Bangladesh Rural Electrification Board and system and also zone-wise peak demands have been laid out in table 3.4.1.

Due to shortage of generating capacity specially in the Western zone, the recorded maximum demand of 436 MW in 1978-79 does not included the amount of power which Bangladesh Power Development Board could have supplied to its consumers, but could not do so, due to peak load restrictions. In the year 1979-80, a maximum demand of 449 MW(East 333MW and West 108MW, Isolated 8MW) was recorded. A demand of 486MW, including suppressed demand for the year 1979-80 has been considered while projecting the future demand.

Considering all of the above and also judging the proprotion of peak demand for the whole country, the following growth rates have been considered.

Period	PDB(Urban System)		Whole country
	East Zone	West Zone	
1980 - 85	11%	16%	16%
1985 - 90	9%	9%	12%
1990 - 95	8%	8%	11%
1995 - 2000	7%	7%	10%

TABLE - 3.4.1

ZONE WISE GROWTH OF PEAK DEMAND

CAL AR	EAST ZONE		WEST ZONE		WHOLE COUNTRY				
	PDB	REB	PDB	REB	PDB	% increase over previous yr.	REB	TOTAL	% in re
-79	331	-	105	-	436	-	-	436	-
-80	334	5	123	4	447	9.40	9	486	11.
-81	383	9	142	8	525	-	17	542	11.
-82	421	17	167	14	588	12.00	31	619	14.
-83	460	33	198	27	658	12.00	60	718	16.
-84	503	61	234	51	737	12.00	112	849	18.
-85	550	113	275	97	825	12.00	210	1035	22.
-90	846	322	423	233	1269	9.00	555	1824	12.
-95	1243	725	622	483	1864	8.00	1219	3074	11.
-200	1743	1426	872	908	2614	7.00	2337	4951	10.

District Forecasts

Power demand forecasts have been made up to district level . Urban and rural classification is also made for each district. The computer program of year wise and also district wise forecasted peak demands of Bangladesh have been laid in Appendix - B.1 and B.2.

CHAPTER - 4

OPTIMUM DESIGN OF DISTRIBUTION SYSTEM

INTRODUCTION

4.1. Cost of High Voltage Branch Loops.

4.2. Cost of Distribution Sub-station.

4.3. Cost of Low Voltage Cables.

4.4. Optimised Design of Distribution System.

  4.4.1. Calculation of Optimised Total Cost.

  4.4.2. Calculation of Optimum Sub-station Area.

  4.4.3. Calculation of Optimum Sub-station Load and Cross-section of Conductor.

4.5. Discussion of the Results of Optimised Design Considering other Factors.

4.6. Integration of Existing System in the Optimised Design.

CHAPTER - 4

OPTIMUM DESIGN OF DISTRIBUTION SYSTEM

INTRODUCTION

After properly forecasting the load demand of an area the next important task is the optimum design of distribution system planning properly for ensuring declared distribution voltage and frequency at all load points, reliable and economic demand supply with a certain (6%) maximum allowable voltage drop.

Optimum design is that design which offers minimum cost satisfying its all the constraints. Optimum design of distribution system is that design which gives the minimum cost per KVA distribution, satisfying all the conditions which mentioned above like ensuring declared proper distribution voltage and frequency at all load points, reliable demand supply with a certain maximum allowable (6%) voltage drop.

The factors affecting the optimum design of distribution network for rural distribution are different from those for urban distribution. In residential urban areas the consumers are concentrated in smaller areas and the load density is much greater for which laying of distribution networks in an optimum manner is important. However, the factors affecting the optimum cost of distribution system are many, therefore, no direct precise formulae are available for optimum design of distribution system.

One method would be to find the optimum size of area of sub-station for minimum cost after calculating the factor 'b'(by which the area change to get optimum cost). From which we can also find the optimum sub-station load, knowing the load density, the optimum number of sub-station and finally the optimum size of conductor assuming a certain maximum allowable voltage drop (6%). From this method considering Jessore Sadar sub-division distribution system I have calculated the above optimised variable factors from which a design Engineer can select easily the number of sub-stations with its rating according to its existing load demand in the existing area with optimum conductor size for minimum cost. With the help of this optimum design of distribution system, design Engineer can also integrate the number and size of additional distribution sub-station required to meet the increased load demand with the desired expansion of the area by expending minimum amount of additional cost(i.e. optimum expansion can also be made).

There is more than one approach to carryout such design. One approach is discussed here. Kelvins Law assumes that the fixed cost of sub-station etc. are negligible. If other costs are taken into consideration then the cost equation is modified. The costs to be considered are:-

1. Cost of high voltage branch loops.
2. Cost of distribution sub-station.
3. Cost of low voltage cable.

Considering Jessore Sadar sub-station distribution system the above components of cost are as follows:

4.1. Cost of 11 KV High Voltage Branch Loops

The high voltage feeders are laid along certain paths for optimum transmission of power from generation station to intermediate load centre(ILC) and branch loops are provided to the distribution sub-stations from these lines. For the above mentioned Jessore Sadar Power distribution system the ILC i.e. the 33/11 KV sub-station is at Chittra from which distribution sub-stations are at an average distance of 1.5 Km. Cost of 11 KV high voltage branch loops depends on the distance between the through going feeders and KVA rating of each distribution sub-station. Let the cost of an average branch feeder be 'U' Taka which is the sum of its constant and variable components.

Calculation of average Cost of 11 KV High Voltage Branch Loops for Each Distribution Sub-station.

If we plot the cost (Taka in lacs) per Km. of 11 KV High Voltage Cable in y axis corresponding to different values of cable cross-section in sq. mm. (Data from table 4.1.a) in x axis, we can have the curves like in fig. 4.1.a. Now combining this curve and data from table 4.1.b, another curve can be drawn like in fig. 4.1.b taking different values of cable cost (Taka in lacs) per Km. in y axis with corresponding different values of its KVA rating.

From the fig. 4.1.b, the fixed part (U) of high voltage cable cost is the length GH and can be found 1.7×10^5 Taka/Km. For the average of 1.5 Km. high voltage feeder length (l_1) for each distribution sub-station the fixed part of high voltage cable cost,

$$U_1 = U \times l_1 = 1.7 \times 10^5 \times 1.5$$

$$= 2.55 \times 10^5 \text{ Taka} \qquad \ldots\ldots(4.1.1)$$

From the same figure the variable part (U_2) of high voltage cable cost which varies with the variation of cable rating, is the slope of the curve HJ, which can be calculated as:

TABLE 4.1 a

Data for Fig. 4.1 a. (supplied by U.P.State Electricity Board)

High Voltage Cable	Cost per Km.(Lakh in lacs)
11 KV 3 core 400 Sq.mm.	9.2
11 KV 3 core 185 Sq.mm.	5.0
11 KV 3 core 120 Sq.mm.	4.0
11 K.V. 3 core 70 Sq.mm.	3.3
11 KV 3 core 50 Sq.mm.	2.7

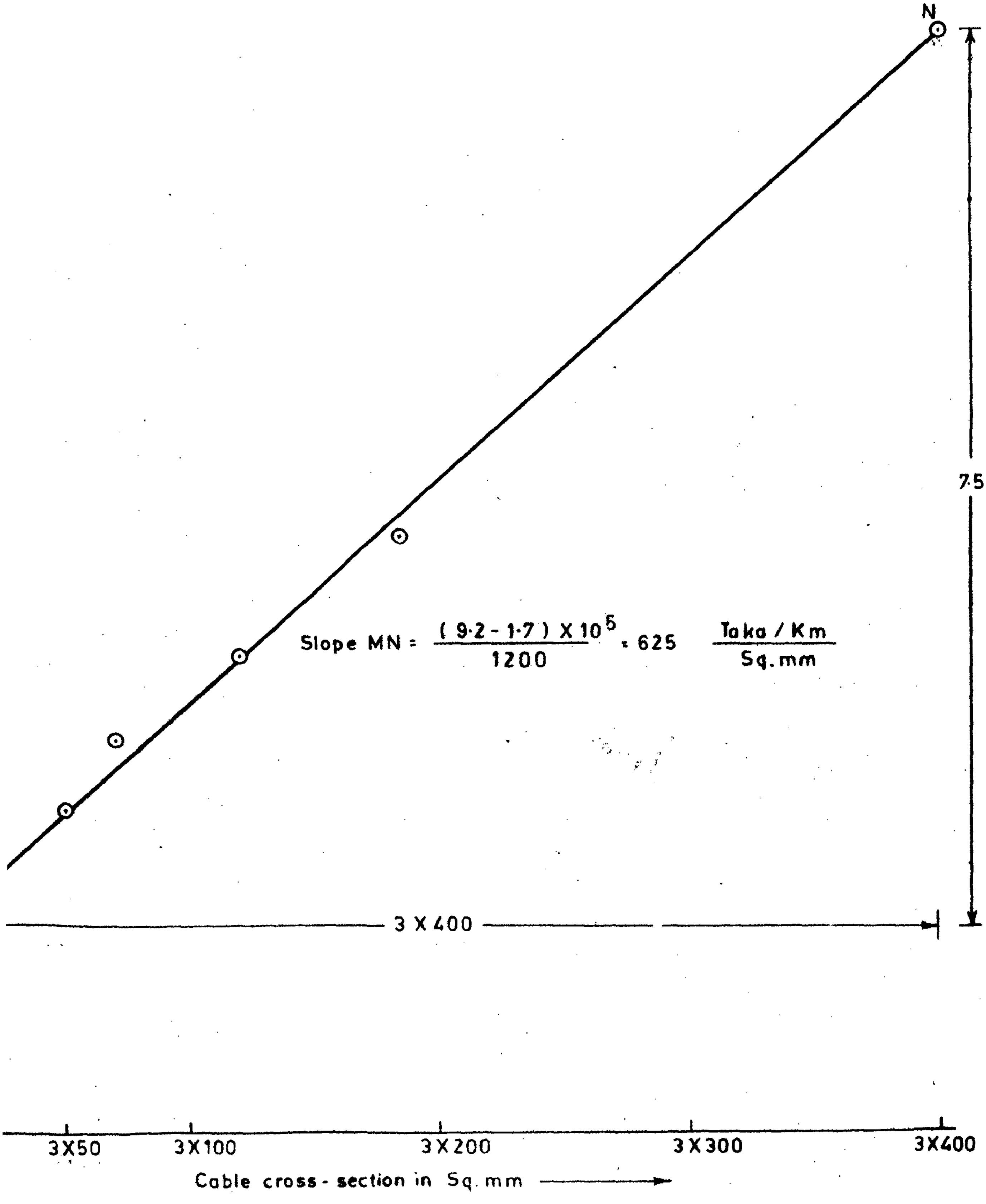
TABLE 4.1 b

Data for Fig. 4.1b.

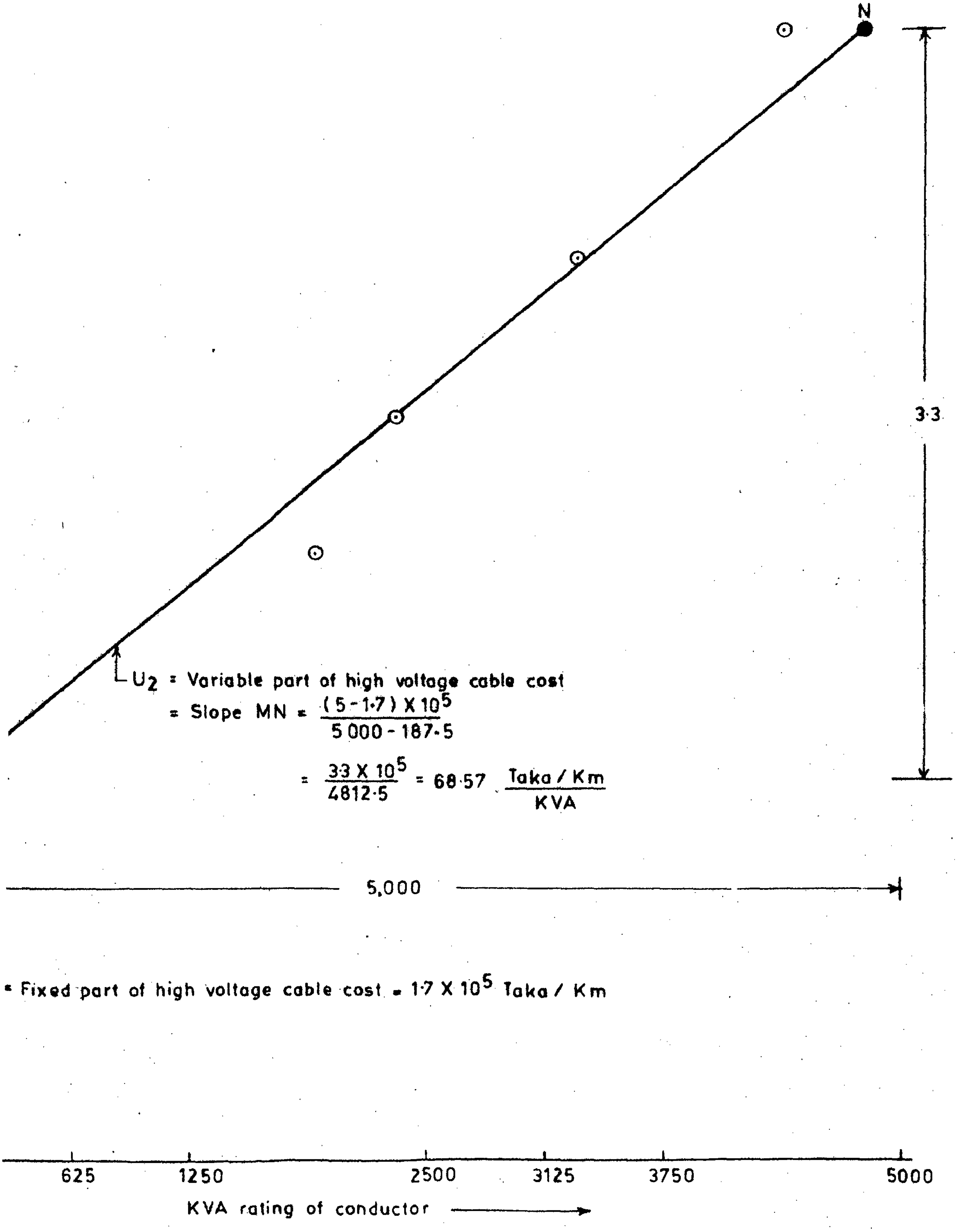
Electrical Characteristic of Aluminium Conductor 11 KV Paper Insulated Cable (Maximum conductor Temp 65°C)

(Ref- Electricity distribution Manual - by C.P.Agrawal

No. of cores & Cross-sectional area in Sq.mm.	Current rating	KVA rating of conductor	Cost for 3 core (Lakh in lacs)
3x25 = 75	68	1295.58	
3x35 = 105	80	1524.204	
3x50 = 150	100	1905.3	2.7
3x70 = 210	125	2381.57	3.3
3x95 = 285	155	2953.146	
3x120= 360	175	3334.1978	4
3x150= 450	200	3810.5118	
3x185= 555	230	4382.1	5
3x225= 675	260	4953.6653	
3x240=720	275	5239.4537	7.3
3x300= 900	310	5906.2933	
3x400= 1200	340	7049.4468	9.2



) CHARACTERISTICS OF 11KV 3 CORE PAPER INSULATED ALUMINIUM CONDUCTOR (Cost Vs Cross-sectional area)



U_2 = Variable part of high voltage cable cost

$$= \text{Slope MN} = \frac{(5-1{\cdot}7)\times 10^5}{5000-187{\cdot}5}$$

$$= \frac{3{\cdot}3\times 10^5}{4812{\cdot}5} = 68{\cdot}57\ \frac{\text{Taka / Km}}{\text{KVA}}$$

= Fixed part of high voltage cable cost = $1{\cdot}7\times 10^5$ Taka / Km

) CHARACTERISTICS OF 11KV 3 CORE PAPER INSULATED ALUMINIUM CONDUCTOR (Cost Vs KVA rating)

$$U_2 = \frac{(5 - 107) \times 10^5}{5000 - 187.5} = \frac{3.3 \times 10^5}{4812.5}$$

$$= 68.57 \ \frac{\text{Taka/Km.}}{\text{KVA}} \qquad \ldots\ldots\ldots(4.1.2)$$

For the average distance of 1.5 Km. of 11 KV high voltage cable from ILC to distribution sub-station , the value of

$$U_2 = 68.57 \times 1.5 = 102.86 \text{ Taka/KVA} \ \ldots\ldots(4.1.3)$$

Now the total cost of high voltage branch loops per KVA which depends on the distance between through going feeder and KVA rating(N) of distribution sub-station is the sum of its constant and variable parts of high voltage cable cost for each distribution sub-station,

$$U = U_1 + U_2 \qquad \ldots\ldots\ldots(4.1.4)$$

$$= \left(\frac{2.55 \times 10^5}{N} + 102.86 \right) \text{Taka/KVA} \ \ldots\ldots(4.1.5)$$

4.2 Cost of Distribution Sub-station

The total cost of distribution sub-station consists of a fixed part which includes cost of buildings, switchgear and a small part of transformer cost and let this part of cost be 'B'.- Taka. The second part depends on the sub-station output KVA and consists of a large part of the cost of transformer. Let this part of cost be 'A' Taka per KVA.

Calculation of Fixed Part 'B' and Variable Part 'A' for Each Distribution Sub-station.

If we plote the estimated capital cost in Taka of 11/0.415 KV distribution sub-station versus transformer size in KVA as supplied by Bangladesh Power Development Board shown in table 4.2, we will get the curve like in fig. 4.2. From this figure the line MN which is designated as 'B' is the cost of a fixed part which includes cost of buildings, switchgear and a small part of transformer cost. From the same fig. the value of B is found to be,

$$B = 60{,}000 \text{ Taka} \qquad \ldots\ldots.(4.2.1)$$

The second part which is shown in the same figure by the slope of the curve and which is designated by 'A' depends on the size of the transformer i.e. depends on the output KVA of the transformer. From the fig. 5.2. the slope of the curve ,

$$a = \text{slope} = \frac{(1.755 - 0.60) \times 10^5}{500}$$

$$= 231 \text{ Taka/KVA} \qquad \ldots\ldots.(4.2.2)$$

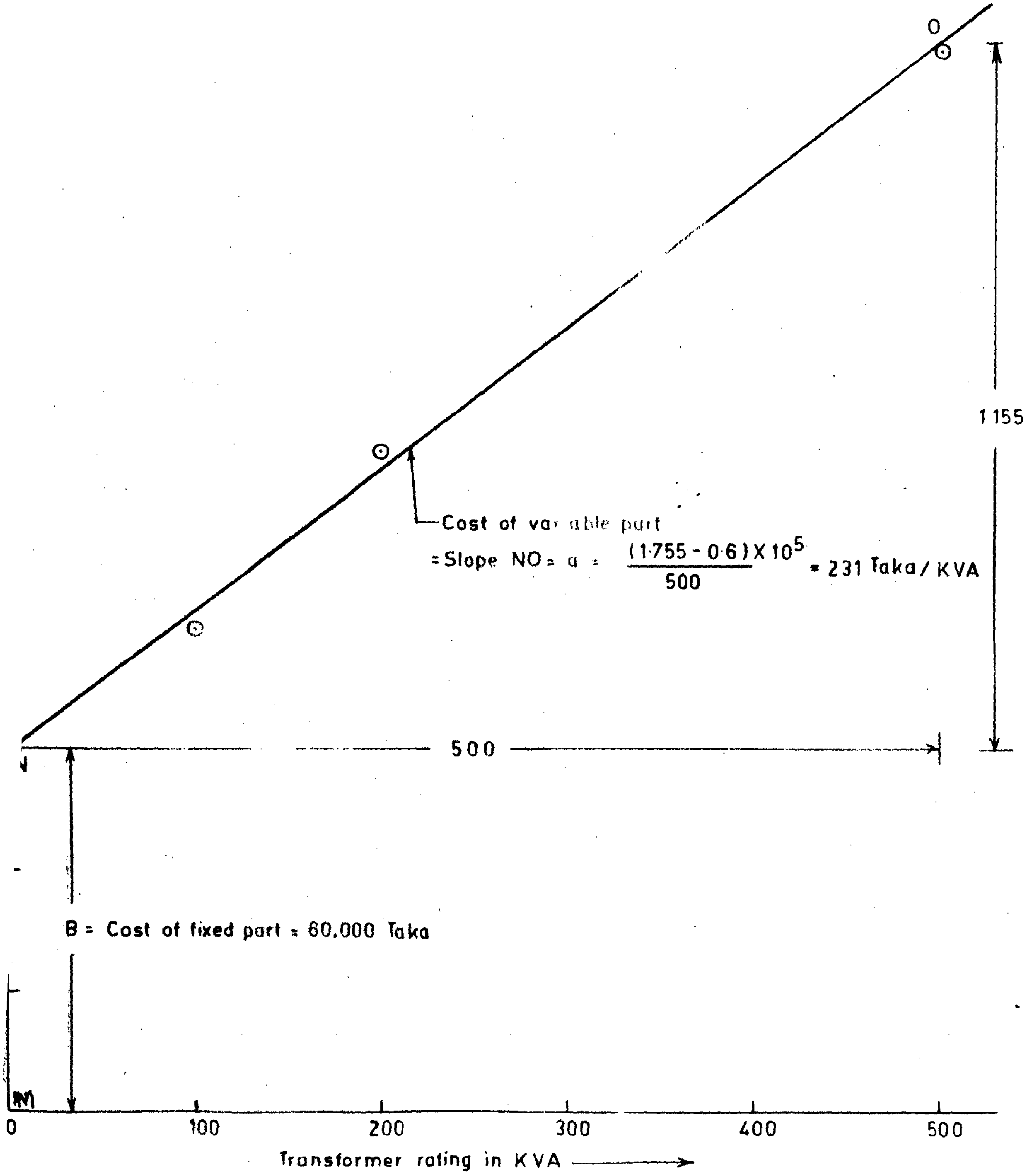
4.3 Cost of Low Voltage Cables

For the low voltage cable the constant cost being the cost of excavation, laying the cable and a small part of the cable. This part depends on the total length

TABLE 4.2

Supplied by the Bangladesh Power Development Board (

Sl. No.	Description	Quantity	TAKA IN LACKS Foreign exchange	 Local
5.	11/0.415 K.V. S/S			
	(a) 500 KVA and spares.	10nos.	15.91	1.50
	(b) 200 KVA and spares	225nos.	227.98	18.00
	(c) 100 KVA and spares.	285 nos.	206.51	21.37



·2 CHARACTERISTICS OF 11/0·415 KV SUB- STATION (Cost Vs KVA rating) of the route covered by the cable and it may be assumed proportional to the size of the cable i.e. it is the cost of cable conductivity. Let 'd' be the constant part of cable cost per KVA and 'c' be the cost per KVA of the variable part.

Calculation of 'd' and 'c' for Each Distribution Sub-station

If we plot the cost(Taka) per meter of low voltage cable on y axis corresponding to different values of cable cross-section in sq. mm. in x axis(Data from table 4.3.a). We can have the curve like in fig. 4.3.a. Again by plotting the cost(Taka) per meter of low voltage cable alongwith the cost of excavation - and laying the cable in y axis corresponding to different values of cable cross-section in sq. mm. in x axis(Data from Table 4.3.a.). We can get the upper curve in fig. 4.3.a The vertical distance between these two curves(upper and lower one) which is constant throughout is the cost of excavation and laying the cable only as designated by d_2.

From the same figure the constant part of the cable cost is shown by d_1, where as the cost of excavation and laying the cable which is also a constant cost is shown by d_2. Now the total constant cost being the cost of

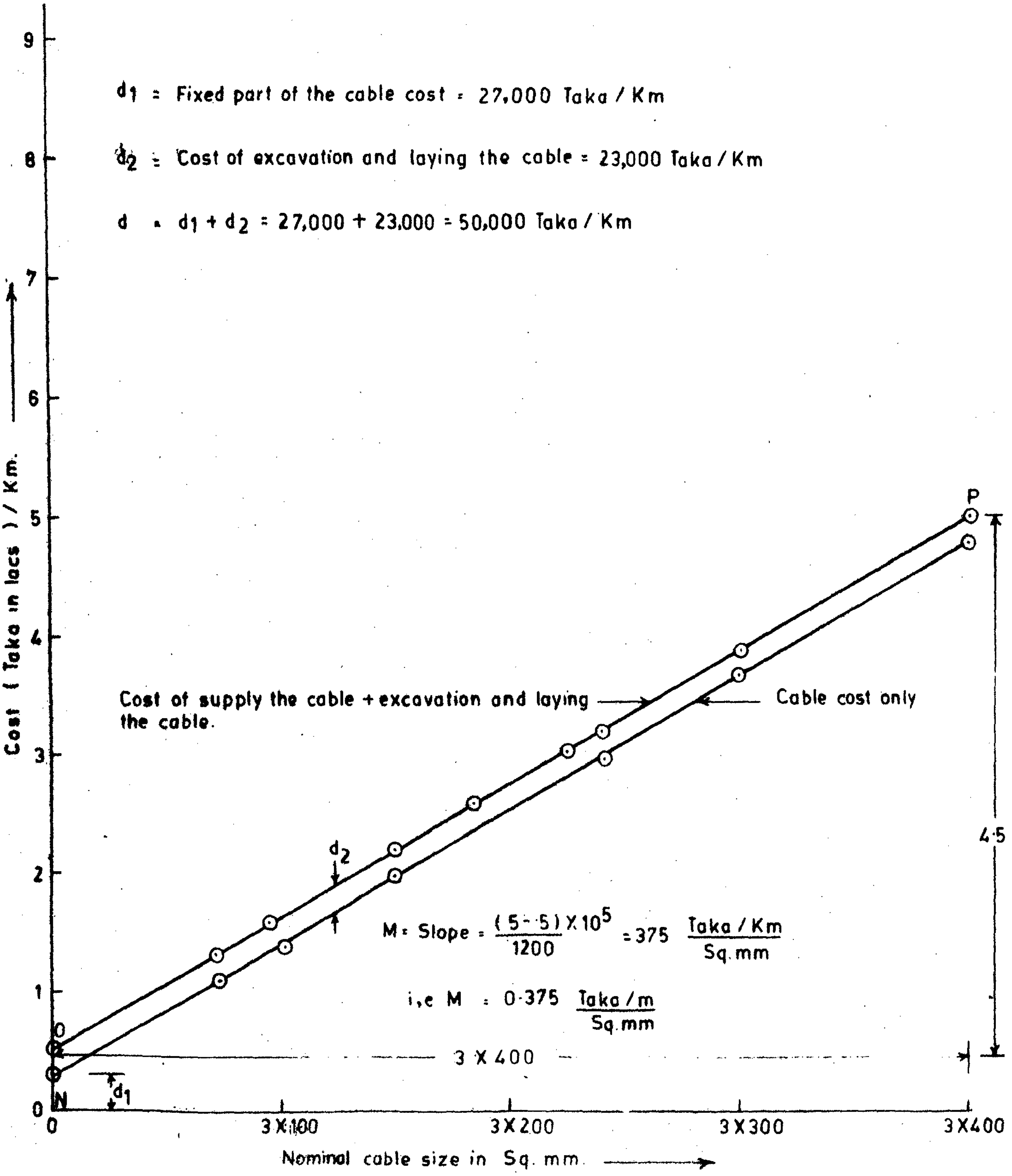


Fig.4.3(a) CHARACTERISTICS OF LOW VOLTAGE (UPTO 1100 V) ALUMINIUM CONDUCT
PVC INSULATED CABLES (Cost Vs Cross-sectional area)

Table 4.3.a

(Supplied by the Uttar Pradesh/State Electricity Board)

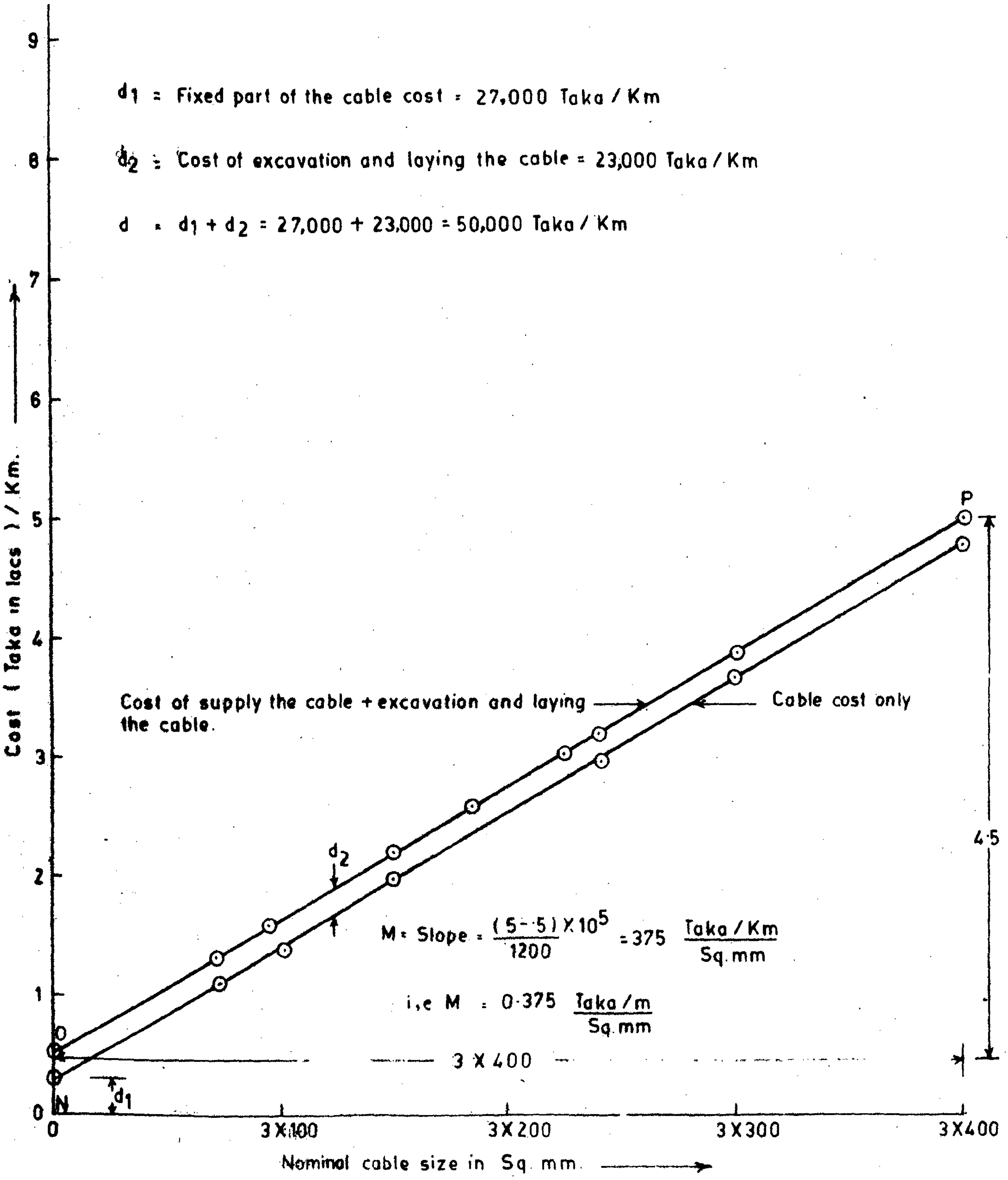
LOW VOLTAGE CABLE: (a) Cable Cost Only

Nominal Conductor size in Sq.mm.	Cost(Taka)/meter
240	300
150	190
70	110

(b) Cost of supply the cable + excavation and laying the cable (P.W.D. estimate book supplied by Roorkee University electrical construction division)

5

Nominal Conductor size in Sq.mm.	Cost(Taka)/meter
400	500
300	384
240	320
225	300
185	260
150	220
120	190
95	160
70	130



d_1 = Fixed part of the cable cost = 27,000 Taka / Km

d_2 = Cost of excavation and laying the cable = 23,000 Taka / Km

$d = d_1 + d_2 = 27{,}000 + 23{,}000 = 50{,}000$ Taka / Km

$$M = \text{Slope} = \frac{(5-\cdot5)\times10^5}{1200} = 375\ \frac{\text{Taka / Km}}{\text{Sq.mm}}$$

$$\text{i,e } M = 0{\cdot}375\ \frac{\text{Taka / m}}{\text{Sq.mm}}$$

Fig. 4·3 (a) CHARACTERISTICS OF LOW VOLTAGE (UPTO 1100 V) ALUMINIUM CONDUCT
P.V.C. INSULATED CABLES. (Cost Vs Cross-sectional area)

excavation, laying the cable and a small part of the cable which is the sum of the above two component parts of constant cost,

i.e. d = Total constant cost

= Constant part of cable cost + Cost of excavation and laying.

$= d_1 + d_2$ ......(4.3.1)

= 27,000 + 23,000

= 50,000 Taka/Km.

As it depends on the total length of the route covered by the cable and the total length of the route covered by the cable for each distribution sub-station is assumed proportional to the size of the cable then from the above (4.3.1) equation, d = 50,000 Taka/KVA.

For the above mentioned area if the load is N KVA, for each distribution sub-station then the total constant part of cable cost,

d = 50,000 Taka/KVA = 50,000 N Taka.

Now plotting the conductor cost per meter in Taka versus the KVA rating of the conductor (Data from table 4.3.b) the curve like fig. 4.3.b. can be found out. The cost per meter per KVA of the variable part of the conductor is

TABLE 4.1.b Current Ratings

Aluminium Conductot P.V.C. Insulated Armoured and Served Cables For Working Voltage Upto 1100 Volts

(Maximum Conductor Temperature 70°C)

(Ref: -INCAB - Cables and Tables 7th Revised Edition,
Published by "The Indian Cable Company Limited".

Nominal Cross-Sectional Area of conductor in Sq.mm.	Current rating I	KVA rating of conductor $\sqrt{3} \times V_L \times I$ (415)	Cost i per meter
1.5	13	9.344141	
2.5	18	12.93842	
4	23	16.532425	
6	30	21.564033	
10	40	28.752043	
16	51	36.658855	
25	70	50.316076	
35	86	61.816893	
50	105	75.474114	
70	130	93.444141	130
95	155	111.41417	160
120	180	129.3842	190
150	205	147.354222	220
185	240	172.51226	260
225	265	190.48229	300
240	280	201.2643	320
300	315	226.42234	364
400	375	269.55041	530
500	420	301.89646	
625	460	345.02442	

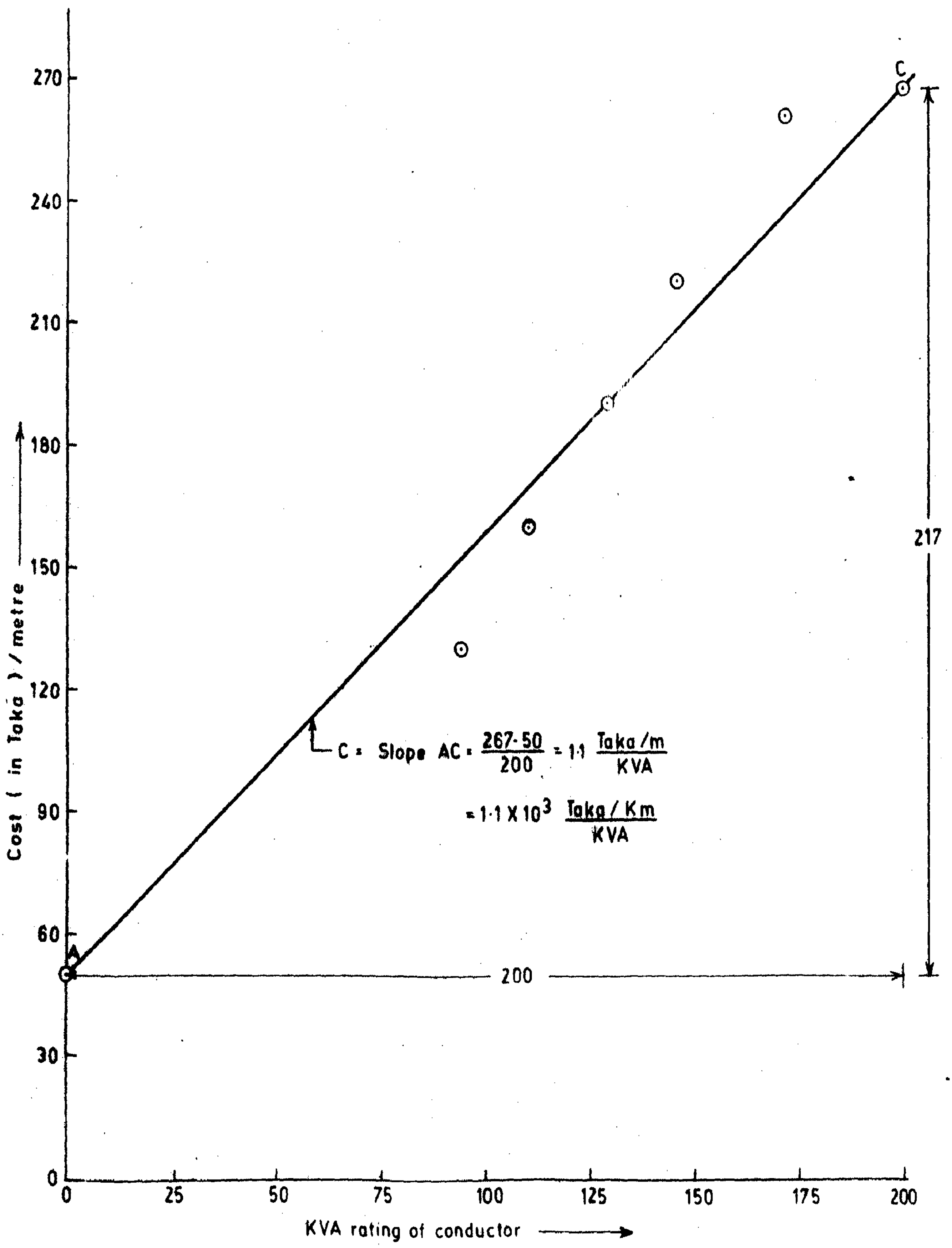


Fig.43(b) CHARACTERISTICS OF LOW VOLTAGE (UPTO 1100 V) ALUMINIUM CONDUCTOR PVC INSULATED CABLES. (Cost Vs KVA rating) the slope AC of the curve in fig. 4.3.b. The slope as calculated from the same figure,

$$\text{Slope} = c = \frac{267 - 50}{200} = 1.1 \ \frac{\text{Taka/m.}}{\text{KVA}} \quad \ldots\ldots(4.3.2)$$

The equivalent length(l_2) of the table meter for KVA for each distribution sub-station whose area is A(sq.m) will be,

$$l_2 = \sqrt{\frac{A}{\pi}} \ . \ \text{meter} \qquad \ldots\ldots(4.3.3)$$

So, the cost per KVA of the variable part of low voltage cables,

$$C = \frac{1.1 \ \text{Taka}}{\text{KVA}} \times l_2$$

$$= 1.1 \times l_2 \ \text{Taka/KVA}$$

From which, $C = 1.1 \times \sqrt{A/\pi}$ Taka/KVA. ....(4.3.4)

4.4 Optimised Design of Distribution System

In order to obtain optimised design of a distribution system, the following factors should be considered as in the following manner.

4.4.1 Calculation of Optimised Total Cost

Assume that the load in an area(sq.m) of a given size with the constant load density L (KVA/sq.m) is N KVA. If the dimensions of the area are changed by a factor 'b', then the load changes to bN. The variable part of the cable cost per KVA (as designated earlier by c) becomes b^2c. As a result the cost per KVA for the area having load b^2N is given by,

$$\text{Cost/KVA} = \left(\frac{U_1}{b^2N} + \frac{B}{b^2N} + U_2 + a + d + b^2c\right) \text{ Taka/KVA}$$

$$= \left\{\frac{(U_1 + B)}{b^2N} + U_2a + d + b^2c\right\} \text{ Taka/KVA} \qquad \ldots.(4.4.1)$$

To find size of the area for minimum cost,

$$\frac{d(\text{Cost})}{db} = \frac{d}{db}\left\{\left(\frac{U_1 + B}{b^2N}\right) + U_2 + a + d + b^2c\right\}$$

$$= \frac{-2(U_1 + b)}{b^3N} + 2bc = 0$$

which gives

$$\frac{U_1 + B}{b^3N} = bc \qquad \ldots..(4.4.2)$$

From which we can get the dimensions of the area which are changed for minimum cost by a factor , 'b',

$$= \left(\frac{U_1 + B}{NC}\right)^{1/4} \qquad \ldots.(4.4.3)$$

Thus if the chosen area is such that $U_1+B = Nc$ then we see that $b = 1$. In that condition the optimum area is same as the chosen area; and the sum of fixed parts of the cost of sub-station and the network is equal to the variable part of the network cost. If Kelvin's law is now applied to this system the annual cost of losses in the conductor should equal the interest and depreciation charges on the cost which are related to conductor cost. It is seen that this cost is twice the cost of conductors which indicates that for optimum utilisation of conductors the current density in the conductor can be increased to higher levels. This may not be advisable, however, because of two reasons. Firstly, due to the reduced efficiency of the system for a given energy distributed on the system losses are more. The second is that the voltage drop for this cheaper system will be higher. As a result the size of the sub-station must be chosen on the basis of above criterion. But the conductor size may be selected on the basis of maximum permissible voltage drop and loss on the system.

Calculating the value of factor 'b' from equation(4.4.3) and then putting the value of factor 'b' in the eqn.(4.4.1), we can get the optimum cost per KVA. Finally, the total optimum cost in Lakhs for each distribution sub-station can be obtained by multiplying N. The KVA demand of each area to the cost per KVA which can be obtained from equn. (4.4.1) i.e. The total optimum cost in Lakhs for each distribution sub-station = $\frac{(U_1+B)}{b^2N}+U_2+a+d+b^2c)\times N$ Lakhs.

4.4.2 Calculation of Optimum Sub-Station area:-

Determination of NC:

The average cost of conductor is determined from the expression for voltage drop on the conductor. The load on conductor is dependent on several factors viz:-

i. Shape and size of area covered by the sub-station.
ii. Number of conductors and their routes.
iii. Load density in the area and its variation
iv. Out of balance load.
v. Position of sub-station in the area
vi. Tapering of conductors etc.

Neglecting voltage drop due to inductance, let the maximum allowable voltage drop from distribution sub-station to load point be D percent and phase voltage be E volts. Then to deliver 1 KVA of power from supply point to load with a conductor resistivity of ρ ohms/meter/sq.mm.

The distance from supply point to load is 'l_1' and neglecting the voltage drop due to inductance the value of nominal cross-section of conductor is given by

$$\text{Nominal cross section} = \frac{10^5 \rho\, l_1}{DE^2}\ \text{mm}^2. \quad \ldots.(4.4.5)$$

when the actual length of conductor is greater than l_1, let it be increased by a factor - 'Y' called the route factor. It's value can be found by taking the r.m.s. value of the ratios of indirect to direct distances from the sub-station to a suitable number of equally distributed load points on the network. Its value usually lies between 1.3 and 1.6. A second factor which increases voltage drop is unbalance factor which is due to unbalanced load as well as power factor. Let the voltage drop be increased by a factor 'q' due to this factor. Its suggested values are 1.4 to 1.8. If the cost of conductor is M Taka per meter sq.mm. cross-section, then the cost of conductor to deliver 1 KVA of power, from supply point to load will be,

Cost of conductor/KVA = M x $(l_1 Y)$ x Nominal cross-section x route factor x unbalance factor.

$$= M \times (l_1 Y) \times \frac{105 \times \rho\, q \times (l_1 Y)}{E^2 D} \Big/ \text{KVA}$$

$$= \frac{105\, \rho\, q\, M Y^2}{E^2 D} \times l_1^2 \Big/ \text{KVA}$$

$$= K\, l_1^2 \ \text{Taka/KVA} \qquad \ldots\ldots\ldots(4.4.6)$$

where may be treated as a constant and K being the value

$$K = \frac{10^5\,\rho_q\,MY^2}{E^2\,D}\ \text{. Taka}/m^2 \ldots\ldots \qquad (4.4.7)$$

If the load is assumed to be concentrated at same radius 'C' from the sub-station such that the cost of supplying load on this radius is same as cost of supplying the load over the given area then for the total load of 'M', KVA, the total cost of conductor will be

$$\text{Total cost} = Kl_1^{\,2} + Kl_2^{\,2} + Kl_3^{\,2} \ldots\ldots Kl_n^{\,2}$$

$$= \sum_{i=1}^{n} Kl_i^{\,2}$$

$$= K \times MC^2$$

$$\left(\text{where } MC^2 = \sum_{i=1}^{n} l_i^{\,2}\right.$$

$$KMC^2 = \sum_{i=1}^{n} Kl_i^{\,2} \ \ldots\ldots \qquad (4.4.8)$$

$$\text{or} \quad C^2 = \sum_{i=1}^{n} l_i^{\,2} / M.$$

Thus C is the r.m.s. distance from the sub-station of all load points and average cost per KVA is KC^2. In case of circular area of radius 'r' then the value of voltage drop calculation for uniformly distributed load is different.

$C = \frac{r}{\sqrt{2}}$. Usually the area shapes are not regular and value of C increases as the shape departs from the circle. A <u>shape factor</u>, 'S' is defined to take this effect into account. If C_r is the radius of gyration of an equivalent circle, the area shall be

$$A = \pi(\sqrt{2}\ C_r)^2 = 2\pi Cr^2 \quad ....(4.4.9)$$

the cost is given by $KWCr^2S$ or $KWAS/2\pi$

$$\text{Value of } S = \frac{\text{radius of gyration of given area}}{\text{radius of gyration of equivalent circle}} \quad ...(4.4.10)$$

which is between 1.05 to 1.23, for a square it is 1.05 and for a rectangle with 4:1 ratio of sides it is 2.228. If the load density is 'L' then the cost is $\frac{KLAAS}{2\pi} = \frac{KLA^2S}{2\pi}$

If the sub-station is not located at the centre of gravity, the cost is increased by the eccentricity factor 'C'. Thus we get the cost equation as,

$$KLA^2Sc / 2\pi$$

so, far it has been assumed that the voltage drop upto all load points is the same and is the maximum. In practice it is not so and only at the periphery points is the voltage drop maximum. Thus the best use of conductor can not be made and cost, therefore, increases. The factor of increase is approximately $\frac{4}{3}$. The factor due to diversity may be termed n. Its value is between 1.05 and 1.15. If the conductors are tapered then some reduction in cost can be expected. Let this factor be accounted by 't' where 't' has a value less than unity. The cost in view of the above factors, becomes cost of conductor $= \frac{4}{3} \times \frac{K\,L A^2 S_c t}{2\pi n} = \frac{2}{3\pi n} . K L A^2 S_c t$...(4.4.11)

since this must equal the fixed cost (U_1+D), then the optimum area A of an average network from the equation

$$\frac{2}{3} \times \frac{K L A^2 S_c t}{\pi n} = (U_1+D) \text{ is } A = \left[\frac{3\pi (U_1+B).n}{2 L S_c t} \cdot \frac{E^2 D}{10^5 \rho\, q N X^2}\right]^{\frac{1}{2}}$$

$$A = \left[\frac{3\pi E^2 D (U_1+B).n}{10^5 \times 2 \times L \times S_c t \times \rho\, q\, N X^2}\right]^{\frac{1}{2}}$$

$$A = \left[\frac{3\pi E^2 D (U_1+B).n}{10^5 \times 2 \times L \times S_c t \times \rho\, q N X^2}\right]^{\frac{1}{2}} \quad \text{Eq.n.} \qquad (4.4.12)$$

Considering the whole distribution system without tapering i.e. the value of t = 1 and of copper conductor whose ρ (resistivity) is 0.01724 ohm/m/mm^2. then putting the following standard values the value of optimum area for each distribution sub-station can be found out, knowing the other values like, U_1, D, N and L.

E = 230, D = 6.3,

s = 1.15

c = 1.8

n = 1.1

q = 1.6

X = 1.45

For the Jessore Sadar sub-division distribution system putting the following values which was found from different figures earlier the optimum area for each distribution sub-station can be fount out by knowing the load density (L) of that area which assumed to be constant for any specific period but it varies from time to time.

M = 0.375 Taka/m. Sq.m. (from fig.4.3.a)

$U_1 = 2.55 \times 10^5$ Taka (from fig. 4.1e and equation 4.1.1)

$D = 0.6 \times 10^5$ Taka (from fig. 4.2 and equation 4.2.1)

$Z = (U_1 + B)$ Taka

$= (2.55 + 0.6) \times 10^5 = 3.15 \times 10^5$ Taka.

4.4.3 Calculation of optimum sub-station load and cross-section of conductor:-

The optimum sub-station load can be obtained by multiplying optimum sub-station area in sq.m. (obtained from equation 4.4.12) with the load density (L) in KVA per Sq.m.

$= \left[(L)\ (A\ \text{optimum}) \right]$ KVA for L in KVA per Sq.m and area in sq.m.

$$= \left[\frac{3 \pi L^2 D\ (U_1 + B).n.L}{10^3 m2.\ \cot \theta\ g\ Y^2 N} \right]^{\frac{1}{3}} \text{KVA} \qquad (4.4.13)$$

Till now the conductivity cost or the variable cost of network is calculated by assuming that the load

If the conductor is tappered, the conductor cross-section is larger near the source and reduces it at the outer end.

4.5 Discussion of the results of Optimized Design considering other factors.

The above calculation was done with the assumption that the total length of the route covered by the low voltage cable is proportional to the size the cable. If we do not make this assumption i.e. neglecting this assumption but assuming first the constant cost of low voltage cable is zero without changing the variable cost i.e. without changing the slope of the curve in fig.4.3c. which will be passing through the origine, then the calculations will be as follows:-

1. Cost of 11 KV High Voltage Branch loops:

Fixed part of high voltage cable cost U' Taka per Km for the average length of l_1 will be U' l_1 taka Variable part of high voltage cable cost U_2 (Taka per Km. per KVA) with the average length of l_1 and with load demand of N KVA will be $U_2 N l_1$ (Taka) . Then the total cost (U) of high voltage branch loops is the sum of its constant and variable parts, i.e.

is concentrated at the radius of gyration of the area. To calculate the nominal cross-section of the cable it may be assumed that actual conductors are untapered and its average length is such that it can supply the load at the circumference of a circle of same area as the area supplied by the sub-station. The length (l) of such a cable is then

$$\pi l^2 = A \text{ Sq. meter.}$$

from which $l = \sqrt{\frac{A}{\pi}}$ meter

Then, from equation 5.4.11. we can have

$$\left(\frac{A}{\pi}\right)^{\frac{1}{2}} \times (\text{Total nominal cross-section}) \times N$$

$$= \frac{2K \cot A^2 L}{3\pi \times n}$$

which gives the cross-section $= \dfrac{2K\, A^{3/2} \cot\phi\, L}{3\pi^{\frac{1}{2}} .\, n N}$ .....(4.4.16)

Substituting the value of K and A(optimum) we get,

Optimum nominal section

$$= \frac{2\times 10^5 \rho\, q N^2}{L^2 D} \times \left[\frac{3\pi E^2 D(U_1+B).n}{10^5 \times 2 \times L \times \cot\phi\, q N^2}\right]^{\frac{1}{2}\times 3/2} \times \frac{\cot\phi\, L}{3\pi^{\frac{1}{2}}.n.N}$$

.....(4.4.15)

$$U = U' l_1 + U_2 N l_1 = (U' + U_2 N) l_1 \text{ Taka} \qquad (4.5.1)$$

2. Cost of Distribution sub-station:-

As before let the cost of fixed part which include cost of buildings, switchgear and a small part of transformer cost be 'D' Taka. The second part which is the variable part of cost depends on the output KVA of the transformer. Let this part be 'a' Taka per KVA. Then for N KVA load demand the total cost of distribution sub-station will be = D + aN Taka (4.5.2)

3. Cost of Low Voltage Cables:-

Neglecting the constant part of cable cost, the variable cost of low voltage cable 'c' be the cost per meter per KVA. If we consider the equivalent length of the low voltage cable per KVA be l_2, then cl_2 will be the cost per KVA of the variable part and for N KVA load demand $CN l_2$ Taka will be the cost of variable part of low voltage cable.

Now the total cost per KVA,

$$= \frac{(U' + U_2 N) l_1}{N} + \frac{D}{N} + \frac{aN}{N} + \frac{c N l_2}{N}$$

$$= \frac{U' l_1 + D}{N} + U_2 l_1 + a + c l_2 \qquad (4.5.2)$$

Now putting $N = L A$, where L = load density in KVA per Sq.m.

A = Area in sq.m.

then the total cost per KVA $\frac{U' l_1 D}{LA} + U_2 l_1 + a + c l_2$ ..

..(4.5.4)

If the dimensions of the area are changed by a factor 'b' then the load changes to $b^2 W$ i.e. $l\, b^2 A$.

The area changes to $b^2 A$.

and l_2 changes to $b\, l_2$. Again $\pi l_2^2 = A$, From which $l_2 = \sqrt{\frac{A}{\pi}}$, then the equation (4.5.4.) becomes -

$$\text{total cost per KVA} = \frac{U' l_1 + B}{L b^2 A} + U_2 l_1 + a + cb\sqrt{\frac{A}{\pi}} \quad \ldots(4.5.5)$$

$$\frac{d(\text{cost per KVA})}{db} = \frac{d}{db}\left(\frac{U' l_1 + B}{L b^2 A} + U_2 l_1 + a + cb\sqrt{A/\pi}\right)$$

~~.....(4.5.5)~~

Now differentiating both the sides of the equation 4.5.5 with respect to b and equating it to zero - to get the value of b which gives the minimum cost per KVA.

$$\frac{d\,\text{cost/KVA}}{db} = \frac{d}{db}\left[\left(\frac{U' l_1 + B}{L b^2 A}\right) + c\, b\sqrt{\frac{A}{\pi}}\right]$$

$$= -\frac{2(U' l_1 + B)}{L b^3 A} + c\sqrt{\frac{A}{\pi}} = 0$$

$$b^3 = \frac{2(U' l_1 + B)\sqrt{\pi}}{C L A A^{1/2}}$$ Putting $U_1 = U' l_1$

from which

$$b = \left(\frac{2\sqrt{\pi}\,(U_1 + D)}{c L A^{3/2}}\right)^{\frac{1}{3}} = \frac{\left[\frac{2\sqrt{\pi}\,(U_1 + B)}{CL}\right]^{\frac{1}{3}}}{A^{\frac{1}{2}}} \quad \ldots.(4.5.6)$$

Now, for $b = \sqrt{\frac{A_o}{A}}$, From which $(A_o)^{\frac{1}{2}}$ = (Optimum Area)$^{\frac{1}{2}}$

$$= \left[\frac{2\sqrt{\pi}\,(U_1+B)}{CL}\right]^{1/3}$$

i.e. $$A_o = \left[\frac{2\sqrt{\pi}\,(U_1+B)}{CL}\right]^{2/3} \quad \ldots\ldots (4.5.7)$$

Now from equation (4.5.5), to get optimum area. which gives minimum cost per KVA, we will have to differentiate both the sides of the equation 4.5.5 with respect to A and equating it to zero, i.e.

$$\frac{d(\text{cost}/KVA)}{dA} = \frac{d}{dA}\left[\frac{U_1+B}{lb^2A} + U_2 l_1 + a + c\,b\sqrt{\frac{A}{\pi}}\right]$$

$$= -\frac{U_1+B}{lb^2A^2} + \frac{1}{2}\,\frac{c\,b}{\sqrt{\pi A}} = 0$$

or $$\frac{2\sqrt{\pi}(U_1+B)}{l\,b^2 c\,b} = A^{\frac{3}{2}}$$, from which,

$$A = \frac{\left[\frac{2\sqrt{\pi}\,(U_1+B)}{cL}\right]^{2/3}}{b^2} \quad \ldots(4.5.8)$$

i.e. $$\text{Optimum Area} = A\,b^2 = A_o = \left[\frac{2\sqrt{\pi}\,(U_1+B)}{C\,L}\right]^{2/3} \quad \ldots(4.5.9)$$

Now considering an area where the load density is for example 1000 KVA/Km^2, the optimum area will be for particular value of $U_1 = 2.55 \times 10^5$ Taka and $B = 0.6 \times 10^5$ Taka and $c = 1.1 \;\frac{\text{Taka/m}}{\text{KVA}}$

which calculated earlier from figure 4.1.c , 4.2 , 4.3 c and equations 4.1.1, 4.2.1 and 4.3.2 for Jessore Sadar sub-division distribution system, from equation (4.5.7)

$$A_o = \left[\frac{2\sqrt{\pi}\ (2.55 + 0.6) \times 10^5\ \text{Tk/km}}{1.1 \times \frac{1000}{10^6} \times \frac{\text{Tk/km}}{\text{m} \times \text{KVA}} \times \frac{\text{KVA}}{\text{m}^2}}\right]^{2/3}$$

$$= (1.0151327\ \text{Km}^2)^{2/3} = 1.0100632$$

For the above distribution system if we consider the area like 0.25 km^2

0.5 km^2, 0.565619 km^2, 1 km^2, 1.076325 km^2, 2 km^2. and if we calculate the cost per KVA for the above corresponding areas, then plotting these cost per KVA against corresponding area we see from fig. 4.5.1 a. that the lowest value of x cost per KVA will occur when the area is 1.0100632 Km^2. From which we can conclude that the optimum value of area for the above mention distribution System from equation (4.5.7) will be ,

$$A_o = \left[\frac{2\sqrt{\pi}\ (U_1 + B)}{LC}\right]^{2/3}$$

in which the cost per KVA is minimum, above and below of which cost per KVA will increase. Different values of areas a-gainst corresponding cost per KVA for the above mentioned Jessore distribution system is shown in fig. 4.5.1a. in which M is the minimum cost/KVA corresponding to area 1.0100632 Km^2, above and below of which cost/KVA is more .

Similarly, if we consider for Urban areas for near future

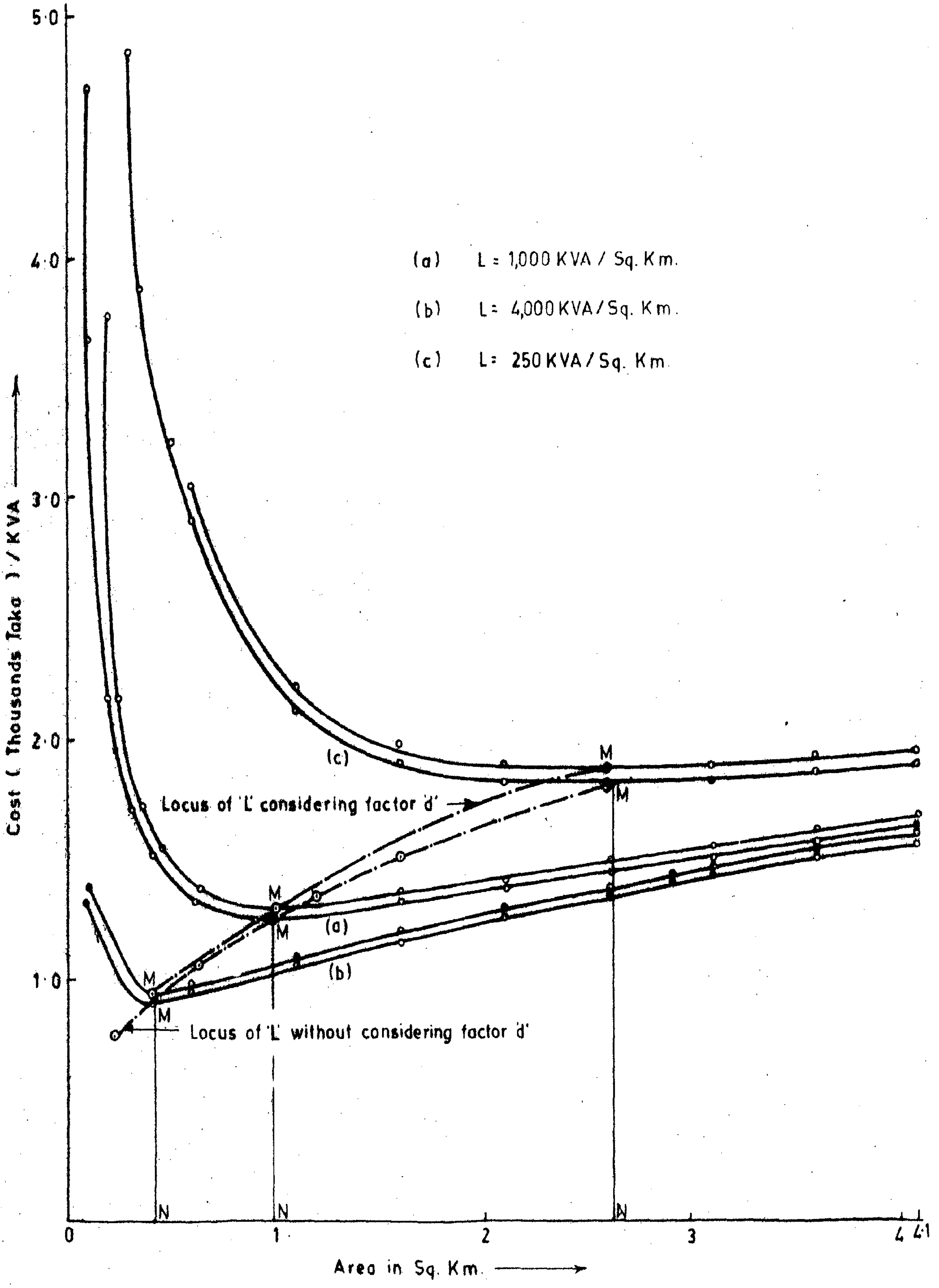


Fig. 4·5·1 SHOWS THE VARIATION OF COST PER KVA WITH THE VARIATION OF LOAD DENSITY L AND AREA A. (Without considering seqyn D) in Bangladesh where the load density will be much higher than present load density in rural area in Bangladesh, the cost per KVA versus area curve can be drawn like in fig. 4.5.1(b)

where $L = \frac{4,000\ KVA}{Km^2}$, $U_1 = 2.55 \times 10^5$ Taka

$B = 60,000$ Taka, $U_2 = 68.57\ \frac{Taka}{Km.KVA}$, $l_1 = 1.5$ Km, $a =$ 231 Taka/KVA

and $c = 1.10$ Taka/m.KVA

Taking the above values for rural area where load density generally much less, like $L = \frac{250\ KVA}{Km^2}$, the cost per KVA versus area curve can be dran as in fig. 4.5.1c. In all the figures the point M shows the minimum cost per KVA, corresponding to the point of optimum area N above and below of this area the cost per KVA will increase which also satisfies the optimum area equation (§ 4.5.6) in all the above three cases.

Now from the equation (4.5.5)

$$b = \left[\frac{2\sqrt{\pi}\ (U_1 + B)}{C\ L\ A^{3/2}}\right]^{\frac{1}{3}}$$

Putting the values as below

$$b = \left[\frac{2\sqrt{\pi}(2.55 + 0.6) \times 10^5}{1.10 \times \frac{1000}{10^6} \times (10^6)^{3/2}}\right]^{\frac{1}{3}} = 1005019$$

For the above distribution system if we consider the values of factor b, like 0.25, 0.5, 1005019 1, 1.5, and if we will calculate the cost per KVA for the above corresponding values of b, we will see that the lowest value of cost per KVA will occurs then the value of b is 1'005019 from which we can conclude that from equation (4.5.5), the optimum value of 'b' will be, $b = \left[\frac{2\sqrt{\pi}(U_1 + B)}{C\ L\ \Delta^{3/2}}\right]^{1/3}$ in which the cost per KVA is minimum, above and below of which cost per KVA will increase. Different values of b against corresponding cost per KVA is shown in fig. 4.5.1.C in which pt M is the minimum cost corresponding to the value of b is 1005019 above and below of which cost/KVA is more.

which is we will now consider the influence of the constant part of of low voltage cable cost which was designated as 'd' and was earlier assumed as negligible. Now if we want to include the constant part of loss voltage cable cost 'd' in total cost per KVA in all the above cases then a constant cost 'd' which strickly depends on the low voltage cable length will increase in all the values of total cost per KVA. The effect of ~~which~~ this on all the graphs in fig. 4.5.1 of total cost per KVA is to raise the graph of total cost per KVA vertically through a distance eq-ual to Take 'd' without any noticeable horizontal displacement of the point of minimum cost per KVA. This also illustrated in fig. 4.5.1. In all the upper curves in fig. 4.5.1 (a), (b) and (c) are shown the effect of 'd' in which the cost

KVA calculated including 'd' and cost/KVA shows without any noticeable horizontal displacement. It follows from this that the constant part of low voltage cable cost 'd' does not have any effect on the values of 'b' and area (A_o) which gives the minimum value of total cost per KVA

Considering factors s (shape factor), e (eccentricity factor), q (unbalance factor) Y(route factor), the equation 4.5.4. for cost per KVA will be modified as below,

$$\text{Cost/KVA} = \frac{(U_1+B)}{L\,A} + U_2\,l_1 + a + c'l' \qquad 4.5.8$$

and also considering the factor 'd' the cost per KVA equation will be as follows,

$$\text{cost/KVA} = \frac{(U_1+D)}{L\,A} + U_2 l_1 + a + c'\,l' + d'\,l' \quad \ldots\ 4.5.9$$

where, $l' = l \times sey = \sqrt{\frac{A}{\pi}} \times 1.15 \times 1.2 \times 1.45$

$c' = c_q = c \times 1.6$

$c'l' = c\,l \times 1.15 \times 1.2 \times 1.45 \times 1.6\ 1\ 1.1 \quad \times 3.202 \times$

$\sqrt{A/\pi} = c_1 l$

$c_1 = c \times 3.202$

$d' = d_q = 1.6 \times d$

$\therefore d'l' = d\,l \times 1.15 \times 1.2 \times 1.45 \times 1.6 = 3.202\, d\,l$

As before if we want to get optimum area which will give minimum cost per KVA for this condition we will have to differentiate both the sides of the equation 4.5.7 with respect to area A and equating to zero, will give the value of optimum area,

$$A_o = \left[\frac{2\sqrt{n}\ (U_1 + B)}{L\ C \times 3.202}\right]^{2/3} \quad \ldots\ldots(4.5.10)$$

From equation 4.5.8, 4.5.9 and 4.5.10 for different values of load density (L), if we plot cost in thousands Taka per KVA versus area in sq.km. we will get curves like in figure 4.5.2 . In the figure three sets of curves are there in which upper curves are shown considering 'd' where as lower curves are with out considering the factor 'd' . In all the curves M points are the optimum area point corresponding to minimum cost KVA which satisfies all the above equations.

Similar way if we consider the factor 'n' due to diversity along with considering all other factors above (Seqy). The equation 4.5.8, for cost per KVA will be modified as below,

$$\text{Cost/KVA} = \frac{U_1 + B}{L\ A} + \frac{U_2\, l_1}{n} + \frac{a}{n} + c'\, l' \qquad 4.5.11$$

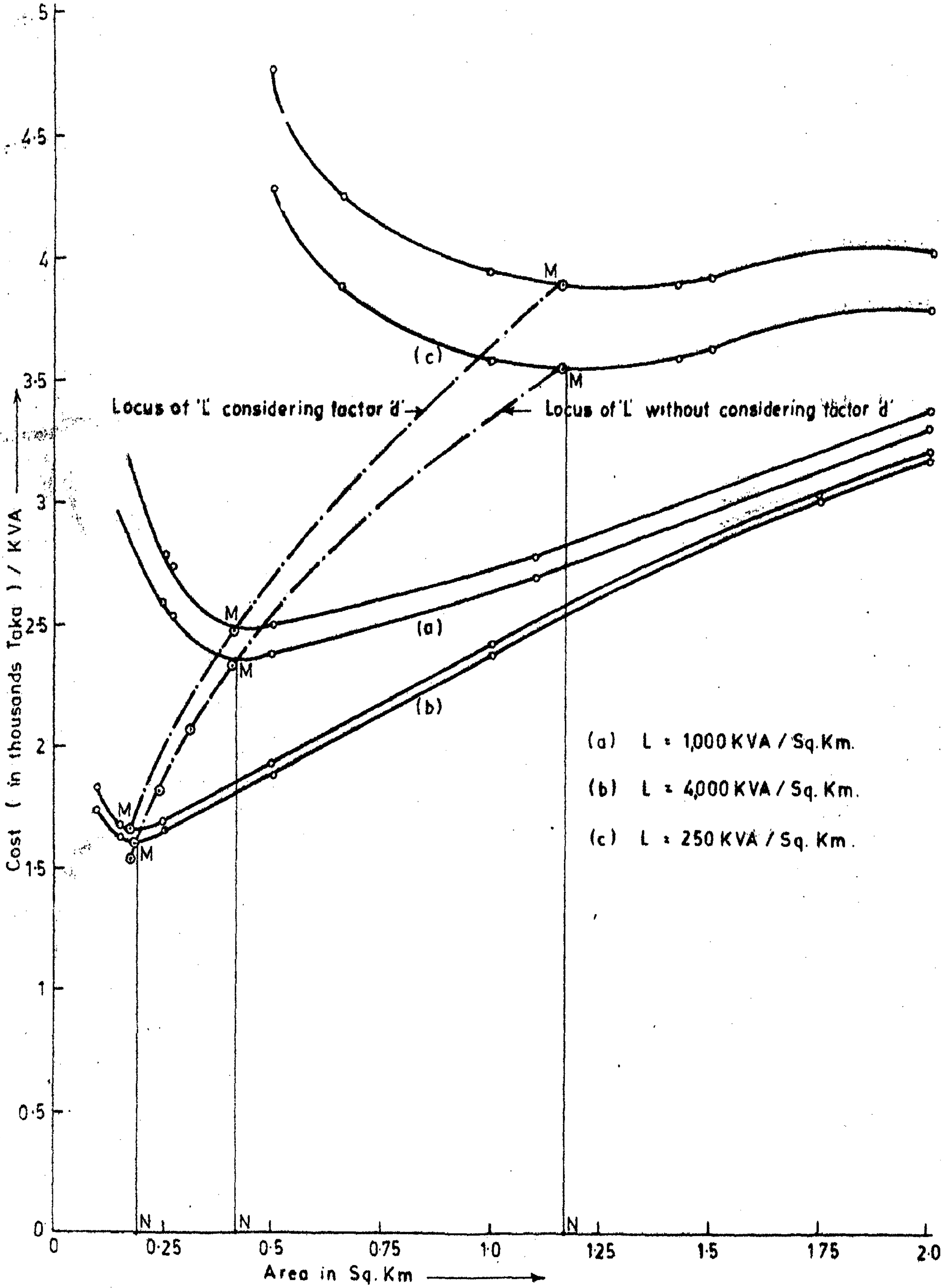


Fig.4·5·2 SHOWS THE VARIATION OF COST PER KVA WITH THE VARIATION OF LOAD DENSITY L AND AREA A. (Considering seqy) and considering the factor 'd' , the cost per KVA equation will be

$$\text{Cost/KVA} = \frac{U_1 + B}{L\,A} + \frac{U_2 l_1}{n} + \frac{a}{n} + c'\,l' + d'\,l' \qquad 4.5.12$$

In the above equations factors are not affecting which are associated with the area A so the optimum area A_o will be same as before , i.e. A_o also for this condition will be

$$A_o = \left[\frac{2\sqrt{\pi}\,(U_1 + B)}{L\,c \times 3.202}\right]^{2/3} \qquad 4.5.10$$

If we plot cost in thousands Taka per KVA versus area in sq. Mi. according to equations 4.5.11 and 4.5.12 for different values of load density we will get figure 4.5.3 In this figure satisfying equation 4.5.12 . That is considering 'd' we will get the upper curves where as lower curves are without considering the factor 'd'. In all the curves in the figure above the minimum cost per KVA occurs at the point of optimum area which satisfied all the above equations.

Finally, if we consider the maximum allowable voltage drop to D per cent in distribution line from 1 LC to load points along with all other factors which considered above $(\cos\varphi)_0$ the equation 4.5.11. for cost per KVA will be

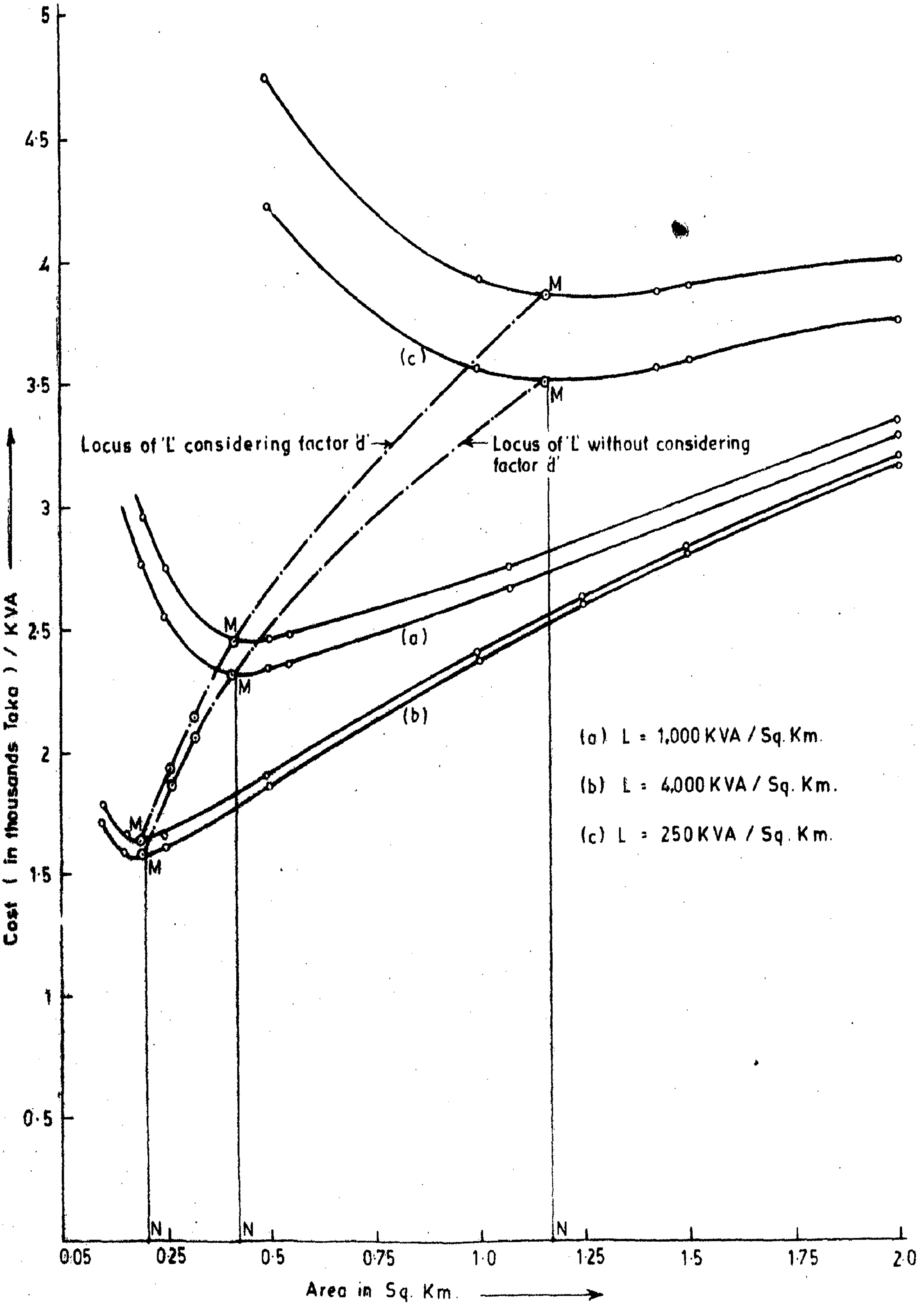


Fig.4·5·3 SHOWS THE VARIATION OF COST PER KVA WITH THE VARIATION OF LOAD DENSITY L AND AREA A. (Considering seqyn) further modified. As considered before the nominal cross-section of the conductor will be equal to $\frac{10^5 \rho\, l_1}{E^2 D}$ where the terms are as designated before. From which the variable cost which is associated with 'c' for delivering 1 KVA of power will be

$$N \times (l_1 Y) \times \text{Nominal cross-section of the conductor} \times (\text{Cogy}).$$

$$= N.\ l_1.Y\ .\ \frac{10^5\ \rho \times l_1 \times \text{Cogy}.}{E^2 D}$$

$$= \frac{c.\text{Cogy}^2.\ \rho \times 10^5}{E^2\ D \times 2.31} \times \frac{A}{n} \qquad 4.5.13$$

Now, if the conductors are not tappered (i.e. t=1), then the total cost per KVA will be

$$\text{Cost/KVA} = \frac{U_1 + D}{L\ A} + \frac{U_2\ l_1 + a}{n} + \frac{c\ \text{Cogy}^2\ \rho \times 10^5}{E^2\ D \times 2.31 \times n} \cdot A$$

$$= \frac{U_1 + D}{L\ A} + \frac{U_2\ l_1 + a}{n} + C_1 A. \qquad 4.5.14$$

where $C_1 = \left[\frac{c\ \delta a y^2 \rho \times 10^5}{L^2 D \times 2.31 \times \pi} \right]$

$= C \times 3.47458 \times 10^3$

$= 1.1 \times 3.47458$

$= 3.822038 \times 10^{-3}$

Differentiating equation 4.5.14 with respect to A and equating to zero we will get optimum area which will give minimum cost per KVA.

Optimum Area $= A_0 = \left[\frac{U_1 + B}{L\ C_1} \right]^{\frac{1}{2}}$ 4.5.15

As before similar effect of 'd' will be in equation 4.5.14 for total cost per KVA. From the above equations for different values of load density (L) if we plot cost in thousands Taka per KVA versus area in Sq. In. we will get curves like in fig. 4.5.4 . In the figure upper curves are shown considering 'd' where as lower curves are without considering the factor 'd' . In all the curves minimum cost per KVA occurs at the point of optimum area which satisfied all the above equations and from which a design Engineer can select the optimum area for any of the above conditions and for any value of load density which varies from time to time.

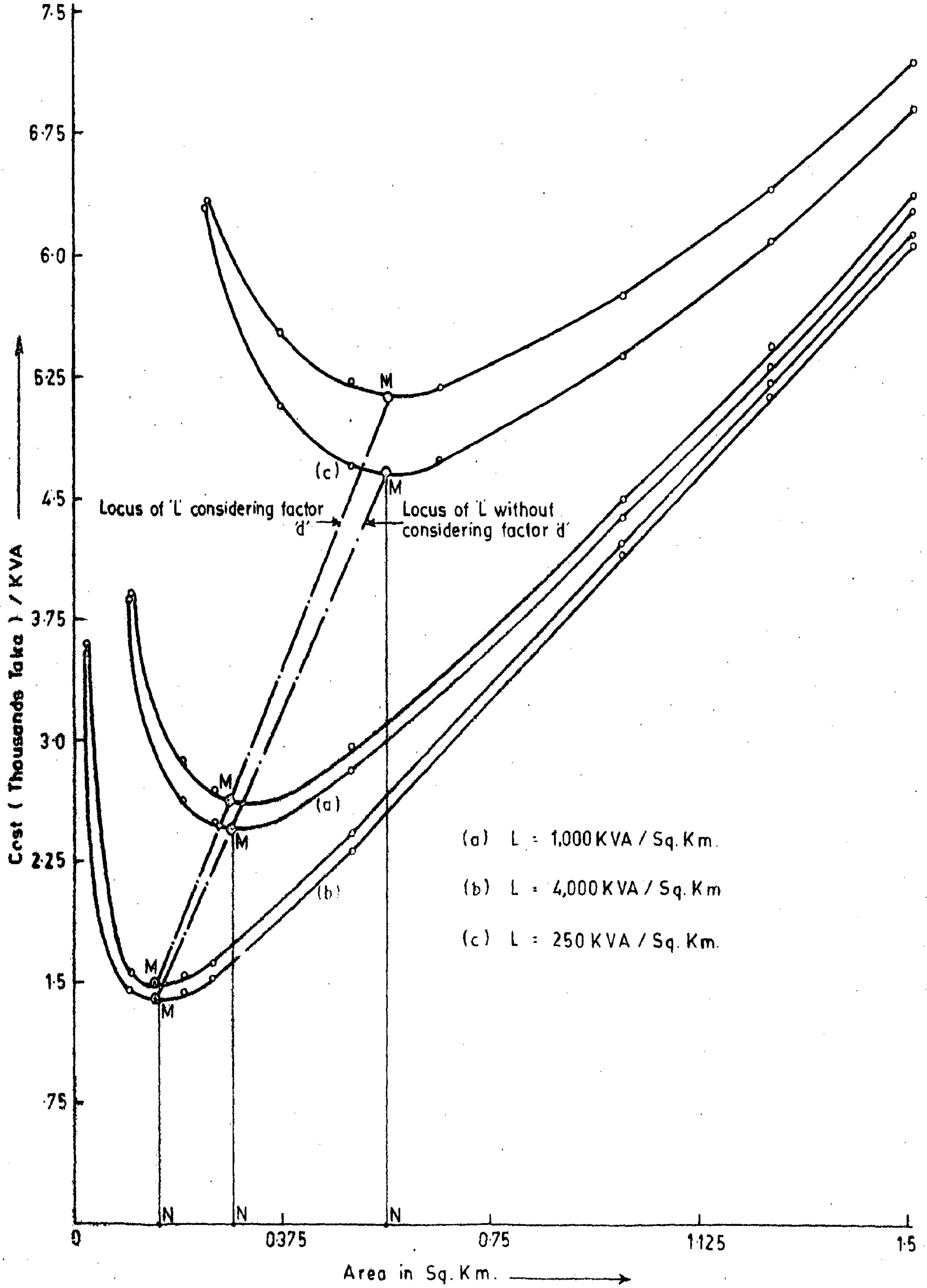


Fig.4·5·4 SHOWS THE VARIATION OF COST PER KVA WITH THE VARIATION OF LOAD DENSITY L AND AREA A. (Considering seqyn D)

4.6 Integration of Existing System with the Proposed System:

From fig. 4.5.1 to fig. 4.5.4 we can have the detailed information regarding variation of total cost per KVA with corresponding variation of area considering and also without considering factors s,e,y,q,n,D and the constant part of low voltage cable cost (d). In the figures, three different sets of curves are shown in each figure in which each set of curves the lower curve shows the variation of total cost per KVA with the variation of area without considering the constant part of low voltage cable cost (d), where as the upper curve shows the variation of total cost per KVA including the constant part of low voltage cable cost(d). For different values of load density(L), we can get the corresponding different values of optimum area from these figures for different conditions(for s,e,q,y,n,D).

So, from these figures a design Engineer can get the detailed information regarding optimum design of any existing distribution system and also for optimum expansion of distribution system with the increase of its load and area in near future. From the above optimised design a design Engineer can select easily the number of distribution sub-station with its rating according to the area and the load demand. He can also select the number and size of additional distribution equipment required to meet the increased load demand in future so that the overall system wil be optimum.

Now considering Jessore Sadar Sub-station distribution system whose 1980-81 load demand was 3850KVA with area approximately 8 sq.Km. from which the load density, L = 3850KVA/8 sq.km. = 481.25(approx. 500 KVA per sq.Km.). From figure 4.5.1 we see that for L = 500 KVA/sq.Km. if we want to meet the required load demand by only one distribution Sub-Station then from the above optimized design the optimum area comes to be 1.6034 sq.Km. which is much less than the existing area. Therefore to meet the load demand of the above given area and also for making provision to meet the future load demand with expansion of area we can easily chose from the figure the number and rating of distribution sub-station required. Assuming the rate of expansion of area to be proportioned to the rate of growth of population which at present in Bangladesh is 2.7 percent per annum mentioned in Appendix A, the area will be expanded to approximately 9.14 sq.Km. in the year 1985-86, for which the forecasted load demand is 6600 KVA mentioned in chapter 3. The corresponding values for area and load forecast are 10.44 sq.Km. and 9350 KVA respectively for the year of 1990-91. Then respective future load density will be 722 KVA per sq.Km. in the year 1985-86 and 896 KVA per sq.Km. in the year 1990-91.

If we want the above mentioned distribution system to be optimum in the year 1990-91 we can select optimum area corresponding to load density (L) approximately 1,000 KVA per sq. Km. (corresponding to 896 KVA per sq.Km.) which is 1.0101 sq.Km. This means to meet the forecasted load demand for the forecasted whole area in the year 1990-91, we will require 11(eleven) dstribution sub-station of 1,000 KVA rating. In 1980-81, to meet the total load demand 3850 KVA for the areq of 8 sq. Km., i.e. for the load density(L) of 481.25 KVA per sq.Km.(approximately 500 KVA per sq.Km.), we would require 5(five) distribution sub-station of 800 KVA rating as from fig. 4.5.1., the optimum area for 500 KVA per sq.Km. load density is 1.6034 sq.Km. In similar manner in the year 1985-86, to make the above system optimum we can find out the optimum area from the same figure corresponding to 722KVA per sq.Km.(app. 750 KVA per sq.Km.) which is 1.2236 sq.Km. From which to make the system optimum in 1985-86 we will require 8(eight) distribution sub-station of 900KVA rating. That is if the system would supply the load demand by 5 distribution sub-station in 1980-81, having each of 800 KVA rating, then the system would be optimum by adding another 3 distribution sub-station of 1,000KVA rating in 1985-86. Similarly, it would be optimum in 1990-91 if we would add another 3(three) (i.e. total 11) distribution sub-station of 1,000KVA rating.

However, at present the system is having total installed capacity of 6,000KVA of 42 distribution sub-station as in single line diagram supplied by Bangladesh Power Development Board of rating ranging from 50KVA to 500KVA. So, we can integrate the existing system with the proposed optimised system by removing and replacing the required number of distribution sub-station as designed above.

We can follow the same procedure considering factors, S(shape factor), e (eccentricity factor), q (unbalance factor), y(route factor), n(due to diversity) and maximum allowable voltage drop D(6%), from the figures 4.5.2 to 4.5.4.

CHAPTER-5

5. Optimum Design of Primary Main Circuit

5.1 Cost of 33 KV High Voltage branch loops.

5.2 Cost of 33/11 KV Sub-Station

5.3 Cost of 11 KV Cables

5.4 Optimised Design of Primary Main

5.5 Integration of Existing system with the proposed system.

CHAPTER - 5

OPTIMUM DESIGN OF PRIMARY MAIN CIRCUIT

After designing distribution system the next important task in the system planning is the Optimum Design of primary main circuit before making optimum design of sub-transmission system. To make the design of Primary Main Circuit Optimum the most important consideration is the cost consideration.

The costs to be considered are:-

1. Cost of 33 KV High Voltage branch loops
2. Cost of 33/11KV Sub-station.
3. Cost of 11KV cable.

5.1 Cost of 33KV High Voltage Branch Loops

The high voltage feeders are laid along certain paths for optimum transmission of power from generation station to the grid sub-station(132/33) and branch loops are provided to the 33/11 KV sub-station(ILC) from these lines. For the Jessore sadar power distribution system the grid sub-station (132/33) is at Chachra from which ILC are at an average distance of 3 Km. Cost of 33KV high voltage branch loops depends on the distance between through going feeders and KVA rating of 33/11 KV sub-station. Let the cost of an average branch feeder be U_h.

Calculation of Average Cost of 33 KV High Voltage Branch Loops for Each 33/11 KV Sub-station.

If we plote the cost(Taka) per Km. of 33KV paper insulated High Voltage Cable in y axis corresponding to different values of cable cross section(as before for 11 KV) in sq. mm. in x axis(Date from table 5.1.a.). We can have the curve like in fig. 5.1.a. Similar way another curve can be drawn as in fig. 5.1.b., taking different values of cable cost(Taka) per Km. in y axis corresponding to its KVA rating in x axis(Data from table 5.1.b.).

From the fig. 5.1.b., the fixed part(U_h) of high voltage cable cost is the length OM and can be found 1.0×10^5 Taka per Km. For the average length(l_1) of 3 Km. 33 KV high voltage feeder for each 33/11 KV sub-station the fixed part of high voltage cable cost,

$$U_{h1} = U_h \times l_1 = 1.0 \times 10^5 \times 3.0 =$$

$$= 3.0 \times 10^5 \text{ Taka} \qquad \ldots\ldots(5.1.1)$$

From the same figure, the variable part(U_{h2}) of high voltage cable cost which varies with the variation of cable rating is the slope of the curve MN, and can be calculated as,

$$U_{h2} = \text{slope MN} = \frac{(18.5 - 1.0) \times 10^5}{32{,}000}$$

$$= 54.69 \ \frac{\text{Taka/KM}}{\text{KVA}} \qquad \ldots\ldots(5.1.2)$$

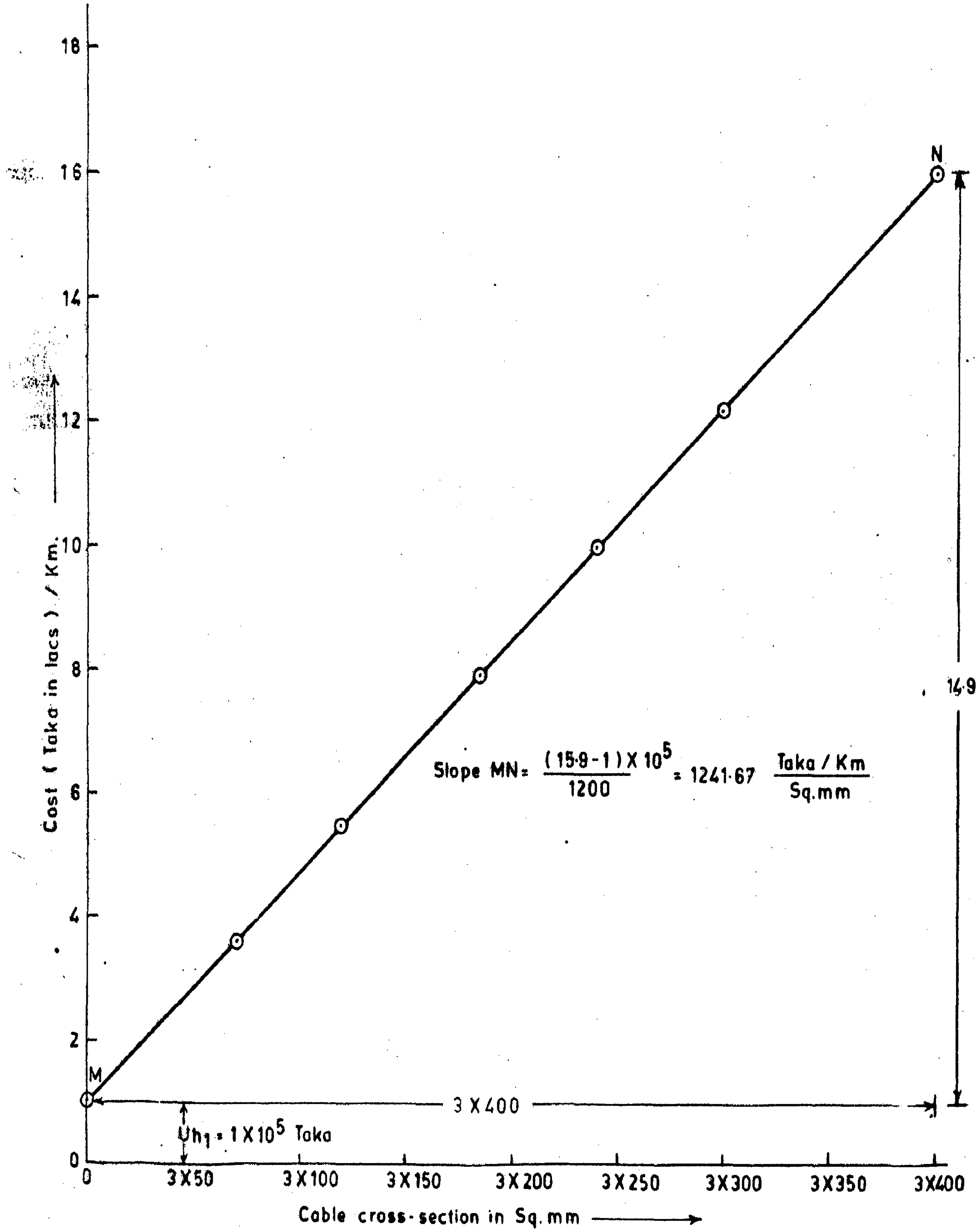


Fig.5.1(a) CHARACTERISTICS OF 33 KV 3 CORE PAPER INSULATED ALUMINIUM CONDUCTOR (Cost Vs Cross-sectional area)

TABLE - 5.1.a

Data for Fig. 6.1.a (Supplied by U.P. State Electricity Board)

High Voltage Cable	Cost(Taka in lacs)/Km
33 KV 3 core 400 Sq.mm.	15.9
33 KV 3 core 240 Sq. m.m.	9.88

TABLE -5.1 b

Data for Fig. 5.1.b)

Electrical Characteristics of Aluminium Conductor

33 KV Paper insulated Cable (Max. conductor Temp. 65°C)

(Ref- Electricity distribution Manual by - S.P.Agrawal)

No. of cores and Cross-sectional area in Sq.mm.	Current rating	KVA rating of Conductor	Cost(Take in lacs/ Km)
210 = 3x70	135	7716.28	
285 = 3x95	160	9145.23	
360 = 3x120	180	10288.38	
450 = 3x150	210	12003.11	
555 = 3x185	240	13717.84	
675 = 3x225	275	15718.36	
720 = 3x240	285	16289.94	9.88
900 = 3x300	320	18290.46	
1200 = 3x400	434	24806.43	15.9

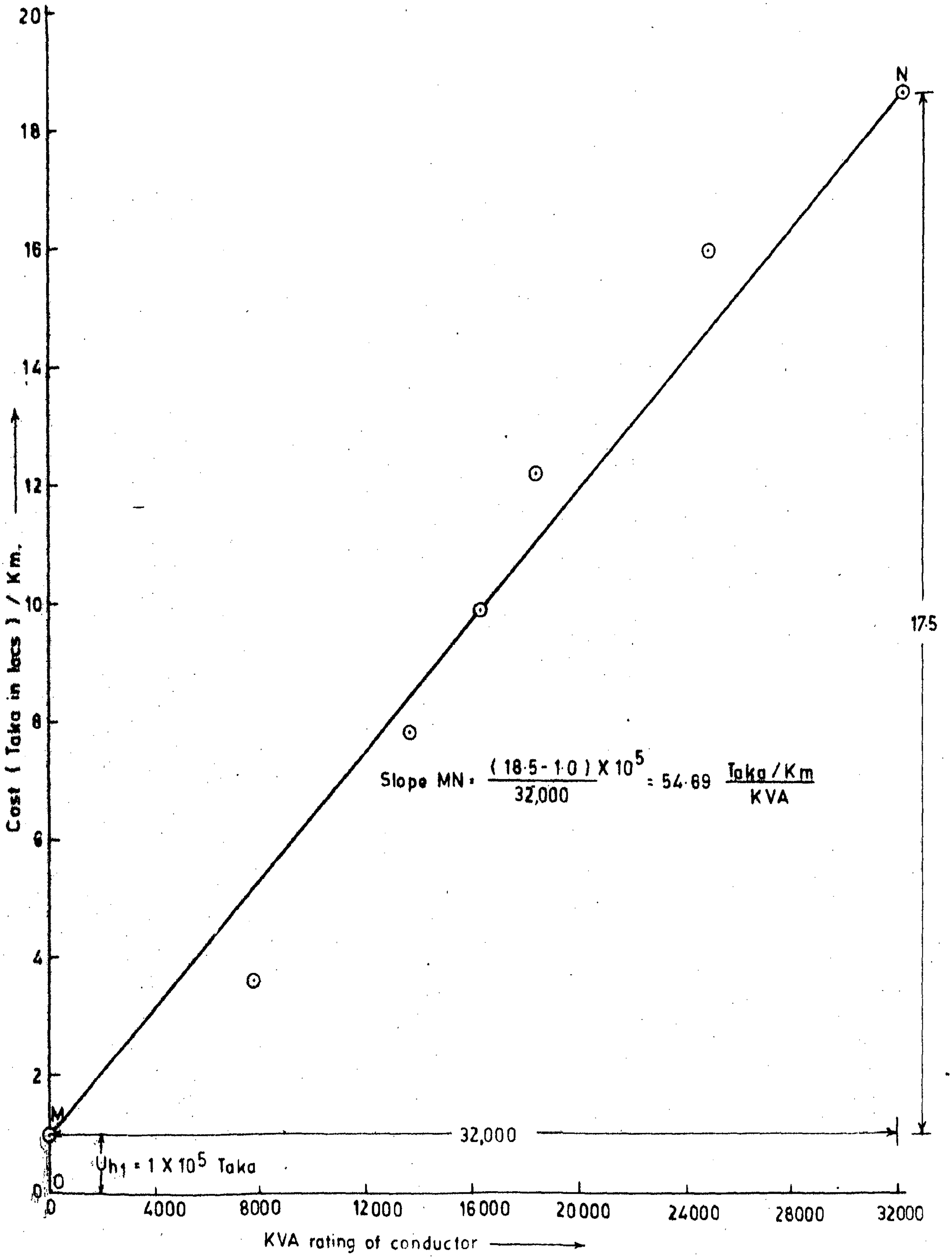


Fig.5·1(b) CHARACTERISTICS OF 33KV 3 CORE PAPER INSULATED ALUMINIUM CONDUCTOR (Cost Vs KVA rating)

For the average distance of 3 Km. of 33 KV high voltage cable from grid sub-station to intermediate load centre(ILC) the value of,

$$U_{h2} = 54.69 \times 3.0 = 164.07 \text{ Taka/KVA} \qquad \text{......(5.1.3)}$$

Now the total cost of 33 KV high voltage branch loops per KVA, which depends on the distance between through going feeder and KVA rating(N) of 33/11 KV sub-station is the sum of its constant and variable parts of 33 KV high voltage cable cost for each 33/11 KV substation,

$$U_h = U_{h1} + U_{h2} \qquad \text{......(5.1.4)}$$

$$= \left(\frac{3 \times 10^5}{N} + 164.07\right) \text{ Taka/KVA} \qquad \text{......(5.1.5)}$$

5.2 Cost of 33/11 KV Sub-station(ILC)

The total cost consists of a fixed part which includes cost of buildings, switchgear and a small part of transformer cost. Let this part of cost be 'B_h' Taka. The second part depends on the sub-station output KVA and consists of a large part of the cost of transformer. Let this part of cost 'A_h' Taka per KVA.

Calculation of Fixed Part 'B_h' and Variable Part 'A_h' for Each 33/11 KV Sub-station(ILC)

If we plote the estimated cost(supplied by Bangladesh Power Development Board as in table 5.2) of 33/11 KV sub-station versus transformer size in KVA, we will get the curve like in fig. 5.2. From this fig. the MN, which is designated

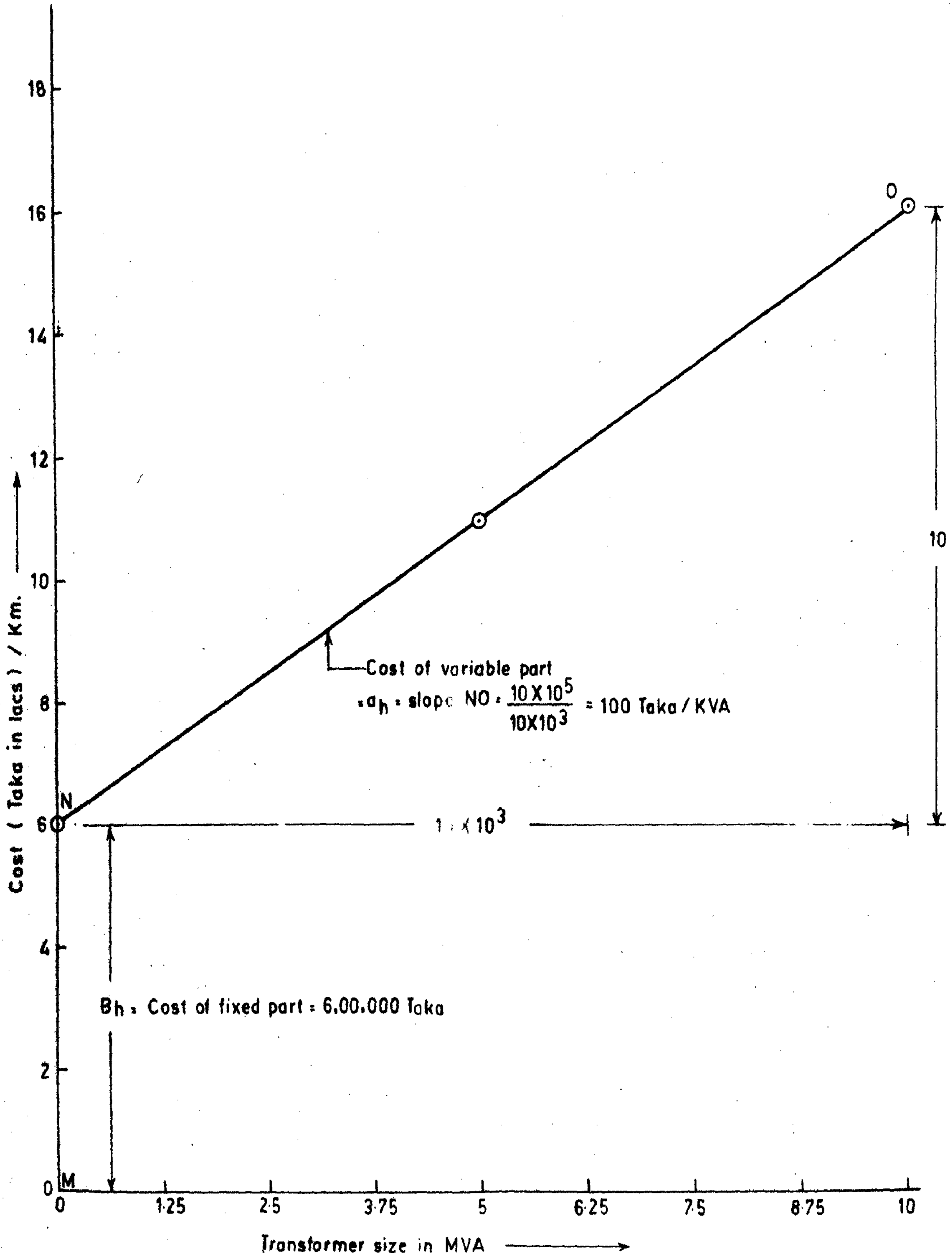


Fig. 5·2 CHARACTERISTICS OF 33/11 KV SUB-STATION (Cost Vs MVA rating)

TABLE 5.2

Data for fig.-5.2

Supplied by the Bangladesh Power Development Board (BPDB)

Sl.no.	Description	Quantity	Foreign Exchange	Local	Total Taka in lacs
3	33/11 KV Sub-station.				
(a)	2x5 MVA	1 no.	16.80	5.00	21.80
(b)	10 MVA and spares	3 nos.	42.22	6.00	48.22

as 'B_h' is the cost of a fixed part which includes cost of buildings, switchgear and a small part of a transformer cost is 6,00,000 Taka.

The second part which is shown in the same figure by the slope of the curve NO and which is designated by 'A_h' depends on the output KVA of the transformer. From the fig. 5.2 the slope of the curve NO,

$$A_h = \text{slope} = \frac{(16-6) \times 10^5}{10 \times 10^3}$$

$$= \frac{10 \times 10^5}{10 \times 10^3} = 100 \text{ Taka/KVA}$$

5.3. Cost of 11 KV Cables

From sub-section 4.1 as found earlier for 11 KV cables,

$$d = U = 1.7 \times 10^5 \text{ Taka/Km.} \qquad ......(5.3.1)$$

and from Eqn. 4.1.1, $U_1 = 2.55 \times 10^5$ Taka

from Eqn. 4.1.2, $C = U_2 = 68.57 \ \frac{\text{Taka/Km.}}{\text{KVA}}$

For average length of 1.5 Km. (from Eqn. 4.1.3)

$$C = U_2 = 102.86 \text{ Taka/KVA.}$$

From which, $U = U_1 + U_2$ ....(4.1.4.)

$$= \left(\frac{2.55 \times 10^5}{N} + 102.86 \right) \text{ Taka/KVA} \quad ....(4.1.5)$$

5.4 Optimised Design of Primary Main

In order to obtain optimised design of primary main the same procedure can be followed as in sub-section 4.4, taking 33 KV line as 11 KV line (i.e. U_h as U), 132/33 KV sub-station as 33/11 sub-station, 33/11 Sub-station as 11/.415 KV sub-station(i.e. B_h as B, and A_h as A) and 11 KV line as 0.415 KV line(i.e. U as d and U_2 as C), with the assumption that the total length of the route covered by the 11 KV cable is proportional to the size of the cable.

Without making this assumption, but assuming first the constant cost of 11 KV cable is zero, i.e. with the same slope the line MN in fig. 4.1.b. will pass through the origine. Then the design will be as follows:

(a) Cost of 33 KV High Voltage Branch Loops

Fixed part of high voltage cable cost U_h Taka per Km. for the average length of l_1 will be $U_h l$ Taka. Variable part of high voltage cable cost U_2h Taka per Km. per KVA with the average length of l_1 and with load demand of N KVA will be $U_{2h}Nl_1$ Taka. Then the total cost U_h of high voltage branch loops is the sum of its constant and variable parts i.e.,

$$U_h l_1 + U_{2h}Nl_1 = (U_h + U_{2h}N)l_1 \text{ Taka}\ldots\ldots(5.4.1)$$

(b) Cost of 33/11 KV Sub-station

As before for the load demand of N KVA, the total cost of 33/11 KV sub-station is the sum of its constant and variable parts, i.e.

Total cost = $(B_h + A_h N)$ Taka ....(5.4.2)

Where, B_h is the fixed part and A_h is the variable part of transformer cost.

(c) Cost of 11 KV Cables

Neglecting the constant part of 11 KV cable cost, the variable cost of 11 KV cable C_h be the cost per meter per KVA. If we consider the equivalent length of the 11 KV cable per KVA be l_2, then $C_h\, l_2$ will be the cost per KVA of the variable part and for N KVA load demand $C_h N l_2$ Taka will be the cost of variable part of 11 KV cable.

Now the total cost per KVA,

$$\underline{U_h l_1} + \underline{U_{2h} l_1 N} + \frac{B_h}{N} + \frac{A_h N}{N} + \frac{C_h N l_2}{N}$$

$$= \frac{U_h l_1}{N} + U_{2h} l_1 + \frac{B_h}{N} + A_h + C_h l_2 \qquad ....(5.4.3)$$

$$\frac{(B_h + U_h l_1)}{lA} + U_{2h} l_1 + A_h + C_h l_2 \qquad ......(5.4.4)$$

Where, $N = lA$

If the dimensions of the area are changed by a factor 'b', then the load changes to b^2W, i.e. $L\,b^2A$,

The area changes to b^2A,

and l_2 changes to bl_2.

Again $\pi l_2^2 = A$, From which, $l_2 = \sqrt{\frac{A}{\pi}}$,

Then the equation (5.4.4) becomes,

$$\text{Total cost per KVA} = \frac{(B_h + U'_h l_1)}{L\,b^2\,A} + U_{2h}l_1 + A_h + C_h b\sqrt{\frac{A}{\pi}} \quad \ldots(5.4.5)$$

Now to get the value of b which gives the minimum cost per KVA

$$\frac{d}{db}\,(\text{Cost/KVA}) = \frac{d}{db}\left(\frac{B_h + U'_h l_1}{L\,b^2 A} + C_h b\,\frac{A}{\pi}\right) = 0$$

or

$$-\frac{2B_h}{L\,b^3 A} + C_h\sqrt{\frac{A}{\pi}} = 0$$

or

$$b^3 = \frac{2\sqrt{\pi}\,(B_h + U_{1h})}{C_h\,L\,A^{3/2}} \qquad \text{Putting } U'_h l_1 = U_{1h}$$

or

$$b = \frac{\left[\dfrac{2\sqrt{\pi}\,(B_h + U_{1h})}{C_h\,L}\right]^{\frac{1}{3}}}{A^{\frac{1}{2}}} = \sqrt{\frac{A_o}{A}} = \frac{A_o^{1/2}}{A^{1/2}} \quad \ldots\ldots(5.4.6)$$

$$\therefore\quad A_o = \left[\frac{2\sqrt{\pi}\,(B_h + U_{1h})}{C_h\,L}\right]^{\frac{2}{3}} \quad \ldots\ldots \qquad (5.4.7)$$

Now from equation (5.4.5), to get optimum area, which gives minimum cost per KVA,

$$\frac{d}{dA}(\text{Cost/KVA}) = \frac{d}{dA}\left(\frac{B_h+U_{1h}}{L\,b^2 A} + U_{2h}l_1 + C_h + C_h b\sqrt{\frac{A}{\pi}} \right) = 0$$

$$\text{or} \quad -\frac{B_h+U_{1h}}{L\,b^2 A^2} + \frac{1}{2}\frac{C_h b}{\sqrt{A\pi}} = 0$$

$$\text{or} \quad A^{3/2} = \frac{2(B_h+U_{1h})}{L\,b^3 C_h}$$

$$\text{or } A = \frac{\left[\frac{2\sqrt{\pi}(U_{1h}+B_h)}{L\,C_h}\right]^{\frac{2}{3}}}{b^2}$$

From which optimum area = A_0 $$Ab^2 = \left[\frac{2\sqrt{\pi}(B_h+U_{1h})}{L\,C_h}\right]^{\frac{2}{3}} \quad (5.4.7)$$

Now like before, from Equations 5.4.6 and 5.4.7 we will get the value of b and A which will give the minimum cost per KVA above and below of which the cost per KVA will increase.

As before from the above equations (5.4.4 and 5.4.7) if we place the values of optimum area corresponding to different value of cost per KVA without considering any factor like (coquence) we will get a curve for particular values of L. In the same manner if we plot for different values of L, i.e. for the values of L like 250, 1000 and 4,000 KVA/Km^2, we will get curves like in figure - 5.4.1 The variation of load density (L) with the variation of optimum area and cost per KVA is shown in fig. 5.4.1(d) b by chained line. In all other figures the variations of load density (L) are shown in the same manner.

Similar way, considering sequence, and finally sequence ~~as~~ we will get curves like in figure 5.4.2, and figure 5.4.3 ~~and figure 5.4.4~~ respectively. The effect for considering constant cost 'd' is shown in figure 5.4.1(c) by dotted line, and for other figures 'd' can be taken care of as discussed in the case of distribution system in which the value of optimum area are not noticeably changed.

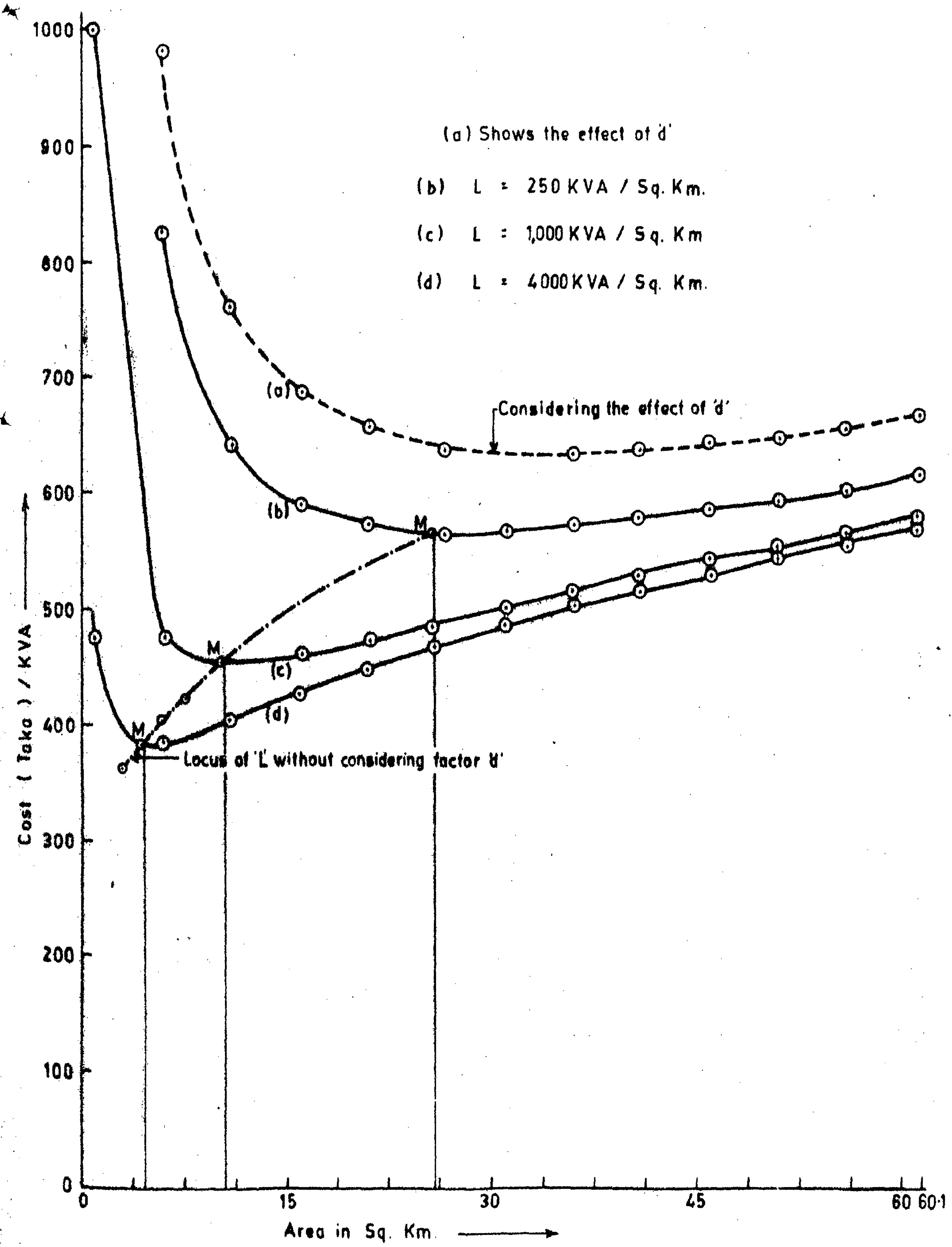


Fig.5·4·1 SHOWS THE VARIATION OF COST PER KVA WITH THE VARIATION OF LOAD DENSITY L AND AREA A. (Without considering seqyn D)

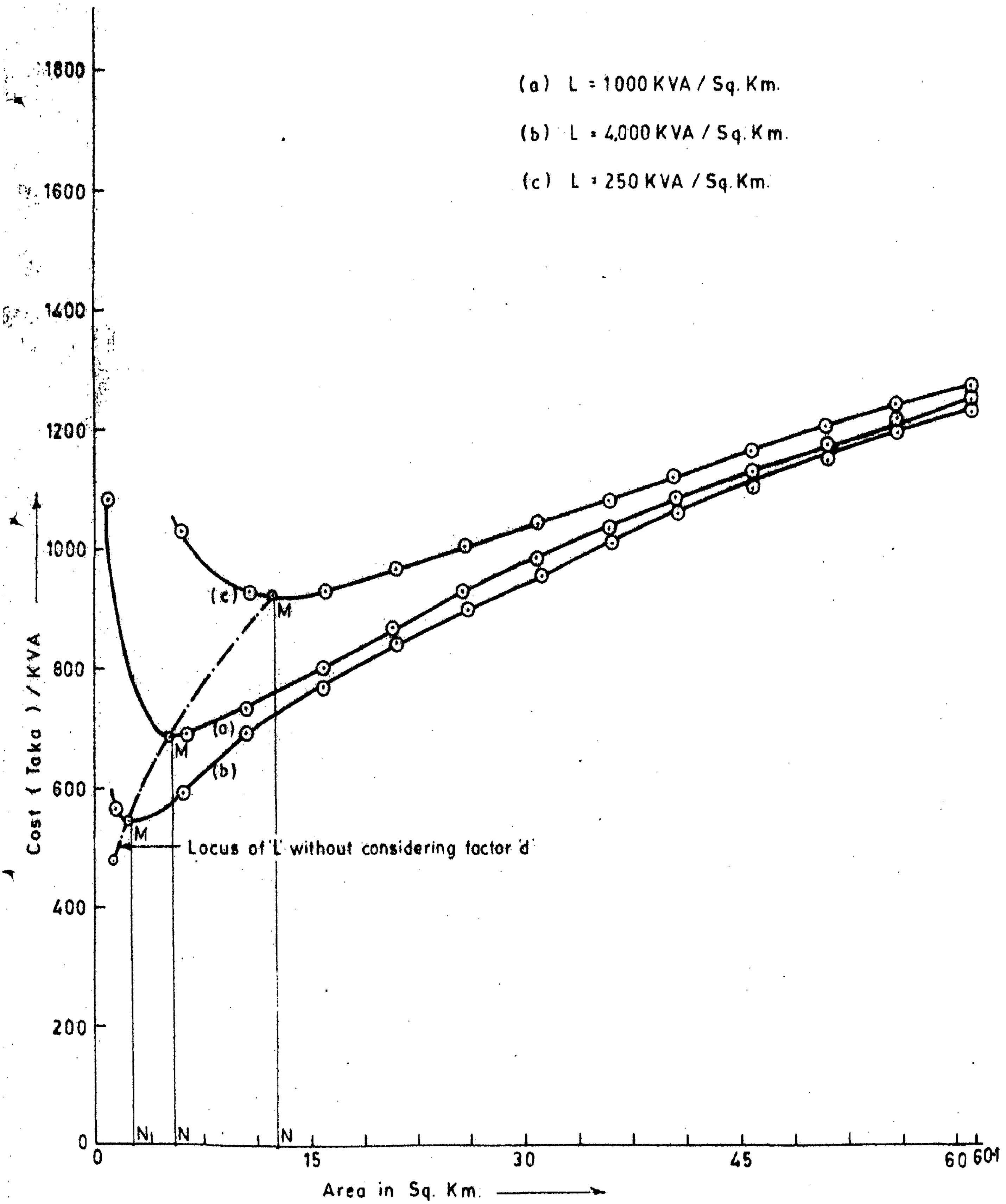


Fig.5·4·2 SHOWS THE VARIATION OF COST PER KVA WITH THE VARIATION OF LOAD DENSITY L AND AREA A. (Considering seqy)

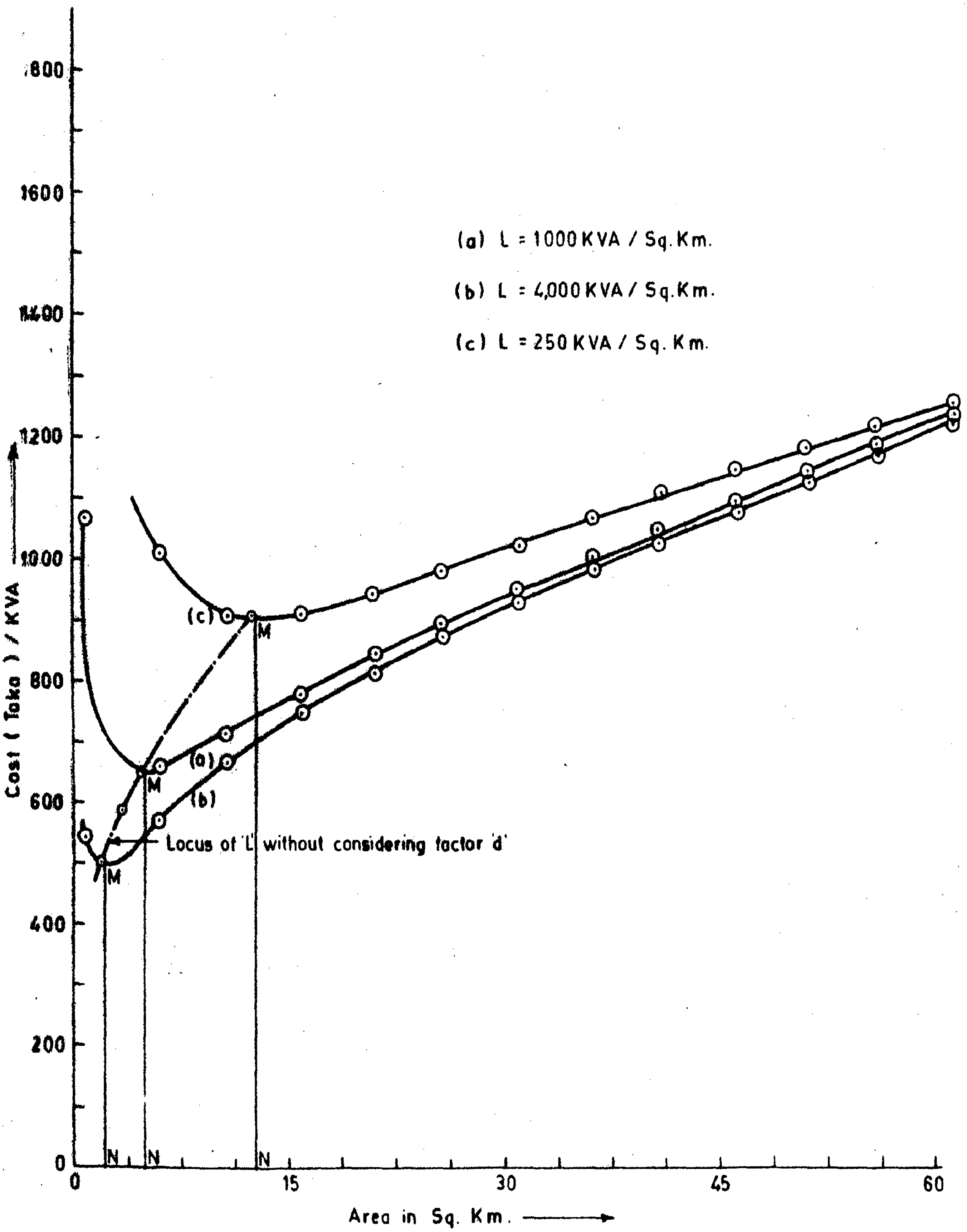


Fig. 5·4·3 SHOWS THE VARIATION OF COST PER KVA WITH THE VARIATION OF LOAD DENSITY L AND AREA A. (Considering seqyn)

5.5 Integration of Existing System with the Proposed System

From fig. 5.4.1 to fig. 5.4.4 we can have the detailed information regarding variation of total cost per KVA with corresponding variation of area considering also also without considering factors seq y,n,D and the constant part of low voltage cable cost 'd'. Four different curves are shown in the fig. 5.4.1. In this figure, curve (a) which is shown by dotted line shows the variation of total cost per KVA(for particular value of L is equal to 250 KVA per sq.Km.) corresponding to area including the effect of 'd' showing the optimum area also. Other curves like (b),(c),(d) are shown the variation of total cost per KVA corresponding to area without considering the factor 'd' for 250, 1,000 and 4,000 KVA per sq.Km. of L respectively. In other figures such as figs. 5.4.2, 5.4.3 and 5.4.4 are showing the variation of total cost per KVA with corresponding variation of area including the total cost per KVA for optimum area considering factors seqy, Seqyn and seqyn D respectively. In each figure the variation of load density (L) with the variation of optimum area and cost per KVA are shown by the chained line. From these figures for different values of load density(L), we can get the corresponding different values of optimum area for different conditions(for seqyn D).

From these figures a design Engineer can get the detailed information regarding optimum design of primary mains of any existing distribution system and also for optimum expansion of primary mains with distribution system for the increased load and area in near future. From the above optimised design a design engineer can select easily the number of 33/11 KV sub-station with its rating according to the area and the load demand. He can also select the number and size of additional primary mains equipment required to meet the increased load demand in future so that the overall system will be optimum.

Now considering Jessore Sadar - sub-division distribution system in which primary mains are connected radially and there 1980-81 load demand was 3850 KVA with area approximately 8 sq. Km. from which the load density, L = 3850 KVA/8 Sq. Km. = 481.25 (approximately 500 KVA per Sq. Km.). From figure 5.4.1 we see that for L = 500 KVA/Sq. Km. if we want to meet the required load demand by only one 33/11 KV sub-station, then from the above optimised design the optimum area comes to be 17.3673 sq. Km. which is much higher than the existing area. Therefore, to meet the load demand for the above given area and also for making provision to meet the future load demand with expansion of area we can easily choose, from the figure-5.4.1 the number and rating of 33/11 KV sub-station required.

Considering forecasted load demand and area, if we want the above mentioned primary mains to be optimum in the year 1990-91, we can select optimum area corresponding to load density (L) approximately 1,000 KVA per Sq.Km. (corresponding to 896 KVA per Sq. Km.) which is 10.9487 Sq. Km. This means to meet the forecasted load demand for the forecasted whole area in the year 1990-91, we will require one 33/11 sub-station of 10 MVA. In 1980-81, to meet the total load demand of 3850 KVA for the area of 8 sq. km. i.e. for the load density (L) is about 500 KVA per Sq. Km, we would require one 33/11 KV sub-station of 5MVA rating. Similarly, for 1985-86, from the same figure for load density 750, optimum area is 17.3673 Sq. Km. and to make the system optimum we can choose the 33/11 KV sub-station accordingly to integrate the existing system with the proposed optimised system. We can follow the same procedure considering factors c.o.q.y.n and maximum allowable voltage drop D (6%), from the figures 5.4.2 to 5.4.4.

CHAPTER - 6

Discussion and Conclusions

CHAPTER - 6

DISCUSSION AND CONCLUSIONS

The result of studying the effects of various parameters on the total cost of the distribution system were presented and discussed in chapters 4 and 5. These results provide valuable information on the optimisation of distribution system. Thus the system planner can have a better perspective of the design procedures of distribution system. The planner has to take into account the results of the short and long term load forecast given in chapter 3.

The apparent relationship between the quantity being forecasted and factors influencing it should be tested by simple graphical analysis. The graphical scatter chart is an essential preliminary part to mathematical manipulation. Actually graph contains more information than an equation, an equation is only a short hand notation of the data. The scatter diagram, on the other hand, shows simultaneously both the individuality of each point and general trend of all the points which the equation can't do.

No individual or small group can possibly know enough about all the factors affecting the future to be able to develop an adequate forecast. Such a person or group of course, can analyse historical data and use various techniques to draw a few conclusion about possible future trends, cycles, and sources of random variations. Evaluating how the future will differ from past however is another question. Hence effective forecasting must be a group effort.

The accuracy of a forecast for distribution system is very crucial to distribution system hence considerable emphasis must be given on reliable information. Poor or incomplete information can lead to just contradictory results and will make the forecast just impossible.

From chapter 3 and above discussion the following conclusions can be drawn:-

(1) A short term for five years period and long term for ten years and twenty years forecast was done in terms of East zone, West zone, East and West combined zone and political districts of Bangladesh. Linear, non-linear and econometric models have been used for making demand estimates. Growth in maximum load is 7.7% simple and 4.7% compound per year which is deemed to be too low.

Considering all other factors the year wise demand forecasted was done which assumed a factor growth rate(18%) which is after five year 2.3 times more than the present level. The area suffered suppressed demand, because of the fact for both generation shortage, inadequate system expansion facilities and non-available of adequate fund.

(8) It is suggested that in future the forecasts should be done in every year and actual load demand should be compared with the forecasted value in each year so that the technique of forecasting can be improved to get accurate forecasts. I feel inclusion of weather variable(temperature) into forecasts presents a substantial improvement over the approach of just extrapolation without taking temperature into consideration. Several weather variables like annual average temperature, July mean temperature, January mean temperature humidity etc. can be had from meteorological department. I could not take those weather variables factors into consideration for forecasting load demand due to non-availability of data. The most important factor in this region for estimate of weather sensitive load is perhaps temperature. Different forecaster may take different factors into account depending upon their judgement and experience.

For successful forecasting historical data is a must hence we should record daily peak, monthly peak, monthly energy consumption etc. at the sub-station for future guidance of forecasting.

The detailed discussions regarding optimum design of distribution system and integration of existing system into the optimised system are given in each chapter

4 and 5 which will also be helpful for integrating any existing system into the optimised system. From the discussion conclusions can be made as follows:-

(1) A design Engineer can get detailed information regarding optimum design of a distribution system for any area A with any load density L. He can also select the number and rating of 33/11 KV and 11/.415 KV sub-station for any newly design distribution system or for extension of any existing distribution system with minimum cost.

(2) The data regarding cost of high and low voltage cable per unit length which was collected from Uttar Pradesh State Electricity Board was compared(considering currency coversion factor also) with the data of the same from Bangladesh and was seen as realistic. Similar way the data regarding cost of 11/0.415 KV distribution sub-station and spares which was collected from Bangladesh Power Development Board(BPDB) (considering currency conversion factor also) was compared with the data of the same from the Uttar Pradesh State Electricity Board and was seen as realistic. So, the whole system design is applicable for both the country and also for any other country after properly converting it from Bangladesh currency to any other country's respective currency with its converting factor which varies from time to time, as all the cost given in this dissertation in Bangladesh currency([illegible]).

(g) The future cost calculation was made for both the cases Primary Main circuit and Distribution system with the assumption that the inflation is zero. To make the cost calculation for future load more accurate the proper rate of inflation must be taken care of which also varies from time to time.

(h) The cable cost is the fixed cost for a certain range of KVA because neither the cables of all different ratings are available nor those stocked by the electricity supply authority.

(i) If we compare from the figs. 4.5.3 and 4.5.4 the total cost per KVA considering factors Sagyn and considering factors Sagyn including maximum allowable voltage drop(6%) we find that in the previous case where the maximum allowable voltage drop was not considered, the calculated voltage drop(considering all other factors are same) would be 11.54%. From which we can make choice any one of these by optimised design. If the system is allowed to make voltage drop upto 12% then we can make the choice of first one where the factors 'Sagyn' were considered without considering the voltage drop condition and the cost per KVA is much less than the later one. If the maximum allowable voltage drop is 6% then the later design should be considered. Similar way if we compare from the figs. 4.5.1 and 4.5.4, the total cost per KVA without considering factors

' cogyn D) and in the second case considering all factors (cogynD) the calculated voltage drop will be about 37.1 (which is 3.202 times more than the previous voltage drop due to the factor cogyn) in the first case from which we can make choice like before which depends on system condition.

Generally feeders are designed on the basis of current carrying capacity where as on the other hand distributors are designed on the basis of voltage drop condition. So in the case of distribution system the voltage drop condition was given out most importance where as in the case of primary main circuit design the results of optimum design presented without considering the voltage drop condition.

Overall loss in an electrical power system is measured in terms of the difference between gross energy generated and energy consumed. If the difference is positive, that is, if energy generated exceeds energy consumed, it is called system loss. Except a few, throughout Bangladesh there is practically no metering facility in the 33/11/0.415KV distribution sub-station. Errors and omissions contained in the monthly operational Data(MOD) coupled with the errors of calculation make it exceedingly difficult to quantify accurately the losses at different voltage levels at present in Bangladesh.

The total system loss arises from a number of sources classified as follows:-

(i) Station service loss.

(ii) Transmission and distribution loss.

(iii) Un-metered energy consumption loss.

(iv) Metering deficiency loss.

(v) Under billing and Pilferage loss.

(vi) Losses due to low power factor.

(vii) Losses due to low voltages.

However, it may be observed from the detailed discussions which were made with concerned Bangladesh Power Development Board and Uttar Pradesh State Electricity Board officials that major portion of the loss occurs at low voltage levels, 11 KV lines and 0.415KV distribution networks. Under billing, pilferage etc. also account for a very high percentage of losses.

Considering the above problems at present facing in Bangladesh which contribute to excess system loss. I suggest the following steps implementation of which may improve the situation:-

Meter and Metering Facility Improvements

1. Metering deficiency in grid sub-stations including 33KV must be quantified.

2. For immediate replacement and repair of the meters, 4 zonal workshops under direct control of Chief Engineers may be set up.

(3) Bangladesh Power Development Board field units shall have to be re-organised under the control of respective Chief Engineer's to assess the metering deficiency at various levels. Timely recording of energy flow shall obviously reduce the extent of energy consumed that goes unrecorded and also prevent illegal uses.

4. Vigorous drive should be under taken to identify and record real consumers by types. Commercial accounts in particular should be renamed by the name of the organisation instead of by name of the owner.

5. Fool- proof devices such as metal clad and locked metering box may be tried.

Improvement in Distribution System

Electrical losses in the low voltage distribution system in Dhaka, Cittagong and Khulna are expected to decrease considerably following the completion of Bangladesh Power Development Board distribution projects now under implementation. However, I suggest the following points for future improvement of the situation for Distribution System.

1. Introduction of ring main system instead of radial feeders as far as possible and particularly in densely populated areas.

2. Service connections should be given with proper jointing materials which reduces voltage drops and interruptions.

3. Where the power factor(P.F.) is suspected to have become excessively low at lower/higher loading period specially in industrial areas, steps should be taken for immediate installation of appropriate sized capacitor banks. Besides this Bangladesh Power Development Board should ask all industrial units, where p.f. is expected to be on lower side, to have their own p.f. correction devices installed at their premises. If this is done, lower p.f. phenomena upto 11 KV system may largely be overcome in near future and thus the system loss caused by low p.f. will be reduced.

Computer analysis and simulation were done on the Roorkee University Regional Computer Centre DEC 2050.

Finally it is hoped that this dissertation will have very important planning and policy implications particularly for Electric Power Distribution for the whole of the country Bangladesh in particular and any where in the world in general.

In addition to this design the optimum design of transmission system should be carried out based on load flow study which will give the complete detailed information to the system planner regarding transmission and distribution system design as a whole which can be used for extension of any existing system and also for completely new system.

APPENDICES

APPENDIX-A

ECONOMIC BACKGROUND AND POWER SYSTEM OF BANGLADESH

Introduction

A.1. Economic background of Bangladesh.
A.1.1. Physical features.
A.1.2. Population.
A.1.3. Administrative Structure.
A.1.4. Infrastructure.

A.2. Present Power System of Bangladesh.
A.2.1. Generating Stations.
A.2.2. Transmission Lines.
A.2.3. Distribution Lines.
A.2.4. Central Load Dispatch and Control.

APPENDIX A

ECONOMIC BACKGROUND AND POWER SYSTEM OF BANGLADESH

INTRODUCTION

Power is one of the most important inputs for productive activities. As a basic infrastructure it plays a crucial role in determining the rate of economic and social development in any country.

The total power generation capacity in the then East Pakistan was only 21MW in 1947. It rose to 475MW by the end of 1970. Similarly the maximum demand for power rose from 42 MW in 1960 to 103MW in 1965 and to 223MW in 1970. The average growth rate of demand thus was 15 percent during the period. However, the per capita consumption of electricity was only 14.7 Kwh in 1970, one of the lowest in the world. Even at this low level the power system had developed certain imbalances, such as imbalance between generation and distribution capacity and unbalanced regional development. The system also suffered widespread destruction and damage during the war of independence in 1971. Details about the present power system of Bangladesh are provided later in this Appendix-A.

A.1. Economic Background of Bangladesh

A.1.1. Physical Features

Bangladesh lies in the North Eastern part of the South Asian Sub-continent roughly between 20.75° and 25.75° north latitudes and 83.30° and 92.75° east longitudes. The country is bounded by the Bay of Bengal on the South, India on the West and North India and Burma on the East. The area of the country is 55,598 sq. miles.

Bangladesh enjoys generally a tropical monsoon climate. Among the six seasons winter, summer and monsoon are prominent. Temperature usually fluctuates between 45°-55°F daily minimum to 75°- 85°F daily maximum during winter which begins in November and ends in February. The highest ever recorded temperature in summer is 116°F. Monsoon starts in June and stays normally upto October. This season accounts for 80 percent of the total rain fall.

A.1.2. Population

Bangladesh is the 8th largest country in the world in terms of the size of population. The 1974 census estimated the total population at 76.4 million. The average family size is about 6 persons per household. Out of the total population about 91 percent live in rural areas while only 9 percent live in urban areas. Population density has been estimated at 1286 persons per sq. mile. The present rate of population growth is stated as 2.7 percent per annum.

A.1.3. Administrative Structure

The country has a unitary form of Govt. headed by the President. On the executive side, the Govt. works through different Ministries which are responsible for policy making in all spheres of national life. There are a number of executing agencies known as autonomous corporations and Directorates under the control of each of the development ministries each of which is responsible for execution of development programs. These Corporations and Directorates have regional offices in all over the country which are engaged in carrying out development activities in their respective fields.

The country has been divided into 5 tiers for general administration purposes: Division - District - Sub-Division - Thana - Union. Each of the first four tiers is headed by a Govt. functionary and the Union is solely under the charge of local Govt.

A.1.4. Infrastructure

Bangladesh imported its infrastructural technology from a world quite unfamiliar with the special problems that its environment creates. The physical make-up of the country results in very high construction. Costs for many types of investments, the soft soil provide poor foundation and piling is often necessary for large buildings, the flatter-rain and monsoon flood create drainage problems and often result in roads and structures being wasted away. The patchwork of rivers necessitates expensive bridging for roads and railways and also increases the cost of nation wide power, natural gas and telecommunication grids. On the other hand, the rivers do permit the development of water transport but even then their suitablity is limited by the low flow in the winter months and the need for dredging to avoid silting up.

Transport and Communication

Transport and Communication system often stated as essential precondition for economic growth is yet undeveloped in Bangladesh due to which the cost of fuel, gas, telecommunication grids and other things relating to power increases which ultimately increases the cost of nation wide power.

Housing and Physical Planning

This sector covers a wide range of activities which are extremely important to the national economy and welfare of the society which are also responsible for the cost of Power.

Social Infrastructure

Creation of a healthy and well educated population is important both from the economic and social point of view which is also related with power economy.

A. 2. Present Power System of Bangladesh

Power, specially, for a developing country like ours constitutes an important infrastructure of national economy. Per capita Generation of Electrical Energy as well as per capita consumption of the same is considered as an important indicator of the degree of development of a country. Country wise growth in different sectors specially in Industry, Agriculture, Commerce and services is more or less directly dependent on a cheap, adequate, and reliable supply of Electrical Energy. The sole responsibility of providing cheap and reliable power to each type of consumer has been entrusted on Bangladesh Power Development Board (PDB) which in turn generates, transmits, distributes and sells electrical energy throughout the country.

From technical point of view the whole power system in Bangladesh has been divided into two zones viz. East Zone and West Zone, separated by a wide and vast river Brahmaputra - Jamuna - Meghna. Generation of power in East Zone largely depends on Karnaphully hydro power station and indigenous natural gas based generating stations. Where as in the West Zone power is being generated mostly from costly imported furnace oils, naptha and diesel oils. At present two separate grids are being maintained, one in each zone, which are supposed to be connected by a interconnector called EAST-WEST interconnector by this year(1982), initially planned to be energized at 132KV but ultimately to be raised to 230KV.

A.2.1. Generating Stations

The existing installed capacity, in both East and West Zones are summarised below:

East Grid Area(East of River Jamuna):

Total existing installed capacity for East grid Area is 506.25 MW.

West Grid Area(West of River Jamuna):

Total existing installed capacity for West grid area is 127 MW.

A.2.2 Transmission Lines

The interconnector which has been already stated in running from Ghorasal to Ishurdi through Tongi totalling 111 miles. Present normal transmission lines used by Bangladesh Power Development Board is energized at 132KV but there is one single line from Rajshahi to Shirajganj via Pabna and Ullapara which is at present energized at 66KV but necessary steps are being taken to convert it to 132KV.

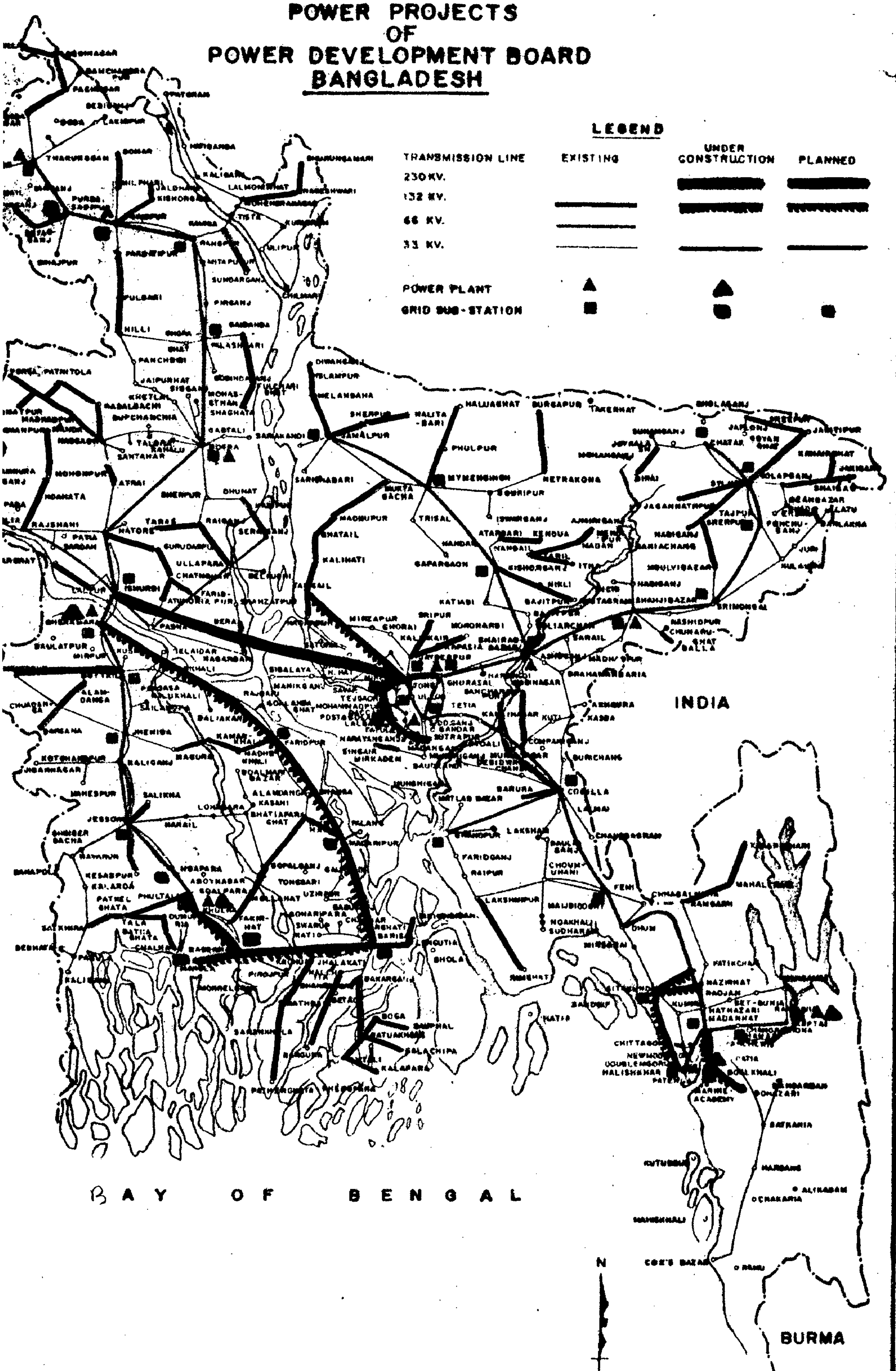
The total mileage of 66KV and 132KV transmission lines in East zone and West zone combined 948.3 miles out of which in East zone 547.3 miles and in West zone 401 miles. In addition to this there are some lines under construction which will be commissioned in near future.

A.2.3. Distribution Lines

Bangladesh Power Development Board(BPDB) held the responsibility of distributing power to all its consumers of major towns, cities, villages etc. till recently. Of late another organisation has been constituted in the name of Rural Electrification Board(REB), having responsibility of constructing distribution lines, forming Biddutayon Samities on Cooperative basis, arranging necessary connections to individuals consumers in Rural Areas. However, the main responsibility lies with Bangladesh Power Development Board, and in doing so they have one 33KV sub-transmission line and one 11 KV and one 0.415 KV distribution lines for taking power to consumers premises. From some bulk consumers they have special 33 KV distribution lines. The existing network consists of 2832 miles of 33KV lines and 7727 miles of 11KV and 0.415KV lines serving a total of 403521 nos. of consumers including 677 nos. of high tension and low tension industrial consumers. Detail power projects of Bangladesh its existing, under Contruction and plans transmission line from 230KV to 33KV with its grid sub-station are shown in fig.A.1.

A.2.4. Central Load Dispatch and Control

The load despatching center for the eastern system is located at the Siddhirganj Power Station, approximately



POWER PROJECTS OF POWER DEVELOPMENT BOARD BANGLADESH

Fig. A·1

40 Km. east of Dacca. This load despatching centre is equipped with a simple load despatching board but is not equipped with S.V.(Supervision) facilities to display the on - off status of the circuit breakers nor with T.M. (Telemetery) equipment for metering display. All load despatching operations are done by means of a power line carrier telephone.

The load despatching center of the Western Grid is located in the Goalpara Sub-station close to Khulna, and operations are similar to those of the Eastern grid.

APPENDIX-B

COMPUTER PROGRAM

B.1 Computer program for calculating factors ABC AND Distric - wise forecasting of Urban and Rural load demand of Bangladesh.

B.2 Computer program for forecasting load demand of Bangladesh.

B.3 Computer program for calculating of Optimum Sub-Station area considering factors Seqyn only.

B.4 Computer Program for calculating of Optimum Sub-station a considering factors Seqyn and Maximum Allowable voltage drop conditions.

15.1

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      AUD.FOR
      CALCULATING ABC AND DISTRICT-WISE FORECASTING OF URBAN AND
      DIMENSION A(29),B(29),C(29),D(29)
      OPEN(UNIT=1,DEVICE='DSK',FILE='AUD.DAT')
      PRINT 2
      FORMAT(/9X,'CALCULATING ABC FOR DISTRICT-WISE FORECASTING
    1 OF URBAN LOAD DEMAND FOR BANGLADESH.'//)
      PRINT 6
      I=1                                                           I4/)
)0    READ(1,*)X1,X2,X3,D1,D2,D3
      TYPE 7 ,I
      FORMAT(1X,'I=',I4)
      FORMAT(9X,'A',10X,'B',12X,'C',10X,'X1',10X,'X2',10X,'X3'
    1 10X,'D1',10X,'D2',10X,'D3')
      A(I)=D1-X1*((D2-D1)/(X2-X1)-(X2+X1)*(D3*(X2-X1)-D1*(X2-X3)
    1 +D2*(X1-X3))/((X2-X1)*(X3*X3+X1*X2-X2*X3-X1*X3)))
    2 -X1*X1*(D3*(X2-X1)-D1*(X2-X3)+D2*(X1-X3))/
    3 ((X2-X1)*(X3*X3+X1*X2-X2*X3-X1*X3))
      B(I)=(D2-D1)/(X2-X1)-(X2+X1)*(D3*(X2-X1)-D1*(X2-X3)
    1 +D2*(X1-X3))/((X2-X1)*(X3*X3+X1*X2-X2*X3-X1*X3))
      C(I)=(D3*(X2-X1)-D1*(X2-X3)+D2*(X1-X3))/
    1 ((X2-X1)*(X3*X3+X1*X2-X2*X3-X1*X3))
      PRINT 200,A(I),B(I),C(I),X1,X2,X3,D1,D2,D3
      TYPE 200,A(I),B(I),C(I),X1,X2,X3,D1,D2,D3
00    FORMAT(//9(4X,F8.4))
      I=I+1
      IF(I.NE.24) GO TO 100
      PRINT 3
      FORMAT(//3X,105('*')//)
      PRINT 4
      FORMAT(//3X,'DISTRICT-WISE FORE CASTING OF URBAN
    1 LOAD DEMAND FOR BANGLADESH.'//)
      NNX=22
      DO 400 J =1,23
      PRINT 5
      FORMAT(/3X,90('*')//)
      IF(J.EQ.1)PRINT11
      IF(J.EQ.2)PRINT12
      IF(J.EQ.3)PRINT13
      IF(J.EQ.4)PRINT14
      IF(J.EQ.5)PRINT15
      IF(J.EQ.6)PRINT16
      IF(J.EQ.7)PRINT17
      IF(J.EQ.8)PRINT18
      IF(J.EQ.9)PRINT19
      IF(J.EQ.10)PRINT20
      IF(J.EQ.11)PRINT21
      IF(J.EQ.12)PRINT22
      IF(J.EQ.13)PRINT23
      IF(J.EQ.14)PRINT24
      IF(J.EQ.15)PRINT25
      IF(J.EQ.16)PRINT26
      IF(J.EQ.17)PRINT27
      IF(J.EQ.18)PRINT28
      IF(J.EQ.19)PRINT29
      IF(J.EQ.20)PRINT30
      IF(J.EQ.21)PRINT31
      IF(J.EQ.22)PRINT32
      IF(J.EQ.23)PRINT33
11    FORMAT(/3X,60('*'),9X,'CTG.LESS CTG.E/S'//)
12    FORMAT(/3X,60('*'),9X,'CTG. HILL TRACTS'//)
13    FORMAT(/3X,60('*'),9X,'COMILLA'//)
14    FORMAT(/3X,60('*'),9X,'DACCA LESS DACCA E/S'//)
15    FORMAT(/3X,60('*'),9X,'JAMALPUR'//)
16    FORMAT(/3X,60('*'),9X,'MYMENSINGH'//)
17    FORMAT(/3X,60('*'),9X,'NOAKHALI'//)
18    FORMAT(/3X,60('*'),9X,'SYLHET'//)
19    FORMAT(/3X,60('*'),9X,'TANGAIL'//)
20    FORMAT(/3X,60('*'),9X,'BARISAL'//)
21    FORMAT(/3X,60('*'),9X,'BOGRA'//)
22    FORMAT(/3X,60('*'),9X,'DINAJPUR'//)
23    FORMAT(/3X,60('*'),9X,'FARIDPUR'//)
24    FORMAT(/3X,60('*'),9X,'JESSORE'//)
25    FORMAT(/3X,60('*'),9X,'KHULNA'//)
26    FORMAT(/3X,60('*'),9X,'KUSHTIA'//)
27    FORMAT(/3X,60('*'),9X,'PABNA'//)
28    FORMAT(/3X,60('*'),9X,'PATUAKHALI'//)
29    FORMAT(/3X,60('*'),9X,'RAJSHAHI'//)
30    FORMAT(/3X,60('*'),9X,'RANGPUR'//)
31    FORMAT(/3X,60('*'),9X,'EAST ZONE'//)
32    FORMAT(/3X,60('*'),9X,'WEST ZONE'//)
33    FORMAT(/3X,60('*'),9X,'BANGLADESH'//)
      PRINT 1
1     FORMAT(/8X,'A',14X,'B',14X,'C',17X,'X',16X,'D(MW)',8X,'YEAR'
      IF(J.GE.21)NNX=27
      DO 400 I =1,NNX
      NIT=1977
      IF(NNX.EQ.27)NIT=1972
```

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      AUD.FOR
      CALCULATING ABC AND DISTRICT-WISE FORECASTING OF URBAN AND RURAL LOAD DEMAND FOR BANGLADESH.
      DIMENSION A(29),B(29),C(29),D(29)
      OPEN(UNIT=1,DEVICE='DSK',FILE='AUD.DAT')
      PRINT 2
      FORMAT(/9X,'CALCULATING ABC FOR DISTRICT-WISE FORECASTING
   1 OF URBAN LOAD DEMAND FOR BANGLADESH.'//)
      PRINT 6
      I=1
0     READ(1,*)X1,X2,X3,D1,D2,D3
      TYPE 7 ,I
      FORMAT(1X,'I=',I4)
      FORMAT(9X,'A',10X,'B',12X,'C',10X,'X1',10X,'X2',10X,'X3'
   1  10X,'D1',10X,'D2',10X,'D3')
      A(I)=D1-X1*((D2-D1)/(X2-X1)-(X2+X1)*(D3*(X2-X1)-D1*(X2-X3)
   1  +D2*(X1-X3))/((X2-X1)*(X3*X3+X1*X2-X2*X3-X1*X3)))
   2  -X1*X1*(D3*(X2-X1)-D1*(X2-X3)+D2*(X1-X3))/
   3  ((X2-X1)*(X3*X3+X1*X2-X2*X3-X1*X3))
      B(I)=(D2-D1)/(X2-X1)-(X2+X1)*(D3*(X2-X1)-D1*(X2-X3)
   1  +D2*(X1-X3))/((X2-X1)*(X3*X3+X1*X2-X2*X3-X1*X3))
      C(I)=(D3*(X2-X1)-D1*(X2-X3)+D2*(X1-X3))/
   1  ((X2-X1)*(X3*X3+X1*X2-X2*X3-X1*X3))
      PRINT 200,A(I),B(I),C(I),X1,X2,X3,D1,D2,D3
      TYPE 200,A(I),B(I),C(I),X1,X2,X3,D1,D2,D3
0     FORMAT(//9(4X,F8.4))
      I=I+1
      IF(I.NE.24) GO TO 100
      PRINT 3
      FORMAT(//3X,105('*')//)
      PRINT 4
      FORMAT(//3X,'DISTRICT-WISE FORE CASTING OF URBAN
   1 LOAD DEMAND FOR BANGLADESH.'//)
      NNX=22
      DO 400 J =1,23
      PRINT 5
      FORMAT(/3X,90('*')//)
      IF(J.EQ.1)PRINT11
      IF(J.EQ.2)PRINT12
      IF(J.EQ.3)PRINT13
      IF(J.EQ.4)PRINT14
      IF(J.EQ.5)PRINT15
      IF(J.EQ.6)PRINT16
      IF(J.EQ.7)PRINT17
      IF(J.EQ.8)PRINT18
      IF(J.EQ.9)PRINT19
      IF(J.EQ.10)PRINT20
      IF(J.EQ.11)PRINT21
      IF(J.EQ.12)PRINT22
      IF(J.EQ.13)PRINT23
      IF(J.EQ.14)PRINT24
      IF(J.EQ.15)PRINT25
      IF(J.EQ.16)PRINT26
      IF(J.EQ.17)PRINT27
      IF(J.EQ.18)PRINT28
      IF(J.EQ.19)PRINT29
      IF(J.EQ.20)PRINT30
      IF(J.EQ.21)PRINT31
      IF(J.EQ.22)PRINT32
      IF(J.EQ.23)PRINT33
      FORMAT(/3X,60('*'),9X,'CTG.LESS CTG.E/S'//)
      FORMAT(/3X,60('*'),9X,'CTG. HILL TRACTS'//)
      FORMAT(/3X,60('*'),9X,'COMILLA'//)
      FORMAT(/3X,60('*'),9X,'DACCA LESS DACCA E/S'//)
      FORMAT(/3X,60('*'),9X,'JAMALPUR'//)
      FORMAT(/3X,60('*'),9X,'MYMENSINGH'//)
      FORMAT(/3X,60('*'),9X,'NOAKHALI'//)
      FORMAT(/3X,60('*'),9X,'SYLHET'//)
      FORMAT(/3X,60('*'),9X,'TANGAIL'//)
      FORMAT(/3X,60('*'),9X,'BARISAL'//)
      FORMAT(/3X,60('*'),9X,'BOGRA'//)
      FORMAT(/3X,60('*'),9X,'DINAJPUR'//)
      FORMAT(/3X,60('*'),9X,'FARIDPUR'//)
      FORMAT(/3X,60('*'),9X,'JESSORE'//)
      FORMAT(/3X,60('*'),9X,'KHULNA'//)
      FORMAT(/3X,60('*'),9X,'KUSHTIA'//)
      FORMAT(/3X,60('*'),9X,'PABNA'//)
      FORMAT(/3X,60('*'),9X,'PATUAKHALI'//)
      FORMAT(/3X,60('*'),9X,'RAJSHAHI'//)
      FORMAT(/3X,60('*'),9X,'RANGPUR'//)
      FORMAT(/3X,60('*'),9X,'EAST ZONE'//)
      FORMAT(/3X,60('*'),9X,'WEST ZONE'//)
      FORMAT(/3X,60('*'),9X,'BANGLADESH'//)
      PRINT 1
      FORMAT(/8X,'A',14X,'B',14X,'C',17X,'X',16X,'D(MW)',8X,'YEAR',/)
      IF(J.GE.21)NNX=27
      DO 400 I =1,NNX
      NIT=1977
      IF(NNX.EQ.27)NIT=1972
```

```
NEAR=NIT+I
NN=NEAR+1
X=I
D(I)=A(J)+B(J)*X+C(J)*X*X
PRINT 300 ,A(J),B(J),C(J),X,D(I),NEAR,NN
FORMAT(3X,F11.7,4X,F11.7,4X,F11.7,8X,F7.3,9X,F9.3,7X,I4,'-',I4/)
CONTINUE
STOP
END
```

```
      [illegible]
      [illegible]
      OPEN ([illegible]IT=1,[illegible]VIC[illegible]='[illegible]',F[illegible]E='[illegible]')
      OPEN ([illegible]=2 , [illegible]VICE='DS[illegible]',FIL[illegible]='[illegible].[illegible]')
      [illegible] ([illegible],[illegible]) [illegible],[illegible],D2,[illegible],AS,CS,DS
      R[illegible] ([illegible],*)C ,
      R[illegible] ([illegible], ) [illegible],[illegible]
      [illegible] = 2*[illegible]1+AS
      [illegible] = [illegible]+[illegible]
      C[illegible]=CS*C
      D[illegible]=[illegible]*[illegible]
      [illegible]([illegible] , 6)A[illegible],C ,D[illegible]
6     F[illegible]([illegible],'A =',F5.3,5X,'[illegible]F=',2F7.[illegible]/)
      S[illegible]=S[illegible](3.1415926)
      C=C[illegible]
      P=[illegible]
      IF([illegible].[illegible].[illegible]) [illegible]=[illegible].[illegible]
      [illegible]([illegible] ,7)
7     F[illegible]([illegible]X,'[illegible]=',F2[illegible].1[illegible]/)
      D[illegible]=25 ,7[illegible],75[illegible]
      A[illegible]=[illegible]
      [illegible]([illegible] , [illegible])[illegible]
      TYP[illegible],[illegible]
8     F[illegible]R[illegible] ([illegible],'[illegible] STIFY=',F1[illegible].3,2X,'([illegible]/[illegible] . )'/)
      [illegible](2 , [illegible])
      [illegible]
9     F[illegible]([illegible],'[illegible] (S[illegible]. )',25X,'COS[illegible]/[illegible] ([illegible]/[illegible])'//)
      C[illegible]=C[illegible]
      D[illegible] 3 = [illegible],[illegible],5
      [illegible]= /[illegible].
      [illegible]=S[illegible]([illegible]/3.1415926)
      [illegible]=[illegible]*
      C[illegible]=[illegible]/[illegible]+[illegible]261[illegible]A/A[illegible]+C*ARPT+D*[illegible]/[illegible]
      [illegible](2 , [illegible])[illegible],C[illegible]
      TYP[illegible],[illegible],CA[illegible]
[illegible]     F[illegible]R[illegible]([illegible],[illegible]7.[illegible],25X,F17.5)
3     C[illegible]
      [illegible](2 , [illegible])
      [illegible]
1[illegible]    [illegible] (//)
      [illegible]=(2.[illegible]*[illegible]/C[illegible])**([illegible].6[illegible]7)
      [illegible]=[illegible]
      [illegible]=[illegible](/3.[illegible])
      [illegible] = [illegible]*
```

```
      C[illegible] = [illegible] + 2*[illegible] +C*(R*PI+[illegible]
      [illegible](2 , 5)[illegible],C[illegible]
      [illegible] 5, [illegible] ,C[illegible]
    5 [illegible](  [illegible],'[illegible]=',F9. ,'(S[illegible] . )'[illegible]=',F12.5//)
      IF(  .  .7  ) STOP
    2 C[illegible]
      C[illegible](  [illegible] =  )
      S[illegible]
      E[illegible]
```

```
[illegible]
      [illegible] ='[illegible],'F=',2F7.[illegible]/)
[illegible]
    7 [illegible] =',[illegible]/)
[illegible]
      [illegible] =',F1[illegible].3,2X,'(K[illegible]/S[illegible])'/)
[illegible]
      [illegible])',25X,'COST/KVA [illegible])'//)
[illegible]
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[illegible]

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