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Republic of Ghana
Ministry of Energy
Electricity Company of Ghana
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Power Distribution System Master Plan Study for Ghana

Final Report
Supplemental Volume 1
Master Plan Manual for Distribution Network Renewal, Reinforcement and Extension

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Master Plan Manual for Distribution Network Renewal, Reinforcement, and Extension

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I. Outline of the Master Plan Manual

1.1 Outline of the Master Plan Manual

(1) Objective of preparation of the Master Plan Manual

The objective behind preparation of the Master Plan Manual (hereinafter referred to as the "Manual") is to facilitate the work of reviewing and updating the Master Plan for renewal, reinforcement, and extension of the distribution network (hereinafter referred to as the "Master Plan") by the counterpart (hereinafter referred to as the "C/P").

The Manual will serve as reference material in preparation of the Master Plan and also set forth methodology for distribution facility operation to contribute to plans for improvement of distribution works management.

(2) Composition of the Manual

The Manual is composed of the following chapters.

I. Outline of the Master Plan Manual

II. Power demand forecasting

III. Distribution planning

IV. Economic and financial analysis

V. Standards for determination of priority

VI. Compilation of Basic data

Chapters II - V set forth specific methodology for preparation of the Master Plan. Chapter VI describes the compilation of basic data to be prepared for more efficient Master Plan preparation and updating.

(3) Caution in Master Plan updating

The work of updating the Master Plan must be undertaken while referring to the Manual. If it is found that the Manual contains items that do not match the actual conditions at the time, the C/P must flexibly revise the items in question as necessary.

1.2 Basic policy in preparation of the Master Plan

Items (1) - (3) below constitute basic guidelines to be followed in preparation of the Master Plan.

(1) Improvement of the profit rates of power companies through facility renewal and system reinforcement in urban areas

The preparation of plans placing priority on system reinforcement through measures such as renewal and reinforcement of power facilities in urban areas will be linked to an increase in supply reliability and improvement of the profit rates of power companies.

(2) Improvement of power supply quality through sure execution of power system analysis and drafting of countermeasures

Sure analysis of the power system with respect to elements such as voltage drop at the distribution line end, together with the drafting of appropriate countermeasures for problem locations, will help to improve the quality of the power supply.

(3) Proper promotion of RE based on economic and financial analysis

The promotion of rural electrification (RE) will be assisted by accurately identifying as yet unelectrified districts, making proper analyses of the economic and financial circumstances, and clearly establishing electrification priorities.

1.3 Procedure for preparation of the Master Plan

Table 1.1 shows the procedure for preparation of the Master Plan, which is to extend ten years into the future and set forth plans for the renewal, reinforcement, and extension of distribution facilities nationwide.

Table 1.3.1 Procedure for Master Plan preparation

Step	Specific procedure
1	Analysis of the existing distribution system and examination to judge whether it is necessary to reinforce it, with consideration of the macroscopic demand estimate
2	Examination of the prospect of extension of the distribution network based on the microscopic demand estimate (survey of village demand) (The network would be extended from the existing medium-voltage distribution lines; this examination would halso have to consider the plans for distribution line extension in SHEP4.)
	Analysis of the distribution system in the context of both the existing system and new system as a whole, and reexamination to judge whether it is necessary to reinforce it, with consideration of the macroscopic demand estimate
3	Examination to judge whether it is necessary to renew the distribution network
4	Adding up of the distribution facility construction costs and determination of priorities
	Preparation of the (draft) plan for distribution network renewal, reinforcement, and extension based on the findings of the above examinations

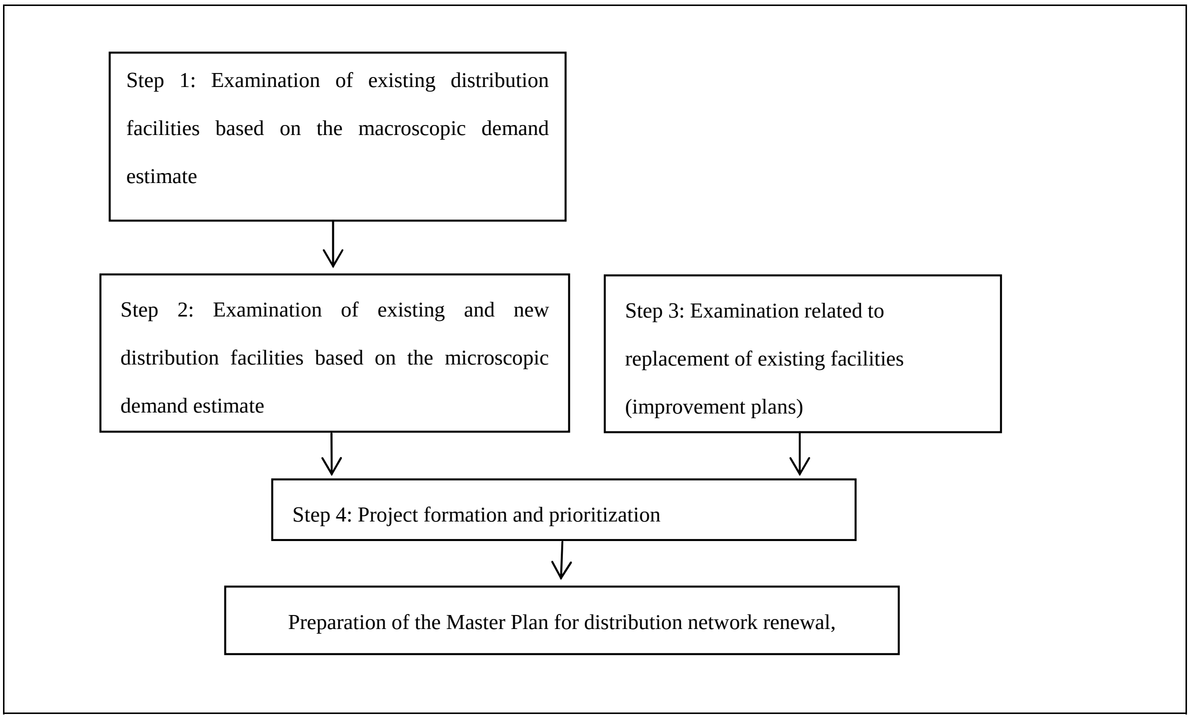


Figure 1.3.1 Flow of Master Plan preparation

The scope of Master Plan preparation is shown in the following table.

Table 1.3.1 Scope of Master Plan

Constituents	Subject scope
Expansion and improvement of existing distribution facilities	Medium-voltage distribution lines and switches
Installation of new distribution lines in RE projects	Medium-voltage distribution lines, switches, and secondary substation transformers

II. Power demand forecasting

2.1 Procedure for macroscopic demand forecasting

2.1.1 Objective of macroscopic demand forecasting

Macroscopic demand forecasts are made for a variety of objectives. The main ones are as follows.

* Preparation of generation plans
* Preparation of transmission and distribution development plans
* Preparation of financial plans and setting of tariffs

The essence of macroscopic demand forecasting is to identify the factors that are related to changes in the power demand. Proper factor identification is followed by preparation of relational expressions and forecast scenarios (consisting of a base case, a low demand case, and high demand case).

2.1.2 Econometric methodology and bottom-up methodology

There are two basic methodologies for estimating power demand. One is the econometric methodology (macroscopic analysis), in which demand estimates are based on correlations with economic and social indicators and the past demand trend. The other is the bottom-up methodology (microscopic analysis), in which they are made by adding up the estimates for the various constituents of the power demand. Each has its own strengths and weaknesses. In the aspect of data, the former can be performed with relatively few types of data, but requires time series data for the whole of the estimate term or even longer. In contrast, the latter is premised on availability of detailed data of various sorts, but does not require time-series data.

Medium- and long-term plans for distribution facilities involve a huge facility capacity, and are therefore generally based on macroscopic analysis. For this reason, the examination of the prospect of expansion and reinforcement of existing distribution facilities entails an analysis of this type. In contrast, installation of new distribution lines through RE requires consideration of the situation in each village, and consequently is based on the results of a microscopic analysis of information obtained from the village survey as well as a macroscopic analysis.

This study will utilize the data and forecast methodology currently applied by the ECG, in light of various factors. These include easier acquisition of data and construction of a demand estimation model, ease of updating the data and model, and adoption of econometric methodology by the ECG already.

Figure 2.1 shows an outline of the flow of the macroscopic demand forecast.

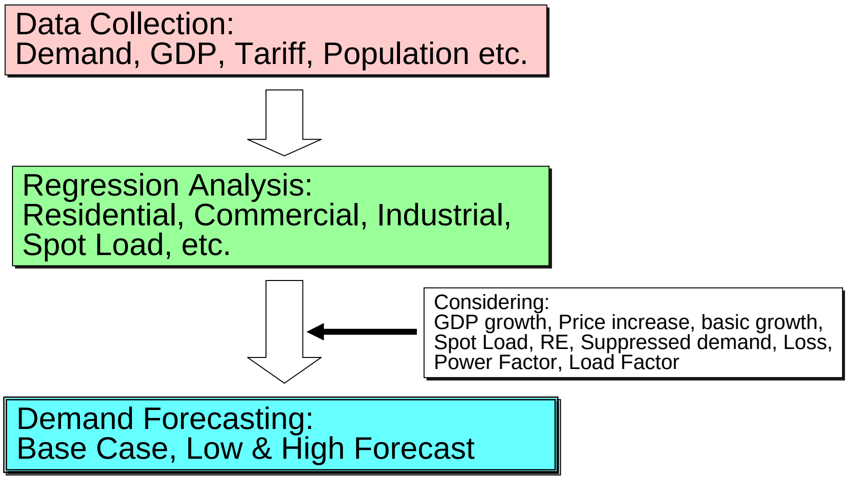


Figure2.1 Demand Forecast Flow

2.1.3. Demand forecasting equations

The demand forecast will be made on the basis of the "Review of ECG's Load Forecast Model" executed in 2006.

Power demand is determined by various factors. The major ones are population growth, level of economic activity, and power tariffs. The relationship between these factors and the power demand can be checked by referring to historical data. The essence of econometric methodology lies in utilization of the confirmed relationship (regression equation) to forecast the future demand.

In almost all countries, economic growth is the factor most involved with increase in the power demand. The gross domestic product (GDP) is the most reliable and usable indicator of the level of economic activity. The power tariff level also has a strong correlation with the demand. The following equation is the basic one.

$$D_i = K * GDP_i^{e} * P_i^{p} \qquad (1)$$

D_i:	power demand
K:	constant term
GDP_i:	gross domestic product
P_i :	power tariff
e:	elasticity relative to the GDP
p:	elasticity relative to the tariff level

Population growth is another factor that is deeply intertwined with the power demand. In countries that are not completely electrified, however, it may not have a direct influence on the demand. In place of population growth, this study will apply a coefficient independent from the GDP and the tariff level in the interest of higher precision.

$$D_i=K*(1+g_b)^i*GDP_i^e*P_i^p \qquad (2)$$

g_b: coefficient for growth independent from the GDP and tariff level

A regression analysis requires the use of a simpler (more linear) relational expression. The constant term can be eliminated by division by the base (zero) year demand.

$$D_i /D_0 =(1+g_b)^i*(GDP_i/GDP_0)^e*(P_i/P_0)^p \qquad (3)$$

Division by the demand in the preceding year produces a relational expression for the terms GDP growth rate and power tariff increase rate.

$$D_i /D_{(i-1)} =(1+g_b)*(GDP_i/GDP_{(i-1)})^e*(P_i/P_{(i-1)})^p \qquad (4)$$

Furthermore:

$$(1+g_{Total})= (1+g_b)* (1+g_{GDP})^e *(1+g_P)^p \qquad (5)$$

g_{Total}: demand increase rate
g_{GDP}: GDP growth rate
g_P: power tariff increase rate

The above equation can be converted into a multilinear one by removing the natural logarithm.

$$Ln(1+g_{Total})= Ln(1+g_b) + e*Ln(1+g_{GDP}) + p*Ln(1+g_P) \qquad (6)$$

This equation will be used to make the regression analysis and the macroscopic demand forecast.

The ECG prepares separate equations of the (6) type for the residential, commercial, and industrial segments, and forecasts demand by multiplying the demand in the previous year by the growth rate (1 + gtotal).

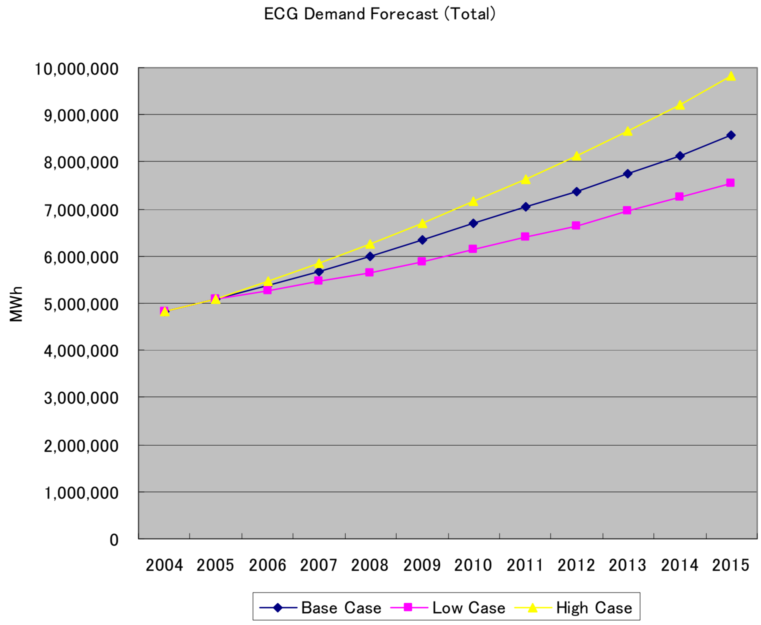


Figure 2.1.2 Results of the macroscopic demand forecast

2.1.4 Examples of macroscopic demand forecasting

To facilitate understanding of the demand forecasting flow, this section presents examples of forecasting of the power demand in Ghana as a whole (including the residential, industrial, and commercial demands as well as loss).

(1) Acquisition of data

Application of the equations presented in Section 2.1.3 requires acquisition of data for total power demand, GDP, and power tariffs. Table 2.1 shows the trend of these data over the years 1997 - 2004.

Table 2.1.1 Trend of power demand, GDP, and power tariffs

	Category	Unit	1997	1998	1999	2000	2001	2002	2003	2004
Demand	Purchase	MWh	3,386,262	3,431,563	3,848,251	3,918,610	4,174,896	4,326,293	4,495,963	4,818,055
GDP	Total	Bill. Cedis	4533.9	4746.9	4956.9	5142.1	5357.1	5600.8	5894.6	6237.8
Tariff	Total Tariff	Cedis/kWh	190	400	500	450	580	750	800	780

(2) Regression analysis

Application of the equations presented in Section 2.1.3 also requires performance of the regression analysis on the following equation.

$$Ln(1+g_{Total}) = Ln(1+g_b) + e*Ln(1+g_{GDP}) + p*Ln(1+g_P) \quad (7)$$

g_{Total}: demand increase rate

g_{GDP}: GDP growth rate

g_P: power tariff increase rate

g_b: growth coefficient independent of the GDP and power tariff

The first step is to calculate the three rates (for demand increase, GDP growth, and tariff increase) and their natural logarithm.

Table 2.1.2 Power demand, GDP, and power tariff increase rates

	1997	1998	1999	2000	2001	2002	2003	2004
1+g total		101.34%	112.14%	101.83%	106.54%	103.63%	103.92%	107.16%
1+g GDP		104.70%	104.42%	103.74%	104.18%	104.55%	105.25%	105.82%
1+g Price		210.53%	125.00%	90.00%	128.89%	129.31%	106.67%	97.50%

Table 2.1.3 Natural logarithms for power demand, GDP, and power tariff increase rates

Ln	1997	1998	1999	2000	2001	2002	2003	2004
1+g total		0.01	0.11	0.02	0.06	0.04	0.04	0.07
1+g GDP		0.05	0.04	0.04	0.04	0.04	0.05	0.06
1+g Price		0.74	0.22	−0.11	0.25	0.26	0.06	−0.03

Performance of a multilinear regression analysis on this basis yields the following results.

Table 2.1.4 Regression analysis results

	Values
e: elasticity relative to the GDP	0.80423
p: elasticity relative to the tariff	-0.02377
$Ln(1+g_b)$	0.01852
gb:	1.87%

Comparison of these results with the actual (measured) figures (1998 - 2004) reveals a gap (error) of no more than 4 percent in all cases. This degree of precision is sufficiently high.

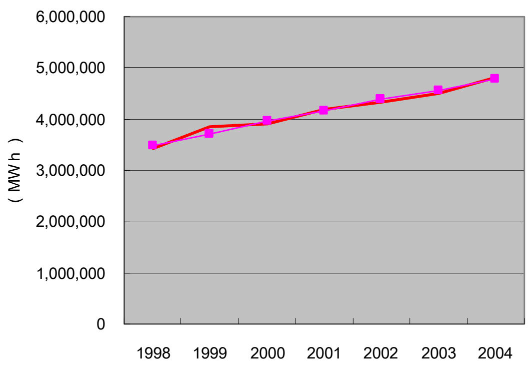


Figure 2.1.3 Comparison of actual and forecast figures for power demand

(3) Demand forecasting

In demand forecasting, a calculation is made of the demand increase rate based on the forecast of the rates of GDP growth and tariff increase.

$$Ln(1+g_{Total}) = 0.01852 + 0.80423*Ln(1+g_{GDP}) - 0.02377*Ln(1+g_P) \quad (7)$$

If the forecast is made with a gGDP value of 6.0 percent and gP value of 10.0 percent, the demand (gTotal) would be 6.51 percent (base case). A continuation of this condition for ten years would yield the following demand forecast results.

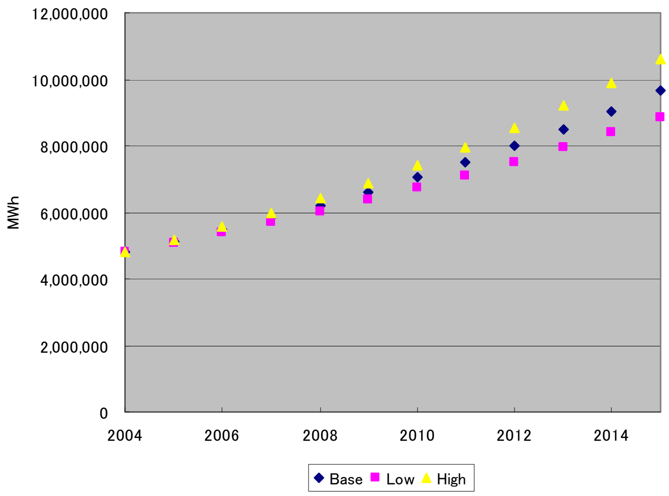


Figure 2.1.4 Power demand forecast results (example)

An actual forecast of the demand requires the preparation of scenarios (including assumed rates of GDP growth etc.) for the base case, low growth, and high growth models, and performance of a regression analysis with subdivision in terms of segment (residential, commercial, and industrial).

2.1.5 Macroscopic demand forecasting with insufficient data

As noted above, in macroscopic demand forecasting with econometric methodology, the basic procedure is to prepare a forecasting equation for each segment (residential, commercial, and industrial) using the GDP growth rate and tariff increase rate, for example, as variables. In macroscopic demand forecasting for distribution planning, it is necessary to forecast the demand at each substation and make the plans accordingly. In many cases, however, there is not a complete set of demand data for each substation.

When complete data are not available for substations and other facilities, the substation current values for the preceding approximately five years may be regarded as indicating the demand (as an alternative to demand data), and used for forecasting based on the methodology described in 2.1.3 and 2.1.4.

2.2 Methodology of Microscopic Demand Estimate

The formulation of distribution network extension plan should be based on the estimate that clarifies the future demand of each community. To estimate the demand, it is necessary to conduct a socio-economic survey on communities to collect information, such as number of households and commercial/public facilities, and use of electric appliances, and then to forecast the scale of communities' power demand. The flow of demand forecast is the following.

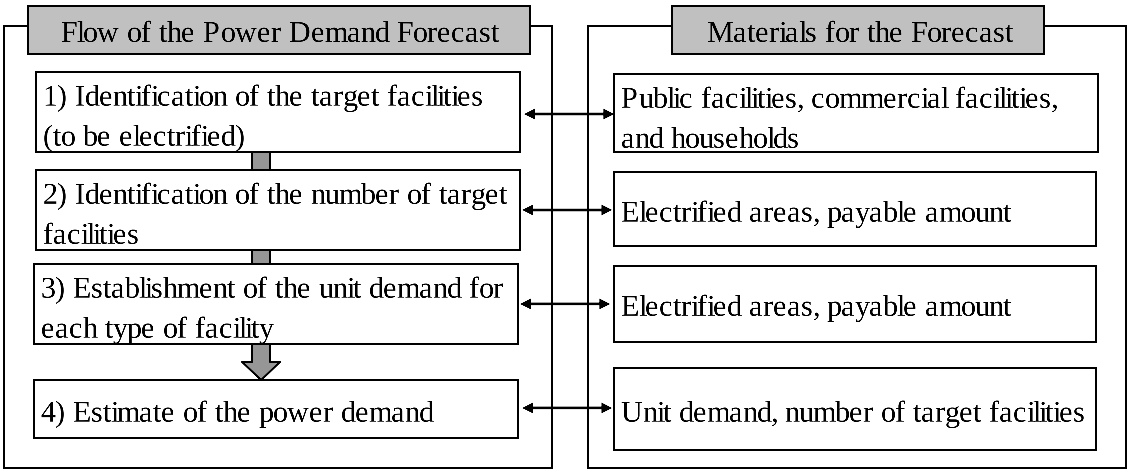


Figure 2.2.1 Flow of Micro Demand Forecast

2.2.1 Identification of the Target Facilities and Their Number

The target facilities and their number are determined by a socio-economic survey on communities. The framework of the survey is as follows.

Table 2.2.1 Framework of Socio-economic Survey on Sample Communities –an Example-

Scope of Survey	Sample villages (the number is determined according to the budget and survey period) - Electrified and Un-electrified Communities - Households, Commercial Facilities and Public Facilities
Survey Contents	**1. Basic information** Community size, household distribution density, number of households, vital population statistics, residential building situation, types of employment, income and expenditure, infrastructural status and plans for development, types and number of commercial and public facilities (stores, restaurants, schools, hospitals, meeting places, etc.), presence/absence of district organizations for mutual aid/water use/etc., and other items. **2. Electrification-related information** (1) Electrified communities Status/duration/hours of use of electric appliances, data on tariff payment, time and method of electrification, household electrification rate, responsibility and management setup of electric system, reasons for a low household electrification rate (supply and demand sides), perception of and satisfaction with power supply, changes in the village situation after electrification, and other items. (2) Un-electrified communities Maximum payable amount as estimated from actual energy-related expenditure (for kerosene, batteries, car batteries, diesel generators, etc.), distribution of target houses and facilities (distance from existing lines to the un-electrified communities), presence/absence of electrification plans and their electrification method, expectations of electricity (comparison between other needs and electrification needs), electric appliances that residents want to use in the future, presence/absence of facilities requiring electrification as viewed from the social standpoint, reasons for lack of electricity (supply and demand sides), and other items. **3. Location and population of un-electrified communities** Identification of the location and population of target un-electrified communities (including those not covered in the sampling survey) based on statistical and other data
Methodology	- Questionnaires need to be modified according to the conditions of each community, such as presence/absence of electricity, differences between on-grid and off-grid sources, and household electrification rate. - Qualitative information will be acquired through various interviews and group discussions. - Information of individual households will be surveyed mainly by questionnaires to 30 - 50 households in each community. Interviews to several households will also be conducted to obtain more detail qualitative information.

The number of target households and commercial facilities to be electrified will be determined based on payable amount and the number of electrified household/facility in electrified communities. In the case of public facilities, the number of target facilities will be determined with reference to the size and necessity of electrification.

2.2.2 Establishment of the Unit Demand for Each Type of Household and Facility

The range of electric appliances in each household and facility is determined by the data acquired through the socio-economic survey on communities. The average capacity of each appliance is determined based on the socio-economic survey and other information. Examples of the unit demand for each appliance type are listed in the following table.

Table 2.2.2 Unit demand for each appliance type

Electric appliance	Capacity(W)	Electric appliance	Capacity(W)
Color TV set (20-inch)	80	Incandescent bulb	60
Color TV set (14-inch)	60	Fluorescent lamp	36
VCR/VCD Player	20	Ceiling fan	60
Stereo (including Radio)	18	Air conditioner	1,200
Medium-sized Refrigerator	135	Electric iron	1,100
Freezer	240	Electric stove (for cooking)	2,200

2.2.3 Electricity Demand Forecast

(1) Forecast for Each Household and Facility

1) Households

Since it is difficult to collect data on the period of time (of day) of electric appliance use, the average power demand (W) of each household is calculated by the following expression.

([Appliance A: Quantity ×Capacity]+[Appliance B: Quantity ×Capacity]+…)

/[Diversity factor]

An example of power demand of an average household is shown in the following matrix. In this example, the demand (W) of an average household is estimated as 121.00 W.

Table 2.2.3 Demand of average household

	Small color TV	Big color TV	Stereo	Cell phone	Incandescent lights	Flourescent lights	Fan	Flash light	Diversity Factor	Total Capacity (W)
Capacity (W)	60	80	18	1	60	36	60	5		
Number	0.20	0.25	0.39	0.38	2.41	0.94	0.36	0.39		
Subtotal	12	20.2	6.93	0.38	144.72	33.95	21.84	1.95	2	121.00

2) Commercial and Public Facilities

Through socio-economic survey, types of electric appliances used in each facility are identified according to the categories of commercial and public facilities. Based on the identified number and capacity of appliance types, the electricity demand of the facilities is calculated as in the case of the households.

(2) Estimation of Household/ Facility Number

When information on the number of household and facility to be electrified is available, electricity power demand will be forecasted on the basis of the information. However, if such information is unavailable, the approximate number of household and facility can be estimated based on population statistics. Specifically, correlation between population and the number of household/ commercial facility/ public facility is defined based on the data of sampled communities. Such correlation can be applied to estimate the number of household and facility in target areas. It is necessary to estimate by region or district to take the regional differences into account.

2.2.4 Summary

In sum, the following equation indicated in Table 2. 2. 4 presents the power demand forecast in each community.

Table 2.2.4 Equation for demand forecast

Facilities	Demand forecast
Households	[Demand per Household]×[Number of Households]×[Electrificaiton Rate of Household]
Commercial facility	[Demand per Facility]×[Number of Facility]×[Electrification Rate of Facility]
Public facility	[Demand per Facility]×[Number of Facility]×[Electrification Rate of Facility]
Public facility *1	[Demand per Facility]×[Number of Facility]

*1 Public facilities all of which are electrified by the government policy (Secondary Schools, Medical Facilities)

"Electrification rate" means the ratio of electrified households or commercial/public facilities to all the households and facilities in electrified communities. For certain types of some public facilities such as junior secondary schools and medical facilities, the government has the policy to electrify all the facilities, and thus electrification rate of such public facilities can be estimated 100%.

III. Distribution planning

3.1 Distribution planning methodology

3.1.1 Demand estimate and efficient investment

In planning for distribution lines, it is extremely important to ascertain the current status of the demand in the supply district. Along with economic and cultural advancement, the demand for power increases, and the scope of its application diversifies. In the preparation of distribution plans, it is vital to get an accurate grasp of items such as the future amount of demand increase and changes in the demand structure, in order to plan for efficient investment and prevent losses due to redundant or excessive investment.

For this reason, in estimating demand, it is the general practice to apply statistical approaches because it would be difficult to make actual measurements except in certain cases.

It is extremely rare for all types of electrical equipment to be used at once, and there is consequently no need to build distribution facilities with an aggregate capacity that is about the same as that of all the electrical equipment on the demand side. Therefore, demand is generally estimated with consideration of the demand factor, diversity factor, and load factor.

(1) Demand factor

The demand factor is equal to the maximum demand among customers in a certain period divided by the facility capacity (the total rated capacity of facilities for supply to those customers).

Demand factor = maximum demand (kW)/facility capacity (kW) x 100%

Because it rarely happens that all facilities are operated at full load simultaneously, the demand factor is usually under 100 percent.

(2) Diversity factor

When taking the same type of demand (e.g., between customers connected to the same distribution line or between distribution line transformers) as a single group, the maximum demand of each component may not occur simultaneously, but instead exhibit a temporal gap. Therefore, the sum total of the component maximum demands may be even bigger than the maximum demand as a whole. The coefficient for this difference is the diversity factor, which is larger than 1.

Diversity factor = total component maximum demands (kW)/total maximum demand(kW)

(3) Load factor

Power usage varies substantially depending on the time (and possibly season as well). The load factor is the ratio of the average demand at customers or substations within a certain period to the maximum demand within the same period, expressed as a percentage.

Load factor = average demand (kW)/maximum demand (kW) x 100%

The load factor indicates the degree to which the electrical facilities are being put to effective use. A higher one indicates more effective use. From the standpoint of power suppliers, it is necessary to install enough facilities to meet the maximum demand, regardless of the size of the load factor.

Load factors can be apprehended in terms of days, months, or years (i.e., daily, monthly, or yearly load factors).

3.1.2 Distribution line planning

The distribution system has an area-wise extension and may be likened to the mesh of a net. It requires a planning methodology that corresponds with the characteristics of the region.

Therefore, the determination of distribution line routes must consider all pertinent factors, including the requisite degree of supply reliability, economic feasibility, operation and maintenance (O&M) aspect, and relation with facilities already installed.

(1) Selection of distribution voltage

There are two voltage classes of medium-voltage distribution lines: nominal 33 and 11 kilovolts. It is important to select the class that is technically and economically better for the estimated distribution line span and load density.

(2) Selection of distribution line routes

For distribution line routes, the fundamental rule is to select the route that yields the shortest distance between the power source and the demand site. At the same time, however, it is also necessary to consider convenience for O&M work, and to avoid locations that make patrol or repair work difficult and are susceptible to the influence of climate conditions.

(3) Determination of cable thickness and type

The major determinants of cable thickness are allowable current, voltage drop, and mechanical strength. Distribution lines in urban areas have a short span, and consequently are under relatively little limitation due to voltage drop. The main determinant is consequently allowable current. In contrast, distribution lines in rural areas generally have less load and a longer span. For them, the main determinant of size is usually voltage drop.

(4) Determination of transformer capacity

To determine the requisite transformer capacity, an estimate is made of the maximum actual load. This is obtained by multiplying the facility load by the demand factor and dividing the product by the intercustomer diversity factor. Even if the maximum load is larger than the transformer capacity, it may be permissible to use the transformer in an overload status for a very short time. Nevertheless, operation in this status has an adverse impact on the service life of transformers, and must be held to extremely limited durations. (Specifically, it should be restricted to cases in which short-time overload holds an economic advantage even at the sacrifice of transformer service life to a certain extent.)

3.1.3 Electrical characteristics of distribution lines

This section describes fundamental knowledge about electricity needed for distribution line planning.

(1) Line constants

Distribution lines are characterized by lower voltages and shorter spans than transmission lines. As such, basically the only factors that must be considered are resistance and inductance. (The calculation of ground current requires consideration of the ground electrostatic capacity, but this is omitted here.)

(a) Resistance

If the resistance per kilometer of cable is expressed as $r[\Omega / \mathrm{km}]$, the line resistance could be found by the following equation. (Length of the line : $\ell[\mathrm{m}]$)

$$R = \frac{r\ell}{1000} \quad [\Omega]$$

A calculation can be made using the following equation, in which the cable cross-section area is $A[\mathrm{mm}^2]$ and the resistivity is $\rho[\Omega\mathrm{mm}^2/\mathrm{m}]$.

$$R = \rho\frac{\ell}{A} \quad [\Omega]$$

Line resistance is generally expressed in terms of the level at a temperature of zero or 20 degrees (centigrade). At other temperatures, a conversion can be made through the following equation.

$$R_t = R_{t_0}\left[1+\alpha\left(t-t_0\right)\right]$$

Here: t_0 : standard temperature (C)

t : chosen temperature (C)

R_{t_0} : resistance at t_0 (Ω)

R_t : resistance at t (Ω)

α : temperature coefficient distinctive to the material at t_0

(b) Inductance

Cable inductance is determined by the magnetic flux induced by the current flowing through the cable and the interlinkage number. It therefore varies with the cable thickness and placement as well as the current flow.

In the case of one-phase two-line and three-phase three-line arrangements, the inductance per line is generally expressed by the following equation.

$$L = 0.05\mu_s + 0.4605\log_{10}\frac{D}{r} \quad [\mathrm{mH/km}]$$

Here:

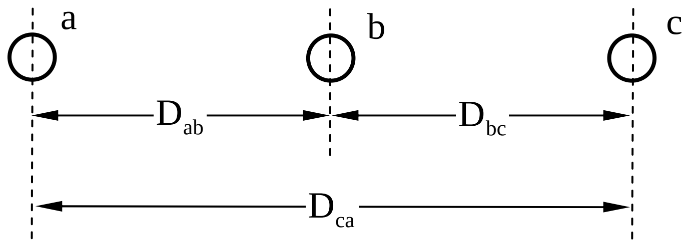
μ_s : relative magnetic permeability

r : line radius ［m］

D : equivalent interline distance ［m］

In the case of two lines: central distance between the two lines

In the case of three lines: $D = \sqrt[3]{D_{ab}D_{bc}D_{ca}}$



(2) Voltage drop

To keep the voltage of supply to customers at an allowable value, it is necessary to ascertain the degree of drop in distribution lines.

(a) General equation

In the equivalent circuit shown in Figure 3.1.1, if Es = sending end voltage, Er = receiving end voltage, I = line current, R = distribution line resistance (per phase), X = distribution line reactance (per phase), and $\cos\theta$ = power factor, then the vector diagram would be as shown in Figure 3.1.2.

As a result, Es could be obtained by the following equation.

$$E_s = \sqrt{(E_r + IR\cos\theta + IX\sin\theta)^2 + (IX\cos\theta - IR\sin\theta)^2}$$

In this equation, the second item has less of an influence on Es and Er than the first item, and could be ignored. If it is omitted, the equation would become as follows.

$$E_s = E_r + IR\cos\theta + IX\sin\theta$$

Therefore, voltage drop e can ̀ee obtained by the following equation.

$$\begin{aligned} e &= E_s - E_r \\ &= I(R\cos\theta + X\sin\theta) \end{aligned}$$

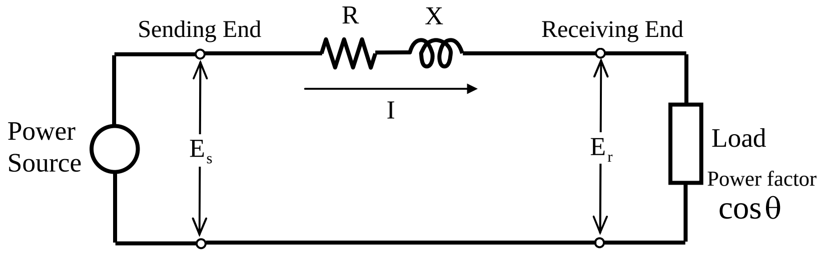


Figure 3.1.1 Equivalent single-phase circuit

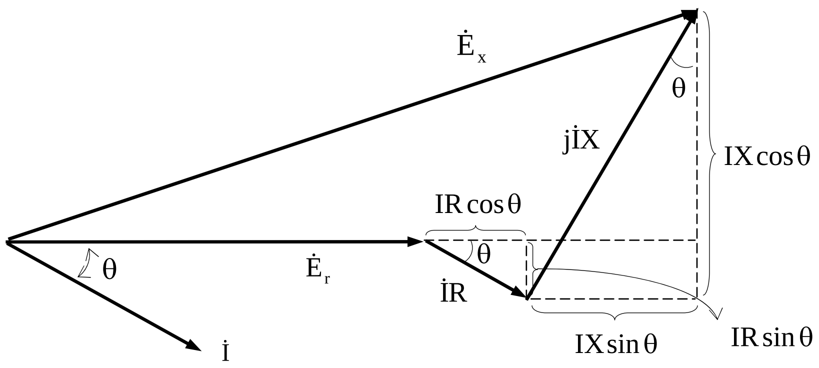


Figure 3.1.2 Equivalent circuit vector diagram

(b) Terminal-concentrated load routes

If there is load only at the distribution line end and not along the way, and if there are no feeders along the way, the current value is constant. In this case, the equations shown below can be used to obtain the voltage drop on one-phase two-line routes and three-phase three-line routes.

＜One-phase, two-line＞

$$\begin{aligned} e &= 2E_s - 2E_r \\ &= 2I(R\cos\theta + X\sin\theta) \end{aligned}$$

＜Three-phase, three-line＞

$$\begin{aligned} e &= \sqrt{3}E_s - \sqrt{3}\,2E_r \\ &= \sqrt{3}I(R\cos\theta + X\sin\theta) \end{aligned}$$

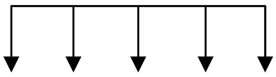
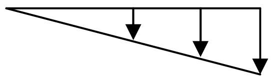
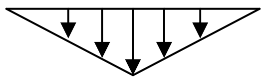
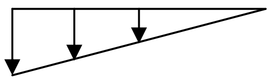
(c) Distributed load route

On actual distribution lines, load exists not only on the line end but also on other sections. The voltage decline e can therefore be found through the following equation, where the load power factor is cos theta, the resistance and reactance per unit of route length are R and X (ohms/km), respectively, the route span is l (km), and the sending end current is I (A).

$$e = f(R\cos\theta + X\sin\theta)\ell I \quad [V]$$

Here, f is the distributed load factor, and differs depending on the pattern of distributed load (see the table below).

Table 3.1.1 Distributed load patterns and rates

Distributed load patterns		Distributed load rates (figures in parentheses indicate percentage)
Terminal-concentrated load		1 (100)
Equally distributed load		$\frac{1}{2}$ (50)
Load that is larger closer to the terminal		$\frac{2}{3}$(67)
Load that is larger closer to the center		$\frac{1}{2}$ (50)
Load that is larger closer to the sending end		$\frac{1}{3}$ (30)

(3) Technical loss

The dominant forms of technical loss are loss due to line resistance, and iron and copper loss in transformers. The latter is determined by the transformer capacity, characteristics, and utilization coefficient. The former is in proportion with the square of the distribution line current and with the line resistance, and is not connected with the power factor or frequency.

Loss due to line resistance loss w (W) can be expressed by the following equation, where the line current = i (A), line resistance (per line) = r (ohms/m), and line length = L (m).

$$w = i^2 \, r \, L$$

Ordinarily, the current (i) is not constant, but instead gradually decreases if there is a load or feeder along the way. Therefore, line resistance loss w (W) could be expressed by the following equation, where the current going through the line at a point located x distance from the source = i (x) (A).

$$w = \int_o^L {i_x}^2 r \, dx = {I_m}^2 rLh$$

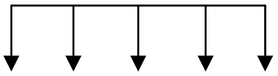
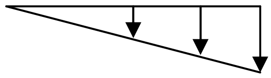
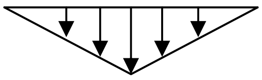
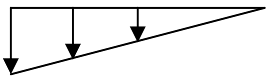
Here:

I_m : sending end current［A］

h : distributed loss coefficient $\left(= \dfrac{\int_0^L {i_x}^2 r}{{I_m}^2 \, r \, L} \right)$

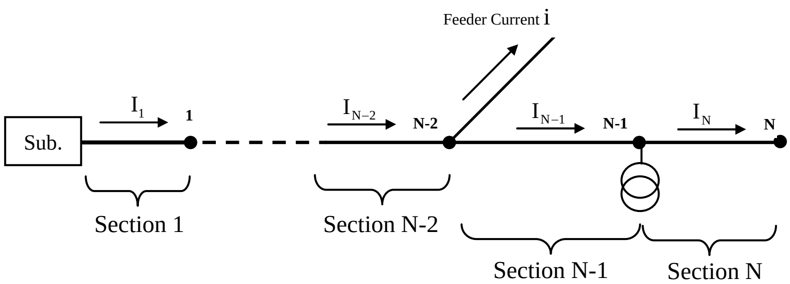
The distributed loss coefficient varies with the pattern of distributed load. Table 3.1.2 shows these patterns.

Table 3.1.2 Distributed load patterns and rates

Distributed load patterns		Distributed load rates (figures in parentheses indicate percentage)
Terminal-concentrated load		100
Equally distributed load		33 $\left(\frac{1}{3}\right)$
Load that is larger closer to the terminal		55 $\left(\frac{8}{15}\right)$
Load that is larger closer to the center		20 $\left(\frac{1}{5}\right)$
Load that is larger closer to the sending end		38 $\left(\frac{23}{60}\right)$

In reality, however, the coefficients noted above may not apply perfectly due to the complex connection of feeders to distribution lines along the way, the outflow of primary current in transformers, and the lack of such uniformity in the distribution of load. (In other words, the coefficients are no more than theoretical values.)

To obtain the resistance loss on medium-voltage lines by an actual calculation, it is necessary to divide the line into sections at each point where the current changes and find the resistance loss for each section.



In the diagram above, the section currents I_{N-1} and I_{N-2} would be as follows.

$$I_{N-1} = I_{N-2} - \text{Feeder Current i}$$

$$I_{N} = I_{N-1} - \text{the primary current of transformer N-1}$$

Therefore, the resistance loss (W) in each section would be as follows.

$$w_{Section\_N} = I_N{}^2 r_N L_N$$

$$w_{Section\_N-1} = I_{N-1}{}^2 r_{N-1} L_{N-1} = \left(I_N + \text{Feeder Current i}\right)^2 r_{N-1} L_{N-1}$$

$$w_{Section\_N-2} = I_{N-2}{}^2 r_{N-2} L_{N-2} = \left(I_N + \text{Feeder Current i} + \text{transformer N} - 1 \text{ primary current}\right)^2 r_{N-2} L_{N-2}$$

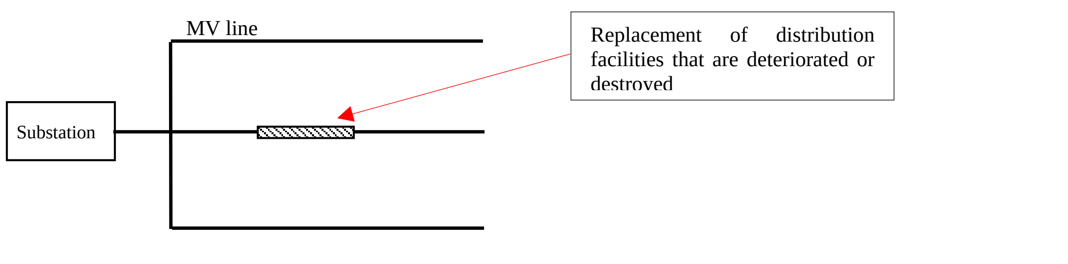
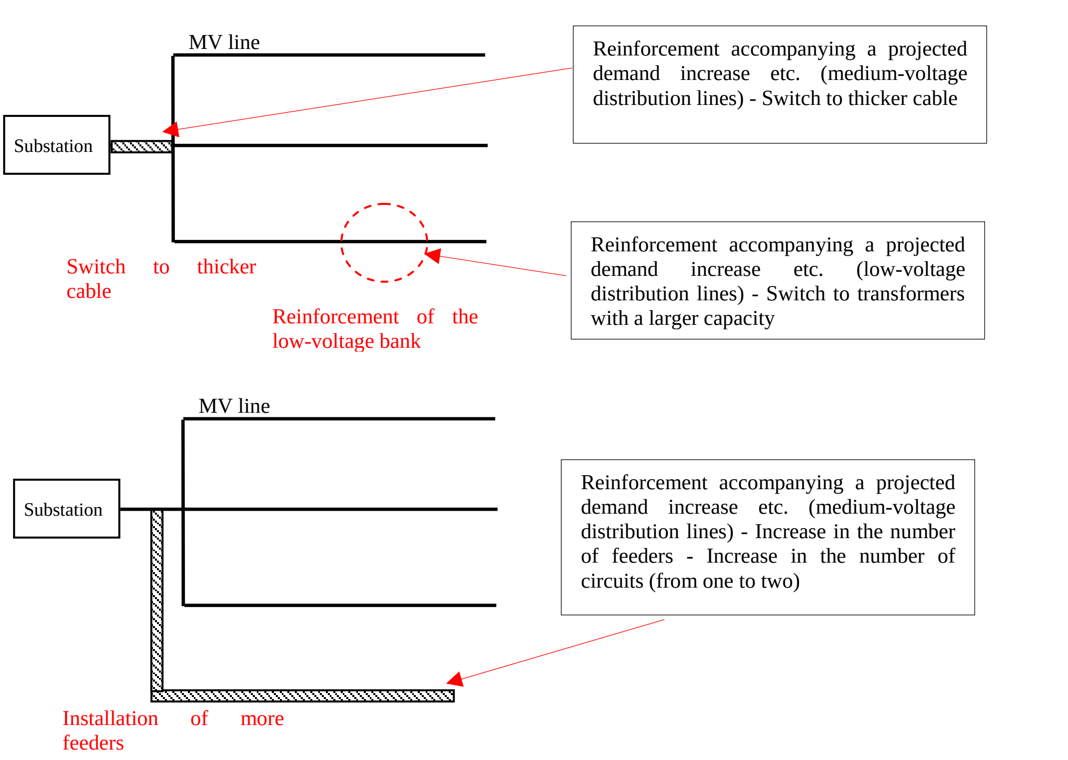
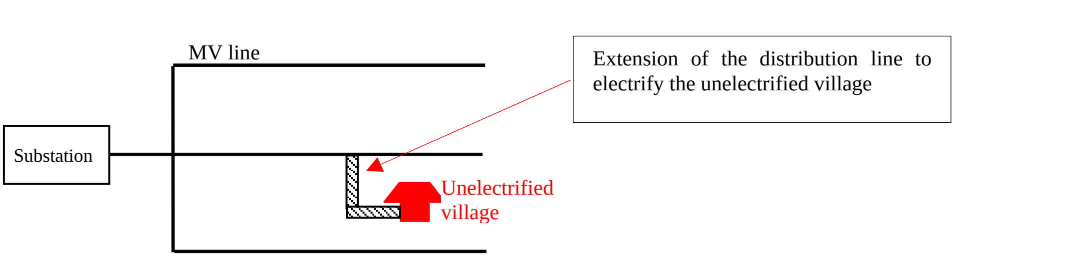
:

:

3.2 Distribution network renewal, reinforcement, and extension methodology

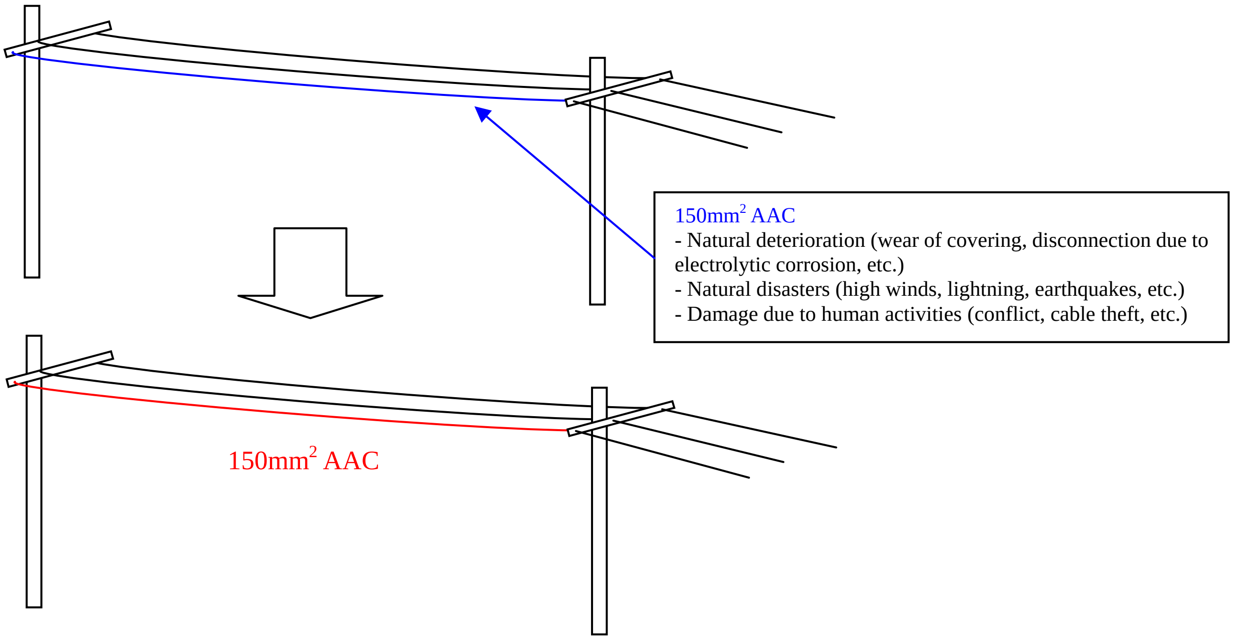
The respective meanings of renewal, reinforcement, and extension of the distribution network are as follows.

Table3.2.1 Definition of Distribution network renewal, reinforcement and extension methodology

Distribution line renewal	
Distribution line reinforcement	
Distribution line extension	

3.2.1 Distribution line renewal

renewal is undertaken in response to deterioration and damage accompanying natural disasters or human activities. It consists of the removal of old distribution facilities and replacement with new ones.



As a general rule, the old facilities are replaced with others that have an identical or equivalent performance. When there are prospects for an increase in the demand or, on the contrary, the emergence of surplus capacity under the status quo, the old facilities may be replaced with those of a different capacity on the occasion of renewal.

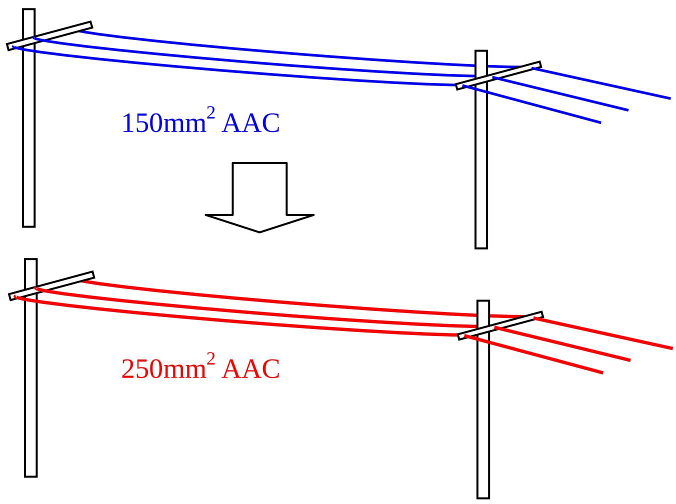
3.2.2 Distribution line reinforcement

Reinforcement proceeds through means such as replacement of existing facilities with others of a larger capacity and increased installation of feeders. It is undertaken in response to an increase in the distribution line load or shortage of line or transformer capacity due to demand growth or a shift from off- to on-grid systems, and a larger drop in voltage such that the voltage reaching customers is below the prescribed value.

(1) Switch to thicker cable (measure for medium-voltage distribution lines)

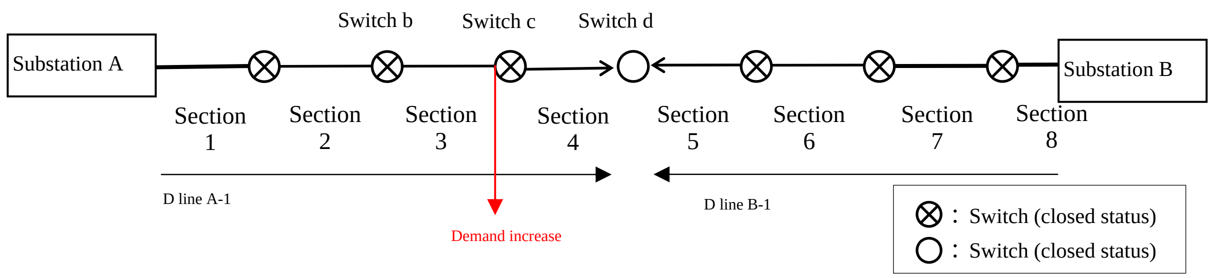
The switch is made by replacing the cable used for medium-voltage distribution lines. Ordinarily, the switch is made for all three phases.

In this work, the following two points require attention.



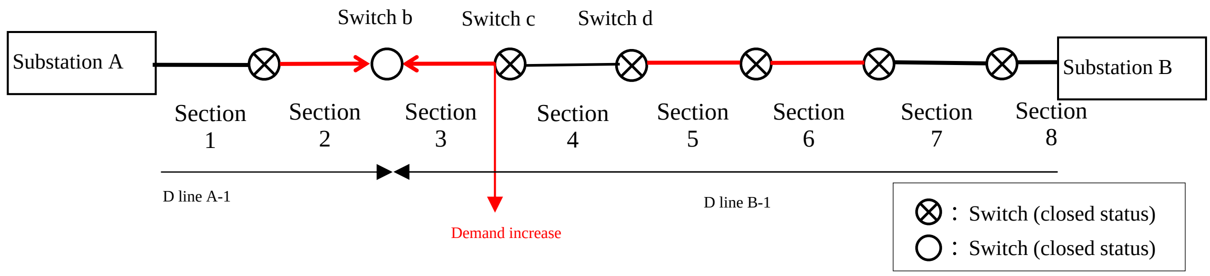
(a) Replacement sections

The cable should be replaced not only for the section immediately before the load but also for sections where the current could become too high (including the send-back sections if there is reverse transmission (?) from the source side or other routes).



In the diagram above, if there is a big increase in demand immediately before Switch c, it would ordinarily be sufficient to replace the cable only in Section 2 and Section 3. If, however, Switch d is installed and Switch b is opened, such that a switch is made to Distribution Line B-1 for Section 4 and Section 5, the cable will also be replaced on sections 4 - 6 as necessary, in view of the current through them.

(In replacement shown in the following diagram, the cable in sections 5 and 6 would also be replaced in the event of an increase in the current through them beyond the allowable level.)



(b) Increase in the load on supporting structures

The following load is imposed on the structures supporting distribution lines.

1) Vertical load

- Dead load of the supporting structures, and weight of attached equipment (cables, insulators, transformers, etc.)

2) Horizontal lateral load

- Wind pressure load imposed on supporting structures, lines, etc. in a direction vertical to the line, and horizontal lateral component of the line tension in line curves

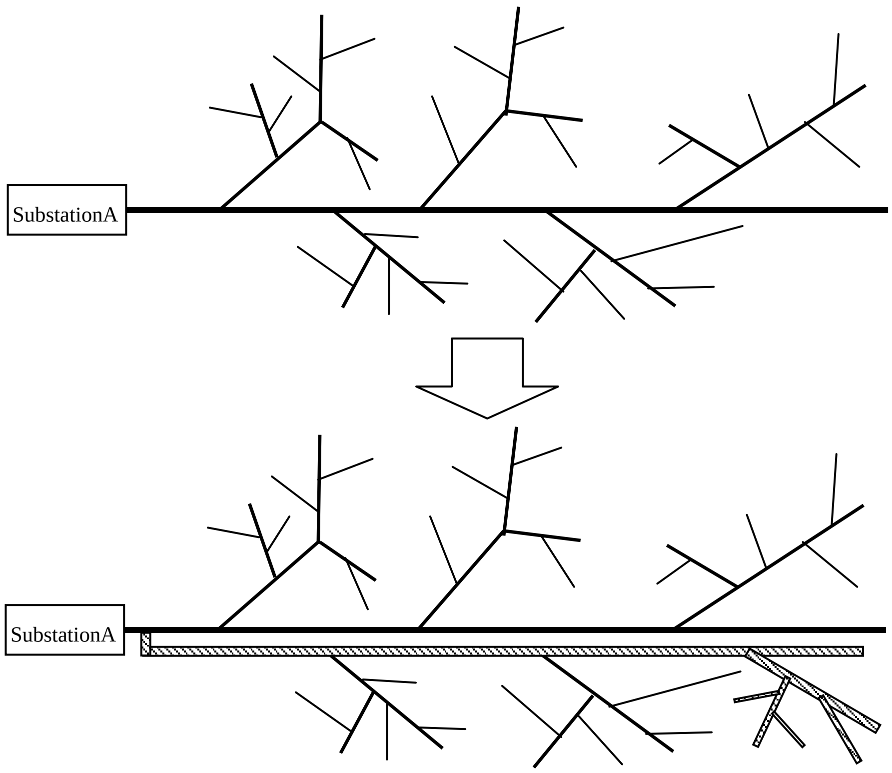
3) Horizontal vertical load

- Wind pressure load imposed on supporting structures etc. in the line direction, unequal tension on the line, etc.

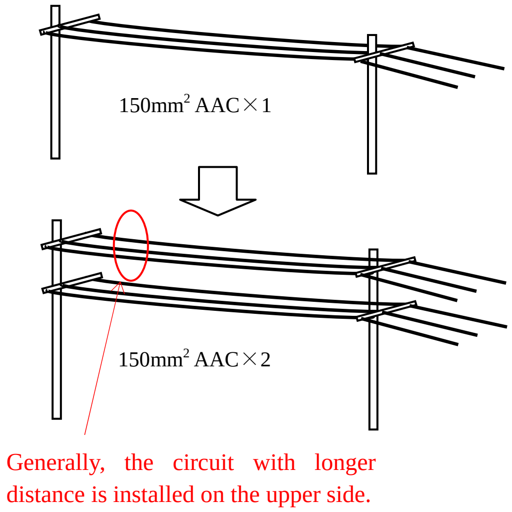
As this suggests, full account must be taken of whether or not the supporting structures are strong enough to withstand the big increase in the cable dead load and horizontal load resulting from the switch to thicker cable. If necessary, the supporting structures must be rebuilt themselves.

(2) Increase in the number of circuits (from one to two)

Another method of coping with load increase is to increase the number of circuits on a single distribution line to two in order to disperse the load (see the diagram below). It can be applied when there is a shortage of line capacity but a surplus of capacity for transmission to feeders.



This method usually requires the construction of an additional distribution line for a considerable distance, but it may be possible to string two circuits on the same supporting structures already standing, provided that these structures are high enough and strong enough. In this case, however, the items noted below must be taken into full consideration. If an overall study concludes that two circuits cannot be strung on the same structures, new structures must be built for the second circuit.



(a) Increase in the load on the supporting structures
- Use of the upper circuit for transmission over short distances and the lower circuit for transmission over long distances
(b) Assurance that the lower circuit is a sufficient distance above the ground
(c) Reliability risk

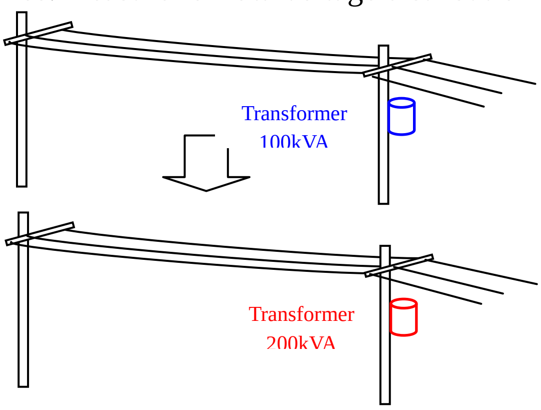
Attachment of two circuits to the same supporting structures increases the number of outages for maintenance, and makes maintenance work more difficult. There is also the possibility of simultaneous failure of both circuits.

(3) Increase in the number of feeders (measure for substations and medium-voltage distribution lines)

If there is margin as regards the number of distribution lines leading away from the primary substation (e.g., bank capacity at the primary substation and space for installation of switches accompanying feeder installation), it may be possible to install more feeders (this method, however, entails a high cost, and should be taken only when the aforementioned methods cannot be taken).

(4) Switch to transformers with a larger capacity (reference: measure for low-voltage distribution lines)

Existing transformers are replaced with others with a larger capacity. In this approach, the following two points require attention.



(a) Replacement of cut-outs and fuses

Cut-outs and fuses are installed on the primary side of transformers. If their capacity is not sufficient for that of the new transformer, they must be replaced with others of a higher capacity.

(b) Optimal transformer capacity

When replacing transformers with others of a higher capacity, it is necessary to select a capacity with margin if there is already, or is projected to be, a substantial increase in the load. It should be noted, however, that transformers cause iron loss in correspondence with their capacity, regardless of the utilization rate. For this reason, it would not be advisable to select transformers with an unnecessarily large capacity and use them for a long duration at a low utilization rate.

The measures described in sections (1) - (3) above are for reinforcement on medium-voltage lines. When lines cannot be reinforced by any of these measures (e.g., in cases such as an insufficient bank capacity at primary substations due to a big increase in load, and inability to send power through distribution lines to the site of load increase, which remote, due to the voltage drop), it is necessary to take others such as construction of additional distribution-use substations, increase in the number of banks, and extension of transmission lines. These methods will not be treated in the Manual because they are not in the distribution division.

3.2.3 Distribution line extension

In electrification of as yet unelectrified villages, a careful estimate must be made of the demand (including the future increase as well as the present level) in those villages.

Distribution lines are designed on the basis of the load current derived from the demand estimate, and with consideration of the following points.

* The determination of the line route and type of cable must take account of not only the demand in the village to be electrified but also those in the next villages that may possibly be electrified later.
* Technicians must consider the increase in load current and voltage drop not only for the extended section but also on the distribution lines already installed on the source side (from the connection).

3.3 Distribution system analysis methodology

Distribution system analysis investigates the loading on medium-voltage distribution lines and voltage drop at their termini. It is based on the single-line connection diagrams and current sent out from the primary substation.

(1) Procedure for execution of distribution system analysis

Distribution system analysis consists of two types of analysis, as follows.

* System analysis of existing distribution facilities based on macroscopic demand forecasting (Step A)
* System analysis of distribution line extensions (Step B)

The procedure for distribution system analysis is detailed in Table 3.3.1.

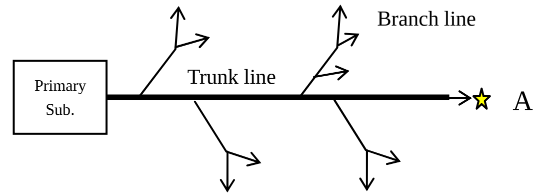
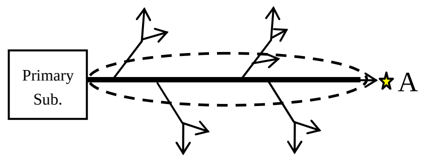
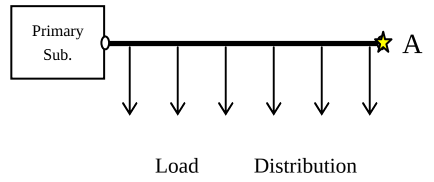
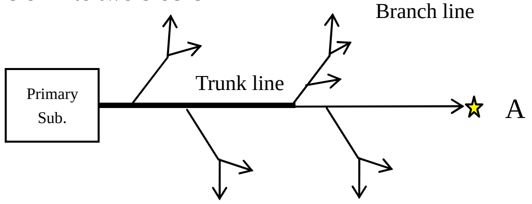
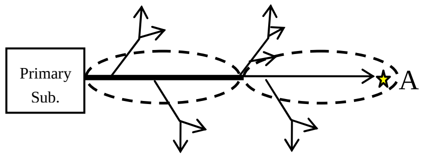
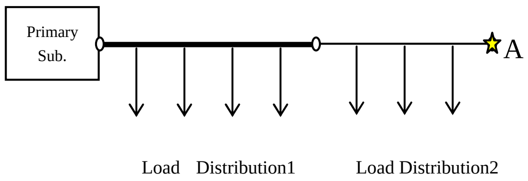
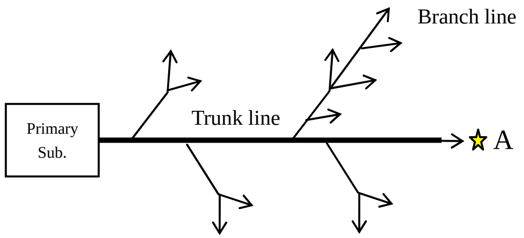
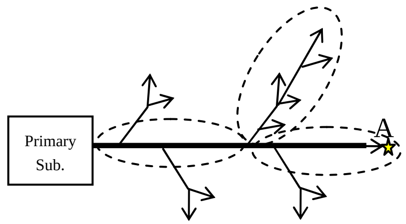
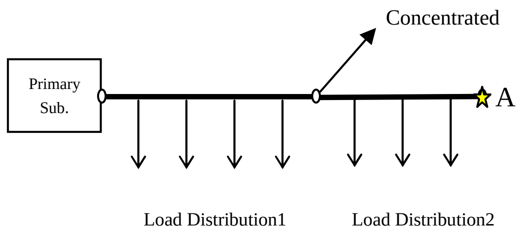
Table 3.3.1 Procedure for distribution system analysis

Procedure			Contents
Step A - System analysis of existing distribution facilities based on macroscopic demand forecasting	A-1	Compilation of data and documentation	- Single-line connection diagrams - Actual maximum current at the outlet of primary substations - Estimated maximum current at the outlet of primary substations based on the macroscopic demand forecast
	A-2	System diagram condensation	- Preparation of single-line connection diagrams for feeders covered by the analysis - Summation of the distribution system diagrams at the analysis points (the detailed system condensation methodology is described in Section (2))
	A-3	Calculation of voltage drop and loading	- Calculation based on the calculation tool
Step B: System analysis of the distribution line extensions	B-1	Compilation of data and documentation	- Pole maps - Location and demand scale of unelectrified villages - Single-line connection diagrams
	B-2	Preparation of contracted system diagrams	- Preparation of calculation tool made in Step A for the analysis points
	B-3	Calculation of voltage drop and loading	- Calculation based on the calculation sheet -- Re-execution of the system analysis for existing facilities taking account of the current in the extended section, followed by analysis of the extended section.

(2) Methodology for system condensation of the distribution system

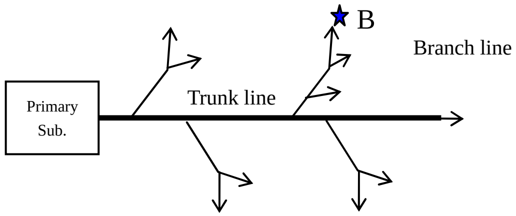
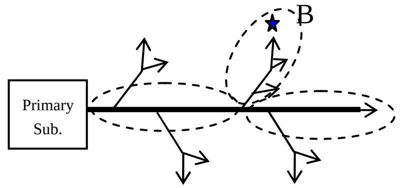
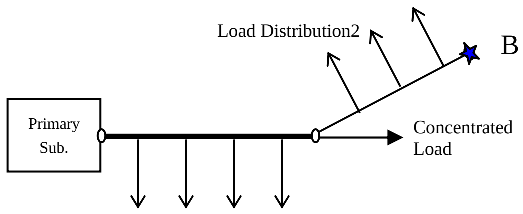
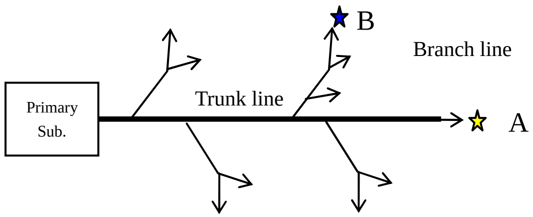
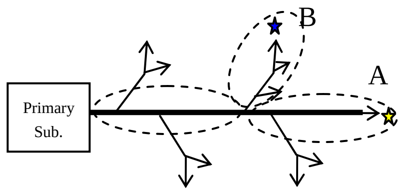
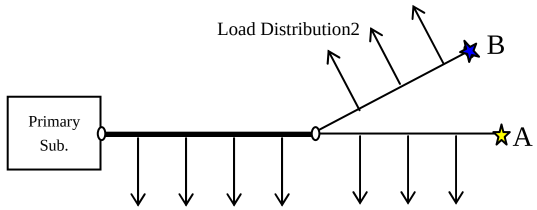
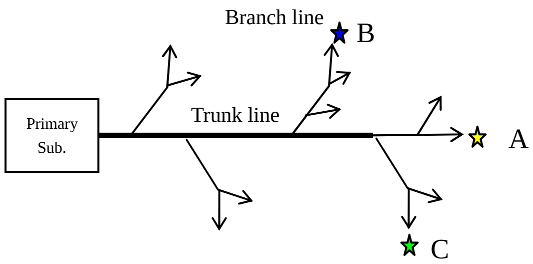
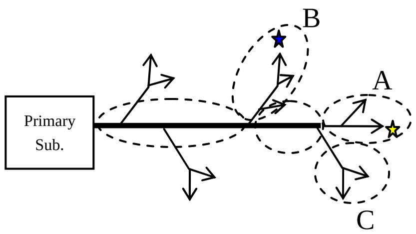
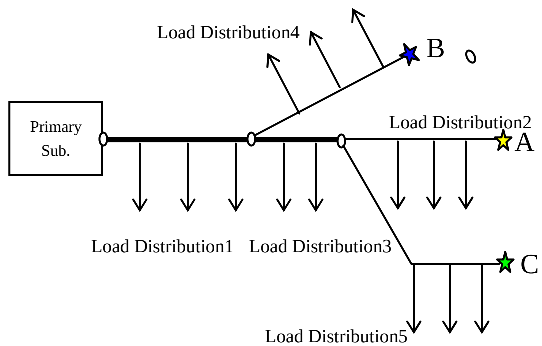
Table 3.3.2 shows examples of system condensation, which is a methodology for more efficient performance of distribution system analysis.

Table 3.3.2 Examples of system condensation (1/2)

	Actual system diagram	Example of system condensation	
		Blocking	System condensation
1	* One analysis point at the distribution line terminus (end) * Same type of cable from the substation to the analysis point 	One block 	
2	* One analysis point at the distribution line terminus * Change of cable type between the substation and the analysis point * Division into two blocks 	Division into two blocks 	
3	* One analysis point at the distribution line terminus * Higher load in a feeder section 	Division into three blocks 	

** Choice of three types of distributed load: equally distributed, higher closer to the terminus, and higher closer to the sending end

Table 3.3.2 Examples of system condensation (2/2)

<table>
<tr><th colspan="2" rowspan="2">Actual system diagram</th><th colspan="2">Example of system condensation</th></tr>
<tr><th>Blocking</th><th>System condensation</th></tr>
<tr><td>4</td><td>* One analysis point at a feeder terminus
* Change of cable type between the main line and the feeder
</td><td>* Division into three blocks
</td><td></td></tr>
<tr><td>5</td><td>* Two analysis points
</td><td>* Division into three blocks
</td><td></td></tr>
<tr><td>6</td><td>* Three analysis points
</td><td>* Division into five blocks
</td><td></td></tr>
</table>

(3) Distribution system analysis tools

Table 3.3.3 shows the distribution system analysis tool calculation sheets corresponding with the condensed diagrams shown in Table 3.3.2. Tables 3.3.4 - 7 show the calculation sheets prepared on this basis.

Table 3.3.3 Types of calculation sheet for distribution system analysis tools

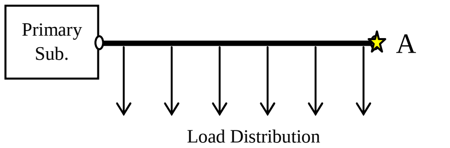
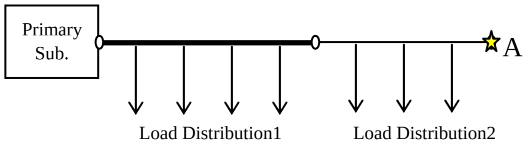
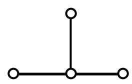
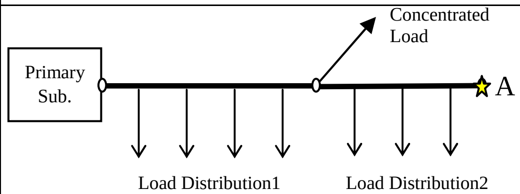
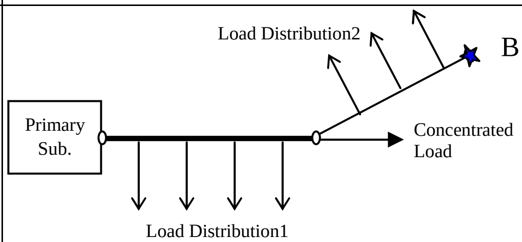
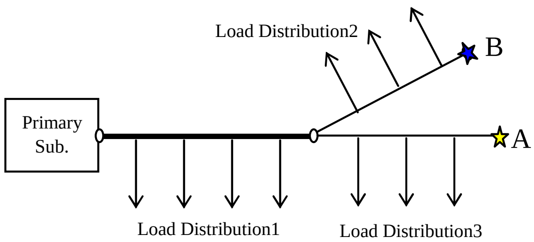
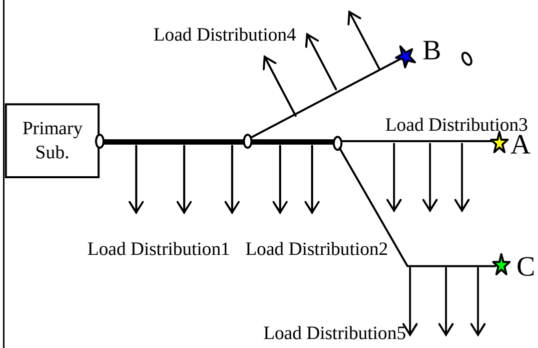
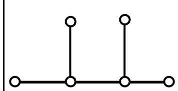
Actual system		System condensation	Types of calculation sheet for distribution system analysis tools	
1	* One analysis point at the distribution line terminus * Same type of cable from the substation to the analysis point		Type 1	
2	* One analysis point at the distribution line terminus * Change of cable type between the substation and the analysis point		Type 2	
3	* One analysis point at the distribution line terminus * Higher load in a branch section			
4	* One analysis point at a feeder terminus * Change of cable type between the main line and the branch line			
5	* Two analysis points			
6	* Three analysis points		Type3	

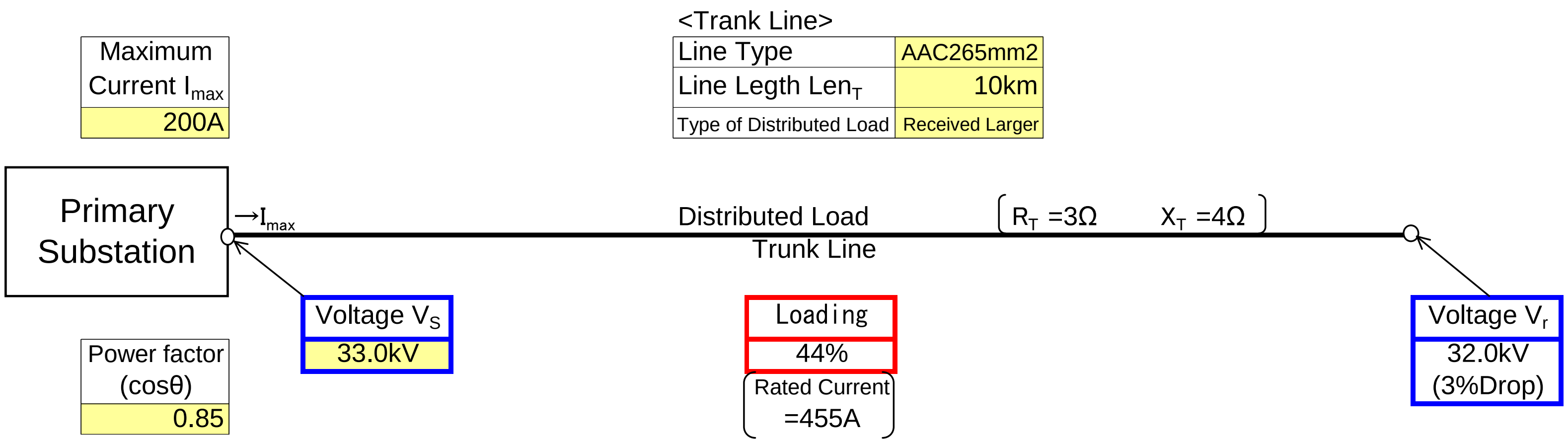
Table3.3.4 Power System Analysis Tool for STEP A, Type1

Power System Analysis for Step A *- Power System Analysis for existing system using Macro demand forecast -*

Substation Name	ABC
Feeder Name	No1

: Input data in colored cells

Type-1



=====Equation=====

$V_r = Vs - 1.732 \cdot I_{max}(R_T \cos\theta + X_T \sin\theta) \cdot f_T$

V_s	: Supply Voltage	R_T	: Resistance	f_T	: Dispersal Load Factor
V_r	: Received Voltage	X_T	: Reactance		
I_{max}	: Maximum Current	cosθ	: Power Factor		

Table3.3.5 Power System Analysis Tool for STEP A, Type2

Power System Analysis for Step A *- Power System Analysis for existing system using Macro demand forecast -*

Substation Name	ABC
Feeder Name	No1

(yellow cell) : Input data in colored cells

Type-2

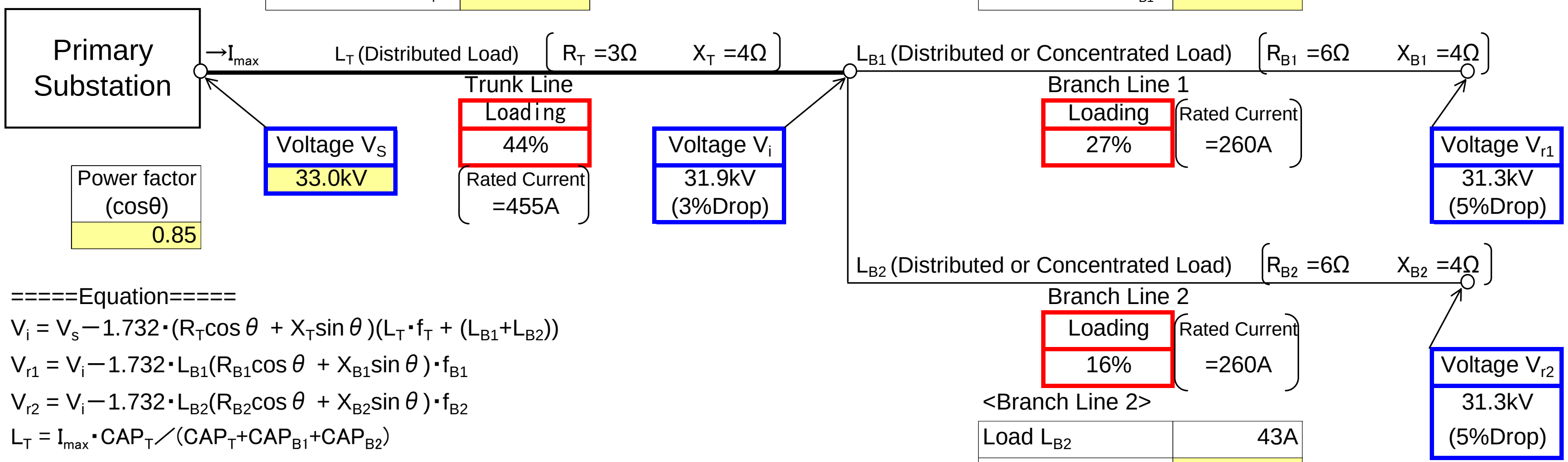
<Trank Line>

Load L_T	86A
Line Type	AAC265mm2
Line Legth Len_T	10km
Type of Distributed Load	Equality
Total Transformer Capacity of secondary substations CAP_T	3000kVA

<Branch Line 1>

Load L_{B1}	71A
Line Type	AAC50mm2
Type of Load	Received Larger
Line Length Len_{B1}	10km
Total Transformer Capacity of secondary substations CAP_{B1}	2500kVA

Maximum Current I_{max}	200A
Power factor (cosθ)	0.85



<Branch Line 2>

Load L_{B2}	43A
Line Type	AAC50mm2
Type of Load	Concentrated
Line Length Len_{B1}	10km
Total Transformer Capacity of secondary substations CAP_{B2}	1500kVA

=====Equation=====

$V_i = V_s - 1.732 \cdot (R_T \cos\theta + X_T \sin\theta)(L_T \cdot f_T + (L_{B1}+L_{B2}))$

$V_{r1} = V_i - 1.732 \cdot L_{B1}(R_{B1}\cos\theta + X_{B1}\sin\theta) \cdot f_{B1}$

$V_{r2} = V_i - 1.732 \cdot L_{B2}(R_{B2}\cos\theta + X_{B2}\sin\theta) \cdot f_{B2}$

$L_T = I_{max} \cdot CAP_T / (CAP_T + CAP_{B1} + CAP_{B2})$

$L_{B1} = I_{max} \cdot CAP_{B1} / (CAP_T + CAP_{B1} + CAP_{B2})$

$L_{B2} = I_{max} \cdot CAP_{B2} / (CAP_T + CAP_{B1} + CAP_{B2})$

$I_{max} = L_T + L_{B1} + L_{B2}$

V_s : Supply Voltage I_{max} : Maximum Current R_T, R_{B1}, R_{B2} : Resistance

V_i : Interim Voltage L_T : Load (Trunk line) X_T, X_{B1}, X_{B2} : Reactance

V_{r1} : Received Voltage L_{B1} : Load (Branch Line 1)   cosθ : Power Factor

V_{r2} : Received Voltage L_{B2} : Load (Branch Line 2) f_T, f_{B1}, f_{B2} : Dispersal Load Factor CAP_T, CAP_{B1}, CAP_{B2} : Total Transformer Capacity of secondary substations

Table3.3.6 Power System Analysis Tool for STEP A, Type3

Power System Analysis for Step A *- Power System Analysis for existing system using Macro demand forecast -*

Substation Name	ABC
Feeder Name	No1

: Input data in colored cells

Type-3

<Trank Line 1>

Load L_{T1}	48A
Line Type	AAC265mm2
Line Legth Len_{T1}	10km
Type of Distributed Load	Equality
Total Transformer Capacity of secondary substations CAP_{T1}	3000kVA

<Trank Line 2>

Load L_{T2}	48A
Line Type	AAC265mm2
Line Legth Len_{T2}	10km
Type of Distributed Load	Equality
Total Transformer Capacity of secondary substations CAP_{T2}	3000kVA

<Branch Line 2>

Load L_{B2}	24A
Line Type	AAC50mm2
Type of Load	Concentrated
Line Length Len_{B1}	10km
Total Transformer Capacity of secondary substations CAP_{B2}	1500kVA

Maximum Current I_{max}
200A

Primary Substation → I_{max}

Power factor (cosθ)
0.85

L_{T1} (Distributed Load) (R_{T1} =3Ω X_{T1} =4Ω)

Trunk Line 1: Loading 44%, Rated Current =455A

Voltage V_S: 33.0kV

Voltage V_{i1}: 31.7kV (4%Drop)

L_{T2} (Distributed Load) (R_{T2} =3Ω X_{T2} =4Ω)

Trunk Line 2: Loading 25%, Rated Current =455A

Voltage V_{i2}: 31.1kV (6%Drop)

L_{B2} (Distributed or Concentrated Load) (R_{B2} =6Ω X_{B2} =4Ω)

Branch Line 2: Loading 9%, Rated Current =260A

Voltage V_{r2}: 30.8kV (7%Drop)

L_{B1} (Distributed or Concentrated Load) (R_{B1} =6Ω X_{B1} =4Ω)

Branch Line 1: Loading 15%, Rated Current =260A

Voltage V_{r1}: 31.4kV (5%Drop)

L_{B3} (Distributed or Concentrated Load) (R_{B3} =6Ω X_{B3} =4Ω)

Branch Line 3: Loading 15%, Rated Current =260A

Voltage V_{r3}: 30.7kV (7%Drop)

<Branch Line 1>

Load L_{B1}	40A
Line Type	AAC50mm2
Type of Load	Received Larger
Line Length Len_{B1}	10km
Total Transformer Capacity of secondary substations CAP_{B1}	2500kVA

<Branch Line 3>

Load L_{B3}	40A
Line Type	AAC50mm2
Type of Load	Received Larger
Line Length Len_{B3}	10km
Total Transformer Capacity of secondary substations CAP_{B3}	2500kVA

=====Equation=====

$V_{i1} = V_s - 1.732 \cdot (R_{T1}\cos\theta + X_{T1}\sin\theta) \cdot (L_{T1} \cdot f_{T1} + L_{T2} + L_{B1} + L_{B2} + L_{B3})$

$V_{i2} = V_{i1} - 1.732 \cdot (R_{T2}\cos\theta + X_{T2}\sin\theta) \cdot (L_{T2} \cdot f_{T2} + L_{B2} + L_{B3})$

$V_{r1} = V_{i1} - 1.732 \cdot L_{B1}(R_{B1}\cos\theta + X_{B1}\sin\theta) \cdot f_{B1}$

$V_{r2} = V_{i2} - 1.732 \cdot L_{B2}(R_{B2}\cos\theta + X_{B2}\sin\theta) \cdot f_{B2}$

$V_{r3} = V_{i2} - 1.732 \cdot L_{B3}(R_{B3}\cos\theta + X_{B3}\sin\theta) \cdot f_{B3}$

$L_{T1} = I_{max} \cdot CAP_{T1} / (CAP_{T1}+CAP_{T2}+CAP_{B1}+CAP_{B2}+CAP_{B3})$

$L_{T2} = I_{max} \cdot CAP_{T2} / (CAP_{T1}+CAP_{T2}+CAP_{B1}+CAP_{B2}+CAP_{B3})$

$L_{B1} = I_{max} \cdot CAP_{B1} / (CAP_{T1}+CAP_{T2}+CAP_{B1}+CAP_{B2}+CAP_{B3})$

$L_{B2} = I_{max} \cdot CAP_{B2} / (CAP_{T1}+CAP_{T2}+CAP_{B1}+CAP_{B2}+CAP_{B3})$

$L_{B3} = I_{max} \cdot CAP_{B3} / (CAP_{T1}+CAP_{T2}+CAP_{B1}+CAP_{B2}+CAP_{B3})$

$I_{max} = L_{T1} + L_{T2} + L_{B1} + L_{B2} + L_{B3}$

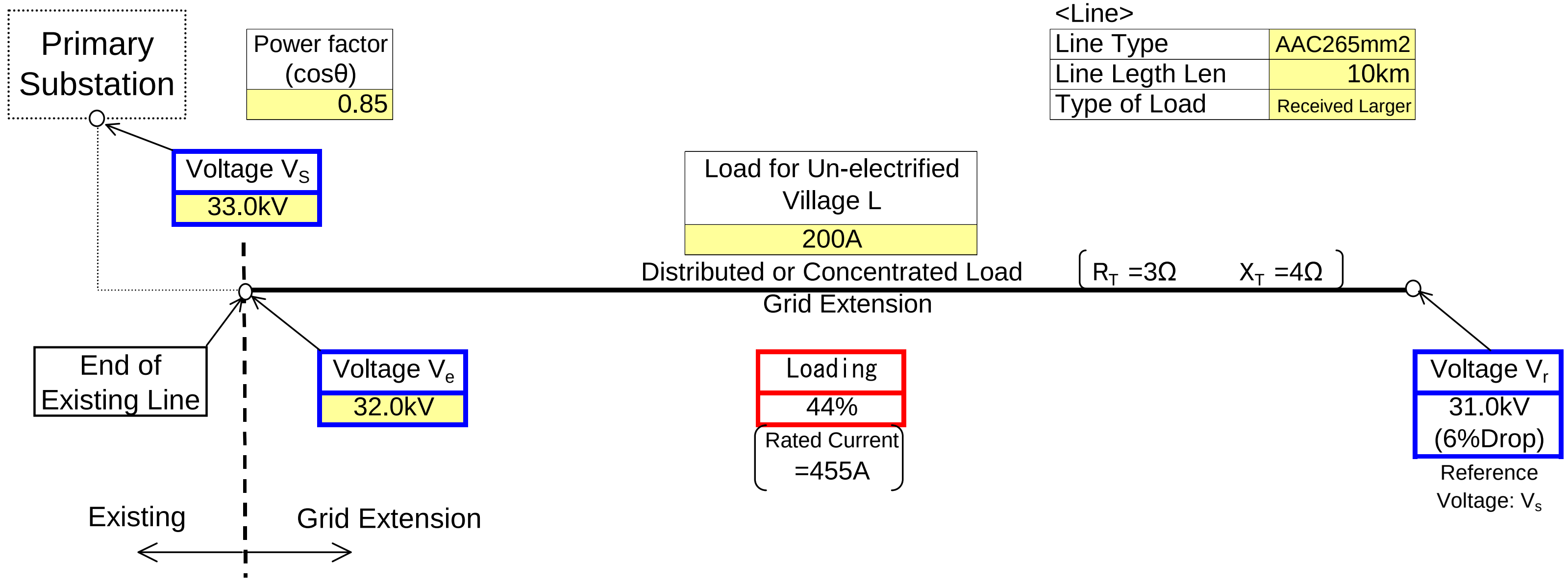
V_s	: Supply Voltage	I_{max}	: Maximum Current	R_{T1}, R_{T2}, R_{B1}, R_{B2}, R_{B3}	: Resistance
V_{i1}	: Interim Voltage	L_{T1}	: Load (Trunk line 1)	X_{T1}, X_{T2}, X_{B1}, X_{B2}, X_{B3}	: Reactance
V_{i2}	: Interim Voltage	L_{T2}	: Load (Trunk line 2)	f_{T1}, f_{T2}, f_{B1}, f_{B2}, f_{B3}	: Dispersal Load Factor
V_{r1}	: Received Voltage	L_{B1}	: Load (Branch Line 1)	CAP_{T1}, CAP_{T2}, CAP_{B1}	: Total Transformer Capacity of secondary substations
V_{r2}	: Received Voltage	L_{B2}	: Load (Branch Line 2)	CAP_{B2}, CAP_{B3}	
V_{r3}	: Received Voltage	L_{B3}	: Load (Branch Line 3)	cosθ	: Power Factor

Table3.3.7 Power System Analysis Tool for STEP B

Power System Analysis for Step B *- Power System Analysis for existing system using Macro demand forecast -*

Substation Name	ABC
Feeder Name	No1

: Input data in colored cells



=====Equation=====

V_r = Ve−1.732･L(Rcos θ + Xsin θ)･f

V_s	: Supply Voltage	L	: Load for Un-electrified Village	f	: Dispersal Load Factor
V_e	: Voltage at the end of Existing Line	R	: Resistance		
		X	: Reactance		
V_r	: Received Voltage	cosθ	: Power Factor		

3.4 Distribution facility design methodology

(1) Objective

In implementation of renewal of a distribution facilities, reinforcement, and extension, it is very important to utilize the capability of the existing distribution facilities for the maximum. This section describes the basic point of the distribution facilities design which is needed when it is assumed that reliability of a power distribution system cannot be maintained to future demand.

(2) Scope of application.

This methodology is applied for design of 33kV and 11kV medium-voltage distribution facilities.

(3) Standards for decision on distribution facility expansion

The general standard for which expansion of distribution facilities is needed is shown below.

(a) New generation or demand facilities are installed.

(b) The reliability of a power distribution system cannot be maintained to new extension and abolition of a demand rise and power generation facilities.

(c) The failure current which flows at the time of short-circuit failure of a power distribution system exceeds the allowable capacity of the existing facilities.

(d) It is considered more rational to perform the measure in respect of facilities since the maintenance cost is high in the existing facilities.

(4) Consideration in distribution facility expansion

In expansion of distribution facilities, the matter which should generally be taken into consideration is as follows.

Moreover, while it is an important element of this master plan to make expansion of a distribution facilities into a suitable scale, the measure against a demand rise needs to examine the validity of the whole power facilities not only including a distribution facilities but those of power generation, transmission lines, primary and secondary substations.

(a) Future forecast

1) Growth of demand

It carries out based on Chapter II ("Power Demand Forecasting").

2) Final scale of facilities

The consistency of distribution facilities capacity and that of other power facilities needs to be inquired.

3) Future system composition

In order to make a future electric power supply efficient, electric power accommodation with the distribution line of an adjacent substation is considered.

(b) Economical efficiency

1) Construction costs for distribution facilities

2) Operation and Maintenance costs

3) Power loss

4) Future expansion and improvement steps

(c) Adaptability to social environment

1) Constraints based on laws and regulations

2) Land acquisition situations

(d) Technical aspect

1) Voltage drop

2) Short-circuit failure current

3) Ease of maintenance

(e) Construction difficulty

1) Assurance of worker safety

2) Necessity for temporary construction

(5) Standard scale of distribution facilities

About the kind and size of a power line, a technical side and economical efficiency are examined synthetically, and the most appropriate thing is selected.

(a) Types and abbreviations for overhead lines

Table 3.4.1 shows the types and sizes of overhead distribution lines in general use.

Table 3.4.1 Name Abbreviation for Conductor Types

Name Abbreviation	Conductor Type	Size
Cu	Copper	$16mm^2$,$35mm^2$,$70mm^2$,
AAC	All Alminium Conductor	$25mm^2$,$50mm^2$, $120mm^2$, $150mm^2$

(b) Cable types and sizes

Table 3.4.2 shows the types and sizes of cables in general use.

Table 3.4.2 Cable Size

Conductor	Voltage Rank	Size
Copper	33kV	$3\times1\times500mm^2$ $3\times1\times240mm^2$
Aluminium		$3\times1\times240mm^2$
	11kV	$3\times1\times240mm^2$ $3\times185mm^2$ $3\times95mm^2$

(c) Minimum clearance

Table 3.4.3 shows the minimum clearance generally applied for overhead distribution lines to prevent electric shock accident and electromagnetic induction.

Table 3.4.3 Minimum Clearances

	33kV	11kV	LV
Between Phases	3.7m	3.15m	3.0m
Phase to earth	3.2m	2.2m	2.0m
Over Open Country	6.0m	6.0m	5.0m
Over Roads and Railways	7.0m	7.0m	6.0m
Over Telecommunication lines	2.5m	2.5m	1.0m
Under 161kV lines	3.0m	3.0m	3.0m
Under 33kV lines	-	2.5m	2.5m
Under 11kV lines	-	-	2.0m
Near buildings(Vertical)	Not allowed	Not allowed	1.5m
Horizontal	2.0m	2.0m	2.0m

(6) Selection of line type and route

(a) Types of lines

Overhead lines are the standard type of distribution line. Nevertheless, underground lines may be installed if installation of overhead lines is not permitted by laws and regulations or is extremely difficult due to technical or economic issues or the local situation.

(b) Selection of route

Selection of the most appropriate route must take account of the following factors.

1) Factors to be considered in the case of both overhead and underground distribution line routes
   - Future prospect
   - Future system composition
2) Land and environmental aspect
   - Natural conditions
   - Land acquisition situation
3) Construction and maintenance aspect
   - Ease of construction and maintenance
4) Economical efficiency
   - Cost of distribution facility construction

(c) Factors to be considered particularly in selection of underground distribution line routes

1) Consistency with urban planning
2) Technical aspect

- Influence on the firm allowable current of other underground distribution lines on the same route

(7) Study of short-circuit failure current

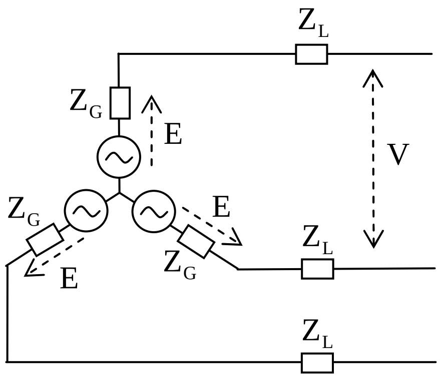
If system conditions are considered harsh as compared to those in the ordinary scope, a calculation must be made of the failure current in the event of a three phase short-circuit. If this calculation finds that the short-circuit current exceeds the capacity of the existing facilities, measures must be taken for the various prospective problems, which include a shortage of capacity in circuit breakers and other facilities connected in the series as well as in the distribution line, and damage to facilities as a result of the short-circuit current.

Table 3.4.4 shows the maximum allowable short-circuit current on medium-voltage distribution lines.

Table 3.4.4 Maximum allowable short-circuit current

Voltage rank(kV)	Permission maximum of a short circuit current（k A）
33	31.5
11	13.1

The equations for calculation of three-phase and two-phase short-circuit currents are as follows.



where,

$Z_G [\Omega]$: Generator impedance

$Z_L [\Omega]$: Line impedance

E [V] : Phase Voltage

V [V] : Line Voltage

$I_{3\varphi s} [A]$: Three phase short circuit current

$I_{2\varphi s} [A]$: Two phase short circuit current

$$I_{3\varphi s} = \frac{E}{Z_G + Z_L} [A]$$

$$I_{2\varphi s} = \frac{V}{2(Z_G + Z_L)} [A]$$

When repeating extension of a power line generally, while the increasing power distribution loss needs to be inquired, since the failure current in distribution line end decreases, we are anxious about it becoming difficult to detect the system failure by protection relay, and causing damage to a distribution facilities. In order to detect certainly the two phase short-circuit failure current in distribution line end and to remove the failure, it is necessary to consider adjustment with the setting value (tap value) of a protection relay. In addition, about the range which cannot be protected by the protection relay of a substation, the measure of installing a branch circuit breaker is required for distribution lines.

3.5 Distribution facility cost estimation methodology

Addition of component costs is the fundamental methodology for calculation of the construction costs and those of materials needed for distribution facility renewal, reinforcement, and extension.

(1) Calculation principles

(a) Contracted construction work costs

Contracted construction work costs are calculated by adding up all of the costs thought to be required for execution of the work by the contracted business through an economically sound method at the time of the contract tender. These costs are divided into the categories of electrical work, civil engineering work, and construction work. The calculation is based on the contract content, specifications, and drawings, and must take account of the construction term and work conditions.

Distribution facilities are enormous in number. For facilities whose requisite work has been standardized, a unit cost is set for the work in each of the categories of installation, removal, and relocation. Removal and relocation costs are calculated by multiplying the installation cost for the same facility by a certain factor. This makes it possible to carry out the calculation work for distribution facility operations more efficiently.

For facilities requiring work that has not been standardized or special expertise or technology, costs must be calculated separately with consideration of the degree of difficulty and the requisite time.

If it is possible to assure power outages needed for performance of work in advance, calculations can be made on the bases described above. Conversely, if constraints on power outages in urban areas, for example, temporary construction costs must be calculated separately.

(b) Materials cost

Like those for contracted construction work, costs for materials are calculated by adding up the costs thought to be required for their production by the manufacturer through an economically sound method. The calculation is based on the contract content, specifications, and drawings, and must take account of the construction term and work conditions.

The promotion of further standardization of distribution facility specifications through consultation with their manufacturers can reduce not only materials costs but also future maintenance costs. In addition, it may be effective to unify the distribution facility specifications of different distribution companies with a view to future consolidation of the distribution enterprise.

(2) Facility specification database and systems

It is more desirable to build a database for distribution facility specifications using general-purpose software such as MS Excel. The database will enable sharing of these data not only at the Head office but also at Regional and Area offices, and thereby facilitate calculation work. Because facility specifications may change along with technical advances, the C/P needs to review the database and update it continuously.

3.6 Facility formation methodology for low-voltage distribution lines

While the formation of facilities for low-voltage distribution lines is outside the scope of the Master Plan, it should be noted that construction of reliable low-voltage lines is required for actual power usage. This section consequently describes the fundamentals of facility formation for low-voltage lines.

(1) Voltage management

As is described in a subsequent section on voltage management, systems must be designed so that the sum voltage drop on the low-voltage and lead-in lines is no greater than the limits noted below.

* Nominal voltage of 230 V: 23 V
* Nominal voltage of 400 V: 40 V

Therefore, it is necessary to determine how to allocate the allowable voltage drop between the low-voltage and lead-in lines while taking account of factors such as load density.

Voltage is a demand item that determines power quality. Caution consequently must be exercised in making approaches to RE by simply extending low-voltage lines and to installation of more facilities. When there is a risk that the voltage drop will exceed the prescribed limit, enterprises must take measures such as extension of medium-voltage lines, as described in Section 3.2.

(2) Low-voltage distribution types

Low-voltage distribution lines are constructed in one of the following formats.

* Three-phase, four-line
* One-phase, two-line
* One-phase, three-line

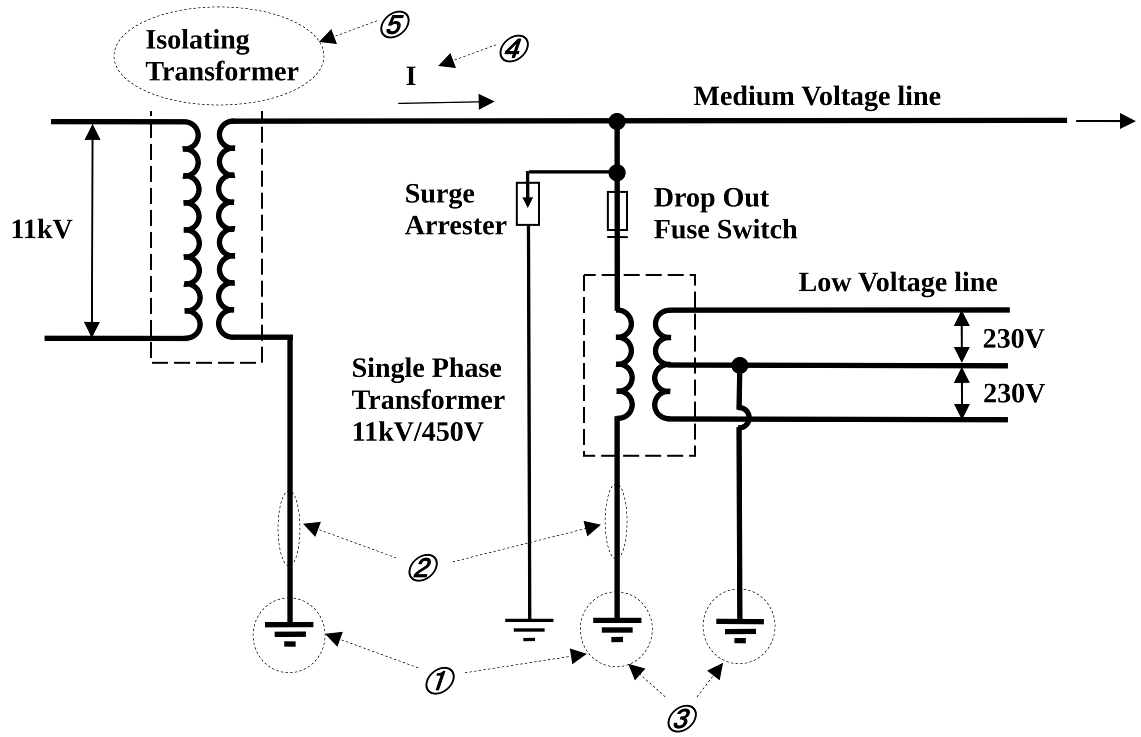
The choice of format is determined by the type of load transmitted. The single wire earth return (SWER) format (described below) may also be selected, depending on the conditions.

(3) SWER system

SWER uses only a single line, and the earth is used as a return line. It is a low-cost method of supply (of one-phase power) to remote areas with very low levels of demand.

(a) Installation conditions

For the purpose of example, Figure 3.6.1 shows the installation conditions that must be present for application of SWER, whose adoption consequently requires careful consideration.



① → The grounding resistance shall be 5 ohms or less.
→ Warning signs to call third persons' attention shall be installed near the grounding point.

② → The cross-sectional areas of grounding conductors shall be 16mm2 or more.
→ The grounding conductors placed up to a depth of 75cm underground or up to a height of 2.0 m aboveground shall be covered by a synthetic resin pipe or another shield of equivalent or higher insulating effect and strength.

③ → The grounding of medium voltage lines and the grounding of low voltage lines are completely separated to keep the safety of low voltage line systems.

④ → The load current in any earth-return circuits shall be 8 amperes or less.

⑤ → SWER circuits shall be supplied from double-wound transformers (isolating transformers).
[Direct connection to a generator or a connection to a high voltage lines by a singe-wound transformer shall be absolutely prohibited.]

Figure 3.6.1 SWER installation conditions

(b) Merits and demerits

Table 3.6.1 shows the merits and demerits of the SWER format.

Table 3.6.1 Merits and demerits of SWER system

Merits	Demerits
(1) A low capital cost (2) Simplicity of design (3) Reduced maintenance cost (4) Reduced bushfire hazard, avoidance of conductor clashing	(1) Potential step-and-touch problems for livestock and humans (2) Worse interference in a communication line than that by three-phase line system or single-phase two-wire system (3) Load density limitations (4) Inability of provision of three-phase electric power (5) High voltage drops and low reliability (6) Frequent power outages by lightning (in case of the shield wire SWER system)

As noted above, the SWER system has many disadvantages, and its installation must be approached with full consideration of not only the cost of installation per se but also that of solutions for the demerits, as well as future load increase and measures to assure the safety of people and livestock.

(4) Installation of transformers

As a general rule, companies select transformers with a capacity that matches the load. A capacity matching the load at present, however, will have to be replaced along with increase in the load in the future. For this reason, it is the ordinary practice to select a capacity with an appropriate amount of margin in consideration of future demand increase.

Customers supplied with power from the same transformer never use the maximum power at the same time. This results in a substantial gap between the total contracted power among customers (kW) and the actual load imposed on transformers (kW). Therefore, decisions on transformer capacity take account of factors including the load demand rate and diversity factor as well as the total contracted power.

(5) Installation of low-voltage lines

As in the case of transformers, low-voltage line size must be selected with consideration of the future load increase, demand factor, and load factor. At the same time, however, the company must see that the extent of voltage drop does not exceed the allowable level. It is also advisable to use insulated instead of bare wire in order to assure safety and to prevent surreptitious use.

(6) Installation of lead-in lines

The perspective is the same as for low voltage lines as regards consideration of the proper capacity and voltage drop, and use of insulated wire. The phase of connection with low voltage lines requires special consideration in the case of a three-phase load. In the case of a one-phase load, full account must be taken of the connection phase to prevent the occurrence of three-phase imbalance due to the concentration in a specific phase.

Note: If excessive, three-phase imbalance can have the following adverse effects and should therefore be held to the minimum in connection.

* Uneven rotation of three-phase load (in electric motors etc), occurrence of reverse transmission voltage and high-frequency harmonic noise
* Misoperation of substation relays due to an increase in the zero-phase voltage
* Exceeding of the allowable line current and need for increased installation due to the current concentration in a single phase
* Increase in technical loss (resistance loss) due to current concentration in a specific phase

(7) Improvement of the power factor

Generally speaking, power factors are poor among customers using equipment that causes reactive power delays in electric motors and transformers. Poor power factors lead to an increase in apparent current and a decrease in the amount of power that can be sent by the same facility as well as a higher level of technical loss.

The delay power factor can be improved by inserting a condenser parallel to the load. The figure below shows vectors for improvement of the power factor. The advance current Ic is supplied by insertion of a condenser with the capacity Qc (kVA), and causes a decrease in the reactive power from Iro to Ir. As a result, the power factor improves from cos-phio to cos-phi. (This also results in a decrease in the apparent current from Io to I and in the apparent power from Po to P.)

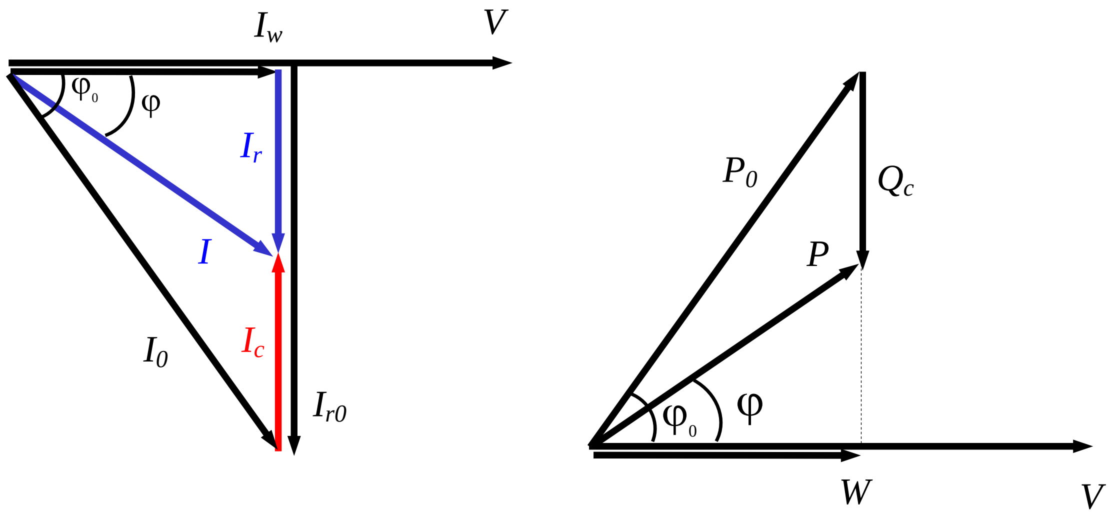


Figure 3.6.2 Vector diagram for improvement of the power factor

3.7 Methodology for electrical facility operation

3.7.1 Distribution loss calculation methodology

(1) Technical loss and non-technical loss

There are two major types of loss on distribution lines: technical and non-technical. The former is inevitably derived, in varying degrees, in transmission of power to the site of consumption. The latter derives from external factors such as surreptitious use.

Table 3.7.1 shows the main factors in technical and non-technical loss.

Table 3.7.1 Classification of factors of loss on distribution lines

Technical loss	Non-technical loss
- Resistance loss on routes - Iron and copper loss in transformers - Dielectric loss in cables	(1) Surreptitous use (theft) - Illegal connection - Tampering with meters - Other (2) Inaccurate measurement - Defective meters, mistaken multiplying factors on meter components - Falsification of meter readings - Unmetered supply - Other (3) Uncollected tariffs - Gratis supply of power (streetlights, public facilities, etc.) - Tariff arrears - Other

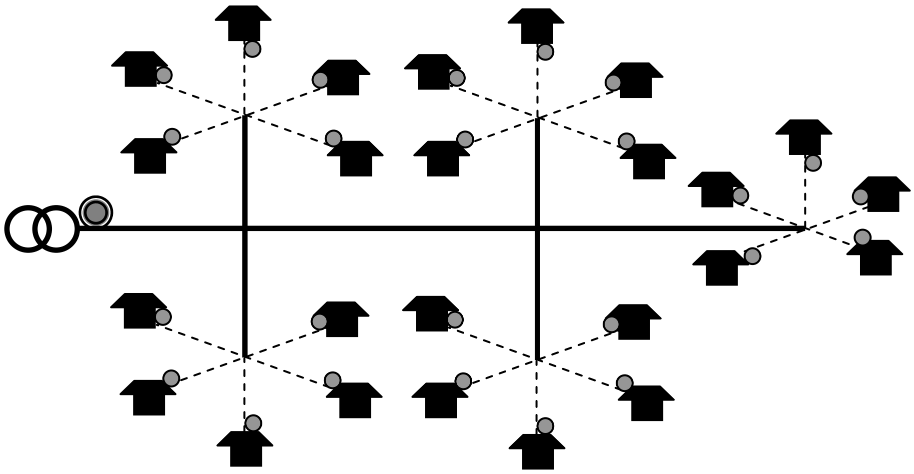
(2) Methodology for calculation of distribution loss

As shown in Table 3.7.1, non-technical loss is caused by uncertain factors such as surreptitous use and inaccurate measurement, and is consequently difficult to quantify. For this reason, it is extremely difficult to separate technical loss and non-technical loss in quantitative terms.

The total distribution loss (i.e., the sum of technical and non-technical loss) can be found by the following method.

(1) Low-voltage distribution lines

Distribution loss on low-voltage distribution lines (kWh)
= Total power sent out from the distribution transformer (kWh) - the total power able to be sold through the low-voltage distribution lines and retrieved in the form of power tariff revenue



Legend

: Distribution Transformer

: LV line

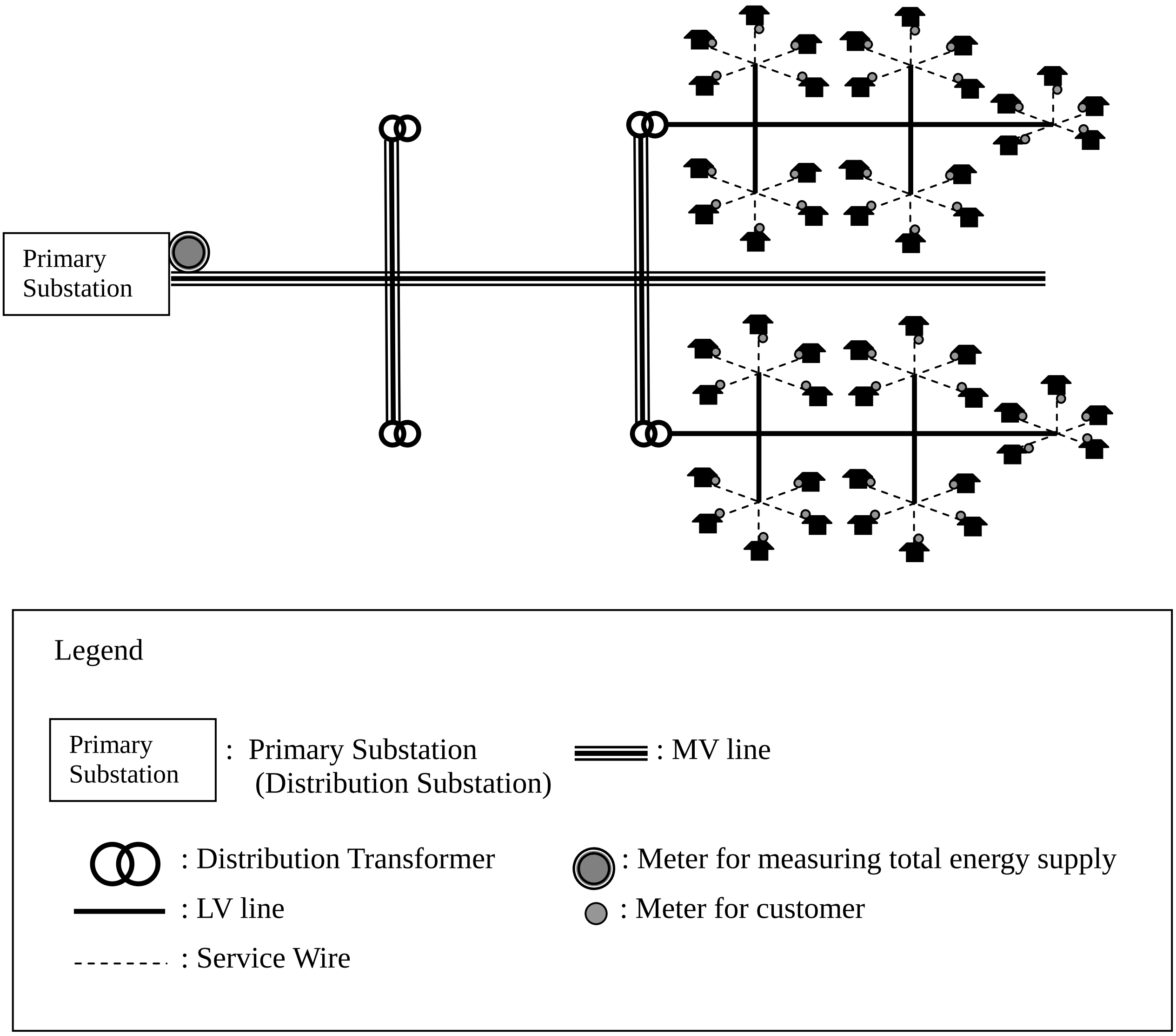
: Service Wire

: Meter for measuring total energy supply

: Meter for customer

(2) Medium-voltage distribution lines

Distribution loss on medium-voltage distribution lines (kWh)
= Total power sent out from the primary substations (kWh) - the total power able to be sold through the low-voltage distribution lines and retrieved in the form of power tariff revenue



3.7.2 Voltage management methodology

(1) Objective

This methodology is aimed at maintenance and management of distribution voltage on the proper level to assure the proper voltage in supply to customers and smooth operation of the service.

(2) Scope of application

This methodology is applicable to voltage management from the medium-voltage distribution line outlets of the generation/transformation facilities to the point of supply to the customer, except when power cannot be supplied in the normal form through the distribution lines due to failure or emergencies.

(3) Proper voltage

The following are the ranges of proper voltage corresponding to the nominal voltage at the point of supply to the customer.

- Nominal voltage of 230 V: 207 - 244 V
- Nominal voltage of 400 V: 360 - 424 V

(Based on the standard voltage figures in IEC-60038)

(4) Management of distribution voltage

The following are the items of management for maintenance of the voltage in supply to the customer within the proper range.

(a) Proper setting (?) of the target voltage in operation of generation/ transformation facilities, determination of the tap change point on transformers, selection of the spot for installation of line voltage regulators, and operation and management of these regulators.

(b) Proper management of voltage, by means such as measurement of the voltage at the terminus, on distribution lines at risk of voltage increase due to the Ferranti effect

(5) Management of the target operating voltage

(a) Setting conditions

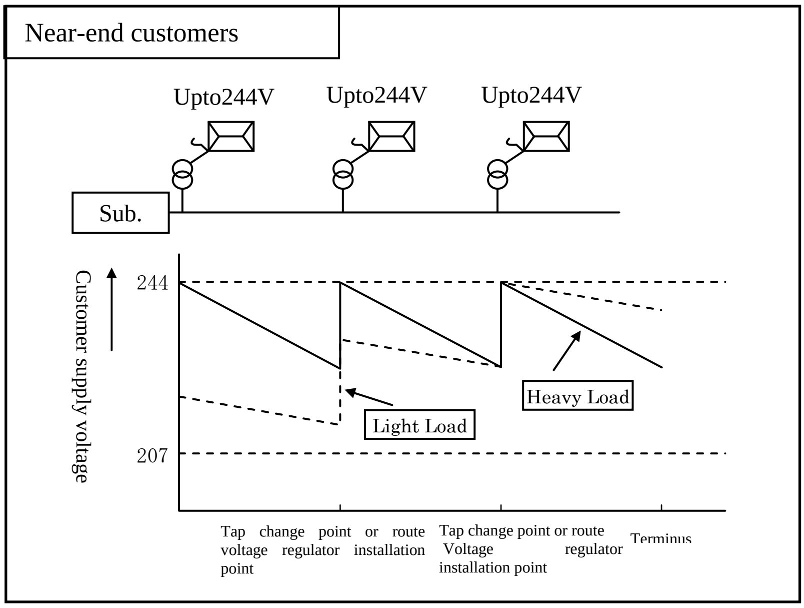
1) In times of heavy load, the voltage in supply to the customer nearest to the transformer immediately after the voltage regulator and tap change point after send-out from the generation/transformation facility (hereinafter referred to as the "near-end customer") must not exceed the upper limit of the proper voltage range (hereinafter referred to as the "upper limit").

2) In times of heavy load, the voltage in supply to the customer on the terminus of the low-voltage distribution line with the maximum voltage drop from the transformer installed at the terminus of the medium-voltage line immediately before the voltage regulator and tap change point after send-out from the generation/transformation facility (hereinafter referred to as the "far-end customer") must

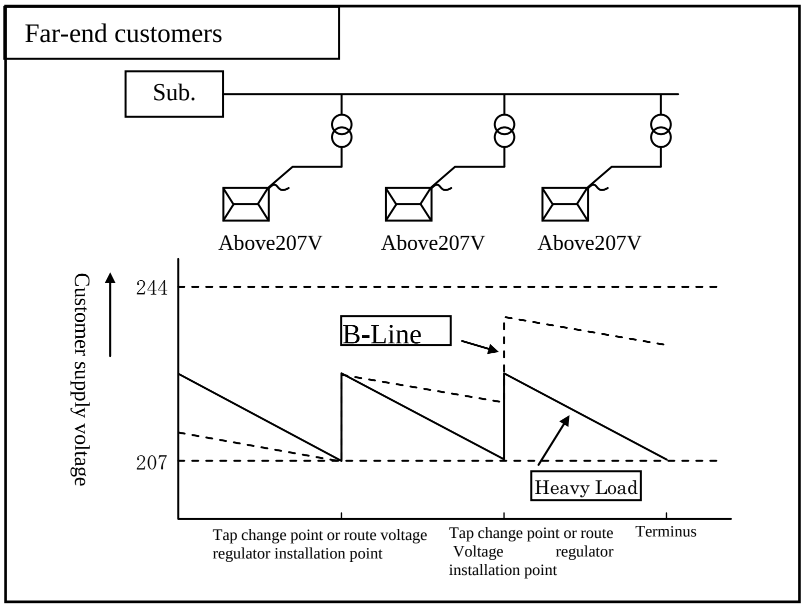
not exceed the lower limit of the proper voltage range (hereinafter referred to as the "lower limit").

3) In times of light load, the voltage in supply to the near-end customer immediately after the voltage regulator and tap change point after send-out from the generation/transformation facility must not exceed the upper limit.

4) In times of light load, the voltage in supply to the far-end customer immediately before the voltage regulator and tap change point after send-out from the generation/transformation facility must not exceed the lower limit.



or



(b) Setting period

The setting should be made as often as appropriate.

However, immediate studies are to be made in the event of installation of new generation/transformation facilities and distribution lines significant fluctuation in load.

(c) Management methodology

The setting is managed on the basis of a record of the bus line voltage at generation/transformation facilities.

(6) Transformer tap management

The transformer tap determination must take account of all pertinent items, including the characteristics of the medium-voltage lines and the operating characteristics of the voltage regulator.

(a) Time of determination

As a general rule, the tap to be used is determined at the start of the fiscal year. However, determinations should also be considered in the event of the installation of new or expansion of existing generation/transformation facilities and distribution lines, or significant change in load.

(b) Management methodology

The tap is managed by keeping a record of it on single-line connection diagrams for distribution lines.

(7) Voltage management for low-voltage distribution lines

(a) Voltage drop limit

The limit is the minimum voltage noted in Section (3).

(b) Management method

Voltage drop is calculated on the basis of the contracted customer capacity, load facility capacity, cable thickness, span, and other factors, and is managed with reference to the limit.

(8) Measurement of voltage in supply to customers

(a) Yearly report measurement

A measurement is made of voltage in supply to customers once a year, in the period designated by the Ministry of Energy (MOE).

1) Preparation of measurement records

The following items are to be recorded at each measurement location.

A. Nominal voltage

B. Name of the generation/transformation facility and medium-voltage distribution line

C. Date of measurement

D. Average maximum and minimum values for measured voltage over a period of 30 minutes, and respective times of occurrence

E. Measurement device model and number

F. Name of the measurer

2) Preservation of the measurement record

The measurement record must be kept for three years.

(b) Measurement as necessary

Measurement is made as necessary, for example, in response to customer requests for studies of voltage or repair.

3.7.3 Manual for preparation and compilation of distribution facility management data setting forth methodology for preparation and compilation of data needed for managing distribution facilities

(1) Objective

It is the aim of this manual to set forth the requisite items and categories to be applied in proper management of distribution facilities, and thereby assist the smooth performance of the management work.

(2) Scope of application

All distribution facilities under jurisdiction of the company.

(3) Key items

The numbers of supporting structures are taken as key items for distribution facility management.

(4) Management subjects

(a) Transformers

The management items for transformers are as follows.

a. Capacity
b. Month and year of manufacture
c. Fiscal year of installation
d. Type B earth resistance value
e. Month and year of measurement of the Type B earth resistance value

(b) Supporting structures

The management items for supporting structures are as follows.

a. Type (wooden pole, concrete pole)
b. Material (wooden material, method of manufacture of concrete poles, etc.)
c. Length (height)
d. Strength
e. Month and year of manufacture
f. Month and year of installation

(5) Management method

A ledger is prepared and managed for each facility (e.g., transformer and supporting structure), substation, and distribution line.

(6) Updating method

The manual is to be updated on the occasion of facility installation, removal, and replacement.

IV. Power system planning

4.1 Power System Composition

The electric power system is a series of the process from a generation of electric energy to a consumption of it. In other words, it is a series of the system of transmission lines, substations, switching station, and so on, in order to maintain the appropriate level of voltage and frequency of electric energy, which is generated at hydropower stations or thermal power stations, and transfer it to the final customers. This system has a particularity as below.

1) No storage function of large dimensions
2) Huge investment is necessary for the construction
3) Growing continually

Accordingly, to attain the mission of electrical power supplier to supply electricity in the low cost and the high quality, fundamental principals as below should be satisfied when constructing the power system.

1) Easiness of power system operation and smaller power loss
2) Stable electrical supply to attain the goal of required supply reliability
3) To maintain the stipulated voltage and frequency
4) To exert the characteristics of each power facility sufficiently

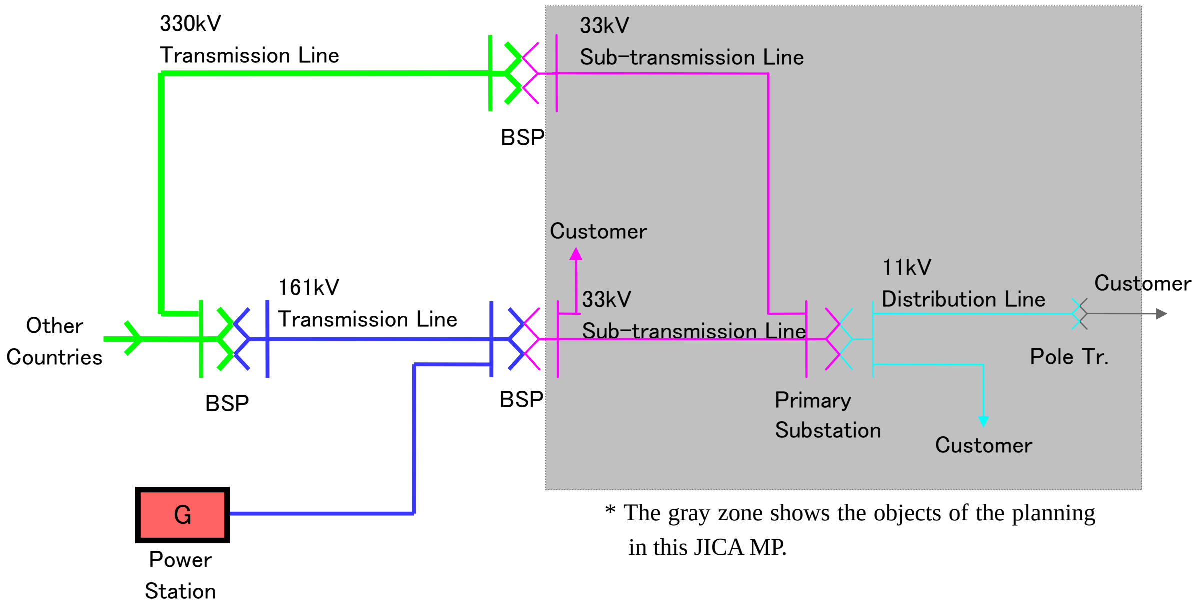


Fig4.1 Electric Power System

The transmission grid is divided into the trunk system and the load supply system in accordance with the intended use.

The trunk system is formulated by power lines, which are used for supplying electric power generated at large scaled power stations, substations (switching stations), which have a role of accumulating and distributing electric power, and transmission lines, which interconnects substations (switching stations). It is a backbone of the power system.

The load supply system is formulated by transmission lines and substations (switching stations), which are used to send electric power to each customer. Besides, it operates as not only supplying load but also adjusting load flow in the upper system or corresponding to faults.

Power system configuration is mainly divided into a radial system and a loop system. These configurations are used, depending on the effective utilization of the existing system and supply reliability.

Table 4.1 Characteristic of power system configuration

	Advantage	Disadvantage
Loop system	- Uninterrupted power supply in case of route cut-off of transmission lines - Improvement of stability, voltage and reduction of system loss due to decreasing power system impedance	- Increase of short-circuit capacity due to decrease of power system impedance - Protection relay operation gets complicated - In case of the occurrence of inoperative of protection relays and circuit breakers and failing to take appropriate measures, it proceeds to a serious fault - It is difficult to control load flow because of complication of load flow when route cut-off fault occurs
Radial system	- Pervasive blackout is avoidable because separation of the power system prevents from spreading to other blocks when fault occurs on transmission lines - Breaking capacity of circuit breakers becomes small because the short circuit current is small compared to the loop system - Easiness of protection relay operation - The restoration operation when fault occurs is simple	- Disadvantage in stability and voltage regulation compared to the loop system

4.2 Supply reliability in System Planning

(1) Supply reliability

The service level of power supply has two aspects. One is the matter of failure frequency and quality of voltage and frequency and so on. Another is the matter of managing the business such as quickness of complaint handling and reception works and so on. The degree of supply interference, frequency of equipment fault, is called supply reliability. It is a very important index to show power quality.

(2) Supply reliability target

The administrative target for supply reliability is simply called supply reliability target or reliability target. The reliability target gets higher and higher, and more investment would be needed.

(3) Concept for reliability target

It is very difficult to prepare system planning based on the supply reliability, because working out of supply reliability quantitatively is very hard. The reliability target is set for what the range of failure is limited and how to restore it for some faults. If we want to make supply reliability higher, generally we need larger investment. To supply electric at a low price with high reliability, we hold the balance between investment and reliability.

Table 4.2 Assortment of failure

Assortment	Simple Failure	Serious Failure	Duplication Failure
	Loss of one circuit, Failure of one transformer	Route cut-off failure of line, Failure of bus	Plural failures occur
Number of Times	Many ←→ Few		

Table 4.3 Way of recover

Recover	No interruption	Switch over to the next system		Use Mobile transformer	Repair facilities
		Simple switch (First step)	Further switch (Second step)		
Outages	Short ←→ Long				

Table 4.4 Reliability target

<table>
<tr><td>In normal operation</td><td colspan="3">- Load flow does not exceed the normal capacity of equipment
- Voltage is maintained properly
- Generator is operated normally</td></tr>
<tr><td rowspan="3">In N-1 contingency -1)</td><td rowspan="2">Supply interruption</td><td>Trunk system</td><td>No supply interruption</td></tr>
<tr><td>Load supply system</td><td>At short times, supply interruption should be resolved for BSPs, primary substations, transmission lines and sub-transmission lines -3)
Supply interruption is allowed till restoration for distribution substations and distribution feeders -3)</td></tr>
<tr><td>Generation interruption</td><td colspan="2">In principle, generation interruption is not allowed
In case the power system is maintained in stable, loss of restrictive generation or generation restraint is allowed</td></tr>
<tr><td rowspan="3">In N-2 contingency -2)</td><td rowspan="2">Supply interruption</td><td>Trunk system</td><td>At short times, supply interruption should be resolved</td></tr>
<tr><td>Load supply system</td><td>In principle, not considered -3)</td></tr>
<tr><td>Generation interruption</td><td colspan="2">In principle, not considered -3)</td></tr>
</table>

1) N-1 contingency: loss of one circuit of transmission lines, loss of one transformer and loss of one generator

2) N-2 contingency: loss of double circuits of transmission lines (route failure), simultaneous failure of over two power equipment and bus-bar failure at substation

3) It would be excluded in case the impact on the power system or social influence is large

4.3 Concept of System Planning

Essential concept of system planning is 'to form power system just enough to supply peak load at the minimum cost'. Therefore, when we plan the expansion of our system, we have to consider the following factors.

(1) Future demand

(2) Supply reliability

(3) Investment

(4) Others (Stability, Short-circuit capacity and so on)

4.4 Criteria for expansion

Countermeasures by upgrading of power equipment would be studied for stable power supply in case the system reliability is not supposed to be maintained by maximum utilization of existing power equipment. Concretely speaking, the countermeasures would be studied upon the occurrence of the following factors.

- In case new generating station or customer equipment is constructed
- In case system reliability is not enough for demand increase, construction of generators, abolishment of generators, and so on
- In case the fault current of short-circuit fault or ground fault is supposed to exceed the allowable limit of the existing equipment

- In case countermeasures has advantage against the high cost of transmission loss and maintenance of existing facilities

4.5 Choices of Expansion

When we plan a system expansion, we consider about economy, acquire of site, term of construction. Then we decide for the way of expansion

Table 4.5 Choices of Expansion (Substation)

Choices	Feature／Choice factor	Cost	Term
Establish a new SS	・We can get a new supply point. (The increase in supply ability is large.) ・We choose the way in the case established substations have full transformers or the choice is most economical.	Large	Middle
Add a new transformer	・We can increase supply ability instantly. (The increase in supply ability is middle.) ・We choose the way in the case nearby substations have reserve ability. (and the choice is most economical.)	Small	Short
Change to a lager capacity transformer	・This expansion is exchange of transformer. (The increase in supply ability is small.) ・We choose the way in the case the substation in need for expansion has a small capacity transformer. (and the choice is most economical.)	Small ～ Middle	Short ～ Middle

If we plan the countermeasure for interruption caused by 1 transformer failure, the way of expansion is not only to add a transformer. Depending on the situation, we will choose the most economical and effective way.

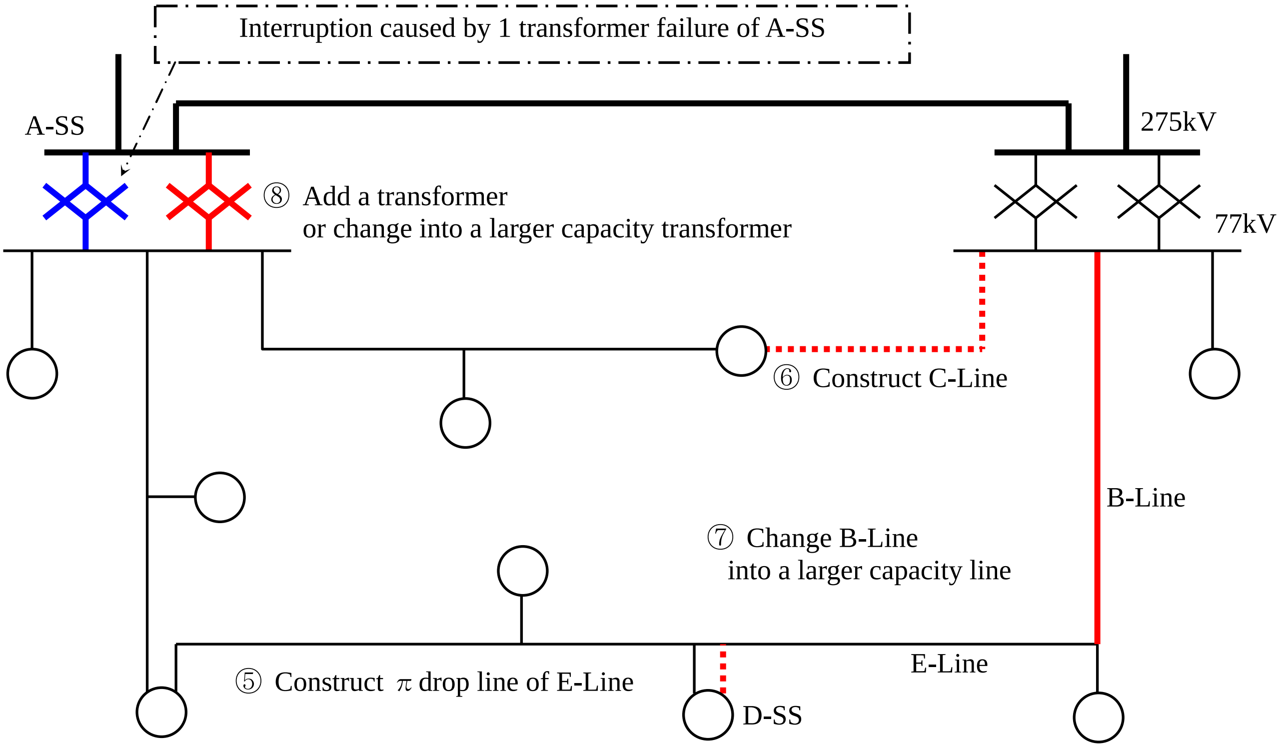


Fig 4.2 Choices of Expansion (Power System)

4.6 Countermeasure for short-circuit capacity

With system expansion, short-circuit capacity is also increasing. The increase in short-circuit capacity brings about the following problems.

- Shortage of capacity in series-connected equipment
- Electro magnetic induction to telecommunication lines

The countermeasures for this problem are as follows.

- System separation
- Adequate allocation of generating station (very difficult)
- Adoption of high impedance transformer
- D.C. separation

V. Economic and Financial Analysis

5.1 Basics of the Economic and Financial Analysis

Analyzing a distribution project is same as analyzing any investment project. You are investing a certain amount of money, in order to achieve something in return. You have to make sure that the return is enough to justify the investment[1]. If not, there is no point in investing.

The difference between an economic analysis and a financial analysis is basically what you consider as the "return." The "return" in a financial analysis is the monetary gain of the operating entity. On the other hand, the "return" to be considered in an economic analysis is the gain to the whole economy, and not just a single entity. This will be explained in their respective explanation.

The basic Idea of a Return

The idea of a return will be simple. You buy some item for $100 and immediately sell it to someone else for $120. The return will be your net profit compared to the original purchase. In this example,

Purchase:	$100
Sales:	$120
Profit:	$20
Return	$20/$100 = 20%

This is quite simple. But in many cases, the return will come later, and will be spread over multiple years. In that case, it is best to let a spreadsheet program (like MS Excel) do the calculation, using the IRR function.

Example 1: New construction

A project requires an initial investment of $500. It will bring in $100 profit from the next year. The equipment will last 6 years, and then break down. You will be able to sell the scrap for $10 on the 7th year.

Year	0	1	2	3	4	5	6	7
Investment	500							
Operating Profit	0	100	100	100	100	100	100	
Scrap sales								10
Cash Flow	−500	100	100	100	100	100	100	10

IRR= 5.9%

The return of this project is 5.9%.

Example 2: Rehabilitation

In the project in example 1, if you make an additional $100 investment for rehabilitation in year 5, you can extend the life of the equipment for another 4 years. What would be the return for the rehabilitation investment in year 5?

In this case, you cannot simply take the whole project from year 0 to 11, since that would mix the original $500 investment with the rehabilitation investment. Therefore, you need to look at the incremental change with and without the rehabilitation investment.

Table1: CF without Rehabilitation

Year	0	1	2	3	4	5	6	7
Cash Flow	−500	100	100	100	100	100	100	10

Table 2: CF with rehabilitation

Year	0	1	2	3	4	5	6	7	8	9	10	11
Investment	500					200						
Operating Profit	0	100	100	100	100	100	100	100	100	100	100	
Scrap sales												10
Cash Flow	−500	100	100	100	100	−100	100	100	100	100	100	10

IRR= 9.7%

Year	0	1	2	3	4	5	6	7	8	9	10	11
Incremental CF	0	0	0	0	0	−200	0	90	100	100	100	10

IRR= 22.1%

The first cash flow is the same as example 1, the project without the rehabilitation. The second table shows the project with the rehabilitation. The whole project has an IRR of 9.7%, which is much higher than the 5.9% in example 1, which makes it a better project.

However, in order to look at the impact of the rehabilitation investment only, you need to subtract the first table from the second, to see the incremental effects of the rehabilitation. This is shown on the third table, that shows a whopping 22.1%, which is extremely high. If you are faced with a choice of a new construction (example 1) and a rehabilitation project (example 2), in many cases, you will want to choose the rehabilitation project As the saying goes, “a stitch in time saves nine.”

[1] In reality, there are many cases where you have to do projects that are not financially or economically viable.

5.2 Financial Analysis

Financial analysis is very straightforward. You can simply take the figures out of the financial statements and other documents that would be made for any projects. The prices can be used directly off the quotes from the vendors. The future performance can be deduced from the past performance of various projects. The only thing that would be hard to understand would be the profits.

Returns

If the project is a factory or a taxi, it is easy to see the returns of a project. It is simply the cash income of your operation, minus the various costs for materials and labor. The difficulty of a distribution project is that you do not necessarily have a clear additional revenue.

New construction

With new construction, there are clear revenues. The fees paid by the newly connected households and business, minus the operaional costs (ex. Power purchase costs, labor costs, collection costs), will be the return for the project.

Renewal/expansion

In case of renewal, there may be no new connections. However, there are measurable financial benefits that can be measured.

a. Additional power sales coming from the reduced loss
b. Longer life span of the existing equipment

In Ghana, where there is a power crisis, the extra distributed power will certainly be sold. Also, as seen in example 2, the longer life span of the equipment can be shown to bring in more income.

Expansion of the existing grid can be understood as a combination of new construction and renewal. It will partly bring in new connections, and it will partly serve more power to existing customers, thus creating additional revenue.

5.3 Economic Analysis

In economic analysis, what is considered as a return is different. The “return” diverts from the purely monetary gains (or loss), and would focus more on the impact on the society as a whole. This is rather complicated, and requires some thought. Although it is named “economic analysis”, it is not simply about money. However, what makes things complicated is that it converts the non-monetary gains and costs into monetary terms in order to enable easier comparison.

1) Returns

What is a return in an economic analysis? Since economic analysis analyzes the gain to the whole society, you should look at the end users of power, rather than the operating entity (like ECG or VRA-NED).

It is, however, difficult to know what kind of gains that the end users are getting. People use power for lights. What is the value of having a light in your house? Note that this value should be higher than the power tariffs that they are paying. If you think the value of the power is $10 but ECG asked you to pay $20, people will not pay. Since people are paying for the power, they clearly value power more than the tariff. But how much more?

One way to find this out is to actually ask them, through various surveys. This, however, can be tricky. If you ask someone how much more you are willing to pay, they will generally SAY the the tariff is already too high, and they will not pay any more.

In rural areas, another way is to look at the light. Many non-electrified village uses kerosene (or paraffin) lamps. Their cost of operation is the fuel cost, which gives them a certain amount of light. Electricity will give them 200 times more light than a kerosene lamp. Therefore, it could be argued that the value of electricity is 200 times the cost of kerosene. This, however, may be subject to a lot of debate.

Another way is to look at alternative source of power. There are people and places that have their own generators. They value power enough to justify the cost of owning and maintaining a generator. The average cost of generation from those generators may show a figure closer to the valuation of their power. This may be the most useful method in urban areas.

The cost side also needs adjustment. One of the easier things to understand is tax. It is an item that you are required to pay, and it is included in the financial analysis. If you pay out certain amount of tax from the revenue, or if you pay tax on some item in the investment, that would register in the cost in a financial analysis. However, if you think about the whole society, the tax is simply a transfer within the society, and does not add or subtract from the overall gains to the society Therefore, we should disregard it.

Also, prices for many of the items that go in (or out) of a project are distorted in many ways. Many of the imports have higher prices due to tariffs , or fuel prices etc. may be subsidized. Those need to be adjusted. The petroleum price may be $3 at the gas stand, but if it is subsidized, the actual price to the society is more than the apparent price. In doing an economic analysis, those distortions need to be corrected, both in the calculation of the investment amount and the returns.

5.4 Evaluating the result

In order to come up with a master plan, the economic an financial analysis of the various projects that goes into the plan should be evaluated. It is important to select projects that bring higher returns, since they represent better projects that would bring more bang to the buck., meaning the they are better use of the money.

There are millions of potential projects that can be included in a single master plan. Some are good and some are bad. Also, there are some projects that can be combined to increase their value. These should be combined to achieve a level of good return in both economic and financial terms, while achieving your engineering and operational goals.

How much is a good return in terms of financial and economic analysis? There are no definite answers, but there are rules of thumbs.

The world bank usually asks for 8% ROA for a power project for its financial analysis. This is one rule of thumb that may be used. There often is a criteria of each individual government or ministry concerning a cut off rate of returns. Projects with lower returns will not be considered. In the case of Sri Lanka, this was 6%.

In terms of economic analysis, Asian Development bank has a cut off ratio of 12%. Any project under this figure will not be financed by ADB.

While these are not definitive, they are easy and useful guidelines.

It should be noted that unless there are major subsidies or distortions, the economic return would usually be much higher than the financial returns. Financial return is simply capturing a part of the gains to the whole society through monetary means (like tariffs). If someone thinks a project gives an overall economic gain of $100, but the tariff is also $100 and takes away all of the gains, the person will not be getting anything from the project. For the project to be viable, the tariff needs to be lower than their valuation of power.

VI. Criteria for Prioritization

6.1 Prioritization of individual plans

6.1.1 Policy for prioritization of grid renewal, reinforcement, and extension

There are three categories of planning for distribution network (i.e., grid) investment.

- Renewal
- Reinforcement
- Extension

With regard to prioritization of investment, in principle, renewal and reinforcement of the existing grid have higher priority than gird extension. This is because unreasonable grid extension imposes an excessive load on the existing distribution network and endangers reliable power supply (as observed in the SHEP scheme, grid-extension projects which were implemented without full consideration of technical and economic factors have resulted in these problems).

If grid extension is implemented without regard for the grid capacity, it may detract from the stability of power supply to not only new customers but also existing ones

Decision-making on renewal and reinforcement plans depends on the urgency of need and the size of investment. If no action is taken, however, it is obvious that an accident may occur some day. For this reason, we cannot postpone the decision on investment.

Renewal of distribution lines is not a measure to increase demand, and thus does not contribute to revenue increase. However, if we negrect deteriorated facilities, they may possibly cause some problems as regards safe and reliable power supply. Therefore, it is necessary to renew the existing grids as appropriate.

Renewal is characterized by the fact that it is not carried out in accordance with a specific schedule but is instead decided flexibly based on the results of routine on-site inspection. If the damage or deterioration of facilities is serious, renewal must be implemented immediately. If this is not the case, it is desirable to implement renewal in the course of other works.

If power demand increases due to the increase in the level of power consumption per customer or in the number of consumers connected, it may result in power supply problems such as a shortage of capacity among existing facilities and power voltage drop more beyond allowable level. Therefore, reinforcement must be carried out before the occurrence of such capacity shortage and voltage drops. In addition, if we do not respond to the increase in power demand, we lose the opportunity of revenue increase.

Unlike renewal, it is relatively easy to schedule reinforcement work. It is also possible to evaluate the margin in the capacity of existing facilities by power demand forecasting. In micro demand forecast focused on social and economic development activities in the region, we must roll a grid-reinforcement plan as well as forecast the demand. In the rolling plan, it is necessary to prepare measures for response to demand among emerging large-volume customers, which are, in effect, in the industrial sector.

When several reinforcement plans must be ordered in respect of priority, the lines showing a stronger increase in demand should be given higher priority from the viewpoint of revenue increase. Areas closer to substations should also have a higher priority for the purpose of reducing distribution loss and voltage-drop.

In accordance with the experience acquired through their operation, the ECG and the NED may have theirown criteria for decision-making on the timing and size of investment for grid renewal and reinforcement. They should apply such criteria in preparation of the first draft of an investment plan discussing the expected scale and scheduling of investment.

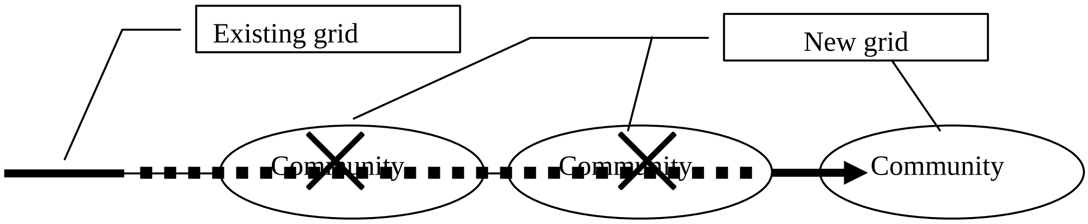
This draft plan should be used as footing for preparation of a grid extension plan. In principle, the grid can be extended only if the existing distribution network has enough supply capacity. If it does not, implementation of the grid extension plan should not be started before implementation of the reinforcement plan.

6.1.2 Criteria for grid extension

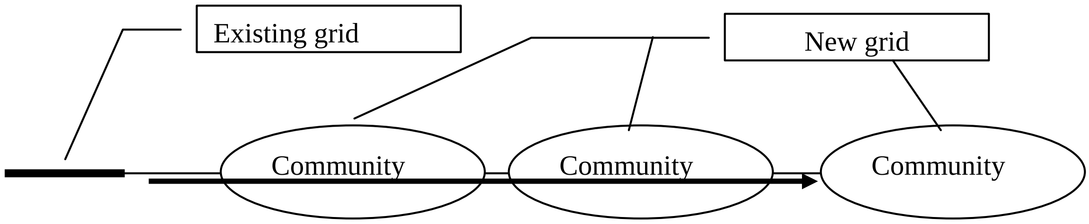
(1) Avoidance of electrification of an enclave community skipping other un-electrified areas on the way

A priority principle of grid extention is that village electrification should be started in the vicinity of the existing grid and that a remote community should not be targeted while skipping other un-electrified communities on the way. If the electrification is targeted at a remote community, the extension cost will be imposed on only that community, and this normally is not economically feasible.

On the other, if electrification begins with the community closest to the existing grid, the grid extension cost for electrifying the first community will be shared and lightened step-by-step, i.e., as the second and third communities are electrified. Due to the increase in the number of customers connected to the same grid, the shared cost per customer will continue to decrease. As such, this approach is the best in respect of economic merit.



<u>In the case that other communities on the way are skipped (SHEP)</u>



<u>In the case that all communities on the way are electrified</u>

Figure 6.1.1 Model of Grid Extension

Source: The Master Plan Study on Rural Electrification Using Renewable Energy Resources in the Northern Part of the Republic of Ghana

(2) Pursuit of economies of scale

If two communities are equally distant from the existing grid, the community with higher population receives higher priority.

Viewed from the standpoint of economic theory, this is a reasonable approach. We may expect the power supply cost to be reduced by bundling as many customers as possible. In the NED franchise in particular, the lifeline tariff scheme may be applied to almost all new consumers. It is difficult to recover the power supply cost from the tariff revenue, and this approach could be taken to minimize the imbalance between cost and revenue. Assuming that the unit cost of grid extension is the same, we must make plans so that power will be supplied to as many beneficiaries as possible.

VII. Compilation of basic data

7.1 Objective of preparation of the basic data collection

The preparation of the compilation of basis data is aimed at the compilation and presentation of information needed for smooth formulation of the Master Plan.

7.2 Methodology for preparation of the compilation of basic data

The compilation of basic data is prepared mainly in the form of an electronic database, and includes the following items.

(1) Single-line connection diagrams

The company is to prepare single-line connection diagrams providing information on medium-voltage distribution lines (11- and 33-kV) leading away from primary substations and on secondary substations. The diagrams are to be used for study of current in the medium-voltage distribution system (load current and voltage drop). They therefore must provide information on all items needed for such study, including primary substation transformer capacity; medium-voltage distribution line cable type, number, and distance; and secondary substation transformer capacity. The data collection is to contain single-line connection diagrams for the entire distribution network in Ghana. It is to be built with Auto CAD and other software currently used by the C/P.

(2) Power demand at load centers

The level of power demand at each load center is an item indispensable for system analysis of medium-voltage distribution lines. Data are to be collected with Microsoft Excel on the peak power and daily load curve for each primary substation bank and medium-voltage distribution line. (Printed forms will be separately determined.)

(3) Basic data on distribution facilities

Basic data on distribution facilities consists of information not reflected in single-line connection diagrams. Data are to be collected on the characteristics of the major distribution facilities needed for calculations. Microsoft Excel is to be used to collect the information shown in Table 7.2.1 for each specification in standard use in facilities. (Printed forms will be separately determined.)

Table 7.2.1 Basic data on distribution facilities

Facility	Basic data
Medium-voltage distribution lines	Route constants
Low-voltage distribution lines	- Route constants
Secondary substation transformers	Impedance and iron loss

(4) Results of distribution system analysis

The results of analysis are to be collected in tabular form using Microsoft Excel. (Printed forms will be separately determined. Section 3.3 presents an image of the analysis tool.)

(5) Results of economic and financial analyses of plans

The results of economic and financial analyses of the various plans are to be collected using Microsoft Excel. (Printed forms will be separately determined.)

7.3 Methodology for updating the basic data collection

It is advisable to revise the basic data collection on the occasion of Master Plan revision or updating, and to keep it always up to date.