THE FEASIBILITY STUDY
ON
THE LOSS REDUCTION PROJECT
OF
DISTRIBUTION NETWORK
IN
THE HASHEMITE KINGDOM OF JORDAN

Manual for Feasibility Study
on Distribution Loss Reduction

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Japan International Cooperation Agency

Tokyo Electric Power Co., Inc.
Tokyo Electric Power Service Co., Ltd.

PREFACE

The Feasibility Study on Loss Reduction Project of Distribution Network in the Hashemite Kingdom of Jordan has been conducted by Japan International Cooperation Agency (JICA) in close cooperation with Ministry of Energy and Mineral Resources (MEMR), National Electric Power Company (NEPCO), Electric Power Company (EDCO), Jordan Electric Power Company (JEPCO) and Irbid District Electric Power Company (IDECO) in the Hashemite Kingdom of Jordan from September, 1999 to December, 2000.

This Manual for Feasibility Study on Distribution Loss Reduction is intended to transfer requisite technology and methodology for the study on distribution network loss reduction. This manual has been compiled in the course of this Feasibility Study and especially based on the explanation in seminars, workshops intended to technology transfer and lively discussions between the Jordanian counterpart and JICA Study Team over the site investigations in Jordan.

Part 1of this manual gives detailed descriptions of procedures such as method, monetary evaluation and notices for establishing plans for distribution network loss reduction. Part 2 of the manual explains the software for the study including treatments of input data and notice on the software.

The procedure of compilation of the manual includes its additional revisions and improvements based on valuable opinions by Jordanian counterpart personnel, which has turned the manual into these present contents.

We hereby express our sincere appreciation to the personnel concerned and hope that the distribution loss reduction project on and after will be carried out successfully by engineers of the Hashemite Kingdom of Jordan.

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Contents

Part 1   FEASIBILITY STUDY ON DISTRIBUTION LOSS REDUCTION

1.   LOSSES IN TRANSMISSION & DISTRIBUTION SYSTEM

Losses in transmission and distribution systems consist of such as conductor losses, transformer core land copper losses, corona losses and other losses due to leak current through insulator. However, these power losses excluding conductor losses and transformer core and copper losses are so small that loss reductions are usually focused on reduction in conductor losses which shares a large part of transmission and distribution losses. The conductor losses are expressed by the following simple formula;

$$L = I^2 R \qquad \qquad \dots (1\text{-}1)$$

Where;

R : Resistance of a conductor

I : Current on conductor

The above formula makes clear that loss reductions can be achieved by decrease in conductor resistance, or decrease in current by power factor correction, system reinforcement such as replacing existing conductor with larger cross-section conductors (re-conductoring), installation of lines at same voltage and introduction of higher voltage system.

It is essential for power loss reduction from economic point of view that how far losses can be reduced while obtaining benefit due to loss reduction. Objective loss –rate is not given in advance, but is the result of the investment for loss reduction.

For power loss reduction of distribution system in Jordan, studies were conducted on respective target feeders seeking the maximum beneficial alternative for respective facilities.

Continuous effort is essential for maintaining loss-rate within appropriate level, which is one of the indices of the system efficiency. In order to maintain appropriate level of loss-rate, studies on such as conductor selection should be conducted based on loss evaluation in economy.

In addition to improvement system efficiency, reduction in voltage drop,

improvement in supply capability and/or system reliability can be realized by investment on facilities for loss reduction. Alternative should be examined in the light of not only economy but also other aspects on system.

2. MENU FOR TRANSMISSION & DISTRIBUTION LOSS REDUCTION

Measures for distribution power loss reduction can be realized by curtailment in resistance, current itself and/or improvement in operating conditions. Followings are measures widely taken for reducing distribution power losses.

- Correction of unbalanced phase current
- Leveling of distribution load (Changing open point of feeder)
- Power factor correction by fixed capacitors
- Re-conductoring of lines with larger cross-section conductor
- Construction of new lines at the same voltage
- Introduction of higher voltage system (Installation of transformers and load shift)

Correction of unbalanced phase current and leveling of distribution load can be carried out with small amount expenses through daily work by changing phases or load to be fed. As to correction of unbalance phase current, not only losses on neutral wires but also phase voltage unbalance can be reduced by shifting load to other phases.

On the other hand, introduction of the higher voltage systems, construction of line at the same voltage and installation of capacitors are measures requiring some amount of investment on facilities to reduce power losses. These investments should be carefully studied taking into account of economic benefit as the result.

Installation of capacitors is especially one of the cost effective measures for system with low power factor because investment cost can be very small compared with the cost for other measures.
Re-conductoring can become one of attractive and economic alternatives in case existing structures or poles can be utilized for larger cross-section conductors. The increase in total cross-section of conductor and its effect on loss reduction is not so large compared with new line addition though, its small amount of investment may result in the most beneficial alternative for power loss reduction.

Among the measures for power loss reduction in distribution system, this manual intends to give items to be studied and attention to be paid on measures of power

loss reduction with some amount of investment such as new line addition and higher voltage system introduction, and so on.

3. CONCRETE MEASURES FOR POWER LOSS REDUCTION

The following explanation intends to give how to conduct the study for loss reduction and important items to be examined or cautions in the course of the study will be described on respective measures of such as power factor correction, re-conductoring, construction of new line at same voltage and introduction of the higher voltage system.

3-1 Power Factor Correction with Fixed Capacitor

The concrete method of the study on power factor correction by fixed capacitor, its effect on power losses and points of notice on the study will be explained. Capacitor with circuit breaker is also utilized for power factor correction and can be switched off during off-peak load when reactive power compensation is not required, however, installation of circuit breaker on respective small capacitors in low voltage system will cost too much. So, studies for power factor correction is focused only on inexpensive fixed capacitors.

3-1-1 Optimal Location and Capacity of Fixed Capacitor

Loss reduction in power system by capacitor has the effect on both demand (kW) and energy (kWh) reduction.

- Demand reduction (kW)

- Energy reduction (kwh)

As the location of fixed capacitor is different for respective objectives, the optimum location of capacitor for respective objectives will be explained hereafter.

Capacity of fixed capacitor is determined based on system load curve in Jordan to be half of the reactive load current at sending end (low voltage terminal of s/s) at peak period so that voltages on the distribution system will not exceed its operating range due to excessive reactive power during light load period. This amount of fixed capacitor provides approximately unity-power factor operation at light-load period. Only load current data at sending end can be available, so load of distribution feeder is assumed to be unified distributed load along the line.

a. Low Voltage Distribution System

i. Capacitor for Reduction in Demand

Study on load current is only concerned with reactive portion of current, as active portion of load current is not affected by installation of capacitors.

Capacity of fixed capacitor in current (I_c) is the same value as reactive load current at sending end of target feeder at light load period, say, a half of peak reactive load. The distribution of reactive load current is changed due to installation of fixed capacitor at location (a) as shown in Figure 3-1.

Figure 3-1   Distribution of Reactive Current

Reactive   current   before
installation of a capacitor

Reactive   current   after
installation of a capacitor
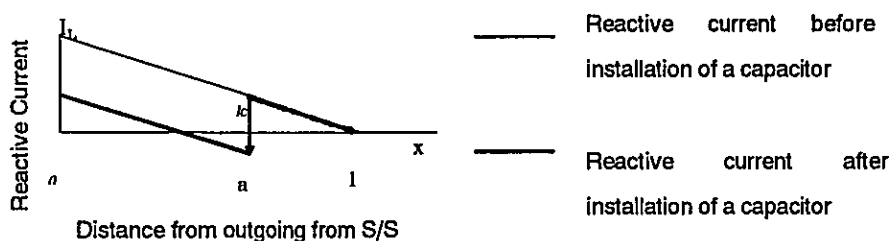
The reactive load current along the feeder from sending end to location (a) is reduced by (I_c), while the reactive load current from location (a) to the end of the feeder does not change.

Losses can be represented as following formula:

$$Losses = R\int_0^a \left[I_L(1-x) - I_c\right]^2 dx + R\int_a^1 \left[I_L(1-x)\right]^2 dX = R\left[1/3 I_L^2 - 2 I_c I_L\left(a - 1/2 a^2\right) + I_c^2 a\right] \quad \cdots (3\text{-}1)$$

Where, R is resistance of feeder per unit length, and I_L is reactive load current.

By differentiating formula (3-1), and let its value be zero in order to obtain the optimum location of fixed capacitor,

d(LOSSES)/da=R(-2$I_c I_L$+2$I_c I_L$a+I_c^2)=0

a=1-I_c/(2I_L)   ...(3-2)

Reactive current at location (a) can be obtained using formula (3-2):

i=I_L(1-a)=1/2I_c ...(3-3)

Formula (3-3) gives that reactive load current at optimal location of fixed capacitor is half of the capacity of fixed capacitor installed.

As load is uniformly distributed along the feeder, the optimal location of fixed capacitor for demand reduction is the middle point of feeder for demand reduction.

ii   Capacitor for Reduction in Energy

Optimum location of fixed capacitor in terms of energy reduction will be explained hereafter. The annual load duration curve is assumed straight line for simplification of explanation.

Annual energy losses due to reactive load can be given by formula (3-4):

Energy Losses

$$= R\int_0^a \int_0^1 [(M - I_L)(1 - x) + I_L(1 - x) - I_c]^2 \, dt\, dx + R\int_a^1 \int_0^1 [(M - I_L)(1 - x) + I_L(1 - x)]^2 \, dt\, dx$$

$$= R[(M - I_L)^2(1/9) + (M - I_L)I_L(1/3) + (M - I_L)I_c(-a + a^2/2) + I_L^2(1/3) - 2I_cI_L(a - a^2/2) + I_c^2 a]$$

...(3-4)

By differentiating formula (3-4), and let its value be zero in order to obtain the optimum location of fixed capacitor that gives minimum energy losses:

a=1-I$_c$/((I$_L$+M))   ...(3-5)

Annual reactive load factor (RLF) is defined by formula (3-6) as in same manner as annual load factor:

RLF=(I$_L$+M)/2 x I$_L$ ...(3-6)

Substituting formula (3-5) into formula (3-6) gives;

a=1-I$_c$/(2RL Fx I$_L$)   ...(3-7)

Reactive load current (i) at x=a is obtained by using formula (3-7) as:

I=I$_L$(1-a)=I$_c$/2RLF   ...(3-8)

Formula (3-8) describes that the optimum location of fixed capacitor is the location where reactive load current is I$_c$/2RLF.

Assumption of straight-line reactive load duration curve is taken in the study on the optimum location of capacitor, though formula (3-8) is valid for general cases.

Annual reactive load factor and the optimum location of fixed capacitor in terms of energy reduction can be summarized as shown in the following table for various Reactive Load Factor (RLF). According to RLF, the optimum location of fixed capacitor changes and becomes apart from sending end as RLF becomes small in value as shown in following table.

Table 3-1   Annual Reactive Load Factor v.s. Optimum Location of Capacitor

RLF	Reactive Load Current	Optimal Location
50%(0.5)	1.000I$_c$ (0.500I$_L$)	Location where reactive load current is 1/2 of sending End
60%(0.6)	0.833I$_c$(0.417I$_L$)	Location where reactive load current is 2/5 of sending End
70%(0.7)	0.714 I$_c$(0.357I$_L$)	Location where reactive load current is 1/3 of sending End

b. Medium Voltage System

As to power factor correction for MV distribution system, two alternatives are applicable, one is to install MV capacitors at appropriate location in the light of energy loss reduction as in the same manner on low voltage feeder and the other is to install low voltage capacitors on low voltage terminals of respective

distribution substations. The former is advantageous in small number of capacitors and in case for lumped large load power factor correction, and the latter is less expensive and easy to increase its capacity in proportion to load growth if room for installation is enough.

As to location of medium voltage capacitor, the formula (3-3) and (3-8) can be applied in the same manner for optimum MV capacitor location.

The optimum location of MV capacitor is the point where reactive load current is 1/3 of sending end in case of 70% annual load factor. In general, load on medium voltage system is generally treated as lump load and is somewhat different from that of low voltage system, but still above relation is valid. The optimum location of medium voltage fixed capacitor is at the MV bus of the medium voltage substation around 2/3 apart from sending end. (The load is uniformly distributed.)

Comparison of MV Capacitor and LV Capacitor

<Location and Capacity of MV and LV Capacitor>

Capacity of MV capacitor is half the reactive power at sending end of feeder in the peak period, which makes the power factor 1.0 during off-peak period. MV capacitor is installed where its reactive power is about one-third the reactive power at the sending end. These conditions are the same as discussed in power factor correction of LV system.

LV capacitors are distributed on secondary side of each distribution transformer for loss reduction. Capacity of each small LV capacitor is distributed in proportion to each transformer capacity under the condition that the total capacity of each small capacitor is about equal to the half of reactive power at the sending end in the peak period.

< Result of the Study >

Result of the study on loss reduction by MV and LV capacitors is shown in Table 3-2. This is the result of total 8 target feeders showing the LV capacitors is beneficial in terms of economy for loss reduction. Investment in LV capacitor is smaller than that in MV capacitor since the capacitor unit price is inexpensive. Loss reduction by LV capacitor is larger than that by MV capacitor since the copper loss of distribution transformer is reduced by installing capacitor on the secondary side of distribution transformers.

Table 3-2   Comparison of Capacitor Location on MV and LV Side of S/S

Measures	MV Capacitor	LV Capacitor
Construction	28MVA	28MVA
Capacitor Price	5JD/kVA	4JD/kVA
Initial Investment (JD) (a)	140,000	112,000
Loss Reduction (kW)	1,198	1,337

3-1-2   Rated Capacity of Capacitor Applied

Capacity of fixed capacitors for loss reduction should be determined based on reactive load current on respective distribution lines. The series of capacity of capacitors should be determined taking into account of reduction in effect of power factor correction due to annual load growth. In this study, the unit capacity of capacitors for loss reduction is selected among standard series of capacities. A series of around 1.5 time rated capacities of capacitors is selected so as to maintain effects for longer than five years under load growth rates around from five to seven percent.

A series of capacity of 5kVA, 10kVA, 16kVA, 25kVA, and 40kVA is selected and combination of these capacitors is studied to compensate appropriately reactive current.

The combination of capacitor is selected under following conditions:

· The number of combined capacitors is limited within two, at most three.

· The reactive power compensation in the initial stage light load period should be nearly unit.

The result of the study is summarized in the following table. The power factor at sending end of feeder at peak period before/after installation of fixed capacitor is tabulated in the following table.

Table 3-3   Capacity of Capacitor and Power Factor at Sending End (Peak Period)

Load Current (Peak) (A)	Pf : 0.85		Pf : 0.80		Pf : 0.75		Pf : 0 70	
	Cap. (kVA)	Pf:at S-End	Cap. (kVA)	Pf:at S-End	Cap. (kVA)	Pf:at S-End	Cap. (kVA)	Pf:at S-End
50	10	0.9598	10	0.9278	10	0.8905	10	0.8489
75	16	0.9653	16	0.9351	16	0.8993	16	0.8589
100	16	0.9415	16	0.9044	16	0.8631	16	0.8184
125	25	0.9598	25	0.9278	25	0.8905	25	0.8489
150	25	0.9448	25	0.9084	25	0.8677	25	0.8235
175	35	0.9598	35	0.9278	35	0.8905	35	0.8489
200	40	0.9598	40	0.9278	40	0.8905	40	0.8489
225	40	0.9500	40	0.9150	40	0.8754	40	0.8320
250	50	0.9598	50	0.9278	50	0.8905	50	0.8489
275	50	0.9518	50	0.9174	50	0.8782	50	0.8350
300	60	0.9598	60	0.9278	60	0.8905	60	0.8489

· 10kVA: 5+5kVA or 10kVA, 35kVA:10+25kVA, 50kVA:25+25kVA, 60kVA:10+10+40kVA

3-1-3   Effects on Current and Power Factor by Fixed Capacitor

As will be explained in Chapter 6, economic value of loss reduction is generally estimated in the following manner. Firstly, reduction in losses at peak in the first year is calculated. Secondary, reduction in losses during 10 years is estimated by multiplying load current based on annual demand growth rate and reduced resistance of facilities. This method is applicable and effective in studying the loss reduction achieved by the reduction in resistance of system such as re-conductoring, installation of line at same voltage and introduction of higher voltage system, because the reduction in losses in such cases is increasing in proportion to square of load current. However, in case of power factor correction with fixed capacitor, afore-mentioned method cannot be directly applicable, because distribution of reactive current along the feeder would be changed by lump reactive load of capacitor, and it will be longhand work to examine effect of power factor correction on respective portions of feeders for at peak and off peak period during 10 years on large number of target feeders. In order to avoid such enormous works, the equivalent current power factor due to capacitor installation was studied.

As the losses are in proportion to current squared, it follows that the losses due to the two components of current can be reckoned separately.

Total losses = R [(I $\cos\theta$)^2+(I $\sin\theta$)^2]

= active-current losses + reactive-current losses

So, Equivalent current and power factor after installing fixed capacitor was studied to obtain the reduced current and power factor that gives same effect on loss reduction for target 10 years. By using equivalent current with improved power factor in the first year, reduction in losses during 10 years can be easily treated in the same manner as other measures such as new line addition at same voltage, so on and this method gives good agreement to estimate losses in study period.

The following procedures are taken to evaluate the loss reduction by fixed capacitor as:

-    Calculating the equivalent reduced current by respective values of power factor by 0.01 in such a manner that losses will result in the same amount of loss reduction in 10 years,

-    Calculating the coefficient between equivalent current and load current before power factor correction by fixed capacitors, (Reduced Current Coefficient)

- Calculating reduction in losses at peak in the first year applying the reduced current coefficient

- Estimating reduction in losses during 10 years by multiplying loss factor, current demand growth rate and so on.

Equivalent reduced current coefficient can be calculated as follows.

As mentioned in clause 3-1-1 and 3-1-2, in order to obtain the maximum effect on loss reduction by fixed capacitor, capacitor should be installed at 1/3 from the end of the feeder. Equivalent reduced current coefficient can be calculated under following conditions. The "losses" mentioned hereafter means only losses due to reactive current.

<Conditions>

- Annual averaged demand growth rate for 10 years: 5%/ year

- Loss factor: 0.5463 (Averaged value of past 3 years ('96~'98)

- Capacitor: A half of the reactive current at peak in the first year

- Location of capacitor: one third of the length of the feeder from the end

Distribution of current after installation of capacitors is shown below. Total losses along feeder can be obtained by integration of square of current in respective portions multiplying resistance of respective portions of feeder. The following formula is obtained for total losses after installation of capacitor at 2/3 from the sending end.

Figure 3-2   Distribution of Reactive Current
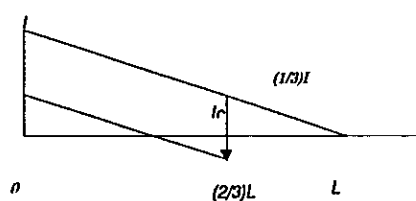
$$Loss = \frac{1}{3}rL \cdot I^2 - \frac{8}{9}rL \cdot I \cdot Ic + \frac{2}{3}rL \cdot Ic^2$$

r : Resistance per length

I : Reactive current at delivering point

Ic : Current of a capacitor

L : Length of a feeder

Annual losses can be calculated by multiplying 8760h and annual loss factor by above formula.

Annual losses= Loss x Loss Factor x 8760   ...(3-9)

Losses due to reactive current during 10 years can be obtained by integrating

square of reactive current at peak period during 10years as shown in following formula.

Lossduringthe10years

$$-\sum_{n=1}^{10}\int_{0}^{8760}\text{Loss } dt - \frac{1}{3}rL\cdot 8760\cdot\text{LossFactor}\sum_{n=1}^{10}I_{n}peak^{2} \quad -\frac{8}{9}rL\cdot 8760\ L\cdot\text{LoadFactor}\ I_{c}\sum_{n=1}^{10}I_{n}peak+\frac{2}{3}rL\cdot 10\times 8760\times I_{c}^{2}$$

$I_n$peak: Peak reactive current in the nth year   ...(3-10)

Loss during the 10 years before installing capacitor can be obtained by substituting $I_c=0$, and Loss-Factor Σ Inpeak^2= I_{1peak} ^{2}8.812, as shown in the following formula. (Substitution $I_c=0$ means deducting effect in loss reduction due to capacitor installation, and loss factor times accumulated square I for 10 years is calculated as 0.5463x Σ (I_{1peak}1.05^n)^2= I_{1peak} ^{2}8.812.)

Loss during the 10 years(With out capacitors) $= \frac{1}{3}rL\cdot 8760\cdot I_1 peak^2 \times 8.812$ ...(3-11)

Losses during the 10 years after installing capacitor can be obtained by substituting IC=1/2 I_1peak.

Loss during the 10 years(With a capcitor) $= \frac{1}{3}rL\cdot 8760\cdot I_1 peak^2 \times 1.556$ ...(3-12)

Compared formula (3-11) and formula (3-12), losses due to reactive current for 10 years will be reduced to 1.556/8.8107=0.1766 by installing capacitor. As resistance of conductor does not change by capacitor installation, root of the 0.1766 is the ratio between reactive load current before and that after installation of capacitor. This means reactive load current can be equivalently reduced to 42.02 % of the reactive load current before capacitor installation.

$I_n peak$(Equivalent to installation of a capacitor) $= R\times I_n peak$

$R = \sqrt{1.556/8.812} = 0.4202$ ...(3-13)

Rate of reduction in load current (apparent current) and improved power factor can be tabulate in the following table. Reduced current coefficient (RCC) and equivalent power factor (EQpf) are rate of apparent load current of after and before capacitor installation, and improved power factor after capacitor installation, respectively.

Table 3-4   Reduced Current Coefficient & Equivalent Power Factor

pf before	After installation of fixed capacitor		pf before	After power factor correction with fixed capacitor	
	Eqpf	RCC		EQpf	RCC
0.70	0.92	76%	0.81	0.96	85%
0.71	0.92	77%	0.82	0.96	85%
0.72	0.93	78%	0.83	0.96	86%
0.73	0.93	78%	0.84	0.97	87%
0.74	0.93	79%	0.85	0.97	88%
0.75	0.94	80%	0.86	0.97	89%
0.76	0.94	81%	0.87	0.97	89%
0.77	0.94	82%	0.88	0.98	90%
0.78	0.95	82%	0.89	0.98	91%
0.79	0.95	83%	0.90	0.98	92%
0.80	0.95	84%	---	---	---

3-2   Reinforcement of Line at Same Voltage

Reinforcement of distribution line at same voltage is one of the means to reduce losses and consists of two alternatives as installation of new line and re-conductoring with larger cross-section conductor. The former costs while effect on loss reduction obtained is larger compared with re-conductoring. Two measures will be compared in terms of economy for loss reduction and cautions to be paid in the course of the selection of alternatives will be explained hereafter.

3-2-1   Critical Load Current

Return of investment for power loss reduction becomes larger as heavier load current on distribution system is and as smaller conductor cross-section is. Studies has been carried out on various conductors with different load to find out the critical load current which results in beneficial alternative in the light of economy for power loss reduction.

a.   Low Voltage Distribution System

Studies on critical current by existing conductors have been examined in term of economic benefit of re-conductoring and new line at same voltage under following conditions. Table 3-5 summarizes the existing conductors studied on reconductoring and new line installation with AA100mm^2 on AA150mm^2.

Table 3-5   Conductors Studied

Aluminum Conductor	Copper Conductor
GANT(25mm^2), ANT(50mm^2), WASP(100mm^2), LAL50, LAL95	LCU25, LCU35, LCU50, LCU70

i. Conditions of Study

Annual averaged growth rate of load and the period of study shall be 5% and 10 years. Conditions of study are tabulated in the following table.

Table 3-6   Conditions of Study (LV)

kW Value	82.24JD	KWh Value	0.02779JD
Loss Factor	0.546	Annual Growth Rate	5%
Period of Study	10 years	Discount Rate	8%
Rate of Annual Cost	9.368%	Annual O&M Cost	2.5%

Construction cost for re-conductoring and new line with AA100mm^2 and AA150mm^2 are tabulated below.

Table 3-7   Construction Cost for Re-conductoring and New Line (LV)

AA100mm^2	Re-conductoring	3,750 JD/km
	New Line	11,250 JD/km
AA150mm^2	New Lne	12,750 JD/km

ii Critical Current and Most Net Beneficial Range (M.N.R)

The result of the studies is summarized below. Figure 3-3 shows an example of the comparison of Net-Benefit between re-conductoring and new line installation.

Table 3-8   Critical Current and Most Net-Beneficial Range (M.N.R) [A]   (LV)

		Re-Con (AA100mm^2)	New Line (AA100mm^2)	New Line (AA150mm^2)
GANT	Critical Current	20	35	37
	Opt. Range	21~94	----	94~
ANT	Critical Current	36	54	55
	Opt. Range	36~83	----	83~
WASP	Critical Current	----	88	88
	Opt. Range	----	----	88~
LAL50	Critical Current	31	49	49
	Opt. Range	31~88	----	88~
LAL95	Critical Current	84	78	79
	Opt. Range	----	78~82	82~
LCU25	Critical Current	27	45	46
	Opt. Range	27~88	----	88~
LCU35	Critical Current	38	56	56
	Opt. Range	38~83	----	83~
LCU50	Critical Current	58	70	70
	Opt. Range	58~79	----	79~
LCU70	Critical Current	----	88	88
	Opt. Range	----	----	88~

Figure 3-3   Comparison of Net Benefit between Re-conductoring and New Line
Installation in LV Feeder. (Existing Conductor : LCU 50 mm^2)
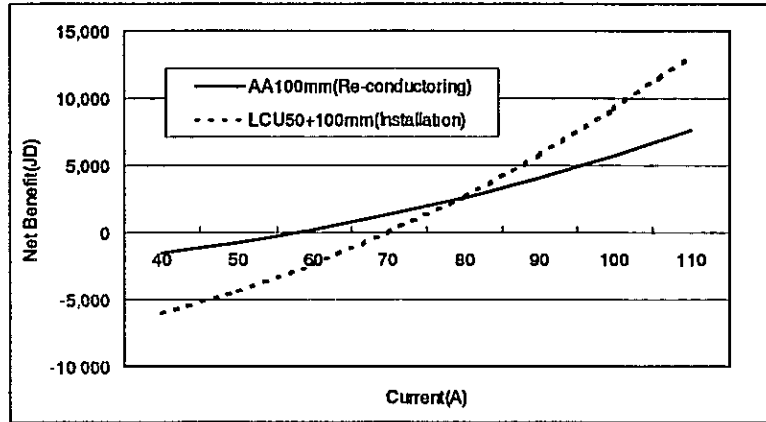
Under 80A, Re-conductoring to AA100mm^2 is more net-beneficial than installation of AA100mm^2.
Over 80A, Installation of AA100mm^2 is more net-beneficial than Re-conductoring to AA100mm^2.

b.   Medium Voltage Distribution System

i   Conditions of Study

Annual averaged growth rate of load and the period of study shall be 5% and 10
years. Conditions of study are tabulated in the following table.

Table 3-9   Conditions of Study (MV)

kW Value	58.71JD	KWh Value	0.02567JD
Loss Factor	0.546	Annual Growth Rate	5%
Period of Study	10 years	Discount Rate	8%
Rate of Annual Cost	9.368%	Annual O&M Cost	2.5%

Construction cost for re-conductoring and new line with ACSR100mm^2 and
ACSR150mm^2 are tabulated below.

Table 3-10   Construction Cost for Re-conductoring and New Line (MV)

ACSR100mm^2	Re-conductoring	4,428 JD/km
	New Line	13,285 JD/km
ACSR150mm^2	Re-conductoring	5,167 JD/km
	New Line	15,500 JD/km

ii   Critical Current and Most Net Beneficial Range (M.N.R)

The result of the studies is summarized below.

Table 3-11   Critical Current and Most Net-Beneficial Range (M.N.R) [A]   (MV)

		Re-Con (AC100mm²)	Re-Con (AC150mm²)	New Line (AC100mm²)	New Line (AC150mm²)
AAA50	Critical Current	42	36	64	60
	M.N.R	----	36~154	----	154~
AAA100	Critical Current	----	72	104	94
	M.N.R	----	72~128	----	128~
AC50	Critical Current	43	36	64	61
	M.N.R	----	36~158	----	158~
AC100	Critical Current	----	71	103	93
	M.N.R	----	71~127	----	127~
AC150	Critical Current	----	----	144	128
	M.N.R	----	----	----	128~

3-2-2   *Study to be examined in the Course of Selection of Alternative*

Following are Items to be examined in case of installing new line from substation. Other cautions on the study will be commented hereafter.

a.   Low Voltage System

Further study or reconsidering on the construction of new line such on its root and/or the way to distribute power should be conducted to correspond to actual conditions of existing system because study for new line installation with the software PLOPT is assumed that new line shall be installed in parallel with existing line.

b.   Medium Voltage System

Re-conductoring of existing feeders, new line installation, and 132/33kV substation installation are viable measures for loss reduction. Among those, re-conductoring may result in difficulty in construction work due to insufficient supply capability of remaining system during the construction work since MV feeder covers wide area and relatively large load.   This makes it necessary to examine supply capability of interconnection to the adjacent system or its source 132/33kV substation during construction work period, as well as feasibility of construction.

3-3   **Introduction of Higher Voltage System**

Installation of step-down substation and higher voltage line along with existing distribution feeder is examined in the soft ware PLOPT. Changing the length and conductor size of higher voltage line and location and capacity of step-down substation for higher side system and open point for existing lower side system, benefit and expenditure due to loss reduction are calculated. The software PLOPT

selects the most beneficial combination of conductor and step-down transformer.

3-3-1 General Cautions on Study for Introduction of Higher Voltage System

If the conditions such as geographic relations of existing facilities and limitations by land acquisition were taken into account on the software, the huge number of information or data would be required and the software would become extremely large and complicated. To avoid such a troublesome situation for the optimization analysis, the studies on reinforcement are carried out provided that the lines should be constructed along the existing distribution lines. Therefore, In case of introduction of the higher voltage lines or the construction of medium voltage lines, the result of the software PLOPT cannot be directly put into practice. Route or land acquisition for large electric facilities such as transmission lines and main substations has various restrictions in reality. Shorter route may exist instead of the route along existing distribution line. Based on the result of the analysis, farther study should be carried out to brush up the alternatives selected by software with utmost use of human knowledge

3-3-2 Study to be examined in the course of Selection of Alternative

a. Low Voltage System

The route of MV feeders and location of distribution substations should be reexamined taking into account the distribution of existing substations and other feeders.

b. Medium Voltage System

Installation of 132kV transmission line in parallel with existing MV feeder may be longer and sometimes be restricted by phisical or other conditions. The study should be re-examined in the light of shortest and economic route of the transmission line. 132kV transmission line should also be studied in terms of long-term perspective, as is a trunk system.

As to 132/33kV substation, the location is carefully studied in terms of delivery of power to regions and future extension of MV system.

3-3-3 Preliminary Study of Introduction of Higher Voltage System

In order to grasp the relations between the existing conductor sizes and critical load currents for introduction of higher voltage system, the preliminary study has been conducted with a model system on how much load current is required to

CONCRETE MEASURES
FOR POWER LOSS REDUCTION

bring about net-beneficial cases of introduction of higher voltage systems. The study has been also carried out on how much load current is to make the alternatives of introduction of higher voltage system superior to reinforcement of LV systems such as construction or re-conductoring of LV lines.

The following figure illustrates the model system for this study.
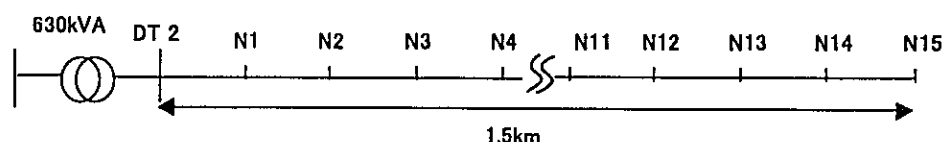
The system model is composed of 1.5km LV feeders with 15 sections of 0.1km length and 630kVA distribution transformer. The load of distribution transformer is 50% of its capacity. Load current is assumed to be unified distributed load. The study has been carried out changing current from 40A to 240A by 10A. The study has been conducted on both overhead and underground system.

The result is shown in Table 3-12. Figure 3-4 shows an example of the comparison of Net-Benefit between reinforcement of line at the same voltage and Introduction of higher voltage system.

Table 3-12   Critical Current for Introduction of Overhead MV System

Conductors of Existing LV Lines	Current (A)	
	Critical Current	Optimal Range
WASP	120	130~
LAL95	110	120~
LCU50	100	120~
LCU35	90	120~
ANT	90	120~
LAL50	80	120~
GANT	60	140~

Table 3-13   Critical Currents for Introduction of Underground MV System

Conductors of Existing LV Lines	Current (A)	
	Critical Current	Optimal Range
LCU70	170	---
LCU50	150	170~
LCU35	120	180~
ANT	120	180~
GANT	90	220~

In case that MV system is overhead and a conductor of a LV line is WASP(100mm aluminum conductor), it can be found out that net-benefit is brought about in the

range from 120A and, in the range over 130A, the case becomes superior to measures of construction or re-conductoring of lines at the same voltage.

Actual feeders have such complicated configurations, varieties of distribution of load current and conductor sizes for respective sections.

The above result can not be directly applied to the study for introduction of higher voltage system. However, it provides an approximate tendency of critical load current for introduction of MV system.

Figure 3-4   Comparison of Net Benefit between Reinforcement of Line at Same Voltage (LV) and Introduction of Higher Voltage (MV) System (Existing Conductor : LCU 50 mm^2)
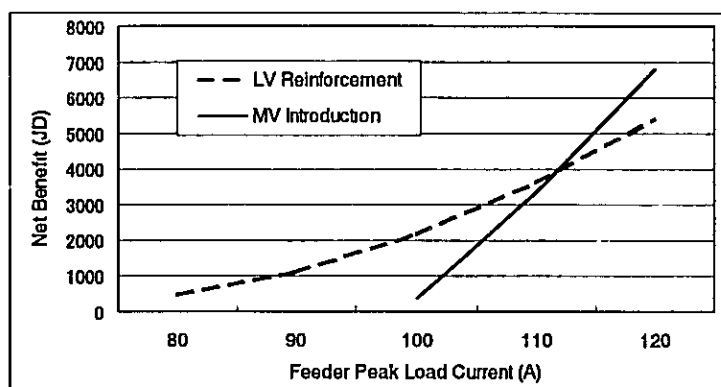
LV Reinforcement is more net-beneficial than MV introduction at feeder peak current of 100 A. At 120 A, MV Introduction is more net-beneficial than LV Reinforcement.

4. COMBINATION OF MEASURES FOR POWER LOSS REDUCTION

Measures to reduce power losses in the network are power factor correction by installing capacities and introduction of higher voltage system, and so on. Generally speaking, the measures with larger investment bring about more benefit but take more time to recover the initial investment. On the other hand, the measures with smaller investment cannot bring about large benefit in amount but swiftly recover the initial investment. Power factor correction by capacitors is such measures that can be applied to the existing distribution system with superiority in economic efficiency. The aim of the study of loss reduction is to select most net-beneficial measures, so combination of alternatives with fixed capacitor should be examined.

4-1 Combinations of Measures

Power factor correction by installing capacitors is the most effective measures in economy among other measures for medium and low voltage target feeders. Thus, the studies on power factor correction with capacitor should be firstly examined to evaluate its effect on loss and voltage reduction. Other measures in combination with power factor correction should be examined in the next step. In other word, other measures should be studied whether they are net-beneficial or not under the given conditions of power factor correction.

Combinations of measures for the studies are listed in following Table.

Table 4-1   Combinations of Measures for the Studies

	Measures
1	Power factor correction by installation of capacities
Combinations of options of measures	
2	Power factor correction by installation of capacities and Re-conductoring
3	Power factor correction by installation of capacities and construction of the same voltage lines
4	Power factor correction by installation of capacities and Introduction of higher voltage lines

4-2 Recovery Term of Total Cost due to Investment

Recovery Term of total cost due to initial investment is one of the indices for evaluating respective alternatives. Investment Efficiency Factor (IE factor) is defined as the ratio of Net Benefit for study period (k years) divided by Initial Investment as shown below.

IE factor $\equiv$ (NET Benefit for study period)/(Initial Investment)

Using the IE factor, Recovery term (Recovering Duration) of total cost due to Initial

Investment can be calculated in such manners that benefit due to loss reduction for k years equals total cost due to Investment on facilities. Relation between coefficient of investment efficiency and term of recovery of total cost due to initial investment is summarized in following Table.

Table4-2   Investment Efficiency Factor vs Term of Recovery

Term of Recovery of Total Cost due to Initial Investment	Investment Efficiency Factor (IE Factor)
The first year	10.43
2nd year	4.68
3rd year	2.80
4th year	1.86
5th year	1.30
6th year	0.93
7th year	0.66
8th year	0.47
9th year	0.32
10th year	0.20

• Investment Efficiency Factor = Net Benefit during the 10 years/ Investment on Facilities

The above table shows that as coefficient of investment efficiency becomes larger, the term of recovery of total cost due to initial investment becomes shorter. Using the coefficient of investment efficiency, measures for loss reduction can be ranked by respective feeder according to the value of investment efficiency. And further, coefficient of investment efficiency can be used for determining the amount of investment and the selection of respective measure based on the order and/or term of recovery.

As mentioned in Chapter 8 of Final Report, measures for respective target feeders have been evaluated accounting the coefficient of investment efficiency.

5. STUDY FLOW

Study flow for power loss reduction and Items to be examined carefully in respective stages of study are illustrated in the following chart.

1. Selection of Target Feeder	• Grasp of Facility Conditions (Load Current, Conductors, System Configuration) • Reference to Critical Current • Correction of Phase and Load Unbalance
2. Studies on PF Correction	• Load Current, PF, Distribution of Load: Selection of Capacitor & Location • Evaluation of Reduction in Load Current & PF
3. Combination of Measures	(Study on Combined Alternatives) • PF + Re-conductoring • PF + New Line Installation • PF + Higher Voltage Introduction • Check on Voltage Reduction
4. Economic Evaluation on Measures	• Analysis by PFLOW, PLOPT • Evaluation of Net Benefit • Check on Voltage Reduction
5. Re-examination of Result in Detail (Improvement of Measures)	(Re-conductoring) • Feasibility of Construction Work (Term, Strength of Structures, etc) (New Installation of Line) • Shortest Route • Switch of Load • Interconnection with Adjacent Line (Introduction of Higher Voltage System) • Location of s/s, Shortest Root of Line • Secondary System (Interconnection, Open Point)
6. Selection of Optimal Solution	• Investment, Effect in Economics • Final Decision of Reinforcement

6. ECONOMY FOR DISTRIBUTION LOSS REDUCTION

Investment on transmission/distribution facilities is requisite to reduce power losses in distribution system. The return of investment in terms of economy is curtailment in fuel cost and investment on power stations and transmission facilities. Studies have to be carefully conducted on amount of investment for power loss reduction taking into account net benefit (the difference of return and cost due to investment).

6-1 Net Benefit due to Power Loss Reduction

Cost such as fuel cost can be saved by power loss reductions, while, investment for reinforcement or improvement of facilities will cause increase in the cost such as depreciation and maintenance cost. The difference between benefit and cost due to investment during study period is Net Benefit and as is defined by following formula.

$$NB = EL - EF \qquad --- \qquad (6\text{-}1)$$

EL :   Reduction in cost of losses

EF :   Cost of facilities due to investment

Goal of the study for loss reductions is to obtain optimal solution in terms of economy and select feasible alternatives. The optimal solution in economy is generally explained hereafter and respective items such as cost of facilities, loss values and evaluation method are later on described in detail.

Figure 6-1 shows the general relation between amount of facility, facility cost, and cost of losses in a power system. Facility cost is the cost due to investment on facilities such as depreciation and O&M cost. Investment on facilities can result in reduction in losses, while, facility cost increases. Generally, the amount of facility is increasing in proportion to investment. The cost for losses reduces as the amount of facilities increases (resistance of system goes down). The total cost defined as 'Cost of Facilities ' +' Cost of Losses' configures concave shape in general and has the optimum point in total cost as shown in Figure 6-1.

Figure 6-1   Cost, Amount of Facility and Cost of Losses
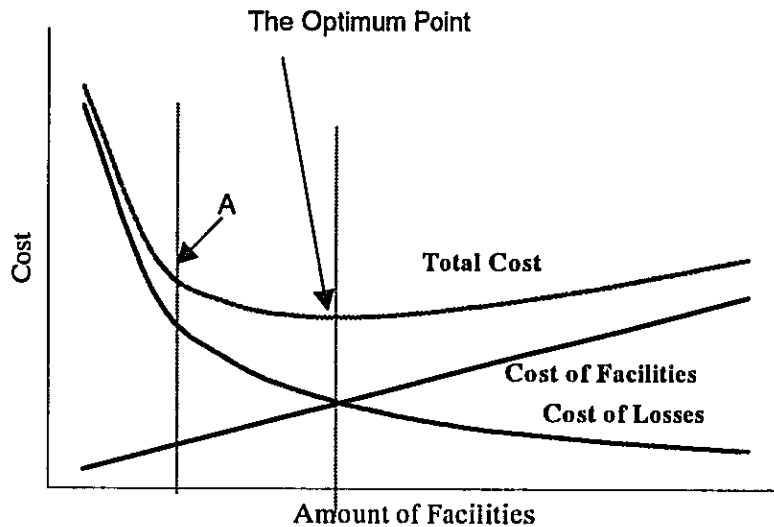
Consider the system condition is at point A in Figure 6-1. If some amount of facilities is added in order to reduce losses, the point will be moved to the right side of the figure. Cost of facilities is increased, while cost of losses is reduced and total cost is reduced. As it is longhand work to study all facilities to pursue the optimal point of cost of the total system, optimal point is usually studied on respective facilities.

The objective study is to obtain maximum net benefit that is the difference between benefit due to loss reduction (EL) and cost due to investment on facilities (EF) as shown in formula (6-1).

6-2   Cost of Facilities due to Investment

Cost of facilities is composed of interest, depreciation and other cost such as O&M cost and taxes. Annual cost of facilities can be represented by initial investment times rate of annual cost that is the ratio of the annual cost to initial investment of facilities. The annual cost for straight-line depreciation is assumed constant value over service time of facilities (life time).

6-2-1   Interest and Cost of Depreciation

Annual cost due to straight-line depreciation can be represented in (6-2), with using investment on facility (C), life time of facility (n), salvage value of facility after n years (RE), and discount rare (i).

$$AC = (C - RE) \, i/(1-(1+i)^{-n}) \qquad\qquad ...(6\text{-}2)$$

Where $AC(1+i)^{-1} + AC(1+i)^{-2} + AC(1+i)^{-3} + ... + AC(1+i)^{-n} = C-RE$

$AC(1+i)^{-1} \,{}^*[(1-(1+i)^{-n})/(1-(1+i)^{-1})] = C-RE$

where: $i/(1-(1+i)^{-n})$ is Capital Recovery Factor.

6-2-2   *Annual Cost due to O&M and Others*

Cost due to O&M and others such as property tax are usually assumed as the rate of the investment on facility and it can be represented as (6-3).

$$AM = C^*b \qquad\qquad ...(6\text{-}3)$$

b is the ratio of O&M and other cost against investment.

6-2-3   *Total Annual Cost and the Rate of Annual Cost of Facilities*

Total of Costs mentioned above provides yearly cost due to investment on facility (annual cost of facility). Summation of (6-2) and (6-3) gives (6-4), annual cost of facility.

$$AEF = \ (C - RE) \, i/(1-(1+i)^{-n}) + C^*b \qquad\qquad ...(6\text{-}4)$$

Where $AEF = AC + AM$

Rate of annual cost of facility against investment on facility is known as rate of annual cost of facility. Annual cost of facilities can be rewritten as (6-5).

$$AEF = AER^*C \qquad\qquad ...(6\text{-}5)$$

Where AER is rate of annual cost of facility, and is defined as

$$AER = AEF/C = (1 - a) \, i/(1-(1+i)^{-n}) + b \qquad\qquad ...(6\text{-}6)$$

Where $a = RE /C$

6-3   Economic Value of Loss Reduction (kW & kWh Value)

Power losses can be evaluated in terms of monetary value of kW and kWh cost. The former reflects reduction in construction costs of power facilities of generating and/or transmission facilities and the latter reflects reduction in fuel and O&M cost for generation.

6-3-1   *kW Value (Cost)*

Generating facilities are installed in accordance with electrical peak demand. kW

cost is defined as the cost of facilities to be paid annually for producing and transmitting one kW which includes 'construction cost of power station' + 'construction cost of transmission and distribution system' . Construction cost during study period can be evaluated on the bases of annual cost due to investment as mentioned in 6-2.

6-3-2 kWh Value (Cost)

KWh cost is the cost as 'Fuel Cost ' + ' O&M cost' to be paid for producing and transmitting energy per one kWh. O&M cost is also added in kW cost as in accordance with cost due to investment.

Weighted average cost of kW and kWh with regard to several power stations are usually used for both of these values.

6-4 Economic Evaluation of Reduction in Transmission and Distribution Losses (Net Benefit)

Reduction in transmission and distribution losses can be evaluated in terms of reduction in kW at peak period and in kWh during a year multiplying kW cost and kWh cost, respectively.

kW unit cost	:	KWC
kWh unit cost	:	KWHC
Reduction in losses of kW at peak in a year	:	ΔAL
Reduction in losses of kWh in a year	:	ΔALH

Economic evaluation of power loss reduction can be described as in (6-7).

$$\Delta AEL = \Delta AL{*}KWC + \Delta ALH{*} KWHC \qquad ...(6\text{-}7)$$

Reduction in kWh losses in one year can be rewritten with loss factor (LossF) as shown below.

$$\Delta ALH = \Delta AL{*}8760{*}LossF \qquad ...(6\text{-}8)$$

Reduction in cost of losses in one year (Benefit) can be given in the following formula.

$$\Delta AEL = \Delta AL{*}KWC + \Delta AL{*} 8760{*}LossF{*}KWHC \qquad ...(6\text{-}9)$$

6-5 Economic Evaluation of Loss Reduction

6-5-1 Calculation of Annual Net Benefit

Net benefit due to loss reduction during one year is the difference between annual

cost due to investment for loss reduction and annual benefit due to loss reduction such as fuel curtailment. Net Benefit can be represented by (6-10).

$$ANB = \Delta AEL - AEF \qquad \qquad ...(6\text{-}10)$$

ANB: Annual Net Benefit of loss reduction

ΔAEL: Benefit of reduction in cost of losses during one year due to investment in facilities

AEF: Increase in annual cost of facilities due to investment on facilities

6-5-2   *Calculation of Net Benefit of Loss Reduction during m Years*

The annual Net Benefit in k-th year is represented ANB(k). Summation of Net Benefits from the first year to k-th year in present value can be represented as (6-11), by (6-10) multiplying present worth factor.

Net Benefit during m years (Present worth)

$$= \Sigma^{k=1 \ to \ m} ANB(k)^*(1+i)^{-k}$$

$$= \Sigma^{k=1 \ to \ m} \Delta AEL(k)^* (1+i)^{-k} - \Sigma^{k=1 \ to \ m} AEF(k)^*(1+i)^{-k} \qquad ...(6\text{-}11)$$

'Benefit during m years' - 'Cost of facilities during m years'

Expression (6-11) can be rewritten as follows using 'C' (investment on measures in the first year).

Net Benefit during m years (Present worth)

$$= \Sigma^{k=1 \ to \ m} \Delta AEL(k)^* (1+i)^{-k} - ER(m, i)^*C \qquad ...(6\text{-}12)$$

Where ER (m, i) $= \Sigma^{k=1 \ to \ m} AER^*(1+i)^{-k}$, and this term corresponds to 'The accumulated rate of cost of facilities during m years against investment' .

6-6   **Economic Value of Power Loss Reduction per kW during m Years**

Reduction in losses during m years and total benefit during m years by reducing one kW in the initial year can be calculated in the following manner. Total benefit during m years by reducing one kW (per kW loss reduction) in the initial year is named as " The Value of Loss Reduction", hereafter. The value of Loss Reduction is very important to estimate economic benefit in PLOPT.

System peak demand in the initial year is defined as:

System peak demand in the 1st year = AP(1)   ...(6-13)

As losses are originated In proportion to the square of load current, losses in the system at peak load in the first year can be described in the following formula. Where, 'G' is the system conditions before investment and W* is the constant of the system.

$$AL(1,G) = W^* \, AP(1)^2 \qquad (kW) \qquad\qquad ...(6\text{-}14)$$

If the system condition is not changed, losses at peak load in the second year will be written as:

$$AL(2,G) = W^* \, AP(2)^2 \qquad (kW) \qquad\qquad ...(6\text{-}15)$$

In the same manner, losses at peak load in k-th year will be represented as:

$$AL(k,G) = W^* \, AP(k)^2 \qquad (kW) \qquad\qquad ...(6\text{-}16)$$

On the other hand, suppose that the condition 'G' changes into the condition 'H' by measures for loss reduction, losses at peak load in k-th year on the condition 'H' will be:

$$AL(k,H) = X^* \, AP(k)^2 \qquad (kW) \qquad\qquad ...(6\text{-}17)$$

Where X is a constant for system condition 'H'.
The reduction in losses due to measures at peak load in k-th year can be calculated by subtracting (6-17) from (6-16):

$$\Delta AL(k) = (W\text{-}X)^* \, AP(k)^2 \qquad (kW) \qquad\qquad ...(6\text{-}18)$$

Reduction in losses in the first year can be represented as formula (6-19).

$$\Delta AL(1) = (W\text{-}X)^* \, AP(1)^2 \qquad (kW) \qquad\qquad ...(6\text{-}19)$$

By dividing formula (6-18) with formula (6-19), formula (6-20) can be obtained showing the ratio of loss reduction in the initial year and that in the k-th year is the ratio of square of loads in the initial year and k-th year.

$$\Delta AL(k)/\Delta AL(1) = AP(k)^2/AP(1)^2 \quad (kW) \quad \quad ...(6\text{-}20)$$

Formula (6-20) can be rewritten as formula (6-21). Reduction in losses at peak load in the k-th year can be calculated by formula (6-21) multiplying the rate of square of loads in k-th year and that in initial year at peak load and loss reduction in the initial year.

$$\Delta AL(k) = (AP(k)/AP(1))^{2*}\Delta AL(1) \quad (kW) \quad \quad ...(6\text{-}21)$$

Substituting formula (6-21) into formula (6-9), we obtain the benefit of loss reduction in k-th year.

$$\Delta AEL(k) = (KWC + 8760*LossF*KWHC)*(AP(k)/AP(1))^{2*}\Delta AL(1)$$
$$...(6\text{-}22)$$

Total amount of reduced cost (benefit) due to loss reduction during m years can be given by summing of reduced cost in the study period.

Benefit during m years (Present worth)

$$= \Sigma^{k=1 \ to \ m} \Delta AEL \ (k)*(1+i)^{-k}$$

$$= [\Sigma^{k=1 \ to \ m}(KWC + 8760*LossF*KWHC)*(AP(k)/AP(1))^{2*}(1+i)^{-k}]*\Delta AL(1)$$

$$= 'The \ Value \ of \ Loss \ Reduction'* \ ER(\ m, \ i \ )*\Delta AL(1)$$

$$...(6\text{-}23)$$

Where

'The values of loss reduction'

$$= (KWC + 8760*LossF*KWHC)* \ [\Sigma^{k=1 \ to \ m} \ (AP(k)/AP(1))^{2*}(1+i)^{-k}] / ER(\ m, \ i \ )$$

$$...(6\text{-}24)$$

Net Benefit that is a difference between the benefit and cost due to reduction in losses during m years can be obtained by substituting expression (6-23) into (6-12).

'Net Benefit during m years (Present worth)'

=' Benefit during m years'-'Cost due to investment during m years'

='The value of loss reduction' $ER(m,i)*\Delta AL(1)$- $ER(m,i)*C$ $\quad ...(6\text{-}25)$

Refer to Part 2, 3-3 on 'The values for loss reduction'.

6-7   Example of Net Benefit

System 'EX1' is composed of one 33/0.4kV distribution substation and two low voltage feeders as shown in Figure 6-2. Conductors of two feeders are ANT (50mm2).   Table 6-1 summarizes load currents on the low voltage system.

Figure 6-2   EX1   Table 6-1 Load Currents on EX1
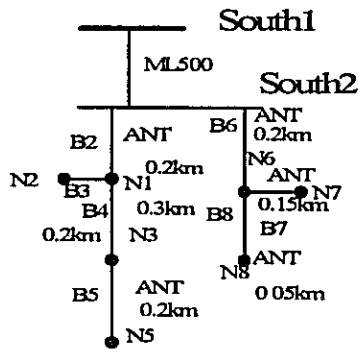
Designation of Distributed Currents

Network Names (The first branch of a Network)	Included Branches	Power Factor	Phases Currents at Entrance of the First Branch of a Network		
			R	S	T
B2	B2,B3,B4	0.83	120	140	100
B5	B5	0.83	31	25	32
B6	B6,B7	0.83	130	150	110
B8	B8	0.83	85	87	68

Designation of Phase Currents at Nodes

Nodes	power Factor/Phase Angle	R	S	T
N8	-60 degrees	45	50	53
N8	90 degrees	30	30	30
N3	0.75	100	110	120

* Designation value of distributed currents does not contain the load of N8 in 90 degrees.

Adding a 0.4kV new WASP (100mm^2) line in parallel with the first section of existing line, we will examine the economic effect of reinforcement on loss reduction. The new reinforced system (Figure 6-3) is named as 'EX1R'.

Figure 6-3   EX1R
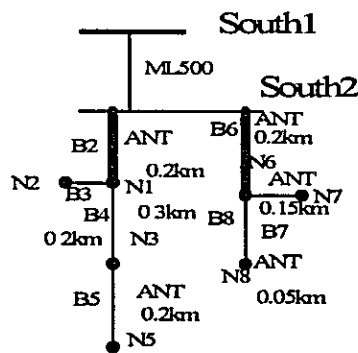
Now, we would like to know Net Benefit of the loss reduction during 10 years from the investment on new lines in parallel with existing B2 B6 section. Loss reduction is the difference of losses in 'EX1' and those in 'EX1R'. Using PFLOW program, the losses on both systems are calculated under the secondary terminal voltages of transformers to be fixed. In load flow calculation, the secondary bus of South2 s/s is set as a slack node.in this case. The result are tabulated in Table 6-2.

Table 6-2   Losses in Both Networks (Result of PFLOW)

(Unit : kW)

Ex1 (Existing)

Branches	Losses
B2	4.498
B3	0.093
B4	1.5
B5	0.111
B6	3.713
B7	0.033
B8	0.225

Ex1R(Reinforced)

Branches	Losses
B2	1.5
B3	0.093
B4	1.5
B5	0.111
B6	1.238
B7	0.033
B8	0.225

Total losses in Ex1 are decreased on Section B2 and B6 and losses on other sections are same as those in Ex1. Reductions in losses are due to reinforcement on the branches where the measures of reinforcement taken.

Table 6-3   Reduction in Losses

(Unit : kW)

Branches	Reduction in Losses(kW)	Countermeasures : Length
B2	2.998	ANT -> ANT + WASP : 0.2km
B3	0.0	-
B4	0.0	-
B5	0.0	-
B6	2.475	ANT -> ANT + WASP : 0.2km
B7	0.0	-
B8	0.0	-
Total	5.473	-

Next, We will calculate economic benefit and cost due to loss reduction for ten years. To make procedure simple, the annual load growth, kW and kWh value for loss reduction, cost due to investment are assumed to be same as those of Table 3-1 in Part 2.

The Value of Loss Reduction = 2570.85 (JD)   (Part 2 Table 1-3)

Accumulated Rate of cost of facilities during 10 years against investment:

ER(10, 0.1)= 0.83055 (discount rate of 0.1(10%))

The loss reduction in kW in the initial year is given by the result of PFLOW as shown in Table 6-3.

$\Delta AL(1) = 5.473$ (kW)

Construction cost of WASP and total length of reinforcement are:

C/km = 11250 (JD/km) (Investment for the construction of WASP per km)

Total length of the construction= 0.4km

We can calculate Net Benefit of investment for loss reduction using formula (6-25),

Net Benefit during 10 years (Present worth) =

'Benefit during 10 years'-'Cost of facilities during 10 years' (Present worth):

=The Value for Loss Reduction *ER(10, 0,1) *$\Delta AL(1)$ – ER(10, 0,1)*C

= 2570.85 (JD)*0.83055*5.473-0.83055*11250 (JD/km)*0.4km

= 7949 (JD)   ...(6-26)

We can find out that in this example sign of Net Benefit is positive and the measures of construction of new lines in the first section become one of the beneficial alternatives for loss reduction due to heavy load current.

Part 2 MANUAL OF PFLOW AND PLOPT PROGRAM

1. SYSTEM OUTLINE

PFLOW (Power Flow) and PLOPT (Power Loss Optimization) are respectively used for the power flow/voltage calculation and for optimization calculations of the study on loss reduction in distribution systems. Features and system configurations of software are hereafter explained.

1-1 Power Flow Program (PFLOW)

The network such as transmission system and its secondary bulk distribution system are usually deemed as three-phase-balanced system. The network of transmission and bulk distribution system is represented as single-phase. Load of respective substations in the network are modeled as lump load based on measurement or estimated / forecasted values. The nodal power equations of the network represent the situation of the systems. Newton-Raphson method is widely used for solving the power flow in view of its nature of good convergence and fast speed of the calculations.

On the other hand, as for low voltage distribution system, respective load data cannot be generally available without special measurement on voltage and current on the low voltage feeders. In addition that, loads on respective phases are usually not balanced. Thus, a power flow calculation for low voltage systems requires the function reflecting phase-unbalance of load and load is usually modeled as uniformly distributed load. Calculation is usually carried out assuming the voltage, current at sending end and distributed load along the feeder. Neutral line and three phase lines are modeled for three-phase four-wire distribution system in order to analyze phase unbalance. FLOW has been developed to calculate the system including network with singe-phase-model of transmission/bulk distribution system with lumped load and three-phase four-wire system with distributed load. The different type of power flow analysis on different system configuration simultaneously carried out on combined system with high-tension system and low voltage distribution system. PFLOW was developed and has been improved to utilize in the study of distribution loss reduction projects. PFLOW is also applied for the study on Power Loss Reduction in Distribution System in Jordan.

Power flow calculation on respective phases is firstly conducted for low voltage systems. Calculations of single-phase model bulk distribution and/or transmission

system are continuously conducted. The iterative procedure is taken up until voltage and current values (Averaged value of three phases) at the junction point of low voltage distribution system and higher voltage system (convergence within tolerance).

1-2 Optimization Program for Loss Reduction (PLOPT)

Reduction in power losses in transmission and distribution system can reduce the amount of required facilities such as generators and transmission lines and the consumption of fuels, which is the benefit due to loss reduction. Investment on transmission and distribution system is necessary for power loss reduction, which brings about annual cost of such as depreciation and O&M.

The difference between "cost due to investment" and "benefit due to loss reduction" is "the net benefit due to loss reduction." It would require large number of case studies and complicated procedure to find which alternative of reinforcement (ex. line conductor, capacity of transformer, etc) result in the most beneficial case for respective distribution feeders. PLOPT has been developed in order to settle such complex procedures and to precede the study efficiently. To be concrete, alternative with various facilities are examined in terms of economy for loss reduction so as to find the maximum net beneficial case.

The procedure in PLOPT is: at first, the load flow and distribution of current are determined by power flow calculation, and next, reduction in power losses is examined for various alternatives pre-designated in the software, and finally comparing the net benefit of alternatives, the most beneficial alternative is selected.

1-3 System Configuration

Figure 1-1 shows the system outline of PFLOW and PLOPT. Solid lines and dotted lines indicate the flow of the data and study procedures of PFLOW and PLOPT, respectively. System outline of these software are as follows.

- Input data files are four, which are PQI Files, Facility Table File, ECONO Table File and OPI Files.
- PFLOW includes "power flow calculation exec. PFLOW.EXE file." With using PQI File and Facility Table File, power flow calculation is carried out. The result of power flow calculation is stored in PQO files and named as "***.pqo. Character string of " *** " is the name of data file same as the name used in PQI

File.

- PLOPT includes PLOPT.EXE, evaluation calculation exec., in term of economics of loss reduction by various alternatives. PLOPT.EXE uses PQI File, Facility Table File, ECONO TABLE file and OPI File in the course of loss and economic evaluation of alternatives. The result is stored in OPO files and named as "***.opo. Character string of " *** " is the name of data file the same as the name of used in PQI File.

- All files used in PFLOW or PLOPT including "exec. file" must be stored in a folder on Microsoft Windows in default of any designations. An input data file has to be text file and can be edit by text editor applications, e.g. "Notepad" or "Word pad." An output file is also produced as a text file in the folder.

Figure 1-1   System Outline

Input Data Files

	FACILITY TABLE	ECONO	
PQI Files	File	TABLE File	OPI Files

Data files for electrical network such as connection of the branches and loads.	Data file of facilities	Data file of economic evaluation	Menu files for optimization

***.PQI   FACILITY.TBL [1]   ECONO.TBL [2]   ***.OPI [3]

PFLOW.EXE   Program Files   PLOPT.EXE

***.pqo   Output Data Files   ***.opo

PQO Files   OPO Files

──────   PFLOW : Power Flow Calculation

■■■■■■■■■■■■   PLOPT : Optimization Calculation

1) File name other than 'Facility.tbl' is available by designating with the command @TBL.

2) File name other than 'Econo.tbl' is available by designating with the command @TBL.

3) Character string of *** in ***. in OPI File has to be the same character string used in ***.PQI Files in default of designation with the command @OPI.

2. POWER FLOW PROGRAM (PFLOW)

2-1 Outline

The network including the system such as transmission system with lump load and represented as singe-phase and the system such as three-phase four-wire system with distributed load can be calculated simultaneously by the power-flow program of PFLOW. On the software program, high/medium voltage system can be represented as single-phase network with constant power, lump and balanced thee-phase load, while, low voltage system is represented as three-phase-four-wire system with unbalanced current for respective phases and/or distributed load.

2-2 Modeling of High/Medium Voltage System

High/medium voltage system such as transmission and/or medium voltage bulk distribution system is represented as single–phase system with lump load. A power-flow calculation for high/medium voltage system is to solve nodal equations with Newton-Raphson iterative algorithm, which is widely used for power-flow analysis on transmission and bulk distribution system.

2-2-1 Components and Models of High/Medium Voltage Systems

- Generator Node

  Generator is modeled as a slack node or node with fixed P (real power) and fixed voltage, or node with fixed P and Q (reactive power).

- Load

  Load is usually modeled as a node with fixed P-Q. Load characteristics are assumed constant power except the load at junction point with low voltage system (i.e.: low voltage terminal bus of distribution substation)

- Transmission Line

  Transmission line is represented as pi-equivalent circuit and as a single phase with lumped resistance, reactance and admittance.

- Transformer

  Transformer is represented as branches with reactance and serial resistance. Copper and iron losses can be taken into account by representing as resistance in series with reactance in transformer branch and as resistance between transformer high tension bus and the ground, respectively. Tap changers of transformer is also provided in the software.

2-3 Modeling of Low Voltage System

It is possible to represent load on low voltage distribution system as lump or distributed load in current. But, the latter is likely for power flow analysis on distribution system as usual. Low voltage network can be represented as respective three phases and a single neutral wire for three-phase four-wire system. Modeling for low voltage system and its power flow calculation are explained as follows.

2-3-1 Modeling of Low Voltage Distribution System

- Load

Load can be represented as both distributed and lump load in current. Load on low voltage system is represented as respective phases. It means possible to analyze three-phase unbalanced system. In case of power flow analysis with unified distributed load, load in current is allocated uniformly along the feeder by designation of the value of sending end current and feeder length. Designating load in current at node can represent lump load.

- Low Voltage Distribution line

Low Voltage Distribution line is represented as branch with only resistance and reactance due to its small admittance.

2-3-2 Calculation of Currents on Distribution Line with Unified Distributed Load

Distributed load currents are distributed in the following manner.

a. Designate load current value at the beginning point of the Partial Network (Partial Network means a partial portion of a low voltage feeder with a same load density along branch.)

b. Load current density of the Partial Network is calculated from the value designated at the beginning point of the Partial Network dividing the designated value by the total length of the Partial Network. Currents on respective branches of the Partial Network are calculated by multiplying load density and respective lengths of branches in the partial Network.

2-3-3 Calculation of Voltages

Voltages on the nodes in a low voltage system are calculated in the following manner.

a. Designate the load angle of current vs. voltage at sending end of a branch.

b. Voltage at receiving end of a branch is calculated by following formula using voltage and current at sending end of the branch.

$$V_t = V_f - (r + jx)\left(I_f \cdot L - \frac{1}{2} iL^2 \right)$$

V_t : Voltage at receiving end of a branch, V_f, I_f : Voltage and curent at sending end of a branch
i : Load current in a branch,   L : Length of a branch

Calculations are based on assumption that power factor of load in a branch is the same as power factor of the sending end of the branch.

2-4   **Boundary Condition of the Node (Low Voltage Bus of Distribution Substation) connecting High/Medium Voltage System and Low Voltage System**

Power flow analysis on High/medium voltage system is conducted including the low voltage buses of distribution substations. In this calculation, Load on the bus in the system is assumed fixed P (constant power) except load on the junction point (low voltage bus of distribution substation) of low voltage system. The load on the junction point is assumed constant current load. Iterative calculation is carried out until error of the voltage at the junction point of both systems (low voltage bus of distribution substation) becomes within the tolerance range designated.

3. OPTIMIZATION PROGRAM FOR LOSS REDUCTION (PLOPT)

3-1 Principal of Optimization

Investment on distribution and transmission facilities is essential for realizing loss reduction. Depreciation, operation and maintenance cost due to investment and reduction in capacity of generation and fuel cost are benefit due to loss reduction. Total economy due to power loss reduction is the Net Benefit, which can be represented by following formula (3-1).

$$NB=EL-EF \qquad --- \qquad (3-1)$$

NB :   Net Benefit

EL :   Reduction in cost such for generation facilities and generation fuel due to loss reduction (Benefit)

EF :   Cost such for installed transmission and/or distribution facilities for power loss reduction

Optimum solution for power loss reduction is intended to select alternatives of investment that maximizes Net Benefit.

3-2 Menus of Alternatives for Power Loss Reduction in PLOPT

Menus of alternatives for power loss reduction in PLOPT are briefly summarized in the following.

a.Reinforcement of the Line at the Same Voltage

- Re-conductoring of Existing Lines

  Re-conductoring with larger size (lower resistance) conductor is one of the economical alternatives to reduce power losses. Cost due to investment for re-conductoring and the economic benefit due to loss reductions are examined varying sizes and/or type of conductors. Economic studies (cost vs. Benefit) are conducted each branch by branch in the distribution feeder. The program outputs the result of the evaluation such as the amount of reduced power losses, section and its length of feeders to be studied, cost and benefit due to re-conductoring, and the most net-beneficial case and so on.

- Reinforcement of Feeder at Same Voltage

  Investment cost and the economic effects of power loss reduction are examined on the new line in parallel with the existing line changing conductor sizes and

type. Studies are carried out branch by branch in the target distribution feeder. The program outputs the result of the evaluation such as the amount of reduced power losses, section and its length of feeders to be studied, cost and benefit due to reinforcement of a feeder in parallel with existing line, and the most net-beneficial case, and so on.

b.Introduction of the Upper Voltage System on the Middle of Existing Lines
   Superimpose of higher voltage system on existing system is one of the effective means to reduce power losses. The study on introduction of higher voltage system along with the existing lines can be carried out by designation of command. Studies on introduction of higher voltage system are conducted as in such a manner that: higher voltage system with higher voltage line in parallel with existing feeder and transformer is superimposed on the existing target feeder. Losses are compared changing facilities for higher voltage system (conductor, transformer) and the open point of the existing lower voltage feeder until maximum loss reduction is obtained. Next, the location of transformer is changed to the adjacent section of the existing lower voltage feeder with increasing higher voltage line, the evaluation of power loss reduction is examined in a same manner afore-mentioned by changing open point of lower voltage feeder, and facilities for higher voltage line (conductor size and/or type) and transformers (capacity). Cost due to investment and the effect of loss reduction are calculated for respective alternatives on all branches. The program finally outputs the facilities for power loss reduction selected such as length and conductor type/size of higher voltage line, type/capacity of transformer and open point of the existing lower voltage target feeder in addition to cost, benefit and net benefit obtained from investment.
   The menus are outlined as shown in Figure 3-1-3-3.

Figure 3-1   Reinforcement of the Same Voltage Lines (Re-conductoring)
             - Re-placing of Existing Conductor with Lower Resistance
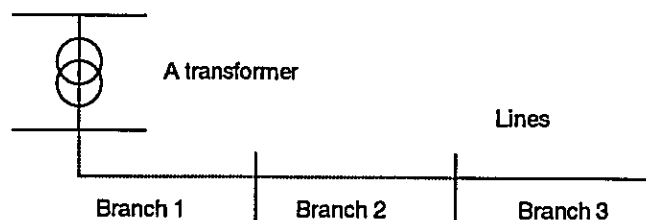
Figure 3-2   Reinforcement of Line at the Same Voltage Lines (Construction of the Same Voltage Lines)

- Construction of New Feeder at the Same Voltage in Parallel with Existing System
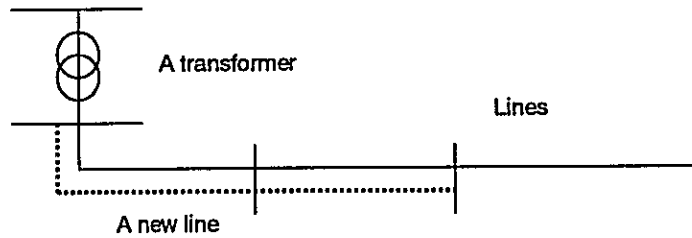
Figure 3-3   Introduction of the Higher Voltage Lines (Installation of a Transformer)

- Construction of the Higher Voltage System (Line and Transformer) superimposing on Existing System
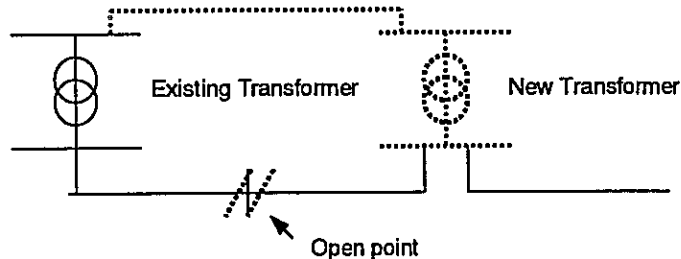
3-3   Additional Explanation on the Value of Net Benefit in PLOPT Software
(Value of Net Benefit converted into Construction Cost)

It is already explained that the most net beneficial alternative is examined on software PLOPT by comparing cost due to investment (construction cost) on facilities designated in Facility Table and benefit due to loss reduction. Investments for various alternatives are evaluated as to whether or not they are worth studying. Comparing directly the investment and the economic benefit brought by loss reductions converted into investment equivalent does the economic evaluation in PLOPT. By converting the benefit for study period into investment equivalent makes not only software algorithm simple and execution time short but also convenient for long hand studies on various facilities with

various construction cost. The conversion of net benefit during study period into investment equivalent hereafter briefly explained for better understanding of the software PLOPT.

Dividing the formula (6-25) in Part 1 by ER(m, i), formula (3-2) is obtained.

"Net Benefit during m years"/ER(m,i)
= ΔAL(1)* The Value for Loss Reduction –C

... (3-2)

Where

ΔAL(1) = Loss reduction at peak load time in the 1st year

C = Investment of Facilities

On the condition that Net Benefit during m years is positive value, the following inequality can be obtained.

C < ΔAL(1)* The Value for Loss Reduction   ...(3-3)

By comparing construction cost (investment on facilities) and the value of right side of inequality, it is easily distinguished the construction cost for alternative is profitable (net-beneficial) or not. The right side of inequality (3-3) is the term multiplying loss reduction in the maximum peak load in the first year (ΔAL(1)) and The Value for Loss Reduction. For such a reason, in the software PLOPT,

ΔAL(1)* The Value for Loss Reduction:

Investment Equivalent Value for Loss Reduction

Is used in the wake of economic evaluation study.

In other words, 'The Value for Loss Reduction' means the minimum in the investments per kW that makes the Net Benefit positive. Table 3-1 shows the example of calculation of 'The Value for Loss Reduction'. The Econo Table used for PLOPT requires 'The Value for Loss Reduction'. These values are to be inputted in the position followed by the Control Words as @VALL=, @VALM= and @VALH= in Econo Table as shown in Table 4-8. PLOPT outputs the value on the left side of equation (3-2) as Net Benefit. Figure 3-4 shows how to treat Net Benefit and The Value for Loss Reduction.

Figure 3-4.   Net Benefit and the Value for Loss Reduction
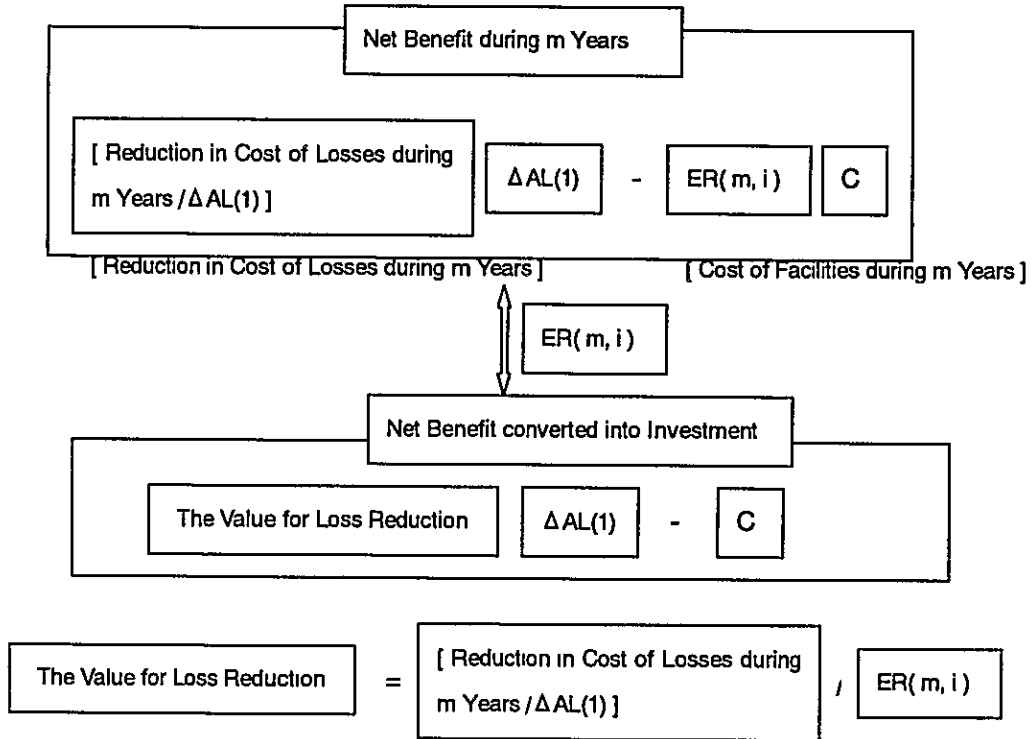
Where;

Investment of Facilities	C
Interest Rate	i
Study Target Duration(Years)	m
Loss Reduction at Peak Demand in the 1st Year	$\Delta AL(1)$
Rate of Cost of Facilities to Investment during m Years	ER(m, i)

3-4   **Software Algorithm for Optimization Study (New Line Construction at the Same Voltage)**

In an optimization procedure, new line construction, re-conductoring and introduction of higher voltage system are examined respectively. Figure 3-5 explains the software algorithm for the study of new line construction at the same voltage.

- Data such as network data, data of facilities and economic data are prepared in data files.

- Distribution of current on network is firstly determined by power flow analysis.

- In the next step, new line is added in parallel with the existing first section of a feeder. Loss reduction and investment on facilities are estimated after adoption of new lines.

- Economic evaluation is examined for respective portion of distribution feeders.

- Net Benefit, which is difference between Benefit due to loss reduction and cost due to Investment, is compared for various conductor sizes and types for respective portion of feeders.

- Analyses are carried out for respective portion of the feeders changing conductor sizes and types pre-designated. Most net beneficial cases are stored for respective portions of feeders and calculation is carried out to the end of the feeders.

- And finally, Most Net-beneficial alternative for respective portion is outputted.

Figure 3-5   Software Algorithm for Optimization Study (New Line Construction)

Table 3-1.

An Example of the Calculation of 'The Value for Loss Reduction' Input In Econo Table Files for PLOPT

(Values were used for M/P)

1. Annual Cost of Facilities

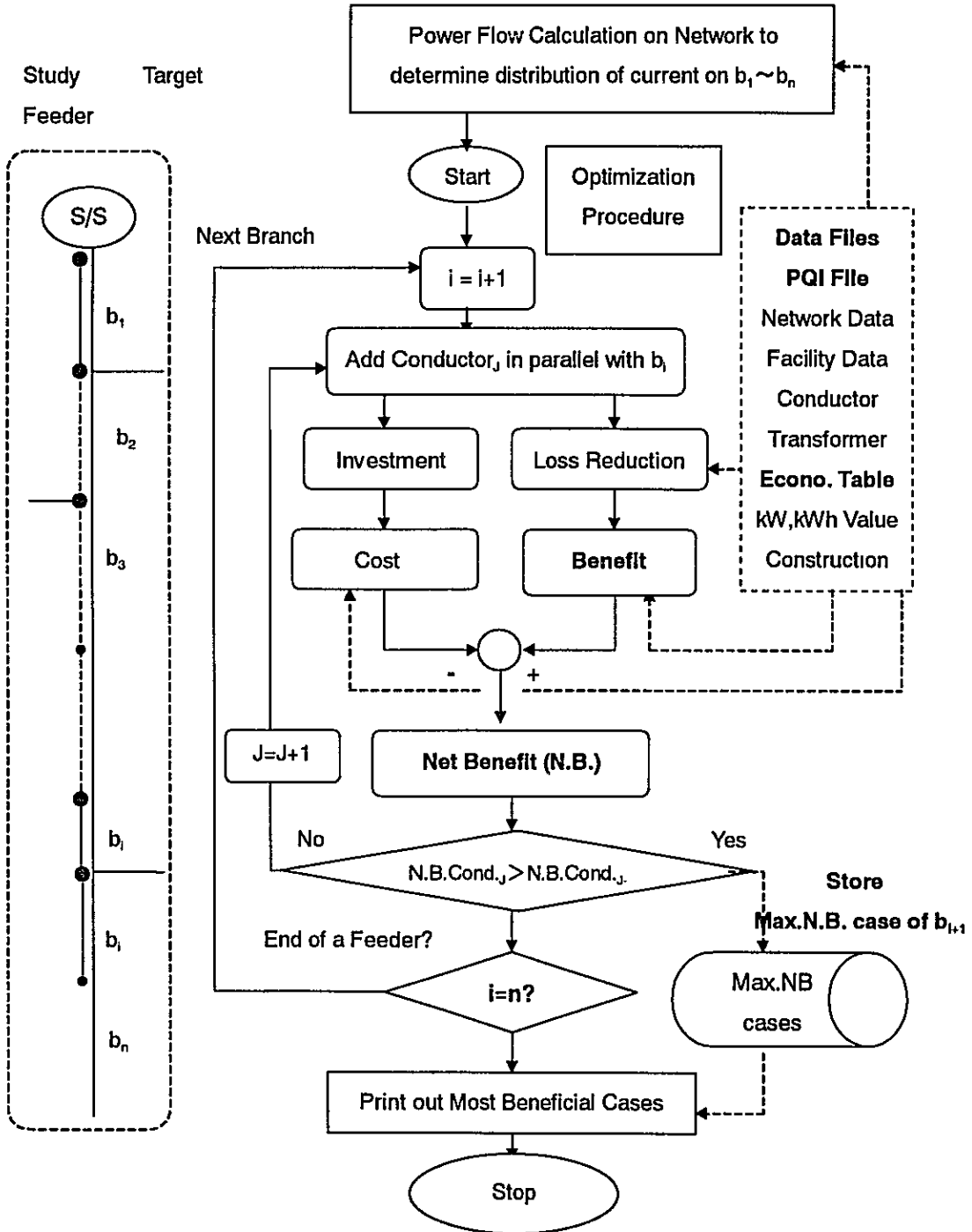|		
Investment of Facilities	C [JD]	
Life time	n [year]	25
Discount Rate	i	0.1
Rate of Salvage Value to Investment	a	0
Salvage Value to Investment of Facilities	RE [JD]	0
Annual Depreciation	AC =(C – RE) i/(1-(1+i)-n) [JD/year]	0 110168072
Rate of O&M cost to Investment of Facilities	b	0.025
Annual cost for O&M	AM	0.025
Annual cost of Facilities	AEF = AC + AM = AER*C	0 135168072

$AC/(1+i)^1 + AC/(1+i)^2 + AC/(1+i)^3 + \ldots + AC/(1+i)^n = C-RE$

2. Rate of Total Cost of Facilities during m years to Investment (ER(m, I))

	Study Target Duration	m	10
Year	Annual cost of Facilities AEF [JD/year]	Present Value Factor $1/(1+i)^{Year}$	Annual cost of Facilities (Present Value) [JD/year]
1	0 135168072	0 909090909	0 122880066
2	0 135168072	0 826446281	0 111709151
3	0 135168072	0 751314801	0 101553773
4	0 135168072	0 683013455	0 092321612
5	0 135168072	0 620921323	0 083928738
6	0 135168072	0 56447393	0 076298853
7	0 135168072	0 513158118	0 069362594
8	0 135168072	0 46650738	0 063056903
9	0 135168072	0 424097618	0 057324457
10	0 135168072	0 385543289	0 052113143
Total Cost of Facilities during m years	ER(m, i)*C [JD/m years]	0 83054929	
Rate of Total Cost of Facilities during m years to Investment	ER(m, i) [/m years]	0 83054929	

* Independent of 'C'

3. Cost of Losses per peak-loss in a year

kW Unit Cost	KWC	99 6
kWh Unit Cost	KWHC[JD/kW/hour]	0.02243
Loss Factor	LossF	0.5783
Cost of Losses per peak-loss in a year	U=KWC+KWHC*8760*LossF [JD/kW/year]	213 2283164

4. Reduction In Cost of Losses during m years / Δ AL(1)

Year	Demand Growing Ratio from year to year	System Peak Demand Ratio to the 1st year	Loss Reduction at Peak Demand in each year		Cost of Losses per peak-loss in a year	Annual Reduction in cost of Losses	Annual Reduction in cost of Losses (Present Value)
		AP(k)/AP(1)	ΔAL(k) =(AP(k)/ AP(1))^2* ΔAL(1) [kW]		U=KWC+KWH C *8760*LossF [JD/kW/year]	ΔAEL(k) =U* Δ AL(k) [JD/year]	$\Delta AEL(k)/(1+i)^k$ [JD/year]
1	0	1	ΔAL(1)		213 2283164	213 2283164	193 843924
2	0 075	1 075	ΔAL(2)	1 156	213 2283164	246 4119732	203 6462588
3	0 064	1.1438	ΔAL(3)	1 308	213 2283164	278 9620092	209 5882864
4	0.061	1 2135718	ΔAL(4)	1 473	213 2283164	314 033392	214 4890321
5	0.063	1 290026823	ΔAL(5)	1 664	213 2283164	354 8479979	220 3326883
6	0.051	1.355818191	ΔAL(6)	1 838	213 2283164	391.9654533	221.2542799
7	0.051	1 424964919	ΔAL(7)	2 031	213.2283164	432.9654317	222 1797262
8	0.045	1 489088341	ΔAL(8)	2 217	213 2283164	472 8090755	220 5689232
9	0.041	1 550140962	ΔAL(9)	2 403	213 2283164	512.3742118	217.2966829
10	0 036	1.605946037	ΔAL(10)	2 579	213 2283164	549 929192	212 0215096
Reduction in cost of Losses during m years		Σ ΔAEL(k) =Σ (KWC+ 8760*LossF*KWHC)*(AP(k)/ AP(1))^2* ΔAL(1) [JD/m					2135 221312
Reduction in cost of Losses during m years / ΔAL(1)		Σ ΔAEL(k)/AL(1) [JD/m years/kW]					2135 221312

5. The Value for Loss Reduction

The Value for Loss Reduction	Reduction in cost of Losses during m years / Δ AL(1))/ER(m, i)	2570 854418

4. INPUT DATA ARRANGEMENT

4-1 Outline

PFLOW requires two types of Input data files and PLOPT needs four types of input data files. All data in the input data files can be edited with editor applications on Microsoft Windows. Types of the data are designated by Control Words headed with '@'.

4-2 Input Data for the Power Flow Calculation (PFLOW)

Two types of input data must be prepared for the power flow calculation (PFLOW). Two types of files are as shown in Figure 4-1. PQI File is data file including electrical network data in the form of nodes, branches and loads. Facility Table File is a data file designating such as rated values, line constant of facilities.

Figure 4-1   Data Files Necessary for PFLOW

PQI Files   Facility Table File

***.PQI   FACILITY.TBL
                                         Other Name

(See clause 4-2-1)   (See clause 4-2-2)
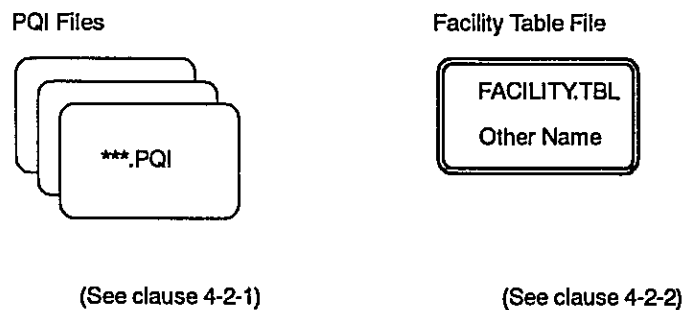
4-2-1   Input Data in PQI Files

The extension of PQI File must be 'pqi'. The files that have the extension of 'pqi' (e.g.: '***.pqi') are recognized as PQI Files in the software. The arrangement of input data on PQI Files is shown in Figure 4-2. Data can be continuously inputted for respective case study and the end of one case data is detected by the @Z mark. Data for one case in PQI Files consists of three main parts controlling power flow calculation.

PQI file is the data file which designate input and output data/file conditions of power flow calculation and optimization calculation. The first part includes common data used for PFLOW and PLOPT on both high/medium and low voltage system. Next part is the part for high/medium voltage system data. Last part includes data for low voltage system. Another case can be followed by @Z. @MI

is the designation of magnificent to change original input load data in proportion to designated value. The value of "@MI " is set to be 1.0 and necessary to be designated.

Figure 4-2   Configuration of PQI File

Common Data Used for Both High/Medium and Low Voltage System
High/Medium Voltage System Data
Low Voltage System Data
@MI
@Z
| |
@MI
@Z

Case 1

Case 2
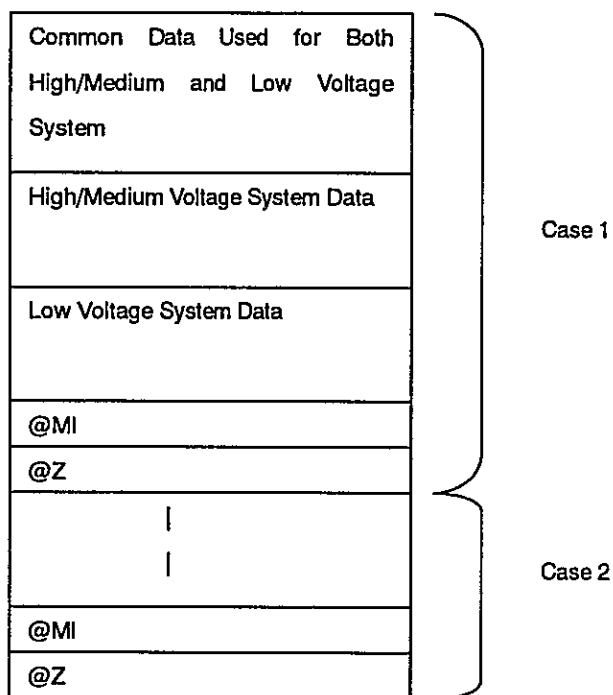
Note for attention in designating system on High/medium and low voltage system in PQI Files is summarized in Table 4-1.

Table 4-1   Note for Attention in Designating System (PQI Files)

	High/Medium Voltage System Data	Low Voltage System Data
System Model	Single-Phase One-Line Model	Three-Phases Four-Wire Model
Application of System Model	Transmission System and MV Distribution System (to LV Bus of Distribution S/S)	LV Distribution System (from LV Bus of Distribution S/S)
Load	Constant Power, Lump Load	Distributed and/or Lump Load
Phase Unbalance	-----	Capable
Loop Analysis	Capable	-----
Rules on Orders of Node	Free order of "From" Node and "To" Node Except for a bus connecting to Low Voltage System, It must be 'To' Node.	Node must be arranged in accordance with Power Flow • "From-Node" : Upstream • "To-Node" : Downstream

4-2-2 Input Data of Facility Table File

Facility Table File consists of electrical data for transformers and lines required for power flow and optimization study such as resistance, impedance, and admittance for line and iron losses for transformer and so on.

Figure 4-3 Configuration of Facility Table File
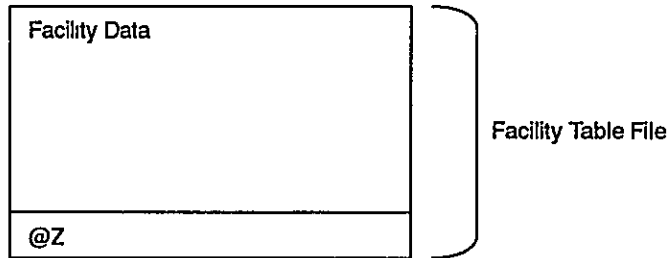
Default value of the file name of Facility Table File is 'Facility.tbl'. Designating with the command @TBL can change it, if necessary.

4-3 Input Data for the Optimization Calculation (PLOPT)

Four types of file are essential for optimization calculation (PLOPT), which are shown in Figure 4-4. PQI Files and Facility Table File are commonly used as the data files for PFLOW and PLOPT. Econo Table File is the data file including economic values for economic evaluation such as values of loss reduction, cost due to investment on transmission/distribution facilities. OPI File is the data files tabulating the menu list which designate alternatives for loss reduction such as "reinforcement of line at same voltage," and "introduction of higher voltage."

Figure 4-4 Data Files Essential for PLOPT

Econo Table File

OPI Files

```
┌──────────────┐
│ ECONO.TBL    │
│ or other name│
└──────────────┘
```

```
┌──────────────┐
│  ***.OPI     │
└──────────────┘
```
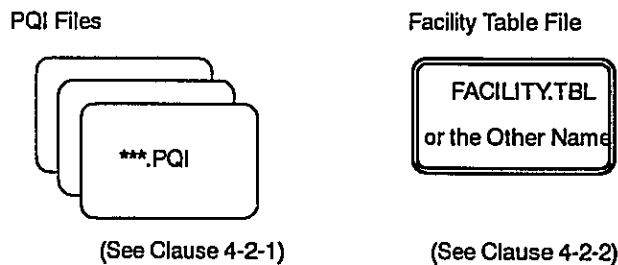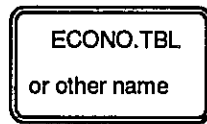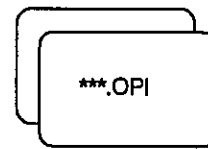
(See Clause 4-3-1)

(See Clause 4-3-2)

4-3-1 Econo Table File

Econo Table File is the data file that contains the data that is used for converting reduction in losses into economic values.

In ECONO Table, numbers of group of facilities can be prepared to study optimization of investment limiting within each group of facilities

Figure 4-5　Econo Table File

```
┌─────────────────────────────────────┐
│ Unit of Currency, Economic Value of  │
│ Loss Reduction, Base System Capacity │
├─────────────────────────────────────┤        Econo Table File
│ Cost due to Investment on Facilities │
│ Iron Loss Rate, Line Resistance, etc │
├─────────────────────────────────────┤
│ @Z                                   │
└─────────────────────────────────────┘
```
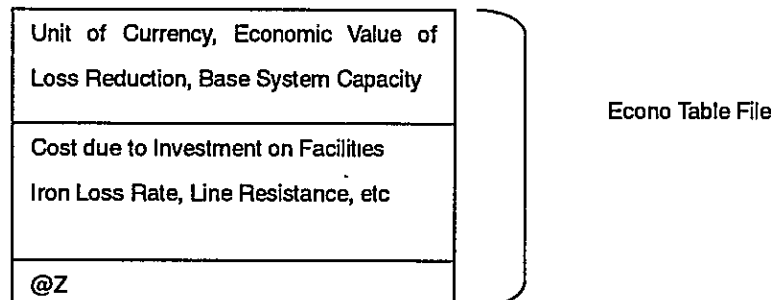
Default value of file name is 'Econo.tbl', otherwise the name of Econo Table File can be set by the command @TBL.

4-3-2 OPI Files

The extension of OPI Files should be 'opi'. The file with '***.opi' is recognized as OPI Files in the program. The file name in OPI file, ***, must be same as that in PQI file in default of designation. The data names in OPI file following @NM= must also be the same as those of PQI file. Designating with the Control Words of @OPI and @OPNM can change OPI file name.

OPI File is the data file containing the data for designation of the selection of loss reduction measures among three alternatives, which are introduction of the higher voltage system, reinforcement of line at same voltage and re-conductoring. Limit

of the number of new lines and operating limit of facilities are also indicated in OPI file. Groups of facilities designated in ECONO Table can be used by @TRYHV and /or @TRYSV command in OPI file.

Figure 4-6   OPI Files

```
┌─────────────────────────────────────┐
│ Designation    of    Menu    for     │
│                                       │          OPI Files
│ Optimization                          │
│ -Case Name, Limit of Numbers of       │
│ Line, Operating Limit of Facilities   │
│ -Group Name of Facilities for Use     │
├─────────────────────────────────────┤
│ @Z                                    │
└─────────────────────────────────────┘
```
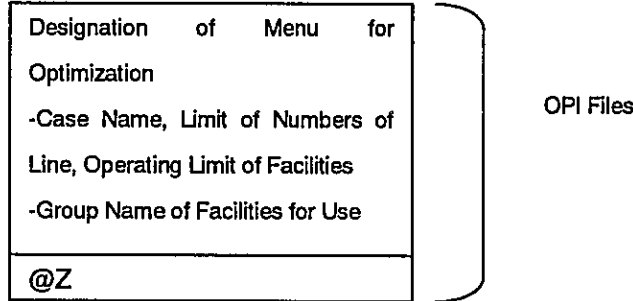
4-4   Directly

The directly/folder for input data files, program files and output files can be specified by designation of an INOUT.MNG File. Input data files, program files and output files must all be stored in a common folder of Microsoft Windows In default of designation.

4-5   Control Words

Words with the head character of '@' in input data files are Control/command Words. Control Words designate data type and calculation conditions. Types and functions of respective Control Words are listed as shown in following tables (Table 4-2 ~ Table 4-10).

Table 4-2   Control Words in PQI File (Commonly used) (1)

	Control Words	Functions of Control Words and Its Input Format
	@IC	Designating description of result of calculations on display (not necessary to designate)
Commonly Used for both High/Medium and Low voltage System	@IT=	Designating the maximum iteration number of calculations (@IT= The maximum iteration number) Default value : @IT=15 (not necessary to designate)
	@EPS=	Designating tolerance of errors (@EPS= Tolerance of errors in p.u.) Default value : @EPS=1e-7 (not necessary to designate)
	@BS=	Designating base capacity of system (@BS= system base(MVA)), Default value : @BS=100
	@SL=	Designating slack node name (@SL= Slack node name)

Table 4-3   Control Words in PQI Files (Commonly Used) (2)

	Control Words	Functions of Control Words and Its Input Format

Commonly Used for Both High/Medium and Low Voltage System	@SD=	Designating output data
		(@SD= output data (0-9))
		The following numbers selects output data.
		0 : No effect
		1 : Node information
		2: Branch information(1)---Current on low voltage system
		3 : Branch information(2)---P-Q load on low voltage system
		4 : Losses (summary)
		5 : No effect
		6 : No effect
		7 : No effect
		8 : Optimal Solution of Loss reduction (Detailed)
		    All net-beneficial solutions are listed in case of introduction of higher voltage system.
		9 : Optimal Solution of Loss reduction(Simplified)
		    Most Optimal Solution is outputted in case of introduction of higher voltage system.
		Default value : @SD=0123456789
		@SD=1249 or @SD=1239 also is enough.

	@TBL=	@TBL= is used for designating table name different from that prepared for FACILITY.TBL or ECONO.TBL, if necessary. (@TBL=***.***/+++.+++) ***.*** is the name of Facility Table, +++.+++ is the name of Econo Table. Different table files/folder can be used with designation of full path name. Default value : @TBL=FACILITY.TBL/ECONO.TBL (not necessary to designate)
	@NM=	Designating a case name of calculation (@NM= Calculation name) The number of letter string is limited within 128.
	@OPI=	A main file name of an OPI file must be same as the main file name of a PQI file. and a study case name of an OPI file must be the same as that in PQI file in default of designation. Control word of @OPI and @OPNM are used for designating different OPI file name and different study case name, respectively.
	@OPNM=	(@OPI= main file name of an OPI File) (@OPNM= study case name in an OPI File) < ex.> @OPI=ABC @OPNM=P3 This example indicates ABC.opi is used and study cases following to @NM=P3 are read for a study. (Capable to omit)
	@ML=	Designating multiplier of lengths converting length from other unit such as mile to km. (@ML= multiplier) < ex.> line length in mile, @ML=1.6093. Default value : @ML=1 (unit of length in km)
	@PF=	Designating power factor to all loads. (node with respectively designated power factor/reactive power is exempted from above) (@PF= Power factor (%)) Default value : @PF=90

Table 4-4   Control Words in PQI Files (High/Medium Voltage System)

	Control Words	Functions of Control Words and Its Input Format
High/Medium Voltage System Data - Branch Composition	@BT	Indicating the beginning of transformer-branch data (data are set apart by 'space'.) [branch code] [from-node code] [to-node code] [Tr's from-node - voltage(kV)/to-node-voltage(kV)] [resistance(%)] [reactance(%)] [core loss(%)] [from-node-tap] [to-node-tap]...
	@BTS	Indicating the beginning of transformer-branch data, electrical constants are used by designating facility code in FACILITY TABLE (data are set apart by 'space'.) [branch code] [from-node code] [to-node code] [facility code] [from-node-tap] [to-node-tap]...
	@BL	Indicating the beginning of line-branch data (data are set apart by 'space'.) [branch code] [from-node code] [to-node code] [voltage(kV)] [resistance(%)] [reactance(%)] [suceptance/2(%)]...
	@BLS	Indicating the beginning of line-branch data, electrical constants are used by designating facility code in FACILITY TABLE. (data are set apart by 'space'.) [branch code] [from-node code] [to-node code] [facility code] [length(km)] ...
High/Medium Voltage System Data - Node Data	@ND	Indicating the beginning of node data (data are set apart by 'space'.) [node code] [designated voltage (%)] [generator active power (%)] [generator reactive power (%)] [load active power (%)] [load reactive power (%)] [capacitor (%)]...
	@NDL	Indicating the beginning of node data (data are set apart by 'space'.) [node code] [load active power (%)] [load reactive power(%)]...
	@NDLA	Indicating the beginning of node data (data are set apart by 'space'.) [node code] [load R phase current(A)] [load S phase current(A)] [load T phase current(A)]... Power factor can be designated in the form of @NDLA(PF=***). *** is power factor in % Active power and reactive power are calculated on the bases of voltage of 100%, averaged phase current and power factor.
	@NDLW	Indicating the beginning of node data (data are set apart by 'space'.) [node code] [load active power(%)] ... Power factor can be designated in the form of @NDLW(PF=***). *** is power factor (%))
	@NDLVA	Indicating the beginning of node data (data are set apart by 'space'.) [node code] [load apparent power(%)] Power factor can be designated in the form of @NDLVA(PF=***). *** is power factor (%)

*Load at secondary bus of distributed transformer (junction point of HV/MV and LV system can not be represented in kW or KVA.)

*Transformer and line branch data must be inputted with designation of control word among @BT, @BTS and @BL, @BLS.

*Node without designation of @ND, @NDL, @NDLA, @NDLW, @NDLVA is deemed as node with no load.

Table 4-5   Control Words in PQI Files (Low Voltage System) (1)

	Control Words	Functions of Control Words and its Input format
Low Voltage System Data - Data Designating Fixed Voltage	@VL=	Designating voltage of node directly followed by @LV. (@LV= voltage(%)) @VL=**** is used to impose LV bus voltage constraint. @VL=**** is effective to the end of a file unless @VL=FREE or @VL=0 is placed. <ex.> @VL=102 Default value : @VL=FREE
Low Voltage System Data - Branch Composition	@LV	Designating a block composed of networks that are described by @NET data. A network is a sub-system/group of feeders with same load density. The name of a block must correspond to the node code of the first low voltage bus in a block. (The name of a block must be inputted without any punctuation after @LV.)
	@NET	@NET indicates the beginning of the Network with same load density. Demand density should be unified (constant) in a network. Next @NET describes the beginning of succeeding network in a low voltage system. (data are set apart by 'space'.) [branch code] [from-node code] [to-node code] [line facility code] [line length (km)]...
Low Voltage System Data - Load Current Data	@ILV	@ILV designates a name of a block corresponding to @LV and following value designates total current within a block. (The value must be inputted without punctuation after @ILV.) [node code of first LV bus in a block] (In case power factor is not designated by @PF=***, power factor can be designated at the first node of block by designating node(PF=***) or node(PA=***).) (*** is power factor(%) or phase angle (degree).)
	@INET	@INET designates total current of Network defined by @NET. (data are set apart by 'space'.) [branch code at the entrance to a network][R phase current(A)] [S phase current(A)] [T phase current(A)]... S phase is determined to be 120 degrees delay from R.

Table 4-6   Control Words in PQI Files (Low Voltage System) (2)

	Control Words	Functions of Control Words and Its Input Format
Low Voltage System - Load Current	@IL	Designating current of lump load on. Connected to node-code. (After 'space', 'Tab' or 'Enter', input the following data indicating lump load current at nodes) [node code][R phase load current(A)] [S phase load current(A)] [T phase load current(A)] ... or [node code] [(PF=***)] [R phase load current(A)] [S phase load current(A)] [T phase load current(A)] ... (*** is power factor (%). In case of designating power factor of current at the node.) or [node code] [(PA=***)] [R phase load current(A)] [S phase load current(A)] [T phase current(A)] ... (*** is phase angle(degree). In case of designating phase angle of current at the node.) @IL is no need for the nodes without currents of lump loads. Currents designated by @IL are included in currents designated by @INET.
	@IPLUS	Designating currents of additional lump loads. @IPLUS data can be added to @IL data in the same node. (Input the following data after 'space', 'Tab' or 'Enter'.) [node name][R phase load current(A)] [S phase load current(A)] [T phase load current(A)]... or [node name] [(PF=***)] [R phase load current(A)] [S phase load current(A)] [T phase load current(A)]... (*** is power factor (%). In case of designating phase angle of current at the node.) or [node name] [(PA=***)] [R phase load current(A)] [S phase load current(A)] [T phase load current(A)]... (*** is phase angle(degree). In case of designating phase angle of current at the node.) Currents designated by @IPLUS are not included in currents designated by @INET.
@MI	@MI	Designating multipliers for active load power and reactive load power. @MI must be put just before @X. Calculations are conducted at all given multipliers. (Input the following data after 'space', 'Tab' or 'Enter'.) [@ MI] [multiplier] [multiplier] [multiplier] ······ [multiplier]
@Z	@Z	Indicating the end of data for a unit

Table 4-9   Control Words in OPI Files

Control Words	Functions of Control Words and Its Input Format
@NM=	Designating naming a calculation (@NM= Calculation name) The number of letters of calculation name is restricted within 128.
@MUE=	Designating column of unit for price to be output on OPO Files (@MUE= Column) For example, @MUE=4 means that unit is 10,000
@OF=	Designating the maximum operation ratio in case of introduction of upper voltage lines (@OF= The maximum operation ratio(%)) In case of exceeding this value, new facilities are installed. Default value : @OF= 70 (Capable to omit)
@OSL=	Designating the starting point for introduction of upper voltage lines (@OSL= The length to the starting point from delivering point(km)) Default value : @OSL= 0 (Capable to omit)
@BC=	Designating base cost (Constant value added to investment for construction of facilities) (@BC= Base cost) Default value : 0 (Capable to omit)
@UPPER	Designating the maximum number of the circuits that are to be constructed in case of 'same voltage line construction'. (@UPPER= The maximum number of the circuits) Default value : @UPPER=1 (Capable to omit)
@TRYHV(HV/LV)	Designating construction of higher voltage lines HV : Higher voltage (kV), LV : Target voltage (kV) (Input the following data after 'space', 'Tab' or 'Enter'.) [A group name of transformers/A group name of upper voltage lines]
@TRYSV(SV)	Designating construction of the same voltage lines SV : Target voltage (kV) (Input the following data after 'space', 'Tab' or 'Enter'.) In case of construction of the new same voltage lines along the existing lines [A group name of the same voltage lines] In case of re-conductoring, [! A group name of the same voltage lines]
@Z	Indicating the end of data for a unit

Table 4-10   Control Words in MNG File

Control Words	Functions of Control Words and Its Input Format
@PQI=	Designating a name of a folder for PQI Files (@PQI= Folder name(Full path with the letter of '\' in the last.))
@OPI=	Designating a name of a folder for OPI Files (@OPI= Folder name(Full path with the letter of '\' in the last.))
@PQO=	Designating a name of a folder for PQO files (@PQO= Folder name(Full path with the letter of '\' in the last.))
@OPO=	Designation a name of a folder for OPO files (@OPO= Folder name(Full path with the letter of '\' in the last.))
@Z	Indicating the end of data for a unit

4-6   Data Format

- All data are to be inputted as text data on Microsoft Windows.

- 'Space' is used as a punctuation of data in input data files.

- Capital letter and small letter are distinguished as different letter.

- Data followed by (*) in a line is deemed as a comment.

- Data between '<' and '>' is also deemed as comment sentences.

4-7   Execution of Software

- All files for PFLOW or PLOPT including program files are to be stored in a common folder on Microsoft Windows in default of designation.

- Input data files are text files and can be easily edited by text editor applications on Windows, e.g. Notepad or Wordpad.

- Output files are produced as text files in the common folder of Microsoft Windows in default of designation.

- Double-click ***.exe file and the name of a PQI file name without extension will be asked. By Input of the PQI file name, the calculation can be done. The result of PFLOW is stored in PQO File with the same name as that of PQI File. The extension "pqo" is automatically added to PQO file data. The result of PLOPT is stored in OPO file with the extension of "opo" and the same main file name as the PQI File.

- You can close the program by pushing 'X' on the upper right side of the window.

5. EXAMPLES OF ANALYSIS

Examples of power flow calculations and optimization calculations give explanation in detail as shown hereafter. These examples are result of analysis on the model system as shown in Figure 5-1.

5-1 Load Flow Calculation

One of the data files essential for load flow calculation is PQI File, and the other is Facility Table File. The data in PQI File for the model system is listed in Example 5-1 and the input data in Facility Table File is shown in Example 5-2.

5-2 Optimization Calculation

For optimization calculation, four data files are required, PQI Files, Facility Table File, Econo Table File and OPI file. The input data for the model system in Econo Table File and OPI Files are shown in Example 5-3 and 5-4.

Figure 5-1. System Example 1
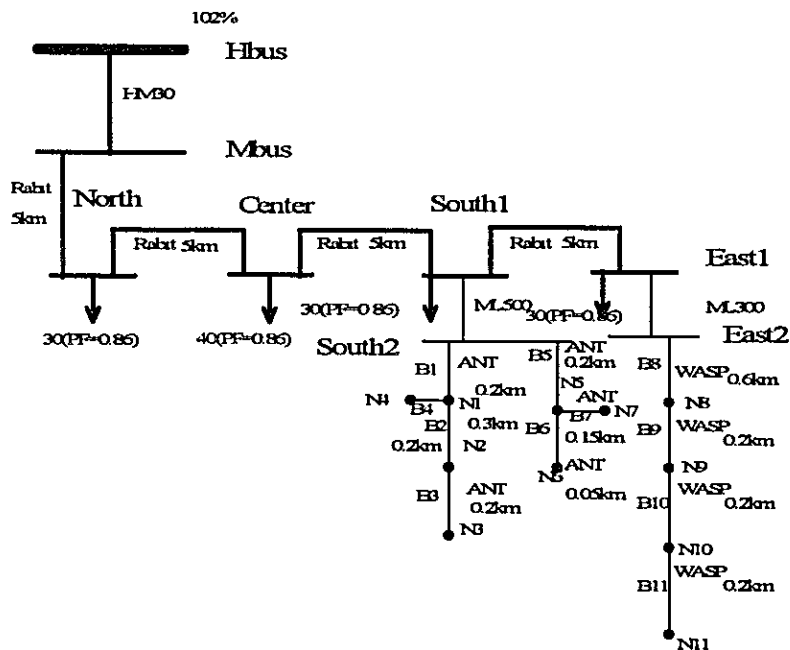
Definition of currents in system example 1

How to give load current

Low voltage distribution feeder can be represented as some blocks of subsystems composed of Networks according to such as load current densities. The name of Network must be the same name of the first branch in the Network. Total load current of the Network (the summation of load current in Network) is designated on the from node of the first branch in the Network. Lump load can be designated on respective node and power flow calculation is carried out taking into account of distributed load and lump load. Capacitor can be represented lump load with 90 degree leading load current (reactive current load).

Designation of Currents in Network

Block: South2

Network Name	Member Branch	Power factor	Load Current on from-node of first branch in Network (A)		
			R-phase	S-phase	T-phase
B1	B1,B2,B3,B4	0.82	120	140	100
B5	B5,B6,B7	0.82	130	150	110

Block: East2

Network Name	Member Branch	Power Factor	Load Current on From-Node of First Branch in Network (A)		
			R-phase	S-phase	T-phase
B8	B8	0.9	200	180	240
B9	B9,B10, B11	0.9	100	60	100

Designation of Lump Load (Current)

	Node Name	Power Factor / Phase Angle	Lump Load Current (A)		
			R-phase	S-phase	T-phase
No.1	N2	90 degrees (Capacitor)	30	30	30
No.2	N10	0.75	50	40	50
No.3	N10	90 degrees (Capacitor)	100	100	100

5-3   Input Data (Example)

Example 5-1.PQI File

@IC

@TBL=Example1.ftb/Example1.etb

@IT=35

@EPS=1e-5

@NM=Example1

@BS=1

@SL=HBus

@PF=90

@BLS

*CODE	NF	NT	W_CODE	LENGTH
Line1	MBus	North	RABIT	5
Line2	North	Center	RABIT	5
Line3	Center	South1	RABIT	5
Line4	South1	East1	RABIT	5

@BTS

*CODE	NF	NT	T_CODE	FTAP	TTAP
HMT	HBus	MBus	HM30	1.00	1.00
DT1	South1	South2	ML500	1 00	1.00
DT2	East1	East2	ML300	1.00	1 00

@ND

*CODE	VS(%)	PG(%)	QG(%)	PL(%)	QL(%)	SC(%)
HBus	102	40000	2000	0.000	0 000	0

@NDLW(PF=86)

North	30
Center	40
South1	30
East1	30

@LVSouth2

@NET	B1	South2	N1	ANT	0.2
	B2	N1	N2	ANT	0.3
	B4	N1	N4	ANT	0.2
	B3	N2	N3	ANT	0.2
@NET	B5	South2	N5	ANT	0.2
	B6	N5	N6	ANT	0.05

Common Data for Both High/Medium and Low Voltage System

Line Data

Transformer Data

High/Medium Voltage System Data

Node Data

Network Data

Low Voltage System Data

```
              B7        N6        N7        ANT       0.15
@LVEast2
@NET    B8        East2     N8        WASP      0.6
@NET    B9        N8        N9        WASP      0.2
        B10       N9        N10       WASP      0.2
        B11       N10       N11       WASP      0.2
@ILVSouth2(PF=82)
@INET   B1        120       140       100
        B5        130       150       110
@IPLUS  N2(PA=90) 30        30        30
@ILVEast2
@INET   B8        200       180       240
        B9        100       60        100
@IL     N10(PF=75)          50        40        50
@IPLUS  N10(PA=90)          100       100       100
@MI 1.0
@Z
```

Network Data	Low Voltage System Data
Current Data	
@MI: Magnification of Load	
@Z: End of Data	

Example 5-2. Facility Table

```
*Example1.ftb
@BS=1
@TR=33/0.415        *Medeum/Low Voltage 33/ 4
*CODE   CAP(%)   TCL(%)   XT(%)   TIL(%)
ML300   30       2.937    12.84   0.056
ML500   50       1.69     8.38    0.074
@TR=132/33          *High/Medeum Voltage 132/33
*CODE   CAP(%)   TCL(%)   XT(%)   TIL(%)
HM30    3000     0.01527  0.356   2.363
@WR=33
*CODE   CAP(%)   R(%/km)   X(%/km)   Y/2(%/km)
RABIT   1057.42  0.057544  0.035845  0 159380
@WR=0.415
*CODE   CAP(%)   R(%)      X(%/km)   Rn(%)
WASP    19.408   181.786   159.149   181.786
ANT     12.22    363.209   171.925   363.209
@Z
```

Transformer Data
Conductor Data
@Z: End of Data

Example 5-3. Econo Table

*ECONO. TBL

@MU=1000JD

@VALL=2564

@VALM=2061

@VALH=2186   *Loss evaluation constant

@BS=1   *1MVA BASE

@TR=34GM   *33/0.415   Ground   Mounted

34GM500 50   16125   1.69   0.074

34GM630 63   16925   1.323   0.087

*LINE DATA:%Capacity:Cost/km:%Resitance:Neutral Line Resistance

@WR=3OH   *33kV   ACSR Overhead line

RABIT   1057.42   13285   0.0575   0

DOG   1588.98   13285   0.0298   0

@WR=4OH   *0.415kV   Overhead line

ANT   12.22   11250   363.209   363.209

WASP   19.408   11250   181.786   181.786

@Z

Common Data — Currency Unit, Value of Losses, Base System Capacity	
Unit Investment Cost, Transformer Loss Rate and Conductor Resistance	
@Z	

Example 5-4. OPI Files

*Example1.OPI

@NM=Example1

@MUE=3 ◄

@TRYHV(33/0.415)   34GM/3OH ◄

@TRYSV(0.415)   4OH ◄

@Z

Designating Column of Currency Unit
For example, @MUE=3 means that Currency Unit is 1,000
Study Case: Introduction of Higher Voltage System
Study Case: Construction of Same Voltage System
@Z: End of File

5-4   Output List (Example)

Example 5-5. PQO File

*********[Example1] 100percent=1.0MVA MI=1.000000 ***************

[Node Information]

CODE	V (kV)	V (%)	ANGLE (degree)	Pgen (%)	Qgen (%)	Pload (%)	Qload (%)	SC (%)
MBus	33.55	101.68	-0.309	0.00	0.00	0.00	0.00	0.00
North	33.35	101.07	-0.332	0.00	0.00	30.00	17.80	0.00
Center	33.19	100.58	-0.353	0.00	0.00	40.00	23 73	0.00
South1	33.08	100.25	-0.370	0.00	0.00	30.00	17.80	0.00
East1	33.03	100.09	-0.384	0.00	0.00	30.00	17.80	0.00
HBus	134.64	102.00	0.000	163.00	85.73	0 00	0.00	0.00
South2	0.41	99.31	-1.000	0.00	0.00	14.69	8.07	0 00
East2	0.41	99.54	-1.379	0.00	0.00	13.70	0.98	0.00
TOTAL				163.00	85.73	158.39	86.19	0.00

[Branch Information(Unit:%)]

CODE	NF	NT	P(NF->)	Q(NF->)	P(->NT)	Q(->NT)	Ploss	Qloss
Line1	MBus	North	160.5	84.6	159.6	84.8	0.92	-0.25
Line2	North	Center	129.6	67 0	129 0	67.5	0.60	-0.44
Line3	Center	South1	89.0	43.7	88.7	44.4	0.28	-0.63
Line4	South1	East1	43.9	18.3	43.8	19.0	0.07	-0.76
HMT	HBus	MBus	163.0	85.7	160.5	84.6	2.51	1.13
DT1	South1	South2	14.8	8.3	14.7	8.1	0.12	0.24
DT2	East1	East2	13.8	1.2	13.7	1.0	0.11	0.24
TOTAL							4.6	-0.5

[Loss summary(Unit.%)]

Mi	Pg	Pl	Line	Lcopp	Lcore	Total	Rate	Vmin[Node]
1.00	163.0	158.4	1.87	0.15	2.59	4.61	2.83	99.31[South2]

---<LVSouth2>---

((Node Voltage Information))

Result of Power Flow Calculation on Medium Voltage System

Voltage
Load

Power Flow
on Branch

Losses

Result of Power Flow Calculation about Low voltage System

Node	Vr-n(V<deg)	Vs-n(V<deg)	Vt-n(V<deg)	Vn(V<deg)
South2	237.95< -1.0	237.95<-121.0	237.95< 119.0	0.00< 0.0
N1	227.29< -0.5	224.88<-120.4	229.70< 119.3	3.84<-126.1
N2	221.08< -1.3	217.09<-121.1	225.08< 118.5	5.26<-126.2
N4	225.19< -0.6	222.48<-120.4	227.91< 119.3	3.36<-126.1
N3	218.71< -1.4	214.41<-121.2	223.02< 118.4	4.30<-126.2
N5	226.56< 0.2	224.52<-119.7	228.60< 120.1	3.25<-125.9
N6	224.87< 0.4	222.53<-119 5	227.20< 120.3	3.66<-125.9
N7	222.02< 0.4	219.31<-119.4	224.74< 120.3	3.05<-125.9

((Branch Current Information))

Branch	From	To	Ifr(A)	Ifs(A)	Ift(A)	Ifn(A<deg)	Loss(kW)
B1	South2	N1	106.4	125.9	87.2	34.5< 54.0	3.472
B2	N1	N2	56.0	66.1	46.4	19.1< 53.9	0.848
B4	N1	N4	26.7	31.1	22.2	7.7< 54.1	0.098
B3	N2	N3	26.7	31.1	22.2	7.7< 54.1	0.108
B5	South2	N5	130.0	150.0	110.0	34.6< 54.1	3.846
B6	N5	N6	65.0	75.0	55.0	17.3< 54.1	0.316
B7	N6	N7	48.8	56.3	41.3	13.0< 54.1	0.242

((Branch PQ Information))

Branch	From	To	PQfrom(kW,kvar)		PQto(kW,kvar)		Loss(kW)
B1	South2	N1 (	70.8,	27.6) (	52.5,	16.4)	3.472
B2	N1	N2 (	37.7,	5.8) (	14.5,	-9 9)	0.848
B4	N1	N4 (	14.8,	10.5) (	0.0,	0.0)	0.098
B3	N2	N3 (	14.5,	10.0) (	0.0,	0.0)	0.108
B5	South2	N5 (	76.1,	53.1) (	35.6,	26.0)	3.846
B6	N5	N6 (	35.6,	26.0) (	26.5,	19.5)	0.316
B7	N6	N7 (	26.5,	19.5) (	0.0,	0.0)	0.242

((LVSouth2 loss summary))

		Ps(kW)	Loss(kW)	Rate(%)	Vmin [Node-Phase]	
[NET	B1]	70.78	4.53	6.39	214.41[	N3-S]
[NET	B5]	76.10	4.40	5.79	219.31[	N7-S]
[LV	South2Total]	146.87	8.93	6.08	214.41[	N3-S]

Voltage
by Each Phase

Result of Power
Flow
Calculation on
Low Voltage
System

Power Flow on
Branch

Losses in
Branch
(3 Phase Total)

---<LVEast2>---

((Node Voltage Information))

Node	Vr-n(V<deg)	Vs-n(V<deg)	Vt-n(V<deg)	Vn(V<deg)
East2	238.51< -1.4	238.51<-121.4	238.51< 118.6	0.00< 0.0
N8	210.87< -9.7	218.62<-129.3	206.03< 109.8	7.98< 46.1
N9	206.76<-12.0	217.38<-131.4	201.93< 107.4	10.13< 40 7
N10	205.09<-14.2	217.71<-133.3	200.27< 105.2	11.38< 38.2
N11	204.68<-14 2	217.70<-133.3	199.85< 105.2	11.06< 38.5

((Branch Current Information))

Branch	From	To	Ifr(A)	Ifs(A)	Ift(A)	Ifn(A<deg)	Loss(kW)
B8	East2	N8	184.6	169.5	223.2	49.6<-113.8	10.971
B9	N8	N9	97.6	82.0	97.7	42.0<-157.8	1.469
B10	N9	N10	87.9	80.6	87.9	31.7<-159 0	1.195
B11	N10	N11	17.1	6.9	17.2	10.4<-154.3	0.020

((Branch PQ Information))

Branch	From	To	PQfrom(kW,kvar)	PQto(kW,kvar)	Loss(kW)
B8	East2	N8 (	137.0, 9.8) (	47.4, -32.6)	10.971
B9	N8	N9 (	47.4, -32.6) (	37.4, -37.2)	1.469
B10	N9	N10 (	37.4, -37.2) (	29.7, -40.3)	1.195
B11	N10	N11 (	8.0, 2.8) (	0.0, 0.0)	0.020

((LVEast2 loss summary))

		Ps(kW)	Loss(kW)	Rate(%)	Vmin [Node-Phase]
[NET	B8]	137.04	10.97	8.01	206.03[N8-T]
[NET	B9]	47.40	2.68	5.66	199.85[N11-T]
[LV	East2Total]	137 04	13.65	9.96	199.85[N11-T]

[Loss summary(Unit:%)]

Mi	Pg	Pl	Lline	Lcopp	Lcore	Total	Rate	Vmin[Node]
1.00	163.0	158.4	4.13	0.15	2.59	6.87	4.21	83.41[N11(East2)-T]

****

Result of Power Flow Calculation on Low Voltage System

* This result was calculated with PFLOW program developed by   *

* Tokyo Electric Power Service Company, Limited (TEPSCO Japan) *

***[Example1]   100percent=1.0MVA

MI=1.000000 **************

[Node Information]

CODE	V (kV)	V (%)	ANGLE (degree)	Pgen (%)	Qgen (%)	Pload (%)	Qload (%)	SC (%)
MBus	33.55	101.68	-0.310	0.00	0.00	0.00	0.00	0.00
North	33.35	101.07	-0.335	0 00	0.00	30.00	17.80	0.00
Center	33.19	100.58	-0.358	0.00	0.00	40.00	23.73	0.00
South1	33.08	100.25	-0.378	0.00	0.00	30.00	17.80	0.00
East1	33.03	100.09	-0 392	0.00	0.00	30.00	17.80	0.00
HBus	134.64	102.00	0.000	163.78	85 08	0.00	0.00	0.00
South2	0.41	99 33	-1.019	0.00	0.00	14.87	7.81	0.00
East2	0.41	99.58	-1 437	0.00	0.00	14.28	0.56	0.00
TOTAL				163.78	85.08	159.15	85.51	0.00

[Branch Information(Unit:%)]

CODE	NF	NT	P(NF->)	Q(NF->)	P(->NT)	Q(->NT)	Ploss	Qloss
Line1	MBus	North	161.3	83.9	160.3	84.2	0.92	-0.25
Line2	North	Center	130.4	66.4	129.7	66.8	0.61	-0.44
Line3	Center	South1	89.7	43.1	89.5	43.7	0.28	-0.63
Line4	South1	East1	44.5	17.9	44.4	18.6	0.07	-0.76
HMT	HBus	MBus	163.8	85.1	161.3	83.9	2.51	1.14
DT1	South1	South2	15.0	8.1	14.9	7.8	0.12	0.24
DT2	East1	East2	14.4	0.8	14.3	0 6	0.12	0.26
TOTAL							4.6	-0.4

[Loss summary(Unit:%)]

MI	Pg	PI	Line	Lcopp	Lcore	Total	Rate	Vmin[Node]
1.00	163.8	159.2	1.88	0.16	2.59	4.63	2.82	99.33[South2]

---<LVSouth2>---

((Node Voltage Information))

Node	Vr-n(V<deg)	Vs-n(V<deg)	Vt-n(V<deg)	Vn(V<deg)
South2	238.00< -1.0	238.00<-121.0	238.00< 119.0	0.00< 0.0
N1	227.23< -0 6	224.81<-120.5	229.65< 119.3	3.84<-125.0
N2	220.96< -1.4	216.95<-121.3	224.98< 118.4	5.26<-125.1
N4	225.13< -0.6	222.41<-120.5	227 86< 119.2	3.36<-125.1
N3	218.60< -1.5	214.29<-121.4	222.92< 118.3	4.30<-125.2
N5	226.51< 0.2	224 47<-119.7	228.56< 120.1	3.25<-124.9
N6	224.81< 0.3	222.47<-119.6	227.15< 120 2	3.66<-124.9
N7	221.96< 0.3	219.24<-119.5	224.69< 120.2	3.05<-124.9

((Branch Current Information))

Branch	From	To	Ifr(A)	Ifs(A)	Ift(A)	Ifn(A<deg)	Loss(kW)
B1	South2	N1	107.0	126.4	87.8	34.5< 55.0	3.512
B2	N1	N2	56.6	66.7	47.0	19.1< 54.9	0 872
B4	N1	N4	26.7	31.1	22.2	7.7< 55.1	0.098
B3	N2	N3	26.7	31.1	22.2	7.7< 55.1	0.108
B5	South2	N5	130.0	150 0	110.0	34.6< 55.1	3.846
B6	N5	N6	65.0	75.0	55.0	17.3< 55.1	0.316
B7	N6	N7	48.8	56.3	41.3	13.0< 55.1	0.242

((Branch PQ Information))

Branch	From	To	PQfrom(kW,kvar)		PQto(kW,kvar)		Loss(kW)
B1	South2	N1 (	71.7,	26.4) (	53.2,	15 4)	3.512
B2	N1	N2 (	38.2,	5.1) (	14.7,	-10.1)	0.872
B4	N1	N4 (	15.0,	10.2) (	0.0,	0.0)	0.098
B3	N2	N3 (	14.7,	9.7) (	0.0,	0.0)	0.108
B5	South2	N5 (	77.0,	51.8) (	36.1,	25.4)	3.846
B6	N5	N6 (	36.1,	25.4) (	26.8,	19.0)	0.316
B7	N6	N7 (	26.8,	19 0) (	0.0,	0.0)	0.242

((LVSouth2 loss summary))

		Ps(kW)	Loss(kW)	Rate(%)	Vmin	[Node-Phase]
[NET	B1]	71.69	4.59	6.40	214.29[	N3-S]
[NET	B5]	77.04	4.40	5.72	219.24[	N7-S]
[LV	South2Total]	148.74	8.99	6.05	214.29[	N3-S]

---<LVEast2>---

((Node Voltage Information))

Node	Vr-n(V<deg)	Vs-n(V<deg)	Vt-n(V<deg)	Vn(V<deg)
East2	238.59< -1.4	238.59<-121.4	238.59< 118.6	0.00< 0.0
N8	211.36< -10.6	219.05<-129.9	206.51< 108.8	8.43< 51.8
N9	207.51< -13.1	217.97<-132.1	202.68< 106.1	10.62< 46.6
N10	205.99< -15.4	218.40<-134.1	201.19< 103.8	11.89< 43.9
N11	205.57< -15.4	218.36<-134.1	200.77< 103.8	11.57< 44.2

((Branch Current Information))

Branch	From	To	Ifr(A)	Ifs(A)	Ift(A)	Ifn(A<deg)	Loss(kW)
B8	East2	N8	192.8	175.1	232.1	53.1<-109.7	12.058
B9	N8	N9	104.7	85.1	105.2	42.8<-151.4	1.665
B10	N9	N10	93.0	82.6	93.4	32.4<-153.3	1.317
B11	N10	N11	17.7	7.2	17.8	10.5<-145.6	0.021

((Branch PQ Information))

Branch	From	To	PQfrom(kW,kvar)	PQto(kW,kvar)	Loss(kW)
B8	East2	N8 (	142.8, 5.6) (	49.7, -36.3)	12.058
B9	N8	N9 (	49.7, -36.3) (	38.7, -39.8)	1.665
B10	N9	N10 (	38.7, -39.8) (	30.5, -41.7)	1.317
B11	N10	N11 (	8.6, 1.6) (	0.0, 0.0)	0.021

((LVEast2 loss summary))

		Ps(kW)	Loss(kW)	Rate(%)	Vmin [Node-Phase]
[NET	B8]	142.80	12.06	8.44	206.51[N8-T]
[NET	B9]	49.71	3.00	6.04	200.77[N11-T]
[LV	East2Total]	142.80	15.06	10.55	200.77[N11-T]

[Loss summary(Unit:%)]

Mi	Pg	Pl	Lline	Lcopp	Lcore	Total	Rate	Vmin[Node]
1.00	163.8	159.2	4.29	0.16	2.59	7.03	4.29	83.79[N11(East2)-T]

Example 5-6.OPO file

*********[Example1] 1~~~~~~~~~~~~~~~~~~~~~~~~~~~~

> *Result of Optimization Calculation on Introduction of Higher Voltage System*

<<Higher Voltage introduction >> [MU:1JD]

DEST	LINE	TRFM	LOC	Open	LOLD	LNEW	LRED	BNFIT	COST(MU)		NETB
NODE	CODE	CODE	(km)	Branch	(kW)	(kW)	(kW)	(MU)	LINE	TRFM	(MU)

--<33/0.415kV 34GM/3OH of=0.70 osl= 0.00 bc= 0>--

[South2]

> *No Profitable Case Obtained for [South2].*
>
> *For [East2], Followings are Net-Beneficial Cases*

[East2]

> *The Most Optimal Case*

<<Same V line construction >> [MU:1JD]

BRANCH	NEWLINE	LENG.	LOLD	LNEW	LRED	BNFIT	COST	NETB
		(km)	(kW)	(kW)	(MU)	(MU)	(MU)	(MU)

--<0.415kV 4OH of=0.70 bc= 0>--

[LVSouth2]

| B1 | WASP | 0.2 | 3.4 | 1.1 | 2.3 | 585 | 225 | 360 |
| B5 | WASP | 0.2 | 3.8 | 1.3 | 2.5 | 652 | 225 | 427 |

[LVEast2]

| B8 | WASP | 0.6 | 10.7 | 5.4 | 5.4 | 1373 | 675 | 698 |
| Total | | 1.0 | 18.0 | 7.8 | 10.2 | 2611 | 1125 | 1486 |

> *Result of Optimization Calculation on Reinforcement of New Line at Same Voltage*

****

* This result was calculated with PLOPT program developed by *

* Tokyo Electric Power Service Company, Limited (TEPSCO Japan) *

****

5-5   Supplementary Explanation on Output List

Example of output list in 5-4 gives supplementary explanation on contents of output, hereafter.

5-5-1   *Output List of Power Flow Calculation (PFLOW)*

Result of power flow calculation on high/medium voltage system is outputted followed by

"********[Example1] 100percent=1.0MVA MI=1.000000 ***************".

The contents of the result on power flow calculation are tabulated as shown in Table 5-1 ～ Table 5-3.

Table 5-1   Node Output

Item	Unit	Explanation
CODE	-	Node Name
V	kV	Node Voltage
V	%	Node Voltage against Rated Voltage (100%)
ANGLE	degree	Phase Angle (0 degree at Slack Node)
Pgen	%	Active Power of Generators against System Base Capacity
Qgen	%	Reactive Power of Generators against System Base Capacity
Pload	%	Active Power of Load against System Base Capacity
Qload	%	Reactive Power of Load against System Base Capacity
SC	%	Capacity of Capacitor or Capacity of Reactor with Minus Sign

(Percent value is the value against system base capacity.)

Table 5-2   Branch Output

Item	Unit	Explanation
CODE	-	Branch Name
NF	-	'From Node' Name
NT	-	'To Node' Name
P(NF->)	%	Active Power at 'From-Node'
Q(NF->)	%	Reactive Power at 'From-Node'
P(->NT)	%	Active Power at 'To-Node'
Q(->NT)	%	Reactive Power at 'To-Node'
Ploss	%	Active Power Loss within Branch
Qloss	%	Reactive Power Loss within Branch

(Percent value is the value against system base capacity.)

Table 5-3   Power Losses

Item	Unit	Explanation
Mi		Magnification of Load (See Chapter 4 Control Word @MI.)
Pg	%	Total Active Power of Generators
Pl	%	Total Active Power of Load
Lline	%	Total Line Losses
Lcopp	%	Total Copper Losses of Transformers
Lcore	%	Total Core Losses of Transformers
Total	%	Total of Lline, Lcopp and Lcore
Rate	%	Loss Rate
Vmin	%	Lowest Voltage in MV System
[Node]	-	Node with Lowest Voltage

(Percent value is the value against system base capacity.)

Result of power flow calculation on low voltage system is followed by

"---<LVSouth2>---".

The contents of the result are listed in Table 5-4 ~ Table 5-7.

Table 5-4   Node Output

Item	Unit	Explanation
Node	-	Node Name
Vr-n(V<deg)	Volt, degree	Voltage across R-phase and Neutral Line
Vs-n(V<deg)	Volt, degree	Voltage across S-phase and Nneutral Line
Vt-n(V<deg)	Volt, degree	Voltage across T-phase and Neutral Line
Vn(V<deg)	Volt, degree	Neutral Line Voltage

(Phase angle : phase angle from that of slack node.)

Table 5-5   Branch Output (1)

Item	Unit	Explanation
Branch	-	Branch Name
From	-	'From-Node' Name
To	-	'To-Node' Name
Ifr(A)	A	R phase Current in Ampere
Ifs(A)	A	S phase Current in Ampere
Ift(A)	A	T phase Current in Ampere
Ifn(A<deg)	A, deg.	Neutral Line Current in Ampere and Phase Angle
Loss(kW)	KW	Losses within Branch

Table 5-6   Branch Output (2)

Item	Unit	Explanation
Branch	-	Branch Name
From	-	From-Node Name
To	-	To-Node Name
PQfrom(kW,kvar)	KW,kVar	Active and Reactive Power at 'From-Node'
PQto(kW,kvar)	KW,kVar	Active and Reactive Power at 'To-Node'
Loss(kW)	KW	Loss within Branch

Table 5-7   LV Losses

Item	Unit	Explanation
(*****)	-	(Network name)
Ps(kW)	-	Total Active Power of Network
Loss(kW)	-	Total Network Losses
Rate(%)	%	Network Loss Rate
Vmin	V	Lowest Voltage in Network
[Node-Phase]	-	Lowest Voltage Node and Phase

5-5-2   Output list of Optimization Calculation (PLOPT)

Result of optimization calculation on higher voltage introduction is followed by

"********[Example1] 100percent=1.0MVA MI=1.000 ***************".

'<<Higher Voltage introduction >> [MU:1000JD]'.

The contents of the result are listed in Table 5-8.

Table 5-8   Result of Optimization Calculation on Higher Voltage Introduction

Item	Unit	Explanation
[****]	-	[Node Name of the Beginning of Higher Voltage System]
DEST	-	Node Name at the End of Examined Route
LINE	-	Selected Conductor in Code Name
TRFM	-	Selected Transformer in Code Name
LOC	km	Distance of New Transformer Location from "[****]" (beginning Point of MV Line)
Open	-	Open Point of Existing Lower Voltage System. Open point of lower voltage system is indicated 't' as to-side of the branch and 'f' as from-side of the open lower voltage branch.
LOLD	kW	Losses before Introduction of Higher Voltage System
LNEW	kW	Losses after Introduction of Higher Voltage System
LRED	kW	Loss Reduction in kW
BNFIT	1)	Benefit due to Loss Reduction for Study Period
COST LINE	1)	Construction Cost (Investment) of Higher Voltage Line
COST TRFM	1)	Construction Cost (Investment) of Step-Down Transformers
NETB	1)	Net Benefit 2) (= Benefit due to Loss Reduction – Cost due to Investment)

1) The currency unit and its decimal of BNFIT, COST, NETB is designated by the control word @MU in Econo Table and @MUE in OPI Files. Currency unit is shown in the form of '[MU:*]' on upper side of output list

2) Net Benefit is the economic revenue and the difference between benefit from loss reduction and cost due to investment for loss reduction for study period (refer to Part 1 Chapter 6 Section 7).

Same voltage line construction

Result of calculation for construction of new line at same voltage is listed followed by following declaration of

'<<Same V line construction >> [MU:1000JD] '.

The contents of the result are listed in Table 5-9.

Evaluations on new line construction in parallel with existing branches are carried out on all the branches in the system for changing conductor pre-designated. The most net-beneficial case is outputted as the result of study by branches. In case the net benefit of the new line addition in parallel with an existing branch is negative, computer will output no indication of the result on study.

Table 5-9   Result of Optimization Calculation for Same Voltage Line Construction

Item	Unit	Explanation
[ ]	-	[Block name]
BRANCH	-	Branch Name in code
NEWLINE	-	A Selected Conductor in Conductor Code
LENG	Km	Length of the Branch
LOLD	kW	Losses before New Line Installation
LNEW	kW	Losses after Construction of New Line.
BNFIT	1)	Benefit due to Loss Reduction for Study Period
COST	1)	Cost due to Investment on New Line
NETB	1)	Net Benefit 2)

1)   The currency unit and its decimal of BNFIT, COST, NETB is designated by the control word @MU in Econo Table and @MUE in OPI Files. Currency unit is shown in the form of '[MU:*]' on upper side of output list

2)   Net Benefit is the economic revenue and the difference between benefit from loss reduction and cost due to investment for loss reduction for study period (refer to Part 1 Chapter 6 Section 7).

5-6   Example of Installation of Capacitors for LV System

Capacity of a capacitor for LV system is determined so as to make approximate unity power factor at the sending end of a feeder in off peak period. An optimal location of a capacitor is at the 1/3 of feeder length from the end of a feeder in simple feeder without branches. However, actual LV systems branch off and consist of many branches. Thus, studies were carried out on optimal locations of capacitors for such LV system model with some tee-off branches.

5-6-1   Model System

The model system "EX" has some branches as shown in Figure 5-2. DT2 is a bus of LV side of a substation and underground cable is used for a first section from DT2 to N1. Main branch is between N1 and N6. A branch with relatively large load tees off at node N2. Load current at the sending end of a feeder at peak period is 200A and becomes half at off peak period. Power factor is 0.82.
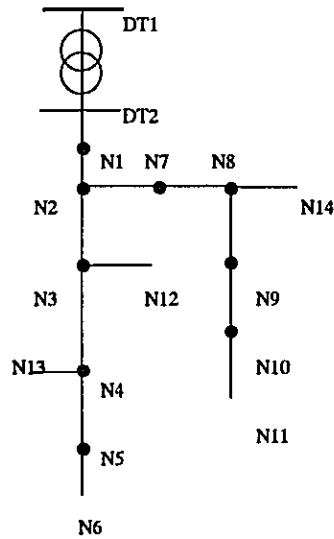
Part 2

Figure 5-2   Model System "EX2"   Table 5-10   Configuration of
                                      Branches and Load urrent of "EX2"

Sections	Length	Condcutors
DT2-N1	20m	LUAL185
N1-N2	50m	WASP
N2-N3	150m	ANT
N3-N4	150m	ANT
N4-N5	200m	GANT
N5-N6	200m	GANT
N2-N7	100m	ANT
N7-N8	100m	ANT
N8-N9	100m	ANT
N9-N10	100m	GANT
N10-N11	50m	GANT
N3-N12	100m	GANT
N4-N13	100m	GANT
N8-N14	100m	GANT

Load current at peak	200A at the sending end of a feeder
Load current at off peak	A half of peak current
Power factor	0.82

Load current is equally distributed along the feeder.

5-6-2   *Combination of Capacities of Capacitors*

Capacities of capacitors are determined so as to maintain unity power factor at off peak period. Table 5-11shows reactive load current at the sending end and total capacity of capacitors for the model system.

Table 5-11   Total Capacity for "EX2"

Load current at peak	Load current at off peak	Reactive load current at off peak	Capacity of capacitors
200A	100A	57A*	41kVA*

*57A=100A×$\sqrt{(1-0.82^2)}$ 57A×415V×$\sqrt{3}$=41kVA

The system requires approximate 40kVA capacitors in total.

5-6-3   *Capacities and Locations of Capacitors*

Figure 5-3 and 5-4 shows the result of the calculation with PFLOW for obtaining distribution of current in "EX2". Reactive load current is represented in

parentheses. The system has two branch-offs in two directions and can be divided into two blocks named A and B respectively. Capacitors are installed in respective blocks. Capacities of the capacitors are determined so as to obtain required total capacity in the system. The capacities are determined in proportion to load currents in respective blocks. The system requires approximate 40kVA capacitors. The 25kVA and 16kVA are selected for A and B blocks respectively among the combinations of capacitors mentioned in 3-1-2 in Part1.

Figure5-3 Current and Voltage in "EX2"
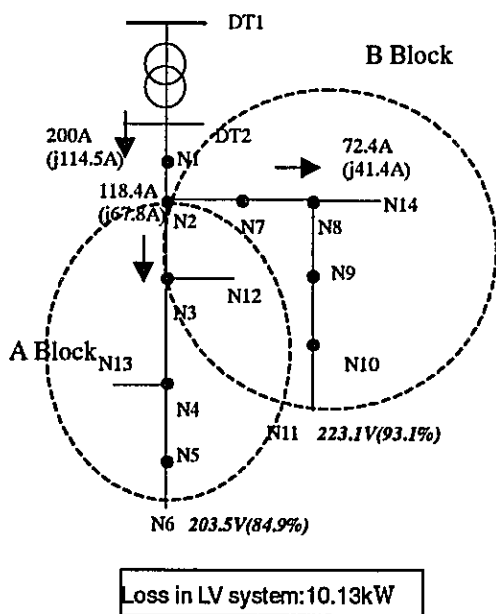
(At Peak : Without Capacitors)

Loss in LV system:10.13kW

Figure 5-4 Current and Voltage in "EX2"

(At Off-Peak : Without Capacitors)
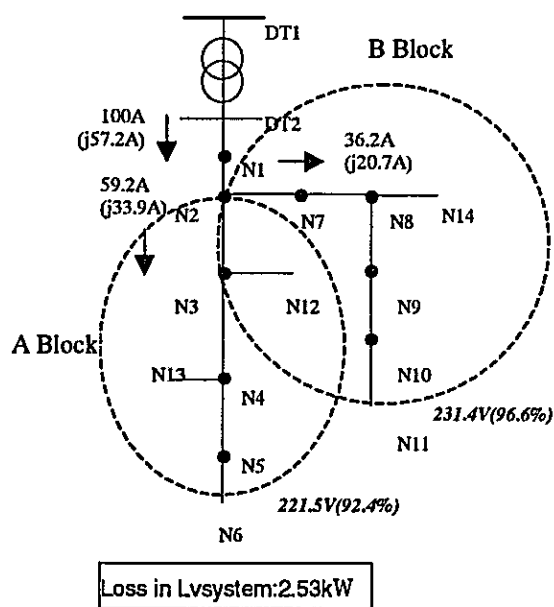

Loss in Lvsystem:2.53kW

Table 5-12   Load Current and Capacities of Capacitors Compensating Reactive Load Current at Off Peak

Blocks	Load Current at Peak	Reactive Load Current at Peak	Reactive Load Current at Off Peak	Capacities of Capacitors that can make Unity Power Factor at the Sending End of Respective Blocks.
Total	200	114.5	57.2	41kVA (=57.2×415V×$\sqrt{3}$)
A	118.4	67.8	33.9	24kVA (=33.9×415V×$\sqrt{3}$)
B	72.4	41.4	20.7	15kVA (=20.7×415V×$\sqrt{3}$)

Locations of respective capacitors are at 2/3 (70%) of the length between the

sending end and the end of respective blocks. Capacities and locations of capacitors can be summarized in Table 5-13.

Table 5-13   Capacities and Locations of Capacitors

Capacities	Locations	Distances from Secondary Bus of a Substation to the Ends of Blocks	Distances from Secondary Bus of a Substation to the Locations of Capacitors
25kVA	N4 (A block)	770m	570m (74% of a distance from the sending end)
16kVA	N9 (B block)	420m	270m (64% of a distance from the sending end))

5-6-4   Current and Voltage with Capacitors

Figure 5-5 and 5-6 shows the result of the power flow calculation on the model system with capacitors at peak period.

Capacitors are modeled as constant current source. Current at the sending end at peak and off peak are 174.8A and 83.4A. Those values are 87.4% and 83.4% of respective peak and off peak current without capacitor. These values are approximately equal to Reduced Current Coefficient (RCC) of 85% shown in Table 3-4 in Part 1.
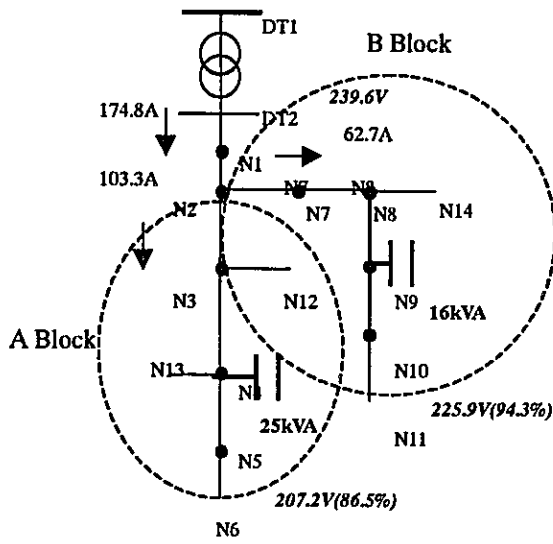
Reactive power at the sending end at off peak is 0.1kVar and power factor is kept on approximate unity. The voltages are maintained within 1.0 pu over the system, and the highest voltage is 239.6V at the sending end.

As shown in this example, capacities of capacitors can be determined on each main branch focusing on respective reactive loads.

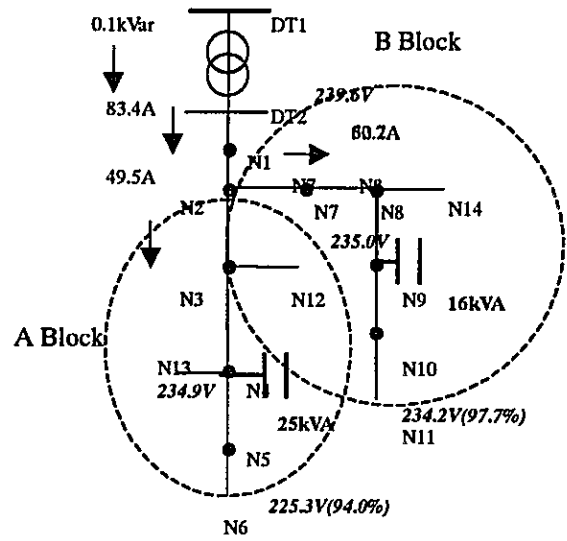Table 5-14   Power Flow before and after Installation of Capacitors in "EX2"

Items	At Peak		At Off Peak	
Capacitor (Capacity)	Before installation	After Installation (16+25kVA)	Before installation	After Installation (16+25kVA)
Current at Sending End(A)	200	174.8 87.4% of current before installation	100	83.4 83.4% of current before installation
Reactive Power at the LV Bus of the Substation	82.3kVA	41.1kVA	41.2kVA	0.1kVA
Power Losses in the LV System(kW)	10.13	7.79 76.9% of current before installation	2.53	1.89 74.7% of current before installation
Lowest Voltage(V)	203.5 (84.9%)	221.5 (92.4%)	207.2 (86.5%)	225.3 (94.0%)
Highest Voltage(V)	239.6 (100%)	239.6 (100%)1	239.6 (100%)	239.6 (100%)

Figure5-5   Current and Voltage in "EX2"   Figure 5-6 Current and Voltage in "EX2"

(At Peak: With Capacitors)   (At Off Peak: With Capacitors)

Loss in LV System:7.79kW

Loss in LV System:1.89kW

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