CHAPTER VIII

STUDY ON OPTIMAZATION OF POWER LOSS REDUCTION

Chapter 8 Study on Optimization of Power Loss Reduction

8.1 Overview of Optimization Study on Loss Reduction

This chapter describes the summary of results of study based on the condition in Chap. 7. A study on the capacity of capacitor to be installed and other reinforcement measures of three- hundred ninety-eight LV target feeders has been completed. A study on reinforcement measures of eight MV target feeders has also been completed.

8.1.1 Loss Reduction by Power Factor Correction

The amount of loss reduction by respective capacitors is comparatively smaller than that by reinforcement such as new line installation at same voltage and higher voltage introduction. It makes efficient investment since Jordanian networks have a low power factor (e.g. from about 0.70 to 0.85 in LV systems) and capacitors require much smaller initial investment than those of reinforcement of distribution facilities.

This measure also improves the quality of power distribution with a small investment in terms of voltage reduction at the end of distribution network during peak periods.

The policy of capacitor installation and its effect on LV and MV target feeders were studied and described below.

8.1.2 Policy of Capacitor Installation on Distribution Network

The capacity of the capacitor was determined to avoid over-voltages due to reactive power produced by capacitors particularly during off-peak period. The capacity of capacitors was determined in such a manner that the power factor at the outgoing portion of distribution line from substation should be unity in off-peak period. Studies proved that voltages during off-peak periods can be maintained within operational voltage range.

The study results show that the capacitor should be installed at the location where reactive power is one-third of the sending end. A study on optimum capacity and location of capacitor has been carried out on a typical distribution system model in terms of energy loss reduction based on the load curve. Prior to the study on respective LV feeders, the merit of loss reduction by installing capacitor (power factor correction) was also examined.

As to the MV system, a comparison has been carried out between the capacitor installed on the MV side at the location, similar to LV system, where reactive power is one-third of the sending end and the capacitor distributed on the secondary side of respective distribution transformers. As a result, the capacitors distributed on the secondary side of distribution transformers were selected as base case for this study, since the comparison found the LV capacitor more beneficial in terms of loss reduction. Described below is an outline of the study.

8.1.3 Loss Reduction by Installing Capacitor on LV Target Feeders

The power factor along the feeder will be changed by installation of capacitors and together with an annual demand growth of target ten years, means that a uniformly distributed current model on LV system in this study cannot be directly applied. In order to properly reflect the changes in losses due to respective lumped load of capacitors on the middle of the feeders, equivalent power factor was applied in this study. In concrete, in order to reflect the effect on load current properly, the equivalent power factor and reduction in load current due to power factor correction by capacitors were studied in such a manner that total loss reduction is equal. In table 8.1-1 shown below, equivalent power factor and reduced coefficient of load current are summarized by respective load power factor prior to the study on power factor correction with capacitors for respective LV target feeders.

Table 8.1-1 : Equivalent Power Factor and Reduced Current Coefficient

Load Power Factor without Capacitor	With Capacitor Installed		
	Equivalent Power Factor	Reduced Current Coefficient	Loss Reduction Ratio (%)
0.70	0.92	0.76	57.76
0.75	0.94	0.80	64.00
0.80	0.95	0.84	70.56
0.85	0.97	0.88	77.44
0.90	0.98	0.92	84.64

Table 8.1-1 shows that the lower the load power factor is, the more loss reduction can be obtained, as losses are in proportional to square of load current/reduced current coefficient.

Table 8.1-2 shows a summary of the study on loss reduction of LV target 398 feeders with capacitors. Loss reduction of 1kW can be obtained by 14kVA capacitor installation and the efficiency of investment in capacitors for loss reduction is very high. The recovery term of investment in a capacitor can be less than one year as the coefficient of investment efficiency is 41.4.

Table 8.1-2 : Capacitor Installation on All LV Target Feeders

Loss before Improve-ment (MW)	After Improvement					Economy (1,000JD/10yr)			(b)/(a)
	Capacity Installed (MVA)	Investment (1000JD) (a)	Loss (MW)	Reduced Loss (MW) (GWh/10Y)		Expense	Benefit	Net Benefit (b)	
3.7	13.6	55	2.7	1.0MW	81.7GWh	44	2,322	2,278	41.4

8.1.4 Loss Reduction by Installing Capacitor on MV Target Feeders

Similar to the study on LV target feeders, MV target feeders were examined in terms of the optimal capacity and location of fixed capacitor and improvement of voltage reduction at the feeder end by fixed capacitor. Studies on power factor correction by solely fixed capacitor were carried out on respective target feeders. A combination of capacitor and other measures was also examined on the target feeders as shown in section 8.3.

8.2 Loss Reduction of LV Feeders

A preliminary study was carried out before the feasibility study on approximately four hundred LV target feeders. This preliminary study was carried out on the critical beneficial load current of LV feeders, which gives net benefit due to investment for loss reduction. The critical load current was examined on measures of re-conductoring, new LV feeder construction and MV introduction under given conditions of power factor correction.

8.2.1 Preliminary Study

(1) Preliminary Study on LV Reinforcement Measure

To grasp the relation between benefit due to energy loss reduction and expenditure due to investment for loss reduction, studies were conducted on two measures of re-conductoring and new line installation by changing initial load current on LV feeders to seek critical beneficial current. The study was carried out based on the conditions in chapter seven and averaged annual demand growth rate is assumed to be five percent for the evaluation period of ten years.

Fig. 8.2-1 shows one of the study results. This figure shows the relation between initial feeder current and net benefit for ten years. Two cases were studied, one was new line installation and the other was re-conductoring with WASP (aluminum bare conductor of cross section of 100mm^2) in the case the existing conductor is LCU35 (copper bare conductor of cross section of 35mm^2).

Fig.8.2-1shows that:

- new LV line installation with WASP becomes net beneficial in the range of 56 amps (peak current) and above, re-conductoring with WASP becomes net beneficial in the range of 38 amps (peak current) and above.

- re-conductoring is more beneficial than new LV line construction in the range of 38 to 88 amps (peak current), and new LV construction is more beneficial than re- conductoring in the range of 88 amps (peak current) and above.

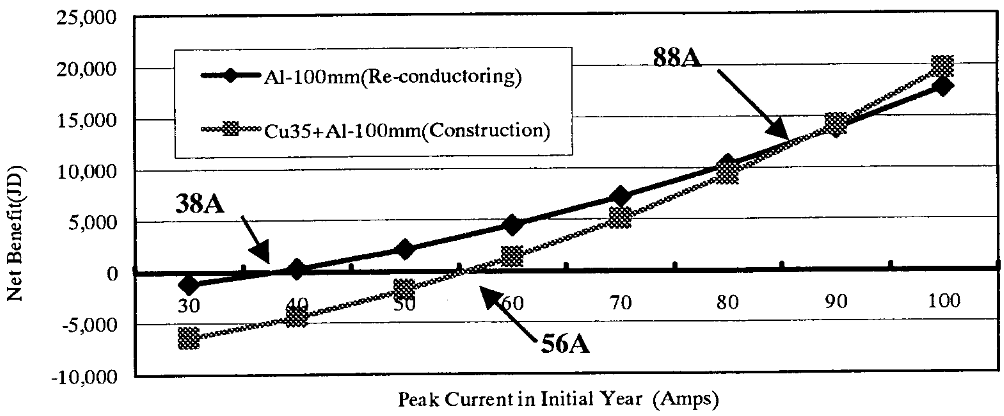

Fig.8.2-1 Initial feeder current Vs. net benefit for ten years

Measures of line reinforcement at the same voltage for loss reduction in LV system can be envisaged from the initial value of load current on feeders. In the next phase of feasibility study carried out by Jordanian engineers, these critical beneficial currents will be helpful for selecting the target feeders for loss reduction. Table 8.2-1 shows critical beneficial currents and their optimal load current range on existing conductors widely applied in Jordan.

Table 8.2-1 : Critical Beneficial Currents of Various Existing Feeders

Existing Feeder		Al-100mm^2 Re-conductoring	Al-100mm^2 New Line Construction
GANT (Al-25mm^2)	Critical Current	20 A	35 A
	Optimal Range	20 ～ 114 A	114A～
ANT (Al-50mm^2)	Critical Current	36 A	54 A
	Optimal Range	36 ～ 92 A	92A～
WASP (Al-100mm^2)	Critical Current	---	88 A
	Optimal Range	---	88A～
LAL50 (Al-50mm^2)	Critical Current	31 A	49 A
	Optimal Range	31 ～ 94A	94A～
LAL95 (Al-95mm^2)	Critical Current	84 A	78 A
	Optimal Range	---	78 A～
LCU25 (Cu-25mm^2)	Critical Current	27 A	45 A
	Optimal Range	27 ～ 98 A	98A～
LCU35 (Cu-35mm^2)	Critical Current	38 A	56 A
	Optimal Range	38 ～ 88 A	88A～
LCU50 (Cu-50mm^2)	Critical Current	58 A	70 A
	Optimal Range	58 ～ 79 A	79A～
LCU70 (Cu-70mm^2)	Critical Current	---	88 A
	Optimal Range	---	88A～

Optimal Range : The current range that the measure is more net beneficial Among Alternatives

(2) Preliminary Study on MV Introduction Measure

To grasp the relation between benefit due to energy loss reduction by MV introduction and expenditure due to investment in MV introduction, studies were conducted on the model system shown in Fig.8.2-2. In order to find critical beneficial load current, studies were conducted by changing initial load current on respective existing LV feeders.

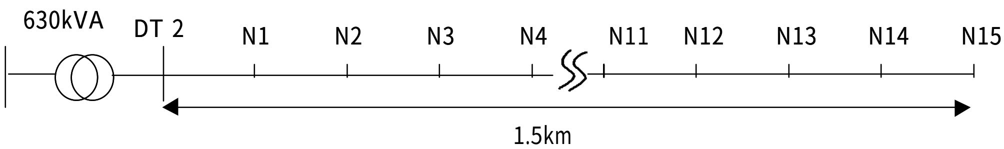

Fig.8.2-2 : LV Feeder Model of Preliminary Study on MV Introduction Measure

As shown in the figure, the total length of the feeder is 1.5km, and consists of fifteen sections of 0.1km length. The capacity of the source transformer is 630kVA and load is set to be 50% (constant) of its capacity. The studies were conducted on both cases, introduction of overhead MV feeders as well as for underground MV feeders. The studies were conducted on existing conductors in the load current range from 40 amps to 240 amps in 10 amps steps.

Table 8.2-2 and Table 8.2-3 show the results of the introduction of overhead MV feeders and underground MV feeders respectively.

Table 8.2-2 : Critical Beneficial Current of Overhead MV Introduction

Existing LV Feeder	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～

Optimal Range : The load current range that MV introduction measure is more net beneficial than LV reinforcement measures

Table 8.2-3 : Critical Beneficial Current of Underground MV Introduction

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

Optimal Range : The load current range that MV introduction measure is more net beneficial than LV reinforcement measures

In the case of overhead MV introduction on existing LV WASP(aluminum bare wire with cross section of $100mm^2$), the measure becomes net beneficial in the range of 120 amps peak current and above, and it is more beneficial than LV reinforcement measure in the range of 130 amps peak current and above. Both critical current and optimal range in Table 8.2-3 (Underground MV) are larger than those in Table 8.2-2 (Overhead MV) because of higher construction cost of underground MV lines.

These values of the study on a model system can not directly be reflected to the actual feeders, because the actual feeders have a much more complicated configuration, and load distribution etc. However, these values are helpful to obtain the approximate range in load current for MV introduction measures.

8.2.2 Policy of Improvement of LV Target Feeder

(1) Policy on Study

Measures such as re-conductoring and new line installation for LV target feeders were studied in combination with power factor correction with capacitors because of its cost efficiency. For measures of MV introduction, the same type of facilities (type of the transformer and MV line) as existing facility were examined, considering actual site condition under the condition that an MV feeder would be introduced along with the existing LV target feeder. Respective sections in both main and branch feeders examine MV introduction for loss reduction. Taking into account of difficulty in siting of facilities, the number of new LV feeders is confined to one circuit.

(2) Policy of Selection of Measures

The objective of this project is to obtain maximum net-benefit by improving distribution network in terms of loss reduction. However, to maintain system voltage within an appropriate range is also essential from the viewpoint of quality. Based on the discussion with Jordanian counterparts and IEC standard 'Standard Voltage', the criteria for selection of alternative for loss reduction was determined as:

- The most net-beneficial case among net-beneficial alternatives that can maintain system voltage in the initial year within 10% should be selected.

(3) Conditions of the Study

Facilities for improvement of the LV system were adopted from those widely applied on the existing LV system in Jordan. WASP (aluminum bare conductor of cross-section of 100mm^2) or smaller size aluminum bare conductors were studied for new LV line construction and/or LV line re-conductoring. In the study of MV introduction, facilities of the same type as existing ones were examined to reflect site conditions. The commissioning year and the evaluation period of the measures of LV feeders should be set in the year 2001 and for ten years (from 2001 to 2010), respectively. Respective phase load currents were averaged in the study, for correction of unbalanced phase current is underway in Jordan. Equivalent power factor and reduced load current due to power factor correction were applied.

8.2.3 Study Result on LV Target Feeders

By using the software PFLOW and PLOPT, load flow and optimization calculations for respective measures were executed and countermeasures were selected taking into account both economy and improvement in voltage profile.

(1) Summary of Study Result

Table 8.2-4 shows the summary of study result on all LV target feeders.

Table 8.2-4 : Summary of Study Result on LV Target Feeders

		EDCO	JEPCO	IDECO	Total
Countermeasure	Capacitor Inst. & MV Introduction	43	14	37	94
	Capacitor Inst. & LV Reinforcement	96	78	92	266
	Capacitor Installation	9	8	21	38
	Total	148	100	150	398
Initial Investment (×1,000JD)	On Capacitor Installation	20	15	19	55
	On Network Reinforcement	1,029	500	876	2,405
	Total	1,049	515	895	2,460
Energy Loss Reduction (MWh/10yr.)	From Capacitor Installation	39,204	16,296	26,130	81,630
	From Network Reinforcement	66,494	30,851	44,514	141,859
	Total	105,698	47,147	70,644	223,489
Net Benefit (×1,000JD/10yr.)	From Capacitor Installation	1,099	451	728	2,278
	From Network Reinforcement	1,071	480	568	2,120
	Total	2,170	931	1,297	4,398
I.E. Factor	Capacitor Installation	54.7	29.7	37.8	41.8
	Network Reinforcement	1.04	0.96	0.65	0.88
	Total	2.07	1.81	1.45	1.79

Table 8.2-4 shows;

- The ratio of the measure of 'MV introduction combined with capacitor installation' of JEPCO is smaller than the other two companies.
- The ratio of the measure of 'capacitor installation solely' of IDECO is larger than the other two companies.

The reason for the smaller ratio of MV introduction measure in JEPCO's target LV feeders is that JEPCO's MV introduction is an underground system and construction cost is therefore higher than for an overhead system. Thus net benefit from underground MV introduction is smaller than for the other two companies which MV introduction was for an overhead system. Table 8.2-5 shows a comparison of new MV line construction cost with overhead/underground line.

Table 8.2-5 : Comparison of MV Line Construction Cost

MV System	Transformer (250kVA)	MV Line (0.5km)	Construction Cost
Overhead	Pole Mounted (9,835JD)	$100mm^2$ Aluminum Bare Wire (6,643JD)	16,478JD
	Ground Mounted (12,125JD)		18,768JD
Underground	Package Unit (16,690JD)	$150mm^2$ Aluminum Cable (13,500JD)	30,190JD

The reason for the larger ratio of capacitor installation of IDECO's target LV feeders is that the number of smaller load current of IDECO is larger than that of the other two companies. (Numbers of target feeders with load current of 100 amps or less in EDCO, JEPCO and IDECO are 21, 18 and 39 respectively.)

Resistances of existing conductors were categorized into four groups as shown in Table 8.. Figure 8.2-3 shows the distribution of feeder resistance of main portion of LV feeders (three sections from substation) of respective distribution companies.

Table 8.2-6 : Grouping of Lines by Resistance

Resistance (Ω/km)	> 0.75	0.5～0.75	0.25～0.5	< 0.25
Line	LUCU6 LCU16 GANT LBAL35 LCU25 LCU25A	LAL50 LBAL50 LUAL50 ANT ANT2 LCU35 LCU35A LBAL70 LUAL70	LCU50 LCU50A LAL295 LAL95 MKT LCU70 WASP WASP2 LUCU70 LCU35M2 LBAL120 LUAL120	LCU95 LCU50M2 LUAL185 LAL295M2 LUCU120 LUAL240

As shown in Fig.8.2-3, resistances of the main portion of lines of IDECO's target feeders are lower than those of other two companies. This is one of the reasons that ratio of network reinforcement for loss reduction of IDECO's target feeders is less than those of other two distribution companies.

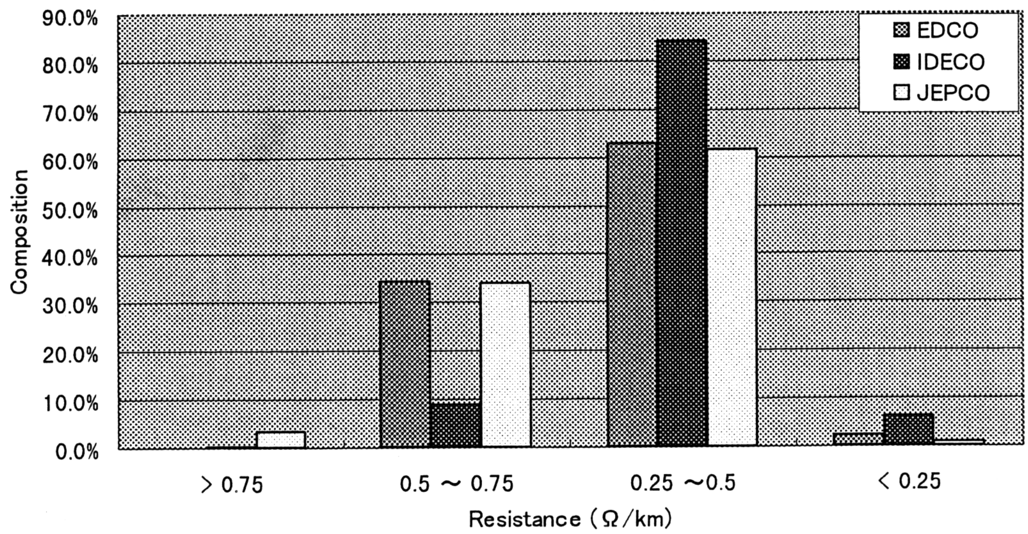

Fig.8.2-3 : Resistance of Lines in Root Portion of Trunk Line

(2) Examples of Result of Study on Target Feeder

An example of the course of the study is as follows. Fig. 8.2-4 shows an LV network of EDCO's target feeder named 'E015'. This feeder consists of eighteen sections and its three phase averaged peak load current in year 2001 is 193 amps. Energy loss of the feeder without network improvement (with only capacitor installation measure) during ten years form year 2001 is 982MWh. The lowest voltage of this feeder in year 2001 will be 206.1 volts at node N7 and N17.

Both an LV reinforcement measure and an MV introduction measures on this feeder were studied with usage of the software PFLOW and PLOPT. Both of the measures gave net-beneficial results. Fig.8.2-4 and Fig.8.2-5 show these measures respectively.

Measures at same Voltage

Fig.8.2-4 shows the result of the study on LV reinforcement measure, i.e. to construct a new LV line along the existing feeder form node DT2 to node N3 with WASP and to re-conductor existing ANT (aluminum bare wire with cross section of 50mm^2) with WASP from node N4 to node N6. There is no net beneficial measure on the section from node N3 to node N4 for this section is already wired with WASP and load current at the entrance of the section is 84 amps. (See Table 8.2-1: Critical beneficial current of various conductors) An initial investment of 4,313JD is required and costs for ten years amount to 3,435JD. On the other hand, an energy loss of 288MWh can be saved in ten years. Monetary value of the loss reduction amounts to 8,196JD. Consequently net benefit of 4,761JD can be obtained during ten years by this measure. Voltages along the feeder in year 2001 can be improved from 206.1 volts to 217.8 volts (△14.1%→△9.3%） at node N7 and N17.

MV Introduction

Fig.8.2-5 shows the result of the study on MV introduction, i.e. to install a ground mounted substation, the same type of the source substation of the LV feeder between node N3 and N4, and a new MV DOG line from existing source substation to this new substation along the LV feeder. The target LV feeder is divided into two networks by opening at node N2 side of node N3. Initial investment of 16,908JD is required for this measure, costs for ten years amount to 13,465JD. While energy loss of 637MWh can be saved in ten years and the monetary value of the reduced loss amounts to 18,118JD. Consequently a net benefit of 4,653JD is obtained during ten years by this measure. Voltages of the feeder in year 2001 is improved from 206.1 volts to 224.2 volts (△14.1%→△6.6%) at node N7 and N17 by this measure.

As the countermeasure of this feeder, LV reinforcement measure was selected because net benefit (4,761JD) was larger than that of MV introduction (4,653JD). Lowest voltage of the network of 217.8 volts in year

2001 satisfies voltage criteria (voltage drop should be less than ten percent).

Countermeasures on 398 target feeders were determined in the same manner and are listed in Appendix 8.2. Single line diagrams of 40 target feeders randomly selected and their countermeasures are shown in Appendix 8.4.

(3) Priority of Investment of Countermeasures on LV Feeders

Table 8.2-7 shows composition of numbers of target feeders, investment and net-benefit of counter-measures on target feeders such LV line construction, re-conductoring and MV introduction combined with capacitor installation by respective investment recovery period.

Table 8.2-7 Numbers, Investment and Net-benefit of Target Feeders by Investment Recovery Period

		Investment Recovery Period		
		5 yr. or less	5〜10 yr.	more than 10 yr.
Composition Ratio	Number of Feeders	12%	50%	38%
	Investment	11%	48%	41%
	Net Benefit	40%	49%	11%

This table shows that the target feeders shall be implemented based on the recovery period of respective counter-measures on target feeders taking into account of efficiency of investment.

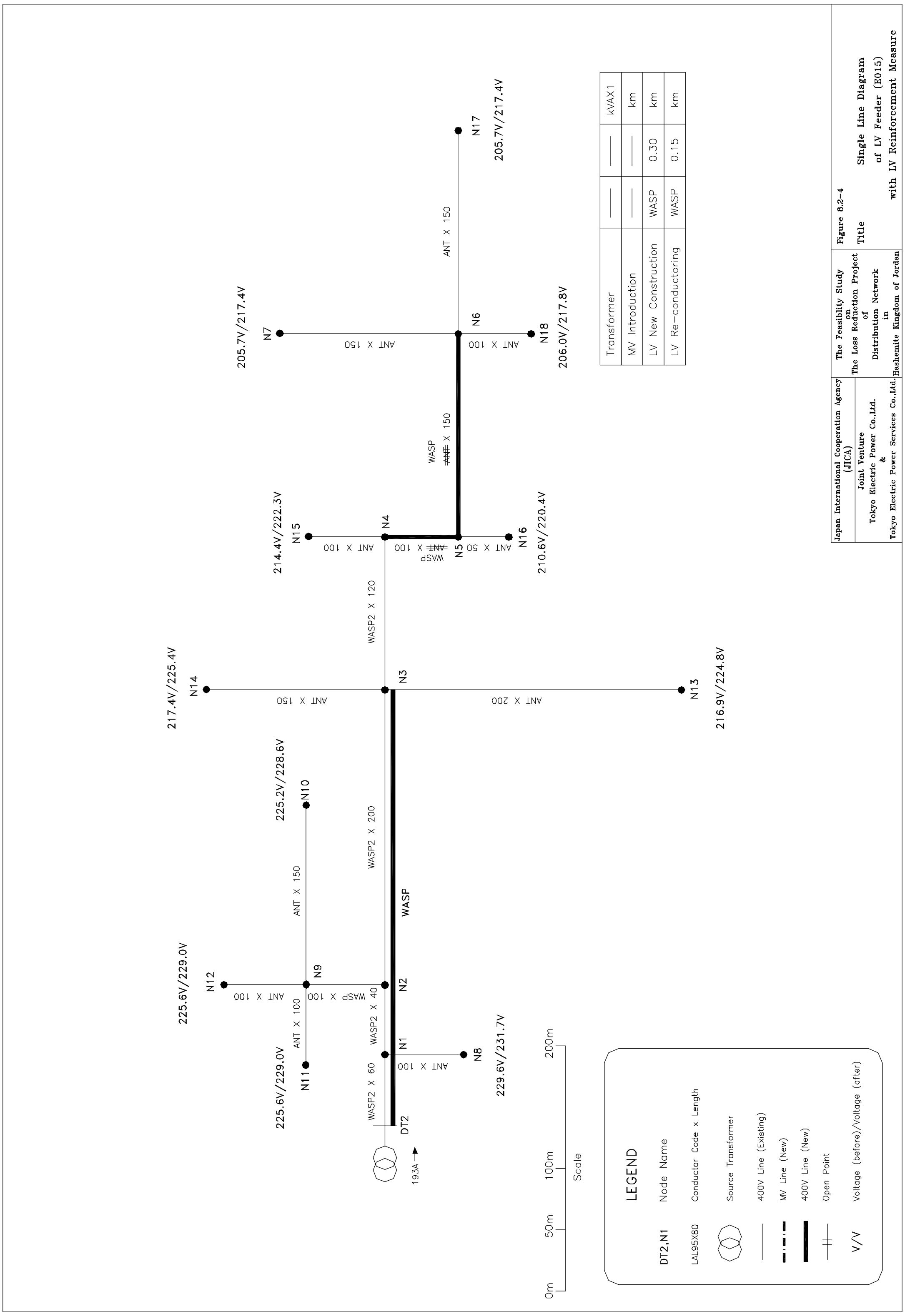

Fig.8.2-4 : Single Line Diagram of E015 Feeder and Reinforcement at Same Voltage

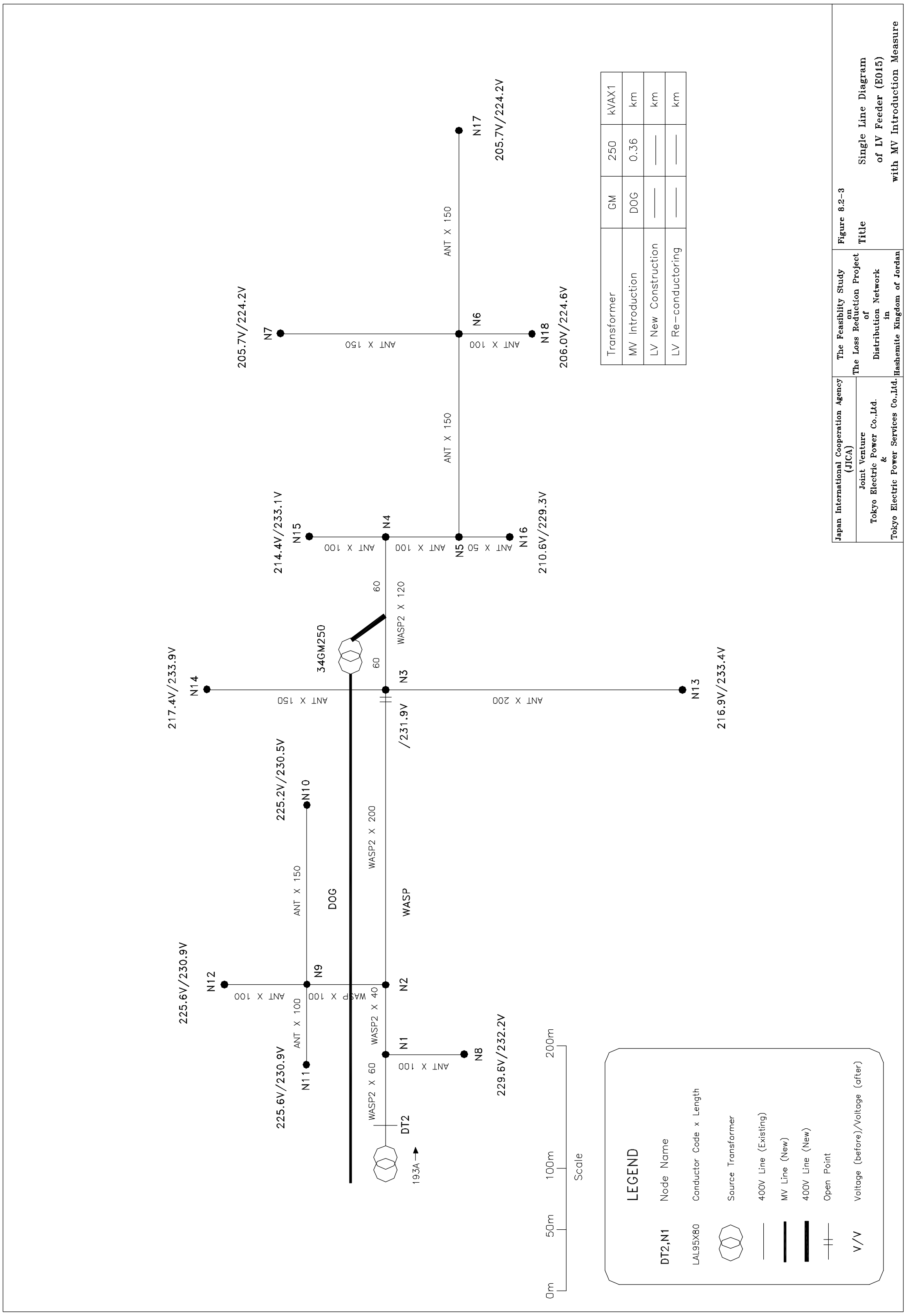

Fig.8.2-5 : Single Line Diagram of E015 Feeder and MV Introduction

8.2.4 Study on Application of LAL150 (aluminum bare wire with cross section of 150mm^2)

Application of LAL150 for a new LV line construction measure (LAL150 Case) was examined expecting a lager amount of energy loss reduction and larger net benefit by the application of larger size conductor. In this study, the maximum size of conductor for re-conductoring was limited to WASP, because existing structures are designed to a cross section of 100mm^2 or smaller. Reinforcement of structures to wire larger size conductors seemed to be less beneficial. Table 8.2-8 shows the result. Table 8.2-9 shows the comparison between 'the base case' (WASP or smaller size aluminum bare wire were applied for both new line construction and re-conductoring) and 'LAL150 Case'.

Table 8.2-8 : Result of LAL150 Case

		EDCO	JEPCO	IDECO	Total
Counter-measure	Capacitor Inst. & MV Introduction	38	13	36	87
	Capacitor Inst. & LV Reinforcement	101	79	93	273
	Capacitor Installation	9	8	21	38
	Total	148	100	150	398
Initial Investment (×1,000JD)		1,024	513	905	2,442
Energy Loss Reduction (MWh/10yr.)		105,850	48,037	71,514	225,401
Net Benefit (×1,000JD/10yr.)		2,195	957	1,313	4,465
I.E. Factor		2.14	1.87	1.45	1.83

Maximum conductor size for new line construction : LAL150 (150mm^2 Aluminum bare wire)
Maximum conductor size for re-conductoring : WASP (100mm^2 Aluminum bare wire)
Voltage drop :10% or less

Table 8.2-9 : Comparison between 'Base Case' and 'LAL150 Case'

		Base Case	LAL150 Case	Difference
Counter-measure	Capacitor Inst. & MV Introduction	94	87	△ 7
	Capacitor Inst. & LV Reinforcement	266	273	7
	Capacitor Installation	38	38	0
	Total	398	398	0
Initial Investment (×1,000JD)		2,460	2,442	△ 18
Energy Loss Reduction (MWh/10yr.)		223,489	225,401	1,912
Net Benefit (×1,000JD/10yr.)		4,398	4,465	67
I.E. Factor		1.79	1.83	0.04

As shown in Table 8.2-9 the study on introduction of bare conductor with cross section of 150m^2 for new LV line construction resulted in slightly advantageous as expected in economy compared with base case. The result of the study also shows that application of 150mmm^2 for new line installation can reduce the number of MV introduction alternatives.

8.2.5 Study on Application of BA120 (aluminum overhead cable with cross section of 120mm^2)

Overhead bundled cable is expected to be more advantageous than bare wire in terms of voltage drop and safety but is expensive in cost. Application of BA120 (aluminum overhead cable with cross section of 120mm^2) or smaller size overhead cables for both new LV line construction and re-conductoring (BA120 Case) was examined on forty feeders randomly selected among the target feeders. Table 8.2-10 and Table 8.2-11 shows the result of the study and comparison between ‘Base Case’ and ‘BA120 Case’.

Table 8.2-10 : Result of BA120 Case

		EDCO	JEPCO	IDECO	Total
Counter-measure	Capacitor Inst. & MV Introduction	6	1	6	13
	Capacitor Inst. & LV Reinforcement	9	9	9	27
	Capacitor Installation	0	0	0	0
	Total	15	10	15	40
Initial Investment (×1,000JD)		132	45	128	305
Energy Loss Reduction (MWh/10yr.)		13,606	4,934	9,757	28,297
Net Benefit (×1,000JD/10yr.)		281	105	175	561
I.E. Factor		2.12	2.33	1.37	1.84

Maximum conductor size for new line construction ： BA120 (120mm^2 Aluminum overhead cable)

Maximum conductor size for re-conductoring : BA120 (100mm^2 Aluminum overhead cable)

Voltage drop : 10% or less

Table 8.2-11 : Comparison between ‘Base Case’ and ‘BA120 Case’

		Base Case	BA120 Case	Difference
Counter-measure	Capacitor Inst. & MV Introduction	13	13	0
	Capacitor Inst. & LV Reinforcement	27	27	0
	Capacitor Installation	0	0	0
	Total	40	40	0
Initial Investment (×1,000JD)		300	305	5
Energy Loss Reduction (MWh/10yr.)		28,150	28,297	147
Net Benefit (×1,000JD/10yr.)		561	561	0
I.E. Factor		1.87	1.84	△ 0.03

Table 8.2-11 shows that the larger cross section of bundled cable of 120mm^2 has advantages over 100mm^2 bare conductor in terms of loss reduction, but the higher construction cost of bundled cable meant a slightly less-beneficial alternative overall. In terms of voltage drop or public safety, bundled cable is advantageous. Especially, for low power factor feeders, it improves voltage drop due to its lower reactance in nature.

Following are the differences of the optimal measures between base case and BA120case resulted from conductor reactance.

The numbers of selected measures are the same as in both cases, but different measures are selected on respective feeders.

Among the forty feeders, there was one feeder that MV introduction measure was selected in 'Base Case' while LV reinforcement was selected in BA120 case. In Base Case, LV reinforcement measure is more net beneficial than MV introduction measure, however it doesn't satisfy voltage criteria. Thus MV introduction measure was selected as a countermeasure of the feeder in base case. In BA120 Case, LV reinforcement measure is also more net beneficial than MV introduction measure, and it satisfies the voltage criteria. Thus LV reinforcement measure was selected as a countermeasure of the feeder taking advantage in voltage reduction. This difference is mainly caused by smaller reactance of bundled cable.

On the other hand, there was one feeder that LV reinforcement measure was selected in 'Base Case' and MV introduction measure was selected in 'BA120 Case'. In Base Case, LV reinforcement measure is more net beneficial than MV introduction measure, and satisfies voltage criteria. Thus LV reinforcement measure was selected as a countermeasure of the feeder in base case. In BA120 Case, MV introduction measure is more net beneficial than LV reinforcement measure, and it satisfies voltage criteria. Thus MV introduction measure was selected as a countermeasure of the feeder. This reduction of net benefit of BA120 Case is mainly caused by higher construction cost of bundled cable.

8.3 Loss Reduction on MV Systems

8.3.1 Preliminary Study

As in the study on LV feeders, measures such as power factor correction and other measures in combination with capacitor installation for loss reduction on the eight MV target feeders have been studied. Measures for loss reduction to be examined comprise of installation of capacitor by itself as well as an installation with reinforcement such as re-conductoring of existing feeders, new line installation and 132/33kV substation installation. Before examining these measures in detail, a preliminary study on the appropriate location/distribution of capacitors was carried out.

As to the power factor correction of MV distribution system, two alternatives are applicable. One is to install one capacitor on the same voltage side (MV side) at an appropriate location in the light of energy loss reduction in the same manner on power factor correction of the LV system. This capacitor installed on the MV side is hereafter referred to as the “MV capacitor” in this study. Another is the case to install small capacitors on the secondary side of each distribution substation. This capacitor installed on the LV side is hereafter referred to as the “LV capacitor”. The MV capacitor is advantageous in number of capacitors and in the case of lumped large load power factor correction, and the LV capacitor is less expensive and makes it easy to increase capacity in proportion to load growth if room for installation in distribution substation is sufficient. The effect of these options on loss reduction was examined as follows*;*

(1) Conditions of MV Capacitor Installation

The capacity of the MV capacitor amounts to half of the reactive power of the sending end of the feeder, which makes the power factor 1.0 during off-peak periods. The MV capacitor is also installed where the reactive power is approximately one-third of the reactive power at the sending end in order to reduce losses. These conditions are the same as discussed in power factor correction of the LV system.

(2) Conditions of LV Capacitor Installation

The LV capacitor is installed at the secondary side of each distribution transformer for loss reduction. The capacity of each small LV capacitor is determined by the transformer capacity under the condition that the total capacity of each small capacitor is approximately equal to half the reactive power at the sending end. Secondary voltages of transformers are adjusted by tap a changer of transformer.

(3) Comparison of MV Capacitor and LV Capacitor

The results of the study on loss reduction by MV and LV capacitors are shown in Table 8.3-1. This demonstrates the result of a total of eight target feeders, thus showing that LV capacitors are preferable in terms of economy for loss reduction. Investment for an LV capacitor is less than that for an MV capacitor since the LV capacitor unit price is inexpensive. Loss reduction by the LV capacitor is more than that of the MV capacitor since the loss of the distribution transformer can be reduced by the installing capacitor on the secondary side of these transformers and the voltage on capacitors is maintained by a tap changer. As a result, both the net benefit and I.E. factor for an LV capacitor are greater than that of the MV capacitor. In addition to better economic reasons, there is another factor worth considering for the LV capacitor in that it makes further installation easier in proportion to load growth since the small rated capacity is distributed at each distribution substation. Consequently, in this study, the LV capacitor was selected as the base case for power factor correction of the MV system and the measures combined with the LV capacitor are studied in light of the economy of loss reduction.

Despite less economic benefits than the LV capacitor, MV capacitor is still attractive from the following perspectives. At first, only one capacitor needs to be installed on the MV side, saving time and energy for installing a lot of small capacitors on the LV side and making it easy to secure the installation space. It is also advantageous in the case of lumped large load power factor correction. Moreover, the voltage drop in the initial year depends on the target feeder ranging from 1.6 to approximately 12%, which achieves the same level as with LV capacitors. Although the net benefit is 10% less than the case of the LV capacitor, the IE factor is still as high as 19.5, and the total investment cost can be paid back within one year. From those perspectives, the measures combined with the MV capacitor should also be studied.

Table 8.3-1 Loss Reduction by MV and LV Capacitors (Total of eight target feeders)

#	Measures	MV Capacitor	LV Capacitor
1	Construction	28MVA	28MVA
2	Capacitor Price	5JD/kVA	4JD/kVA
3	Initial Investment (JD) (a)	140,000	112,000
4	Loss Reduction (kW)	1,198	1,337
5	Loss Reduction (GWh/10Y)	94.24	105.18
6	Merit of Loss Reduction (b) (JD/10Y)	2,839,260	3,168,690
7	Expense Due to Investment (c) (JD/10Y)	112,000	89,600
8	Net Benefit (d)=(b)-(c) (JD/10Y)	2,727,260	3,079,090
9	I.E. Factor (e)=(d)/(a)	19.5	27.5
10	Voltage Drop in Initial Year (%)	1.6～12.5	1.6～12.2
11	Generated Reactive Power (MVar)	25.12	26.50
12	Loss with Capacitor (kW)	4,269	4,130
13	Loss of Distribution Transformers (kW)	513	447
14	Capacity Ratio: Total Capacity of Capacitor/ Total Capacity of Distribution Transformers (%)	15.5 (28/180MVA)	－

8.3.2 Fundamental Policy of Loss Reduction on MV System

As discussed in the previous section, measures for loss reduction on eight MV target feeders have been studied on power factor correction by LV capacitors and on other measures in combination with the LV capacitor installation as a base case. In addition, MV capacitor and other measures combined with MV capacitor have been examined.

Measures for loss reduction to be examined comprise of re-conductoring of existing feeders, new line installation, and 132/33kV substation installation. The re-conductoring may result in difficulties due to insufficient supply capability of the remaining system during the construction work since the MV feeder covers a wide area and a relatively large load. This makes it necessary to examine the capability of the interconnection to the adjacent system or its source 132/33kV substation, as well as the feasibility of the construction.

The combined criteria of alternative selection were determined as follows;

- The most net-beneficial case among alternatives that can maintain system voltage in initial year within 10% regulated by IEC standard should be selected.

- As measures of MV system require larger investment than that of LV system, if the net benefit of the two alternatives differs by less than several percent, the alternative with larger I.E. factor should be selected taking into account its swift recovery period of investment.

Among those target feeders, two of IDECO's and one of EDCO's target feeders relate to the existing new 132/33kV substation installation plan under bidding procedures. This study has been carried out to take existing plans into account. In addition, on one of IDECO's target feeders, a removal plan of the line from private land to public land is in progress, where the existing line is removed and a new line is installed. This is hereafter referred to as "re-routing" in this study. In accordance with this re-routing plan, installation of a new line with a larger size conductor was also analyzed in this study for loss reduction.

Table 8.3-2 Outline of MV Target Feeders (1999)

Distribution Company	Feeder Name	Area	Load・Power Factor (MW・pf)	Existing Plan
EDCO	Wadi Musa	Ma'an	7.6 pf=0.84	
	Tafila	Tafila	4.3 pf=0.82	
	JV2	North Jordan Valley	8.9 pf=0.80	132/33kVWaqas Substation (2001)
JEPCO	Duleel	Zarqa	7.6 pf=0.80	
	Madaba	Madaba	14.3 pf=0.88	
IDECO	Jerash	Jerash	11.6 pf=0.83	Re-routing
	Emrawa	North West of Irbid	11.7 pf=0.82	132/33kVWaqas Substation (2001)
	Samma	West of Irbid	17.7 pf=0.84	132/33kV Waqas Substation (2001)
				132/33kVShtafina Substation (2001)

8.3.3 Method for Improvement of MV Target Feeders

Optimization software extracted beneficial measures of net benefit such as reinforcement plans combined with capacitors. After initial software analysis of a beneficial improvement plan on the target feeder, a solution was selected in accordance with the criteria of measure selection in paragraph 8.3.2 followed by engineering brush-up.

8.3.4 Results of Study on MV Target Feeders

The summary and the results of the respective study on eight target MV feeders are as follows.

(1) Summary of the Study on MV Target Lines

The summary of the study on MV target lines is tabulated in Table 8.3-3. Total investment in MV system is around 1.13mJD and investment in LV capacitors is 112,000JD(10%). Investment in re-conductoring is 231,481JD(20%). Investment in new lines and re-route is 368,600JD(33%) and 415,400JD(37%), respectively. Measures are as in Table 8.3-3(b).

Table 8.3-3 Summary of the Study on MV Target Feeders

(a) Investment in MV Target Feeders (JD)

Co.	Target Feeder		Capacitors	Reconduc-toring	New Line	Rerouting	Total
EDCO	Wadi Musa		12,000	101,790	-	-	113,790
	Tafila		7,000	-	-	-	7,000
	JV2	A	7,000	63,037	-	-	70,037
		B	7,000	42,369	-	-	49,369
	Sub total		33,000	207,196	-	-	240,196
JEPCO	Duleel		18,000	-	-	-	18,000
	Madaba		18,000	-	368,600	-	386,600
	Sub total		36,000	-	368,600	-	404,600
IDECO	Jerash		20,000	-	-	415,400	435,400
	Emrawa & Samma	A	10,000	24,285	-	-	34,285
		B	10,000	-	-	-	10,000
		C	3,000	-	-	-	3,000
	Sub total		43,000	24,285	-	415,400	482,685
Total			112,000 (10%)	231,481 (20%)	368,600 (33%)	415,400 (37%)	1,127,481 (100%)

(b) Measures of Target MV Feeders

Measures	Target MV Feeder
Capacitor Installation Only	Tafila Line, Duleel Line, Emrawa and Samma –B Line Emrawa and Samma –CLine
Capacitor and Re-conductoring	Wadi Musa Line, JV2-A Line, JV2-B Line, Emrawa and Samma –A Line
Capacitor and Same Voltage Line	Madaba Line
Capacitor and Re-routing	Jerash Line

The amount of loss reduction due to measures on MV target lines is summarized in Table 8.3-4. Loss reduction from eight feeders is about 2,400kW, corresponding to 44% reduction by measures combined with LV capacitor. The average loss rate is reduced from 6.8% to 4.0%.

Table 8.3-4 Summary of Loss Reduction on MV Target Feeders (2001)

Co.	MV Lines		Loss Before			Loss After			Reduced Loss	
			Load a (MW)	Loss b (kW)	Loss Rate c (%)	Load d (MW)	Loss e (kW)	Loss Rate f (%)	Loss b-e (kW)	Loss Rate c-f (%)
EDCO	Wadi Musa		8.66	726	8.4	8.35	419	5.0	307	3.4
	Tafila		4.86	202	4.2	4.82	158	3.3	44	0.9
	JV2	A	4.78	209	4.4	4.70	132	2.8	77	1.6
		B	4.76	230	4.8	4.68	151	3.2	79	1.6
	Sub Total		23.06	1,367	5.9	22.55	860	3.8	507	2.1
JEPCO	Duleel		10.57	343	3.2	10.48	254	2.4	89	0.8
	Madaba		16.31	1,490	9.1	15.52	695	4.5	795	4.7
	Sub Total		26.88	1,833	6.8	26.00	949	3.7	884	3.2
IDECO	Jerash		13.29	1,655	12.5	12.45	811	6.5	844	5.9
	Emrawa	A	6.79	300	4.4	6.70	205	3.1	95	1.4
	&	B	7.69	241	3.1	7.64	190	2.5	51	0.6
	Samma	C	2.18	71	3.3	2.17	60	2.8	11	0.5
	Sub Total		29.95	2,267	7.6	28.95	1,266	4.4	1,001	3.2
TOTAL			79.89	5,467	6.8	77.50	3,075	4.0	2,392	2.9

The economy of measures combined with LV capacitor is summarized in Table 8.3-5. From an initial total investment of about 1.1 million JD, a net benefit of about 4.7 million JD for 10 years is obtained. The I.E. factor becomes 4.2, corresponding to the payback period of 3 years.

Table 8.3-5 Summary of Economy on MV Target Feeders

Company	Target Feeder		Investment a (JD)	Loss Reduction (kW)	Loss Reduction (GWh/10yr)	Net Benefit b (JD/10yr)	I.E. b/a
EDCO	Wadi Musa		113,790	307.4	24.18	637,506	5.6
	Tafila		7,000	44.0	3.46	98,680	14.1
	JV2	A	70,037	76.6	6.03	125,512	1.8
		B	49,369	79.0	6.21	147,735	3.0
	Sub Total		240,196	507.0	39.88	1,009,433	4.2
JEPCO	Duleel		18,000	89.0	7.00	196,530	10.9
	Madaba		386,600	795.2	62.56	1,575,344	4.1
	Sub Total		404,600	884.2	69.56	1,771,874	4.4
IDECO	Jerash		435,400	844.1	66.40	1,652,197	3.8
	Emrawa	A	34,285	95.4	7.50	198,670	5.8
	&	B	10,000	51.0	4.01	112,870	11.3
	Samma	C	3,000	11.0	0.87	23,670	7.9
	Sub Total		482,685	1,001.5	78.78	1,987,407	4.1
	Total		1,127,481	2,392.7	188.22	4,768,714	4.2

(2) Result on Respective MV Target Feeder

(a) Wadi Musa (EDCO)

(a)-1 Outline of Feeder

As shown in Fig.8.3-1, the existing 33kV Wadi Musa Line is the secondary network of 132/33kV Ma'an substation and is 156km in total line length. The load and power factor of this feeder are expected to be 8.7MW and 0.84 at the peak period in 2001, respectively. Losses are also envisaged to be 0.73MW and 8% in the loss rate in 2001. The voltage reduction at the distribution end will be approximately 11%. The interconnected neighboring systems are the 33kV Ras Naqab Line, the secondary system of Ma'an substation, and the 33kV Shoubak Line from the adjacent 132/33kV Rashadya substation. Both the Ras Naqab Line and the Shoubak Line are light load distribution feeders with 2.3MW and 1.8MW, respectively in the peak period in 2001.

(a)-2 Comparison of Measures

[Capacitor]:

Table 8.3-6 outlines the result of the study on alternatives for Wadi Musa Line with an LV capacitor. A capacitor on the LV side of each distribution transformer with a total capacity of 3.0MVA was determined for power factor correction and to prevent voltage rise during the off-peak period due to excessive reactive power compensation. From an economic point of view, the capacitor is inexpensive (4JD/kVA) and is so efficient that the total cost from initial investment can be recovered within one year, as the IE factor is 35.3.

[Capacitor and 132kV Line]:

The right hand side of Table 8.3-6 shows the results of the study on measures of re-conductoring and installation of a new 33kV feeder combined with power factor correction with capacitors. The table also demonstrates the results of the study on higher voltage introduction by optimization software PLOPT. The software revealed the construction of a 132/33kV substation to be unprofitable due to high construction cost.

[Capacitor and Re-conductoring]:

The combination of a capacitor and re-conductoring of existing wire from AAA100 mm^2 to AAA150 mm^2, 20km in line length from Ma'an substation gives a net benefit 1.6 times of installation of only the capacitor. In this case, the voltage drop improves to 6% in the initial year and 12% after 10 years. Re-conductoring work is feasible in the light of capability of supply to the target area, since the neighboring light load feeders can burden the load on target feeder during construction work.

[Capacitor and the Same Voltage Line]:

The combination of installation of capacitor and 33kV MV distribution line gave an appropriate solution to construct a new line of AAA150 mm^2, 20km in length from Ma'an substation. In this case, voltage reduction improves to be 5% in the initial year and 9% after 10 years.

Both of re-conductoring and same voltage line with capacitors satisfies the criteria of voltage drop in initial year. Since the difference of net benefit between re-conductoring and same voltage line with capacitors is only 4%, the former measure with a higher IE factor should be selected;

- Total capacity of capacitors 3MVA
- Re-conductoring of AAA100 mm^2 existing wire of to AAA150 mm^2 by 20km in line length from Ma'an substation

The result of the study on measures with the MV capacitor rated at 3MVA, the same amount as LV capacitor, is shown in Table 8.3-7. One or two capacitors will need to be installed on the MV line at the location near Taibeh Line, about 30km from Ma'an substation, where the reactive load is approximately one-third of that of the sending end. Re-conductoring combined with the MV capacitor was chosen for the same reasons of measures with LV capacitors. Although both net benefit and the IE factor of this measure is smaller than that of the measure with LV capacitors, the IE factor is still as high as 5.4 corresponding to a payback period of total cost of initial investment in 2 years. The voltage drop in the initial year improves to approximately 6%, the same level as that of LV capacitor cases.

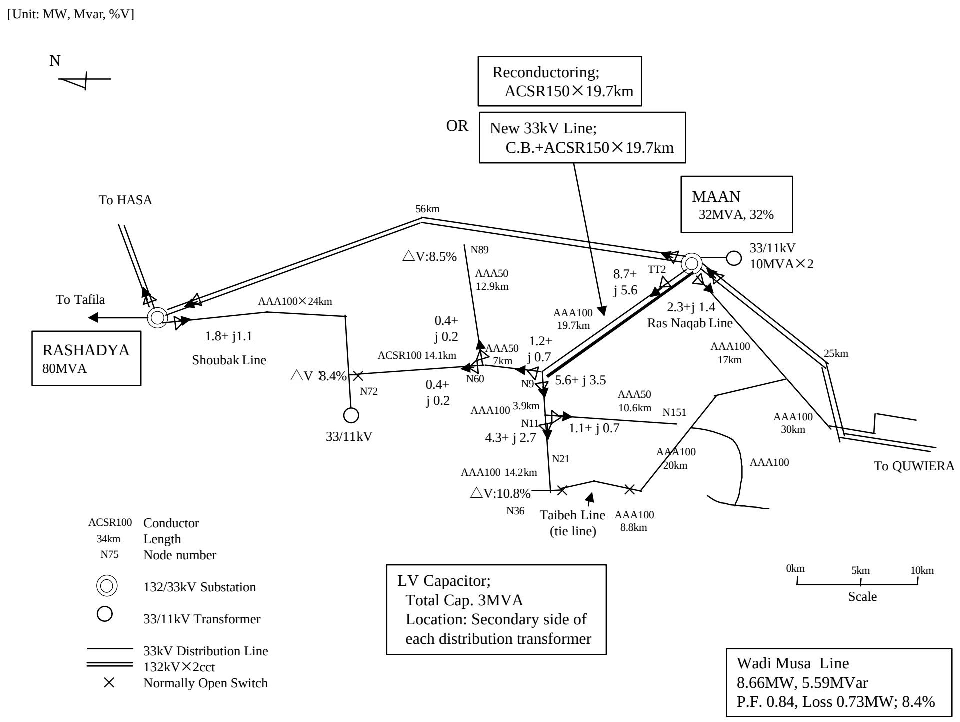

Fig. 8.3-1 Wadi Musa Line

Table 8.3-6 Results of Wadi Musa Line (Base Case: LV Capacitor)

Measures			LV Cap.	Reinforcement Including LV Capacitor		
				Reconduc-toring	Same Voltage Line	132kV Line
Construc-tion	LV Cap.	4JD/kVA	3MVA	3MVA	3MVA	-
	C.B.	40kJD/unit	-	-	1 unit	-
	ACSR150	15.5kJD/km	-	-	19.7km	-
	ACSR150(Recon.)	5167JD/km	-	19.7km	-	-
Initial Investment (JD) (a)			12,000	113,790	357,350	Unprofitable
Loss Reduction (kW)			183.0	307.4	402.2	
Loss Reduction (GWh/10Y)			14.40	24.18	31.64	
Merit of Loss Reduction (b) (JD/10Y)			433,710	728,538	953,214	
Expense Due to Investment (c) (JD/10Y)			9,600	91,032	285,880	
Net Benefit (d)=(b)-(c) (JD/10Y)			424,110	637,506	667,334	
I.E. Factor (e)=(d)/(a)			35.3	5.6	1.9	
Voltage Drop in Initial Year (%)			10.8→8.1	10.8→ 6.3	10.8→ 4.5	-
Voltage Drop after 10 Years (%)			→16.0	→12.5	→ 8.5	

Table 8.3-7 Results of Wadi Musa Line (MV Capacitor)

Measures			MV Cap.	Reinforcement Including MV Capacitor		
				Reconductoring	Same Voltage Line	132kV Line
Construction	MV Cap.	5JD/kVA	3MVA	3MVA	3MVA	-
	C.B.	40kJD/unit	-	-	1 unit	-
	ACSR150	15.5kJD/km	-	-	19.7km	-
	ACSR150(Recon.)	5167JD/km	-	19.7km	-	-
Initial Investment (JD) (a)			15,000	116,790	360,350	Unprofitable
Loss Reduction (kW)			173.0	305.6	406.7	
Loss Reduction (GWh/10Y)			13.61	24.04	31.99	
Merit of Loss Reduction (b) (JD/10Y)			410,010	724,272	963,879	
Expense Due to Investment (c) (JD/10Y)			12,000	93,432	288,280	
Net Benefit (d)=(b)-(c) (JD/10Y)			398,010	630,840	675,599	
I.E. Factor (e)=(d)/(a)			26.5	5.4	1.9	
Voltage Drop in Initial Year (%)			10.8→7.7	10.8→ 5.9	10.8→ 3.8	-
Voltage Drop after 10 Years (%)			→15.6	→ 12.1	→ 7.0	

(b) Tafila Line (EDCO)

(b)-1 Outline of Feeder

The existing 33kV Tafila Line is the secondary system of 132/33kV Rashadya substation and is 28km in total line length, as shown in Fig.8.3-2. The load and the power factor of this feeder are expected to be 4.9MW and 0.82 at peak period in 2001, respectively. Losses are also envisaged to be 0.20MW, 4.2% in 2001. Voltage reduction at the distribution end is 4%. This MV feeder does not have interconnections to adjacent systems. There is no existing plan to reinforce MV feeders and construct a 132/33kV substation in the vicinity of Tafila Line.

(b)-2 Comparison of Measures

[Capacitor]:

Table 8.3-8 outlines the result of the study on Tafila Line with capacitor. The capacitor on the LV side of each distribution transformer with total capacity of 1.75MVA was determined for power factor correction, preventing voltage rise during off-peak period due to excessive reactive power compensation. Although the Tafila Line has a relatively light load of 4.9MW compared with other target feeders, capacitor installation still has a large effect due to its low power factor of 0.82. In the case of capacitor installation, the IE factor becomes approximately 14.1, making it possible to recover the total investment cost within one year. In this plan, voltage drop improves to be 3% in the initial year and 6% after 10 years.

[Capacitor and Re-conductoring]:

The right hand side of Table 8.3-8 shows the results of the study on reinforcement of the system combined with power factor correction with capacitor. Optimization software showed re-conductoring as only one profitable solution among all reinforcement plans since this has the least initial investment. In this case, the IE factor is 4.1 making it possible to recover the total investment cost in three years. In economic terms, the net benefit is 7% larger than the case installing only capacitor. Moreover, the Tafila Line does not have enough interconnection for re-conductoring work.

Both voltage drops of installing capacitor by itself and the re-conductoring with LV capacitor satisfy the criteria for selection. The net benefit of re-conductoring with LV capacitor is 7% higher than the case installing only the LV capacitor. The latter case, however, was selected since Tafila Line does not have sufficient interconnection for re-conductoring work;

- Total capacity of capacitors 1.75MVA.

Installing LV capacitor solely is better choice in the short term the time being and other measures should be reexamined when remarkable net benefit due to demand growth can be obtained in the future.

The result of the study on measures with the MV capacitor rated at 1.75MVA, the same amount as the LV capacitor, is shown in Table 8.3-9. One capacitor rated at 1.75MVA must be installed on the end of the feeder, where the reactive power is approximately one-third of that of the sending end. The case of installing only a MV capacitor was selected by the same reasons with LV capacitors. Although both net benefit and IE factor of this measure are less than that of the measure with LV capacitors, the IE factor is still as high as 10.8 corresponding to one year of the payback period of total investment cost. The voltage drop in initial year improves to be about 3%, the same level as that of LV capacitor cases.

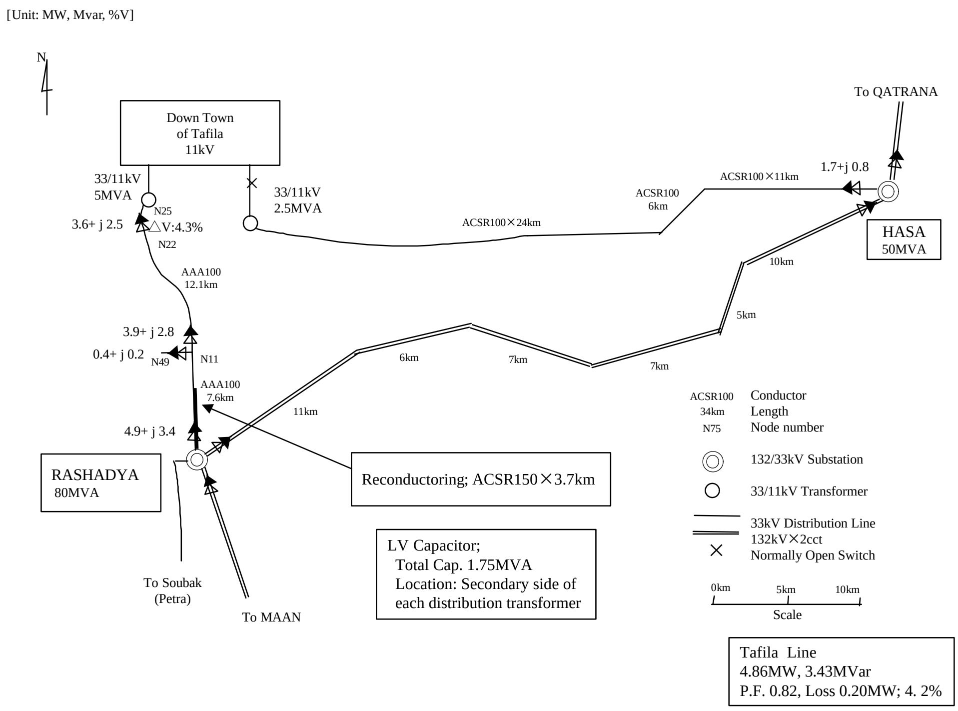

Fig. 8.3-2 Tafila Line

Table 8.3-8 Results of Tafila Line (Base Case: LV Capacitor)

Measures			LV Cap.	Reinforcement Including LV Capacitor		
				Reconductoring	Same Voltage Line	132kV Line
Construction	LV Cap.	4JD/kVA	1.75MVA	1.75MVA	-	-
	ACSR150(Recon.)	5167JD/km	-	3.7km	-	-
Initial Investment (JD) (a)			7,000	26,118		
Loss Reduction (kW)			44.0	53.5		
Loss Reduction (GWh/10Y)			3.46	4.21		
Merit of Loss Reduction (b) (JD/10Y)			104,280	126,795	Unprofitable	Unprofitable
Expense Due to Investment (c) (JD/10Y)			5,600	20,894		
Net Benefit (d)=(b)-(c) (JD/10Y)			98,680	105,901		
I.E. Factor (e)=(d)/(a)			14.1	4.1		
Voltage Drop in Initial Year (%)			4.3→ 3.4	4.3 → 3.2	-	-
Voltage Drop after 10 Years (%)			→ 6.0	→5.6		

Table 8.3-9 Results of Tafila Line (MV Capacitor)

Measures			MV Cap.	Reinforcement Including MV Capacitor		
				Reconduc-toring	Same Voltage Line	132kV Line
Construc-tion	MV Cap.	5JD/kVA	1.75MVA	1.75MVA	-	-
	ACSR150(Recon.)	5167JD/km	-	3.7km	-	-
Initial Investment (JD) (a)			8,750	27,868	Unprofitable	Unprofitable
Loss Reduction (kW)			43.0	52.7		
Loss Reduction (GWh/10Y)			3.38	4.15		
Merit of Loss Reduction (b) (JD/10Y)			101,910	124,899		
Expense Due to Investment (c) (JD/10Y)			7,000	22,294		
Net Benefit (d)=(b)-(c) (JD/10Y)			94,910	102,605		
I.E. Factor (e)=(d)/(a)			10.8	3.7		
Voltage Drop in Initial Year (%)			4.3→ 3.1	4.3 → 2.9	-	-
Voltage Drop after 10 Years (%)			→ 5.6	→ 5.4		

(c) JV2 Line (EDCO)

(a)-1 Outline of Feeder

[Outline]:

The existing 33kV JV2 Line is the secondary system of 132/33kV Subehi substation and has 125km in total line length. Load and power factor of this feeder are expected to be 10.1MW and 0.80 at peak period in 2001, respectively. Losses are also estimated to be 1.0MW (10% loss rate) in 2001. Voltage reduction at distribution end will be approximately 15%. It has interconnection with the 33kV JV1 Line, secondary system of Subehi substation, and with the 33kV Wadi Al-Arab Line from adjacent 132/33kV Irbid substation.

[Existing Plan]:

As shown in Fig.8.3-3, new 33kV feeders from the planed 132/33kV Waqas substation are supposed to supply power to JV2 Line. With installation of new 33kV lines from Waqas substation, the JV2 Line will thus be divided into two portions, one from Subehi substation side and the other from Waqas substation side. It was presumed that these two new lines have the same amount of load of 4.8MW, where the new Line from Subehi substation side and another new Line from Waqas substation side are referred to as JV2-A and JV2-B Line, respectively in this study. Due to changes in system configuration, the total power loss in both new lines is greatly reduced to be 0.44MW. The voltage drop improves to be 4% (JV2-A Line) and 6% (JV2-B Line) respectively in the initial year of the study period. Based on discussion with counterparts, studies on loss reduction were conducted on JV2-A and JV2-B lines since the new substation will be put into operation in the early 2000's.

(a)-2 Comparison of Measures

[Capacitor]:

Table 8.3-10 shows an outline of the results of the study on JV2-A and JV2-B with the LV capacitor. For both lines, capacitors on the LV side of each distribution transformer with total capacity of 1.75MVA was selected for loss power factor correction, preventing voltage rise during off-peak period due to excessive reactive power compensation. The IE factor becomes as high as 14.4 (JV2-A Line) and 18.8 (JV2-B Line) respectively, making it possible to recover the total investment cost within one year. Voltage reduction at distribution end improves to be 3% (JV2-A) and 4% (JV2-B) in the initial year and 5% (JV2-A) and 8% (JV2-B) after 10 years, respectively.

[Capacitor and Re-conductoring]:

The right hand side of Table 8.3-10 gives the results of the study on the measures combined with power factor correction with capacitor. For both lines, optimization software showed re-conductoring combined with capacitor to be the only profitable solution among all the measures. Net benefit increases by 24% (JV2-A) and 14% (JV2-B) compared with the case installing only the capacitor. Their IE factors become 1.8 (JV2-A) and 3.0 (JV2-B), making it possible to recover the total investment cost in five years and three years respectively. Voltage reduction at distribution end improves to be 2% (JV2-A) and 4% (JV2-B) in the initial year and 4% (JV2-A) and 7% (JV2-B) after 10 years, respectively. Capability of supply to the target area during re-conductoring work of JV2-A and JV2-B is expected to be sufficient by exchanging power mutually.

Both for JV2-A and JV2-B, re-conductoring with the LV capacitor was selected since it seems to have the highest net benefit among measures and satisfies the criteria of voltage drops in the initial year in 8.3.2. Supply capability is also expected to be sufficient by supplying power to each other during re-conductoring work of JV2-A and JV2-B;

JV2-A Line

- Total capacity of capacitors 1.75MVA
- Re-conductoring of the existing wire of ACSR100 mm^2 to ACSR150 mm^2 by 12km in line length from Subeihi substation

JV2-B Line

- Total capacity of capacitors 1.75MVA

- Re-conductoring of existing wire from ACSR100 mm^2 to ACSR150 mm^2 , by 8km in line length, 8km to 16km from Waqas substation

The result of the study on measures with the MV capacitor rated at 1.75MVA, the same amount as LV capacitor, is shown in Table 8.3-11 for both JV2-A and JV2-B. One capacitor rated 1.75MVA needs to be installed on the MV line at a location approximately 13km from Subeihi substation on JV2-A and approximately 25km from Waqas substation on JV2-B, where the reactive power is around one-third of the sending end, respectively. On both lines, re-conductoring combined with MV capacitor is selected by the same reasons with LV capacitors. Although both net benefit and IE factor of this measure are smaller than that of measure with LV capacitors, the IE factor is still as high as 1.5 and 2.3 corresponding to five years and three years respectively of the payback period of total investment cost. Improvement in voltage drops is the same level as that of LV capacitor cases.

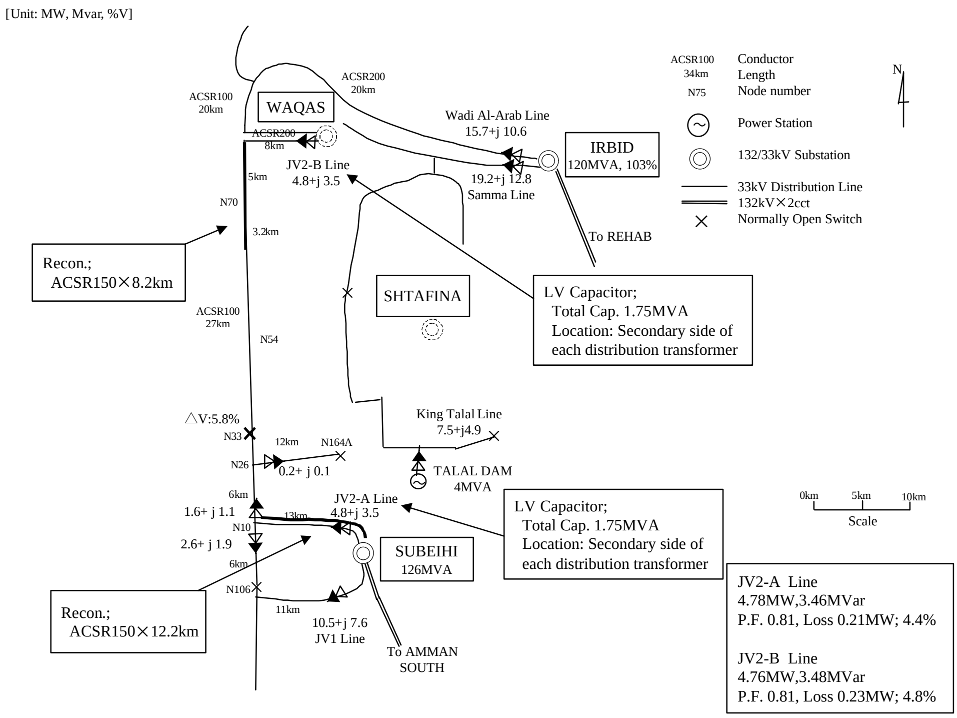

Fig. 8.3-3 JV2 Line

Table 8.3-10 Results of JV2 Line (Base Case: LV Capacitor)

(a) JV2-A Line

Measures			LV Cap.	Reinforcement Including LV Capacitor		
				Reconduc-toring	Same Voltage Line	132kV Line
Construc-tion	LV Cap.	4JD/kVA	1.75MVA	1.75MVA	-	-
	ACSR150(Recon.)	5167JD/km	-	12.2km	-	-
Initial Investment (JD) (a)			7,000	70,037	Unprofitable	Unprofitable
Loss Reduction (kW)			45.0	76.6		
Loss Reduction (GWh/10Y)			3.54	6.03		
Merit of Loss Reduction (b) (JD/10Y)			106,650	181,542		
Expense Due to Investment (c) (JD/10Y)			5,600	56,030		
Net Benefit (d)=(b)-(c) (JD/10Y)			101,050	125,512		
I.E. Factor (e)=(d)/(a)			14.4	1.8		
Voltage Drop in Initial Year (%)			3.9→3.0	3.9→ 2.3	-	-
Voltage Drop after 10 Years (%)			→5.3	→4.3		

(b) JV2-B Line

Measures			LV Cap.	Reinforcement Including LV Capacitor		
				Reconduc-toring	Same Voltage Line	132kV Line
Construc-tion	LV Cap.	4JD/kVA	1.75MVA	1.75MVA	-	-
	ACSR150(Recon.)	5167JD/km	-	8.2km	-	-
Initial Investment (JD) (a)			7,000	49,369	Unprofitable	Unprofitable
Loss Reduction (kW)			58.0	79.0		
Loss Reduction (GWh/10Y)			4.56	6.21		
Merit of Loss Reduction (b) (JD/10Y)			137,460	187,230		
Expense Due to Investment (c) (JD/10Y)			5,600	39,495		
Net Benefit (d)=(b)-(c) (JD/10Y)			131,860	147,735		
I.E. Factor (e)=(d)/(a)			18.8	3.0		
Voltage Drop in Initial Year (%)			5.8→4.0	5.8→ 3.5	-	-
Voltage Drop after 10 Years (%)			→7.6	→6.8		

Table 8.3-11 Results of JV2 Line (MV Capacitor)

(a) JV2-A Line

Measures			MV Cap.	Reinforcement Including MV Capacitor		
				Reconduc-toring	Same Voltage Line	132kV Line
Construc-tion	LV Cap.	5JD/kVA	1.75MVA	1.75MVA	-	-
	ACSR150(Recon.)	5167JD/km	-	12.2km	-	-
Initial Investment (JD) (a)			8,750	71,787	Unprofitable	Unprofitable
Loss Reduction (kW)			37.0	69.3		
Loss Reduction (GWh/10Y)			2.91	5.45		
Merit of Loss Reduction (b) (JD/10Y)			87,690	164,241		
Expense Due to Investment (c) (JD/10Y)			7,000	57,430		
Net Benefit (d)=(b)-(c) (JD/10Y)			80,690	106,811		
I.E. Factor (e)=(d)/(a)			9.2	1.5		
Voltage Drop in Initial Year (%)			3.9→3.2	3.9→2.5	-	-
Voltage Drop after 10 Years (%)			→5.4	→4.4		

(b) JV2-B Line

Measures			MV Cap.	Reinforcement Including MV Capacitor		
				Reconduc-toring	Same Voltage Line	132kV Line
Construc-tion	LV Cap.	5JD/kVA	1.75MVA	1.75MVA	-	-
	ACSR150(Recon.)	5167JD/km	-	8.2km	-	-
Initial Investment (JD) (a)			8,750	51,119	Unprofitable	Unprofitable
Loss Reduction (kW)			46.0	67.7		
Loss Reduction (GWh/10Y)			3.62	5.33		
Merit of Loss Reduction (b) (JD/10Y)			109,020	160,449		
Expense Due to Investment (c) (JD/10Y)			7,000	40,895		
Net Benefit (d)=(b)-(c) (JD/10Y)			102,020	119,554		
I.E. Factor (e)=(d)/(a)			11.7	2.3		
Voltage Drop in Initial Year (%)			5.8→4.3	5.8→3.8	-	-
Voltage Drop after 10 Years (%)			→7.8	→7.1		

(d) Duleel Line (JEPCO)

(d)-1 Outline of Feeder

As shown in Fig.8.3-4, the existing 33kV Duleel Line is the secondary system of 132/33kV Husseinmain substation and is 48km in total line length. Load and power factor of this feeder are expected to be 10.6MW and 0.79 at the peak period in 2001. Losses are also expected to be 0.34MW(3.2% loss rate) in 2001. Voltage reduction at the distribution end will be 4.5%. It has an adjacent feeder of 33kV Hashmia University Line (5.2MW) from 132/33kV Abdali substation. Construction work finished in 1999 has switched the load around the end of Duleel Line to Hashmia University Line.

(d)-2 Comparison of Measures

[Capacitor]:

Table 8.3-12 gives an outline of the results of the study on Duleel Line with an LV capacitor. A capacitor on the LV side of each distribution transformer with a total capacity of 4.5MVA was selected for power factor correction and to prevent voltage rise during off-peak period due to excessive reactive power compensation. By only installing a capacitor, the IE factor becomes 10.9 making it possible to recover the total investment cost within one year. The voltage drop in the initial year improves to be 3%.

[Capacitor and Re-conductoring]:

The right hand side of Table 8.3-12 shows the results of the study on measures combined with power factor correction with the LV capacitor. Using optimization software it was found that re-conductoring would be unprofitable since Duleel Line already is wired with the largest size wire of ACSR150 on its existing trunk portion. Further re-conductoring with larger conductors seems difficult/impossible due to strength of poles and structures.

[Capacitor and Same Voltage New Line]:

Combined with the capacitor, constructing the new 33kV line with UGC300 and ACSR150 by 5.5km from Husseinmain substation is the only profitable solution among all reinforcement measures in terms of economy of loss reduction. Combined with same voltage line construction, the net benefit increases slightly by 4% compared with only installing a capacitor. As to the investment efficiency, the IE factor becomes 1.1 corresponding to the 6 year payback period of total investment cost. Voltage reduction improves to 2.4% in the initial year and 4.5% after 10 years. Since there is a large pump load of approximately 3.4MW around 5.5km from Husseinmain substation, the new 33kV line can be used for supply to this load. This system configuration can improve the power supply quality by reducing voltage fluctuation due to pump load.

Both measure of sole capacitor installation and same voltage line construction combined with capacitor satisfies the criteria of voltage drop. The difference of net benefit between those two measures is only 4%, and the former measure with a higher IE factor of 10.9 was selected.

- Total capacity of capacitors 4.5MVA

The result of the study on measures with the MV capacitor rated at 4.5MVA, the same amount as the LV capacitor, is shown in Table 8.3-13. One or two capacitors need to be installed on the MV line at a location approximately 9.5km from Husseinmain substation, where the reactive power is approximately one-third of the sending end. The case for installing the MV capacitor is only selected in accordance with criteria of measure selection. Although both net benefit and IE factor of this measure are smaller than that of measure with LV capacitors, the IE factor is still as high as 6.9 corresponding to the two years of payback period of total investment cost. The voltage drop in the initial year improves to be approximately 3.2%, the same level as those of LV capacitor cases.

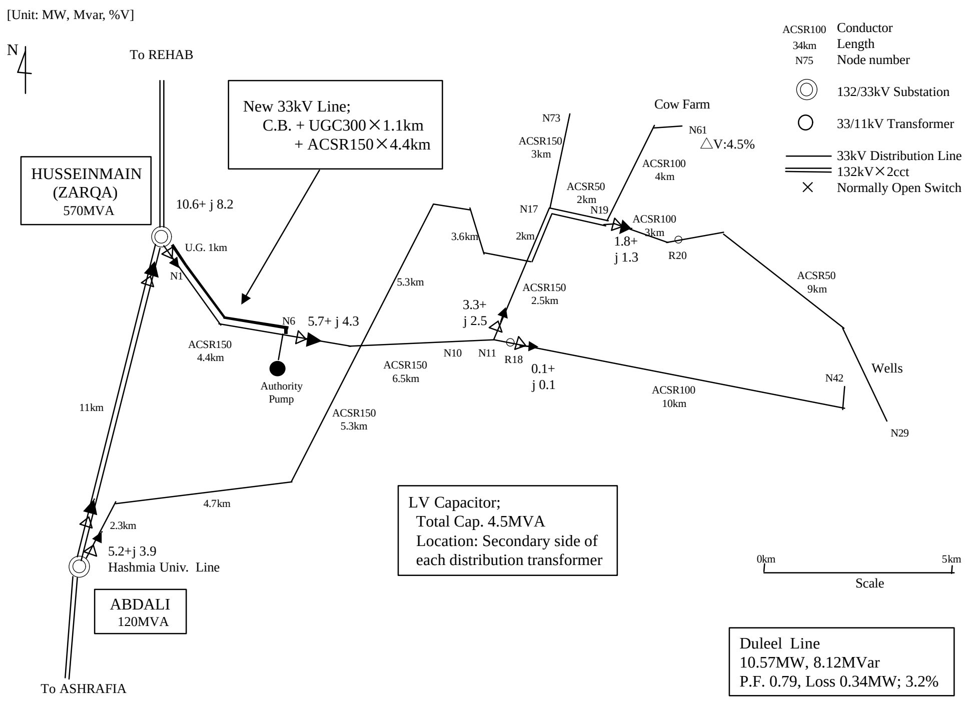

Fig. 8.3-4 Duleel Line

Table 8.3-12 Results of Duleel Line (Base Case: LV Capacitor)

Measures			LV Cap.	Reinforcement Including LV Capacitor		
				Reconduc-toring	Same Voltage Line	132kV Line
Construc-tion	LV Cap.	4JD/kVA	4.5MVA	-	4.5MVA	-
	C.B.	40kJD/unit	-	-	1 unit	-
	UGC300	50,000/km	-	-	1.1km	-
	ACSR150	15.5kJD/km	-	-	4.4km	-
Initial Investment (JD) (a)			18,000	Existent conductor size ACSR150 does not make sense of re-conductoring	181,200	Unprofitable
Loss Reduction (kW)			89.0		148.0	
Loss Reduction (GWh/10Y)			7.00		11.64	
Merit of Loss Reduction (b) (JD/10Y)			210,930		350,760	
Expense Due to Investment (c) (JD/10Y)			14,400		144,960	
Net Benefit (d)=(b)-(c) (JD/10Y)			196,530		205,800	
I.E. Factor (e)=(d)/(a)			10.9		1.1	
Voltage Drop in Initial Year (%)			4.5→ 3.0	-	4.5 → 2.4	-
Voltage Drop after 10 Years (%)			→ 5.8		→ 4.4	

Table 8.3-13 Results of Duleel Line (MV Capacitor)

Measures			MV Cap.	Reinforcement Including MV Capacitor		
				Reconduc-toring	Same Voltage Line	132kV Line
Construc-tion	MV Cap.	5JD/kVA	4.5MVA	-	4.5MVA	-
	C.B.	40kJD/unit	-	-	1 unit	-
	UGC300	50,000/km	-	-	1.1km	-
	ACSR150	15.5kJD/km	-	-	4.4km	-
Initial Investment (JD) (a)			22,500	Existent conductor size ACSR150 does not make sense of re-conductoring	185,700	Unprofitable
Loss Reduction (kW)			73.0		128.0	
Loss Reduction (GWh/10Y)			5.74		10.07	
Merit of Loss Reduction (b) (JD/10Y)			173,010		303,360	
Expense Due to Investment (c) (JD/10Y)			18,000		148,560	
Net Benefit (d)=(b)-(c) (JD/10Y)			155,010		154,800	
I.E. Factor (e)=(d)/(a)			6.9		0.8	
Voltage Drop in Initial Year (%)			4.5→ 3.2	-	4.5 → 2.2	-
Voltage Drop after 10 Years (%)			→5.9		→4.3	

(e) Madaba Line (JEPCO)

(e)-1 Outline of Feeder

As shown in Fig.8.3-5, the existing 33kV Madaba Line is the secondary system of 132/33kV QAIA substation and is 156km in total line length. Load and power factor of this feeder are expected to be 16.3MW and 0.88 at peak period in 2001, respectively. Losses are envisaged to be 1.49MW and 9.1% in loss rate in 2001. Voltage reduction at the receiving end is estimated to be 14%. It connects the 33kV Village Line (4.2MW) and the secondary system of Madaba substation.

(e)-2 Comparison of Measures

[Capacitor]:

Table 8.3-14 gives an outline of the results of the study on Madaba Line with the capacitor. The capacitor on the LV side of each distribution transformer with a total capacity of 4.5MVA was determined for power factor correction, preventing voltage rise during off-peak periods due to excessive reactive power compensation. By only installing the capacitor solely, the IE factor becomes as large as 37.4 making it possible to recover the total initial investment within one year. But the voltage drop of 10% in the initial year is on limitation of criteria of measure selection in 8.3.2 because of heavy load and long line length.

[Capacitor and Reinforcement measures]:

Optimization software showed both re-conductoring and same voltage line measures combined with capacitor to be profitable. Among them, same voltage line combined with capacitor produces the highest net benefit, 2.3 times of the case installing only the capacitor. The IE factor is 4.1, making it possible to recover the total initial investment in three years. Voltage drop improves to be 5.9% in the initial year and 11.8% after ten years.

New line installation combined with capacitor was selected since it seems to have the highest net benefit among measures satisfying the voltage drop criteria;

- Total capacity of capacitors 4.5MVA
- Installing a new line with ACSR150 along the existing line by 21km in line length from QAIA substation

The results of the study on measures with the MV capacitor rated as 4.5MVA, the same amount as the LV capacitor, are shown in Table 8.3-15. Only one capacitor needs to be installed on the MV line at a location approximately 21km from the QAIA substation, where the reactive power is approximately one-third that of the sending end. The same voltage line with MV capacitor was selected for the same reasons as the LV capacitor. Although both net benefit and IE factor of this measure are smaller than that of measure with LV capacitors, the IE factor is still as high as 3.9. The voltage drop in the initial year improves to approximately 6.5%, almost the same level as those of LV capacitor cases.

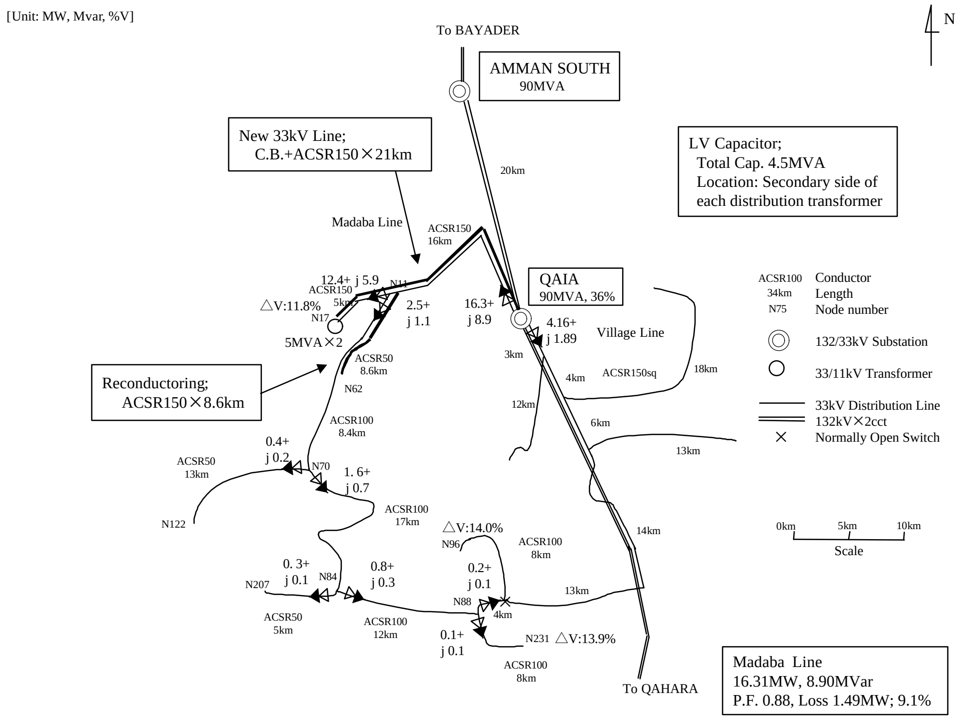

Fig. 8.3-5 Madaba Line

Table 8.3-14 Results of Madaba Line (Base Case: LV Capacitor)

Measures			LV Cap.	Reinforcement Including LV Capacitor		
				Reconduc-toring	Same Voltage Line	132kV Line
Construc-tion	LV Cap.	4JD/kVA	4.5MVA	4.5MVA	4.5MVA	-
	C.B.	40kJD/unit	-	-	1 unit	-
	ACSR150	15.5kJD/km	-	-	21.2km	-
	ACSR150(Recon.)	5167JD/km	-	8.6km	-	-
Initial Investment (JD) (a)			18,000	62,436	386,600	
Loss Reduction (kW)			290.0	313.6	795.2	
Loss Reduction (GWh/10Y)			22.81	24.67	62.56	
Merit of Loss Reduction (b) (JD/10Y)			687,300	743,232	1,884,624	Unprofitable
Expense Due to Investment (c) (JD/10Y)			14,400	49,949	309,280	
Net Benefit (d)=(b)-(c) (JD/10Y)			672,900	693,283	1,575,344	
I.E. Factor (e)=(d)/(a)			37.4	11.1	4.1	
Voltage Drop in Initial Year (%) Voltage Drop after 10 Years (%)			14.0→10.0 →21.8	14.0→9.0 →20.0	14.0→ 6.0 →11.8	

Table 8.3-15 Results of Madaba Line (MV Capacitor)

Measures			MV Cap.	Reinforcement Including MV Capacitor		
				Reconduc-toring	Same Voltage Line	132kV Line
Construc-tion	MV Cap.	5JD/kVA	4.5MVA	4.5MVA	4.5MVA	-
	C.B.	40kJD/unit	-	-	1 unit	-
	ACSR150	15.5kJD/km	-	-	21.2km	-
	ACSR150(Recon.)	5167JD/km	-	8.6km	-	-
Initial Investment (JD) (a)			22,500	66,936	391,100	
Loss Reduction (kW)			264.0	292.3	772.1	
Loss Reduction (GWh/10Y)			20.77	22.99	60.74	
Merit of Loss Reduction (b) (JD/10Y)			625,680	692,751	1,829,877	Unprofitable
Expense Due to Investment (c) (JD/10Y)			18,000	53,549	312,880	
Net Benefit (d)=(b)-(c) (JD/10Y)			607,680	639,202	1,516,997	
I.E. Factor (e)=(d)/(a)			27.0	9.5	3.9	
Voltage Drop in Initial Year (%) Voltage Drop after 10 Years (%)			14.0→11.4 →23.2	14.0→10.4 →21.3	14.0 → 7.4 → 13.3	

(f) Jerash Line (IDECO)

(f)-1 Outline of Feeder

As shown in Fig.8.3-6, the existing 33kV Jerash Line is the secondary system of 132/33kV Rehab substation and is 155km in total line length. Load and power factor of this feeder are expected to be 13.3MW and 0.82 at the peak period in 2001, respectively. Losses are also expected to be 1.66MW (12.5% loss rate) in 2001. Voltage reduction at the receiving end is estimated to be 17%. It has interconnection with the 33kV King Talal Line (8.5MW) from King Talal Dam and the Kufranja Line from the adjacent Irbid substation. It is planed that Shtafina substation will be constructed near the distribution end of the Kufranja Line.

(f)-2 Comparison of Measures

[Capacitor only]:

Table 8.3-16 details the results of the study on Jerash Line with the capacitor. The total capacity of capacitor on the LV side of each distribution transformer was determined to be 5.0MVA for power factor correction, preventing voltage rise during off-peak periods due to excessive reactive power compensation. By installing the capacitor solely, the IE factor becomes 57.4, making the total initial investment recovered within one year. The voltage reduction of 12.2% at the distribution end exceeds the measure selection criteria in 8.3.2.

[Re-conductoring combined with Capacitor and Same Voltage Line combined with Capacitor]:

Optimization software showed it unprofitable to construct a 132/33kV substation due to high initial investment. On the other hand, the study results show that re-conductoring and new line construction combined with the capacitor results in beneficial measures. A new 33kV line construction in combination with a capacitor has the highest net benefit and the IE factor becomes 4.8 making it possible to recover the total initial investment within two years. The voltage drop improves to 7.3% in the initial year and 14.8% after ten years.

[Capacitor and Re-routing]:

As discussed in 8.3.2, the Jerash Line has a re-routing plan where the existing line is removed and a new line installed. In accordance with this plan, installation of a new line with a larger size conductor combined with capacitor was studied. Loss reduction is almost the same level as the case of re-conductoring combined with capacitor. The initial investment becomes the same as in that of the new 33kV line in combination with a capacitor. As a result, the IE factor becomes 3.8, the smallest among those measures. It is, however, still possible to recover investment within three years. Voltage drop improves to 8.8% in the initial year and 18.9% after ten years.

The re-routing by larger size conductor with capacitor was selected since it satisfies the measure selection criteria on voltage drops in initial year, produces a net benefit of about 1.65 milion JD and the re-routing work is under progress.

- Total capacity of capacitors 5MVA

- Removing the existing line with AAA100 mm^2 and installing new line will with AAA150 mm^2 by 26.8km in line length from Rehab substation

The results of the study on measures with a MV capacitor rated as 5MVA, the same amount as LV capacitor, is shown in Table 8.3-17. Only one capacitor needs to be installed on the MV line at a location approximately 24km from Rehab substation, where the reactive power is about one-third that of the sending end. Rerouting combined with the MV capacitor is selected for the same reasons of measures with LV capacitors. Although both net benefits and IE factors of this measure are smaller than that of the measure with LV capacitors, it is still as high as 3.6. The voltage drop in initial year improves to approximately 9.5%.

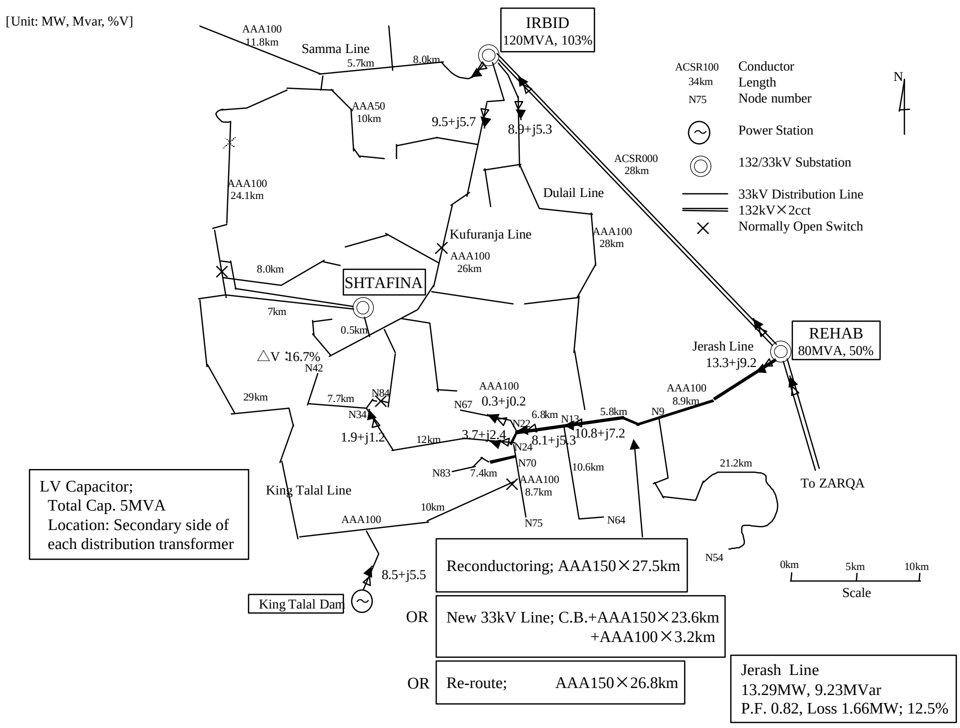

Fig. 8.3-6 Jerash Line

Table 8.3-16 Results of Jerash Line (Base Case: LV Capacitor)

Measures			LV Cap.	Reinforcement Including LV Capacitor		
				Reconduc-toring	Same Voltage Line	Rerouting *
Construc-tion	LV Cap.	4JD/kVA	5MVA	5MVA	5MVA	5MVA
	C.B.	40kJD/unit	-	-	1 unit	-
	AAA150	15.5kJD/km	-	-	23.6km	26.8km
	AAA150(Recon.)	5167JD/km	-	27.5km	-	-
	AAA100	13.285kJD/km	-	-	3.2km	-
Initial Investment (JD) (a)			20,000	162,093	468,312	435,400
Loss Reduction (kW)			491.0	846.1	1101.1	844.1
Loss Reduction (GWh/10Y)			38.63	66.56	86.62	66.40
Merit of Loss Reduction (b) (JD/10Y)			1,163,670	2,005,257	2,609,607	2,000,517
Expense Due to Investment (c) (JD/10Y)			16,000	129,674	374,650	348,320
Net Benefit (d)=(b)-(c) (JD/10Y)			1,147,670	1,875,583	2,234,957	1,652,197
I.E. Factor (e)=(d)/(a)			57.4	11.6	4.8	3.8
Voltage Drop in Initial Year (%)			16.7→12.2	16.7→8.8	16.7→7.3	16.7→ 8.8
Voltage Drop after 10 Years (%)			→27.0	→18.8	→14.8	→18.9

** Rerouting: Removing existing line and installing new line with larger size conductor.*

132kV Line：Unprofitable in light of loss reduction

Table 8.3-17 Results of Jerash Line (MV Capacitor)

Measures			MV Cap.	Reinforcement Including MV Capacitor		
				Reconduc - toring	Same Voltage Line	Rerouting *
Construc-tion	MV Cap.	5JD/kVA	5MVA	5MVA	5MVA	5MVA
	C.B.	40kJD/unit	-	-	1 unit	-
	AAA150	15.5kJD/km	-	-	26.8km	26.8km
	AAA150(Recon.)	5167JD/km	-	30.2km	-	-
Initial Investment (JD) (a)			25,000	181,043	480,400	440,400
Loss Reduction (kW)			461.0	827.6	1078.4	819.1
Loss Reduction (GWh/10Y)			36.27	65.10	84.83	64.44
Merit of Loss Reduction (b) (JD/10Y)			1,092,570	1,961,412	2,555,808	1,941,267
Expense Due to Investment (c) (JD/10Y)			20,000	144,834	384,320	352,320
Net Benefit (d)=(b)-(c) (JD/10Y)			1,072,570	1,816,578	2,171,488	1,588,947
I.E. Factor (e)=(d)/(a)			42.9	10.0	4.5	3.6
Voltage Drop in Initial Year (%)			16.7→12.5	16.7→9.1	16.7→6.5	16.7→9.1
Voltage Drop after 10 Years (%)			→27.1	→19.1	→13.8	→19.1

** Rerouting: removing existing line and installing new line with larger size conductor.*

132kV Line： Unprofitable in light of loss reduction

(g) Emrawa and Samma Lines (IDECO)

(g)-1 Outline of Feeder

[Present Feeder]:

As shown in Fig.8.3-7, the existing 33kV Emrawa Line is the secondary system of its source 132/33kV Irbid substation and is 163km in total line length. Load and power factor of this feeder are expected to be 13.3MW and 0.81 at the peak period in 2001, respectively. Losses are also expected to be 1.24MW (9% loss rate) in 2001. Voltage reduction at the receiving end is 15%. The existing 33kV Samma Line is also the secondary system of 132/33kV Irbid substation and is 182km in total line length. Load and power factor of this feeder are expected to be 20.1MW and 0.84 at the peak period in 2001. Losses are also envisaged to be 1.32MW (7%) in 2001. Voltage reduction at the feeder end is 13%. These Emrawa and Samma lines are interconnected and the Emrawa line also has interconnection with the 33kV Hausha Line (8MW), secondary system of Irbid substation.

[Present Plan]:

The Irbid area has plans to construct 132/33kV Waqas and Shtafina substations, which are related to the target Emrawa and Samma Lines. At Waqas substation, it is proposed to install one and two new feeders to supply power for Emrawa and Samma Line respectively. One new feeder for the Samma Line should be also installed at Shtafina substation. Additionally, the present Irbid substation has one new underground feeder for the Samma Line, which will be put into operation in the near future. Due to these plans, the existing two lines, Emrawa and Samma Lines, will be divided into seven systems in total from three substations, Irbid, Waqas and Shtafina. Based on an agreement with counterparts, studies on loss reduction were conducted on the upgraded networks since the two new substations would be put into operation early in the first decade of 2000's.

The seven lines in the changed system configuration were named A, B, C, D, E, F and G Lines in this study. Table 8.3-18 displays their profile. Every line of A to G are relatively light load distribution lines and voltage drops improve to less than 6% as shown in the table. Every measure for loss reduction was solely examined on seven feeders. Among those lines, optimization software showed A and B to be profitable measures since they have a relatively heavy load compared with others. C was also found as a profitable measure since this has small size conductor of AAA50 on its trunk portion.

(g)-2 Comparison of Measures

[Capacitor]:

Table 8.3-19 outlines the results of the study on Lines A, B and C with the capacitor. The capacitor on the LV side of each distribution transformer with a total capacity of 2.5MVA (Line A), 2.5MVA (Line B) and 0.75MVA (Line C) was selected for power factor correction, preventing voltage rises during off-peak periods due to excessive reactive power compensation. By only installing inexpensive capacitors, the IE factor becomes as high as 17.0 (A Line), 11.3 (B Line), and 7.9 (C Line), respectively.

[Measures with Combined with Capacitor]:

Combined with the capacitor, reinforcement measures only on Line A turned out to be profitable due to the largest loss rate in studied feeders. In this case, both re-conductoring and a new 33kV line are beneficial. Re-conductoring combined with capacitor requires less investment and obtains almost same amount of net benefit as the case of the same voltage line. In consequence, re-conductoring is superior in economic terms and recovery of initial investment. The IE factor is 5.8, making it possible to recover the total initial investment within two years. Capability of supply to the target area during re-conductoring work is expected to be sufficient.

On Line A, voltage drop of both re-conductoring and same voltage line with capacitor satisfies the criteria of measure selection. Since the difference of net benefit between these measures is less than 1%, the former measure with higher IE factor of 5.8 was selected. On Lines B and C, the measure of installing LV capacitor by itself was selected since this is the only profitable measure satisfying the voltage criteria;

Line A

- Total capacity of capacitors 2.5MVA
- Re-conductoring of the existing wire of AAA100 mm^2 to AAA150 mm^2 by 4.7km in line length from the place of 6.8km to 11.5km off Irbid substation

Line B

- Total capacity of capacitors 2.5MVA

Line C

- Total capacity of capacitors 0.75MVA

The result of the study on measures with the MV capacitor rated at 2.5MVA (Line A), 2.5MVA (Line B) and 0.75MVA (Line C) is shown in Table 8.3-20. One or two capacitors need to be installed respectively on the present Emrawa Line at a location of about 16km (Line A), 25km (Line B) and 30km (Line C) from Irbid substation, where the reactive power is about one-third the one at the sending end.

Re-conductoring combined with MV capacitor was selected on Line A and the case installing MV capacitor by itself was selected on Line B and C from the same reasons of measures with LV capacitors. Although both net benefit and IE factors of these measures are smaller than that of measures with LV capacitors, the IE factor is still as high as 4.3 (Line A), 5.8 (Line B) and 4.3 (Line C). These factors correspond to two or three years of payback period of total investment cost. The voltage drop in initial year improves to be approximately 2～4%, the same level as in the measures with LV capacitors.

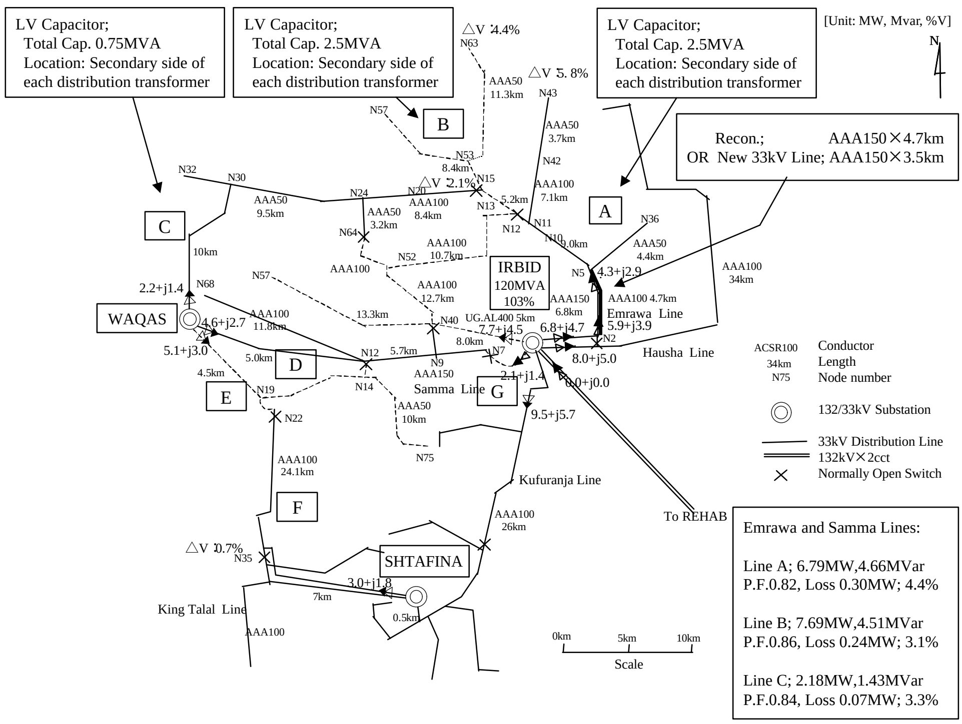

Fig. 8.3-7 Emrawa and Samma Lines

Table 8.3-18 Emrawa and Samma Lines under New Network (2001)

Feeder	Capacity (MVA)	Load (MW)	Loss (kW)	Loss (%)	Voltage Drop (%)
A	15.5	6.8	300	4.4	5.4
B	15.5	7.7	241	3.1	4.3
C	10.5	2.2	71	3.3	2.0
D	20.0	4.6	67	1.5	1.4
E	15.5	5.1	71	1.4	2.0
F	15.5	3.0	51	1.7	1.4
G	20.0	2.1	27	1.3	0.3

Table 8.3-19 Results of Emrawa and Samma Lines (Base Case: LV Capacitor)

(a) Emrawa and Samma Lines - A Line

Measures			LV Cap.	Reinforcement Including LV Capacitor		
				Recon.	Same Voltage	132kV Line
Construc-tion	LV Cap.	4JD/kVA	2.5MVA	2.5MVA	2.5MVA	-
	ACSR150	15.5kJD/km	-	-	3.5	-
	ACSR150(Recon.)	5167JD/km	-	4.7km	-	-
Initial Investment (JD) (a)			10,000	34,285	64,250	Unprofitable
Loss Reduction (kW)			75.0	95.4	105.9	
Loss Reduction (GWh/10Y)			5.90	7.50	8.33	
Merit of Loss Reduction (b) (JD/10Y)			177,750	226,098	250,983	
Expense Due to Investment (c) (JD/10Y)			8,000	27,428	51,400	
Net Benefit (d)=(b)-(c) (JD/10Y)			169,750	198,670	199,583	
I.E. Factor (e)=(d)/(a)			17.0	5.8	3.1	
Voltage Drop in Initial Year (%)			5.8→4.1	5.8→ 3.8	5.8→3.5	-
Voltage Drop after 10 Years (%)			→7.7	→7.1	→6.6	

(b) Emrawa and Samma Lines - B Line

Measures			LV Cap.	Reinforcement Including LV Capacitor		
				Recon.	Same Voltage	132kV Line
Construction	LV Cap.	4JD/kVA	2.5MVA	-	-	-
Initial Investment (JD) (a)			10,000	Unprofitable	Unprofitable	Unprofitable
Loss Reduction (kW)			51.0			
Loss Reduction (GWh/10Y)			4.01			
Merit of Loss Reduction (b) (JD/10Y)			120,870			
Expense Due to Investment (c) (JD/10Y)			8,000			
Net Benefit (d)=(b)-(c) (JD/10Y)			112,870			
I.E. Factor (e)=(d)/(a)			11.3			
Voltage Drop in Initial Year (%)			4.5→3.1	-	-	-
Voltage Drop after 10 Years (%)			→5.8			

(c) Emrawa and Samma Lines - C Line

Measures			LV Cap.	Reinforcement Including LV Capacitor		
				Recon.	Same Voltage	132kV Line
Construction	LV Cap.	4JD/kVA	0.75MVA	-	-	-
Initial Investment (JD) (a)			3,000	Unprofitable	Unprofitable	Unprofitable
Loss Reduction (kW)			11.0			
Loss Reduction (GWh/10Y)			0.87			
Merit of Loss Reduction (b) (JD/10Y)			26,070			
Expense Due to Investment (c) (JD/10Y)			2,400			
Net Benefit (d)=(b)-(c) (JD/10Y)			23,670			
I.E. Factor (e)=(d)/(a)			7.9			
Voltage Drop in Initial Year (%)			2.1→1.6	-	-	-
Voltage Drop after 10 Years (%)			→2.8			

Table 8.3-20 Results of Emrawa and Samma Lines (MV Capacitor)

(a) Emrawa and Samma Lines - A Line

Measures			MV Cap.	Reinforcement Including MV Capacitor		
				Recon.	Same Voltage	132kV Line
Construc-tion	MV Cap.	5JD/kVA	2.5MVA	2.5MVA	2.5MVA	-
	ACSR150	15.5kJD/km	-	-	3.5	-
	ACSR150(Recon.)	5167JD/km	-	4.7km	-	-
Initial Investment (JD) (a)			12,500	36,785	66,750	Unprofitable
Loss Reduction (kW)			58.0	78.8	89.8	
Loss Reduction (GWh/10Y)			4.56	6.20	7.06	
Merit of Loss Reduction (b) (JD/10Y)			137,460	186,756	212,826	
Expense Due to Investment (c) (JD/10Y)			10,000	29,428	53,400	
Net Benefit (d)=(b)-(c) (JD/10Y)			127,460	157,328	159,426	
I.E. Factor (e)=(d)/(a)			10.2	4.3	2.4	
Voltage Drop in Initial Year (%)			5.8→4.2	5.8→3.9	5.8→3.6	-
Voltage Drop after 10 Years (%)			→7.8	→7.2	→6.6	

(b) Emrawa and Samma Lines - B Line

Measures			MV Cap.	Reinforcement Including MV Capacitor		
				Recon.	Same Voltage	132kV Line
Construction	MV Cap.	5JD/kVA	2.5MVA	-	-	-
Initial Investment (JD) (a)			12,500	Unprofitable	Unprofitable	Unprofitable
Loss Reduction (kW)			35.0			
Loss Reduction (GWh/10Y)			2.75			
Merit of Loss Reduction (b) (JD/10Y)			82,950			
Expense Due to Investment (c) (JD/10Y)			10,000			
Net Benefit (d)=(b)-(c) (JD/10Y)			72,950			
I.E. Factor (e)=(d)/(a)			5.8			
Voltage Drop in Initial Year (%)			4.5→2.6	-	-	-
Voltage Drop after 10 Years (%)			→5.3			

(c) Emrawa and Samma Lines - C Line

Measures			MV Cap.	Reinforcement Including MV Capacitor		
				Recontoring	Same Voltage	132kV Line
Construction	MV Cap.	5JD/kVA	0.75MVA	-	-	-
Initial Investment (JD) (a)			3,750	Unprofitable	Unprofitable	Unprofitable
Loss Reduction (kW)			8.0			
Loss Reduction (GWh/10Y)			0.63			
Merit of Loss Reduction (b) (JD/10Y)			18,960			
Expense Due to Investment (c) (JD/10Y)			3,000			
Net Benefit (d)=(b)-(c) (JD/10Y)			15,960			
I.E. Factor (e)=(d)/(a)			4.3			
Voltage Drop in Initial Year (%)			2.1→1.6	-	-	-
Voltage Drop after 10 Years (%)			→2.8			