Appendix D
Power Development Study

FEASIBILITY STUDY
ON
THE DEVELOPMENT OF MUNDA DAM MULTIPURPOSE PROJECT
IN
ISLAMIC REPUBLIC OF PAKISTAN

FINAL REPORT
VOLUME III
SUPPORTING REPORT

Appendix D : Power Development Study

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APPENDIX D POWER DEVELOPMENT STUDY

D1 HEPO, NWFP Government and SHYDO

Brief description of the three organizations of HEPO, NWF Provincial Government, and SHYDO related mainly to the hydroelectric power development in the project area is made below.

D1.1 Hydro Electric Planning Organization (HEPO)

HEPO was established in 1983 as a hydroelectric power planning organization under the Water Wing of WAPDA as seen in the organization chart of WAPDA. HEPO cooperates also with the Power Wing of WAPDA. The organization chart of HEPO is shown in Figure D1.1.

HEPO is in charge of preparing pre-feasibility study, feasibility study and detailed design including preparation of bidding documents for hydroelectric projects as a supporting organization of WAPDA. HEPO is executing hydroelectric power investigation on behalf of WAPDA, and it is also assisting hydroelectric power management of WAPDA basically not including construction activities with its office in a WAPDA compound. HEPO is capable to prepare a basic plan of a hydroelectric project, if available head and flow duration curves of one year long are available.

HEPO is carrying out investigation and planning activities covering the whole country, having specific divisions for the Indus main stream projects, high head projects in Northern Provinces and AJK, and low head projects in Punjab and Sindh.

In NWFP, HEPO is carrying out investigation and planning of large hydroelectric projects (over around 1,000 MW, such as 2,400 MW Dassu and 2,270 MW Thakot), while SHYDO of the provincial government is in charge of smaller projects. GTZ of Germany is cooperating with HEPO in hydro power planning by providing technical expertise.

D1.2 NWFP Provincial Government

The NWFP Provincial Government formerly executed the power supply activities in its own province. It owned the Warsak power station (240 MW) and two other power stations (Malakand and Dargai, 20 MW each), and was sending power up to Rawalpindi through its 132 kV transmission system. According to a government policy all the power stations and transmission and distribution facilities were handed over to WAPDA, and the provincial government ceased its role as the major power supplier.

Under the 1998 Policy for New Private Independent Power Projects, one window supports to IPP activities at the provincial level are to be provided by Provincial and AJK Private Power Cells (PPCs) for projects in respective territories. Various activities covering water use license, environmental assessment, bidding process, assistance to PPIB in issue of LOS, etc. are to be carried out by PPC in cooperation with PPIB.

The provincial and AJK governments are in charge of preparing rural electrification plans in the provinces for execution under the public sector. The NWFP provincial government is going to extend its power supply to remote FATA areas by constructing small hydropower stations and extending WAPDA's power system, under cooperation of its affiliated organization of SHYDO. Their first project for rural power supply in Chitral District, the Reshun Hydel Power Station with 2.8 MW capacity (1.4 MW addition in future) and a 33 kV line of 67 km, are to be completed in 1999. As the next project, the Shishi project (1.9 MW) on the same river system is being undertaken for construction.

D1.3 Sarhad Hydel Development Organization (SHYDO)

SHYDO is a public organization under the provincial government of NWFP. This organization is in charge of implementing feasibility studies for medium to large run-of-river hydroelectric projects in NWFP. SHYDO was set up in 1986, and became an autonomous body in 1993. Many hydroelectric projects identified by SHYDO are expected to be implemented under the private sector participation as mentioned in Clause 4.4. SHYDO is also cooperating with the provincial government in promotion of the power supply to the northern remote areas of NWFP.

These activities are performed with funds provided by the NWFP Government, and the foreign technical assistance provided by GTZ of Germany is available for hydroelectric power studies.

D2 Loss Reduction Study on Transmission and Distribution Systems

D2.1 Transmission and Distribution System Loss

(1) Transmission and Distribution Loss of the WAPDA System

The T&D loss factor of the WAPDA system was 24.0% in 1997-98. The loss factor of over 30% in the 1970s had decreased to 20.3% in 1991, and turned to an increasing trend thereafter. As for the historical transition of the loss factor, Table 4.1.5 is referred to. The loss factor of the KESC system in 1995 was 31.8% which had been gradually increasing since the 1970s as seen in Table 4.1.6. These loss factors are very high based on the technical analysis and as well as international comparison, and must be improved through all means.

Though detailed studies have not been performed, the breakdown of the entire T&D loss factor is roughly estimated as follows based on results of analysis in other similar countries:

Estimated Breakdown of Loss Factors

System		Loss Factor (%)
500/220/132 kV system	:	7 – 8%
MV (33/11 kV) system	:	4 – 5%
LV (400-230 V) system	:	12 – 13%
Total		24.0%

The total line ohmic loss in a transmission and MV distribution system under a certain loading condition can be calculated with the help of computer programs; for instance power flow calculation by the PSS/E software for a transmission system and analysis by the Scott and Scott or another software for a MV distribution system. To obtain system loss as a total, the estimated transformer loss must be added to the line ohmic loss. However, it is difficult to accurately estimate the energy loss in a system under actual varying operating conditions.

Site measurement is possible theoretically, but it is very difficult to obtain proper results due to constraint of accuracy of measuring instruments.

The loss in the LV distribution system usually includes non-technical loss comprising illegal use and metering and billing losses. Though confirmation is not possible, actual loss of this category may be larger than the losses in transmission and MV distribution systems.

Reduction of loss factor in T&D system contributes to increase of sales income and is equivalent to the construction of costly power stations. Therefore, the loss reduction is a great concern to GOP and WAPDA.

(2) Comparison with Situation of Other Countries

The T&D loss factor of the Pakistan power system was compared with values of other Asian countries including both developed and developing as given below:

T&D Loss Factors of Asian Countries

Country	Year	T&D Loss Factor (%)
WAPDA of Pakistan	1997/98	24.0%
Japan	1997	5.5%
Taiwan	1996	6.1%
Thailand	1997	8%
Malaysia	1997	10%
Indonesia	1997/98	12.2%
Philippine (MERALCO)	1996	12.2%
Sri Lanka	1995	17.8%
Vietnam	1997	18%
India	1994/95	20.9%
Nepal	1993/94	24.9%
Syria	1997	25.7%

The 1997 average T&D loss factor of the 10 Japanese power companies was 5.5%. In international comparison, the loss factor is generally high in developing Asian countries; less than 10% in China and Thailand, around 12% in Indonesia, around 20% in Vietnam, and exceeding 20% in India, Nepal, and Syria according to available 1991 to 1997 records. There are certain countries with loss factor exceeding 30%. The loss factor is generally low in developed countries. To reduce the loss factor, actually a certain amount of investment is required. The loss factor of WAPDA is fairly high in international comparison taking into account the current situation of economy of the country.

In Japan, during the period from 1951 to 1960 the average T&D loss factor of the 9 major power companies had fallen from 25.3% to 11.4%, more than halved, due to the raising of the MV distribution voltage from 3.3 kV to 6.6 kV, use of insulated wires to both MV and LV distribution lines and resultant increase in conductor sectional areas, decrease in pilferage, and other system improvement efforts. However, the declining rate became slow after the loss factor became less than the 8% level.

D2.2 Review of Loss Behaviors

The T&D loss energy of the WAPDA system is obtained by deducting the sales energy and station service energy from the generated energy. The generated energy is measured by watt-hour meters installed at the generator terminals, while the sales energy is the sum of various classes of non-simultaneous meter readings which include estimation for non-metered consumers. The sent out energy from grid substations can be measured by watt-hour meters on distribution feeders.

The T&D losses are characterized as follows:

(a) The transmission system loss comprises the ohmic loss in line conductors and the loss in transformers for stepping up from the generator voltage to the transmission voltage and then down to 11 kV at grid substations. The transmission system loss will not exceed 7 to 8%.

(b) The MV distribution system loss comprises the ohmic loss in 11 kV line conductors and the loss in stepping down transformers, 11 kV/ 240-415 V. The loss is estimated at 4 to 5% referring to similar systems.

(c) The LV distribution system loss can be estimated on assumed models. Actually, the total T&D loss deducted by the estimated transmission and MV distribution system losses was defined as the LV distribution system loss in Clause D2.1 above. The non-technical loss in the distribution system is usually included in this category.

According to the statistical yearbook of WAPDA, the total length of LV distribution lines of 8 distribution companies is 2/3 of that of MV lines. Though actual line loss is affected by conductor sizes, line loading, etc., the ohmic loss in the LV system will not be larger than loss in the MV system.

The LV distribution system loss involves both technical loss and non-technical loss. The former is the physical loss; mainly ohmic loss in distribution line conductors and the latter comprises illegal use like pilferage, metering error, billing loss, etc.

Without laborious studies for a long time on the actual situation, quantification of these losses is not possible.

D2.3 Loss Reduction Measures

D2.3.1 Transmission System

Both of the ohmic loss in the line conductors and the transformer loss in the transmission system can be decreased to some extent by increasing the cost for equipment and installation. The most cost-effective measures shall be sought out as mentioned below.

(1) Transmission Lines

Power loss in transmission line conductors can be reduced by the following two measures:

(a) By raising transmission voltage

The ohmic loss in a line decreases in reverse proportion to the square of system voltage for sending a certain power over a fixed distance. However, the cost of substation facilities and the construction cost of a transmission line significantly increases with increase in line voltage. It is required to select the most appropriate line voltage from the standard voltages so as to attain the maximum economy. WAPDA's present transmission system consisting of 500/220 and 132 kV lines is of proper voltage level taking into account the present power transfer requirement.

To keep transmission system voltage as high as possible results in smaller line current and reduces the ohmic loss in line. In principle actual operating voltage should be selected high within the limit in technical standards, being 240 kV for the 220 kV system and 145 kV for the 132 kV system in IEC. The raising of operating voltage is effective also to improve the voltage profile in line.

This practice is followed in many countries. In the WAPDA system, though the upper limit of bus operating voltage is plus 5% the actual operating voltage seems somewhat lower.

(b) By increasing conductor size

For the same voltage, the ohmic loss in the line conductors decreases in reverse proportion to the sectional area of line conductors. However, the construction cost of the line increases with increase in the conductor sectional area. When a transmission plan is planned, a schedule of anticipated transmitting power (maximum power and energy) shall be determined at first. Then an overall cost schedule shall be prepared covering the whole economic life period for candidate conductor sizes including construction cost and maintenance cost, and evaluated loss values for kW and kWh. The conductor size that gives the lowest evaluated cost shall be selected.

Usually, a power flow calculation computer program for transmission system has a function to calculate the sum of ohmic loss in all connected transmission lines and indicate in the calculation result. Also the MV system loss can be calculated using a computer software.

(2) Transformers

In purchasing transformers on tender basis, it is a widely applied practice to favor transformers with low loss by awarding contract to the tenderer who offered the lowest evaluated price including evaluated loss values including loaded and no-load conditions.

(3) Accurate Energy Measuring Arrangement

Records of the electric energy, generated at and sent out from the power stations, and received and sent out from the grid substations, should be collected and compiled properly. Actual loss in various parts of the power system can be analyzed based on these records. In modern technologies, this function is being performed in power control centers with the help of computer. To accurately quantify loss values, measuring meters must have high accuracy. Small error of measured values results in relatively large error of loss value as the balance of two readings.

In case that meters of high accuracy are not available, measured losses as the balance of meter indications can be used only for rough estimation. Practically, the calculated results using computer software is more accurate than the measured values.

D2.3.2 MV and LV Distribution Systems

Widely applied measures to reduce the distribution system loss in distribution systems are enumerated below:

(a) By adopting higher voltage, the distribution loss can be reduced. For the WAPDA MV system, the 33 kV system had better be extended as far as possible instead of the current 11 kV system. A distribution voltage level higher than 33 kV is not practical. Also for the LV system, adoption of a voltage higher than the present 230/400 V can not be considered.
The keeping the MV operating voltage as high as possible is effective to reduce the ohmic loss in line from the same reason mentioned for the transmission system. However, care should be taken that a higher operating voltage in the LV system results in increase of power consumption.

(b) Proper siting of grid substations and distribution transformers (100 - 250 kVA) is important. Addition of grid substation will shorten length of MV distribution lines. Distribution transformers should be located at or close to consuming centers, and their capacity and installation spacing should be determined depending on load density. Both distribution loss and voltage variation should be carefully checked and the voltage drop in LV main should be reviewed.

(c) The most economic conductor sizes should be selected. The relation of appropriate conductor size vs. sending power, which shows the most economic conductor size for a certain sending power, should be obtained taking into account the future demand growth through calculations.

(d) Use of insulated wires for distribution lines results in selection of larger conductors, which results in lower ohmic loss. The erection of insulated wires is effective also to reduce chance of faults due to touching of vegetation and other items and to reduce pilferage from LV lines.

(e) Avoidance of unbalanced loading and trying to attain proper distribution of loads among a number of distribution lines are also helpful to reduce the overall distribution loss.

(f) Power factor improvement at the consumer ends is very effective to reduce loss in lines. The reactive current in line decreases, and resultant power loss and voltage drop in the line also decreases significantly. It will be the most effective measure to request large consumers to install static capacitors in a power supply regulation. There is an idea to decrease power tariff against the power factor improvement (this practice is applied in Japan).

(g) Static capacitors for power factor improvement should be installed on 33/11 kV feeders as required by distribution companies. This installation is considered to be essential to minimize voltage variation at the consumer ends and at the same time reduces the line loss as has been confirmed by WAPDA with the help of computer software.

(h) Phase balance of power flow contributes to reduction of the distribution loss. Measured imbalance of exceeding 15 to 20% shall be remedied.

D2.3.3 Consumer Service Facilities

The pilferage or illegal use of electric energy at the consumer ends usually takes place at or near the consumer service points; i.e., between the terminal points of dropwires and watt-hour meters and their vicinities. The consumer service facilities need to be designed so as to prevent attempts for power pilferage. Careful planning is required in selecting wiring materials and watt-hour meters, and their fixing points and methods.

In Japan, overhead distribution lines are normally aligned along roads and dropwires to consumers are terminated on eaves or side walls of the houses at points easily visible from the roads. Periodically calibrated and then sealed watt-hour meters are installed on outside walls of the houses at a height easy for meter reading near the dropwire terminal points and also near the entrances of houses. The outdoor installation of watt-hour meters is beneficial also to the monthly meter reading. Security of installation should also be taken into account. Stout cables installed at easily visible surfaces connect the dropwires and watt-hour meters. In some countries, consumer WH meters are installed on distribution poles at roadsides.

In many developing countries, steel or plastic boxes with padlock keys are provided to encase watt-hour meters and switches. This practice contributes to reducing the illegal use.

Improvement of meter reading and billing procedures will also contribute to increasing sales incomes for power utility.

Watt-hour meters for consumer metering are properties of power utilities and should be calibrated at official laboratories at predetermined intervals (10 years for normal meters, and 5 to 7 years for precision meters in Japan) to maintain the specified accuracy. The use of meters for a prolonged duration results in slowing the rotating speed of meters and increases the metering loss.

There are cases to provide anti-reverse rotation watt-hour meters to reduce influence of illegal use by avoiding rotation in the reverse direction.

D2.3.4 Relation with Voltage Keeping Measures

In Pakistan, the consumer supply voltage is required to be kept within a certain range according to a regulation. As on-load tap changers are provided with the substation transformers, the 11 kV bus voltage is usually kept at a control level. However, the receiving end voltage drops in the long MV and LV distribution lines as capacities of static capacitors in the distribution system are not sufficient. It is noted that the following typical measures to reduce voltage drop basically coincide with measures to reduce line loss:

(a) Raising line voltage
(b) Use of large conductors
(c) Improvement of power factor at supply points

All measures to reduce variation of the consumer supply voltage result in reduction of line loss. In case of Japan, measures to maintain quality of power supply (to keep supply voltage and frequency) and reliability of supply (reduction of supply interruption) mostly result in the reduction of T&D loss. The conductor size must be determined based on criteria of the maximum economy taking into account construction and O&M costs, and loss evaluation.

D2.3.5 Non-technical Approaches

The following are conceived measures to reduce non-technical losses.

(a) Public campaign for prevention of illegal use will be effective to make the general public fully aware of intentions of the government and WAPDA and consequences of power pilferage.

(b) Improvement of moral senses of power utility's technicians is also effective to reduce the illegal use.

(c) The penalty system including supply cutting and fine imposing to illegal users is also a measure to reduce pilferage. Such clauses are required to be included in the power supply regulation and well known to all power users.

(d) Improvement in the billing and tariff collecting procedures will contribute to increasing collection of electricity charges.

(e) Provision of meter calibrating laboratories by third parties for regular calibration and replacement of consumer meters at a predetermined interval is essential to maintain proper accuracy of meter indication.

D2.4 Action Plans

(1) Loss Measurement

For analyzing actual loss behavior, it is necessary to accurately measure flowing energy at various sending and receiving points as given below:

- Generated energy at the generator terminals
- Sent out energy at the outgoing points of power stations
- Received energy at the grid substations
- Sent out energy at the outgoing points of distribution feeders
- Sold energy

In principle, the measured losses must coincide with theoretically calculated values. It is necessary to check accuracy of all metering apparatus at predetermined intervals.

Actually, accurate meters to measure loss values with practical accuracy cost much, and there will be technical difficulties to maintain their accuracy under the present situation of WAPDA. Under such consideration, it is required to decide how to handle calculated and measured values.

(2) Selection of Most Appropriate Conductor Sizes

For transmission lines (500/220 kV and 132 kV) and MV distribution lines (11 kV, 33 kV in some part), the relation of the most appropriate conductor size vs.

sending power shall be obtained based on economic calculations and make known to design engineers.

(3) Control of System Operating Voltages

The current upper limit of transmission voltage in the WAPDA system is around plus 5%. While the system facilities are designed to withstand the voltage limit in the IEC standard (around plus 10%) and actually the operating voltage is selected higher in many countries. WAPDA is recommended to initiate proper studies on this point.

At grid substations, the secondary sending out voltage is set at the rated 11 kV. To raise the sending end voltage around 5% higher than the rated will contribute to reduction of distribution loss and as well as improvement of voltage profile.

(4) Thorough Studies for Loss Reduction

At first thorough loss studies covering all voltage classes of the system, 500/220 and 132 kV transmission, MV (11 kV, partly 33 kV) distribution and LV (240 - 415 V) distribution, involving the following items will be required:

- Analysis of current causes of loss in transmission, MV distribution and LV distribution systems.
- Review and evaluation of metering apparatus in the WAPDA's transmission and distribution systems.
- Establishment of selecting procedures of conductor sizes taking into account loss evaluation.
- Economic evaluation of various loss reduction measures including but not limited to addition of substations, power factor improvement in various levels, proper limits of route length of distribution lines, proper unit capacities of distribution transformers, improvement of consumer service facilities, watt-hour meter calibration and replacing, etc.
- Preparation of proposals for action plans to reduce illegal uses.

As for the transmission and MV distribution systems, the loss of existing transformers is out of control and effective methods to reduce the ohmic loss in lines will mainly be use of larger conductors and power factor improvement. It will not be economically practical to restring the existing conductors unless there is current capacity problem. For new lines, the economically most appropriate conductors shall be selected. The power factor in the WAPDA's power system shall be reviewed at various levels and improving plans shall be worked out. Proper installation of static capacitors will reduce the ohmic loss. Around 10%

reduction of line loss in these systems can be expected by 5% improvement of power factor.

Remarkable reduction of the T&D loss is not expected by improving the transmission and MV distribution systems. Significant loss reduction will only be achieved by improving the LV distribution system, which is considered to be the largest source of T&D loss, including the consumer service facilities. Usual loss reduction studies in developing countries focuses on the improvement of LV system especially on the reduction of illegal uses, which is considered to be the most cost effective measures obtaining effects with relatively small investment.

The technical loss can be decreased by addition of new substations, proper siting of distribution transformers, selection of conductors with appropriate sizes, improvement of power factors by installing static capacitors by both consumers and WAPDA, and other measurers.

Utmost efforts should be exercised to reduce pilferage or in other words illegal use.

WAPDA's efforts are required for improving metering system including calibration and replacement, and billing and tariff collecting systems, organization of consumer service facilities improving gangs, campaigning for consumer education, etc.

Execution of any loss reduction measure requires certain amount of investment. Therefore, it is required to determine priority referring to economic merit of each province and execute one by one based on priority. There is also an idea to execute loss reduction plan area by area according to studies by consultants.

Even small, any loss reducing measures shall be taken up one by one or step by step with some investment.

D.3 Review of Annual Demand Pattern and Future Load Factor

D3.1 Monthly Pattern of Peak Demand and Energy Generation

(1) Obtained Data

The monthly peak demand and energy generation of the WAPDA and KESC systems for the recent three (3) years, 1995-96, 1996-1997, and 1997-98, were obtained as the LDC data. The two (2) figures of WAPDA and KESC were added to obtain the country data as their sum taking into account diversity factor. The computed peak demand that was assumed taking into account load shedding is taken as the real peak value. The data of WAPDA, KESC and the combined systems are shown in Table 4.3.7.

(2) Review of Monthly Patterns

Both computed peak demand and energy generation are largest in July, the hottest summer, and smallest in February in winter. The monthly load factor is also highest in July due to the off-peak use of air-conditioners. To obtain the monthly patterns, the 2 July maximum values of consecutive years are connected with a straight line and the difference between this line and monthly values were calculated to indicate in percent. The averages of the 3 years were obtained for the calculated peak demand and energy generation of each month. The result is shown in Table D3.1. The resultant monthly patterns are given below:

Monthly Pattern of Computed Peak Demand and Energy Generation

Month	Difference (%)	
	Computed Peak	Energy Generation
July	0.00	0.00
August	-1.42	-3.18
September	-1.91	-8.12
October	-6.22	-19.26
November	-13.74	-26.22
December	-12.37	-20.30
January	-13.36	-17.60
February	-15.36	-29.22
March	-14.33	-22.62
April	-10.10	-19.29
May	-5.27	-8.91
June	-1.88	-5.61

D3.2 Future Trend of Load Factor

(1) Present Situation

The daily load curves of the Pakistan power system is of typical evening-peak pattern. The daily peak load appears at around 8 o'clock in summer and at around 7 o'clock in winter, and the duration of peak load is around 4 hours throughout the year.

The annual load factor is in an increasing trend recently. The annual load factor of 62.4% in 1983-84 has increased to 66.8% in 1997-98, and the highest value of 69.3% was recorded in 1996-97.

(2) Comparison with Other Countries

The load factor and shape of daily load curve generally vary with growth of economic situation of a country. The annual load factor is generally low in lower developing countries, and is normally less than 60% if the supply capacity is sufficient to satisfy the demand. In such developing countries, the daily load curves are of evening-peak pattern and the peak load duration is around 4 hours. With growth of economy, the day time demand increases and the shape of load curve changes from evening-peak pattern to daytime-peak pattern. At the same time, peak duration of around four (4) hours for the evening-peak pattern, changes to around eight (8) hours of the daytime-peak pattern. The annual load factor goes up to the maximum of around 70% or slightly higher when the daytime peak becomes comparable to the evening peak, and peak load duration becomes around 12 hours. But thereafter, the annual load factor goes down with growth of economy to around 60% in present developed countries (58.4% in average in Japan at the transmission outlets in 1997). The developed countries are making efforts to attain the annual load factor of at least 60% by the DSM promotion and other incentives.

In Japan, the high annual load factor of over 70% in the beginning 1960s gradually decreased to less than 60% at present. According to records of higher developing countries the recent shifting from evening peak to daytime peak occurs when the per capita GDP is 1500 to 2000 US Dollars. In case of recent Thai power system, the shifting occurred when the per capita GDP was around 2000 US Dollars.

(3) Affects of Insufficiency in Power Supply Capacity

In developing countries there are a lot of cases that the daily load curves are deformed due to suppression of peak value caused by insufficiency in supply capacity, generation, and/or transmission/ distribution. In such a case, power shortage appears in the peak time, which restrict the peak load. While enough power can be supplied during off-peak time. This results in larger daily and annual load factors.

In Pakistan, the construction of power stations progressed well in recent years and at present the generation system has sufficient capacity to satisfy the demand. While, the capacity of substation transformers is not sufficient to meet the demand, and in recent years many grid substation transformers are overloaded during the peak load time.

The present high annual load factor of Pakistan, 69.3% in 1996-97, seems to be caused by insufficiency in supply capacity. The normal value of annual load factor of the current Pakistan power system would not exceed 60% according to examples of countries under similar economic situation.

(4) Forecast for Economic Situation

The present per capita GDP of Pakistan is around 500 US$, and the future growth of the per capita GDP will be 3 to 4% if the GDP growth of 5 to 6% and population growth of exceeding 2% are taken into account. Therefore, it is forecasted that the per capita GDP does not reach 1500 to 2000 US$ that results in high load factor and change of peak load duration, 4 hours to 8 hours, and reaching the maximum load factor within the foreseeable future.

(5) Expected Changes

Under such situation, the following changes are assumed for future load factor and duration of peak time:

- The present situation of shortage in supply capacity is solved gradually and does not occur in future.
- The annual load factor is assumed to go down from the present value to the final value of 64.7 to 64.8% as shown in the 1999 demand forecast of the government and keep constant during the time horizon of the study.
- The monthly pattern of power consumption during the study period will basically follow the average of the past 3 years of 1995-96, 1996-97 and 1997-98 with minor adjustment to solving the present situation of power shortage.

D3.3 Daily Duration of Peak Demand

(1) Present Situation

The daily power consumption of the Pakistan system is of evening peak pattern, and the daily duration of peak demand is around 4 hours. WAPDA at present is not expecting change of the consumption pattern from evening pattern to daytime peak pattern in the foreseeable future, and the daily peak duration of 4 hours is adopted for their power development plans.

World-wide, the daily peak duration is around 4 hours in case of evening peak in developing countries and 8 hours in case of daytime peak in relatively developed countries. Such transition usually takes place when the per capita GDP reaches around 1,500 to 2,000 US$ as mentioned above.

(2) Peak Load Duration for Study

As mentioned in Clause D3.2, the per capita GDP of Pakistan is not expected to reach the above transition level within the plan period. Therefore, the present evening peak pattern of daily load curve will not change to the daytime peak during the plan period. From such considerations, the peak load duration of 4 hours was adopted for the study of this report.

D4 Power Demand Forecast

D4.1 Regression Analysis

The future power demand of Pakistan, for the present WAPDA and KESC systems combined, was estimated with a regression analysis to review the obtained forecast of the government. The amount of sold energy for the Total of the country, and category-wise sales to the Domestic, Industrial, Commercial and Agricultural consumers were reviewed in relation to the relevant economic indicators as given below:

Total energy sales	: GDP of the country
Domestic energy sales	: GDP of the country
Industrial energy sales	: GDP of Mining and Manufacturing sector
Commercial energy sales	: GDP of Commercial sector
Agricultural energy sales	: GDP of Agricultural sector

At first, the historical correlations between the GDP growth and the growth of sold energy were reviewed taking into account various components that would affect the energy sales. These trends were extended to the future for forecasting energy sales with modifications as deemed necessary according to changes in situations.

D4.2 Prospect for Growth of Economic Indicators

The Pakistan economy achieved a relatively high GDP growth rate of 5.4% in 1997-98, and high future growth rate of 5.0 to 7.0% were targeted by the government. In the revised 9th 5-Year Plan, the economic growth rate of 6% was assumed for the recent normal growth scenario of load forecast and 5% for the realistic low growth scenario.

The GDP growths for the total of the country and itemized categories of Mining and Manufacturing, Commercial and Agricultural estimated by GOP based on the two growth scenarios of Normal and Low are tabulated in Tables D4.1 and D4.2. The growth rates of the major sectors, Mining and Manufacturing and Commercial, are much higher than the GDP growth of the country. The resultant GDP growths as the sums of sector-wise GDPs are much larger than the country's estimated GDPs. Then the estimated sector-wise GDP growths were reallocated so as to compensate the discrepancy between overall GDP and sector-wise GDPs as seen in Tables D4.3 and D4.4.

D4.3 Analysis of Historical Trends of Growths of Economy and Energy Sales

Historical trends of the correlations between economic growth and the growth of energy sales were reviewed for the period of recent 15 years from 1982-83 to 1997-98. Correlations between these two ingredients were reviewed for the entire period, for the recent 10 years and the recent 5 years as mentioned below. The regression relations for the five cases mentioned in Paragraph 1 are shown in Figure D4.1.

Major findings from the review of the historical trends are mentioned below:

- The resultant correlation factors observed between the growth of sector GDP and the growth of energy sales are summarized below:
  - · Total energy sales : 1.527 for past 15 years and 1.276 for 10 years
  - · Domestic energy sales : 2.088 for past 15 years and 1.971 for 10 years
  - · Industrial energy sales : 1.322 for the period, 1982-83 to 1992-93, and no growth of demand is observed after 1993 in spite of economic growth.
  - · Commercial energy sales : 1.582 after 1991-92 (trend is different up to 1991 and thereafter due to the change in scope of the sector)
  - · Agricultural energy sales : 1.782 for 15 years and 1.218 for 10 years

The correlations are presented in a logarithmic chart in Figure D4.1. It is evident that all the correlation factors are in a declining trend.

- In recent years, the regional load shedding takes place due to insufficiency in power system capacity, generation and transmission. At present, the installed generating capacity is sufficient to meet the demand, however there are many distribution transformers (mostly 132/11 kV) overloaded during the peak load time. This seems to be a cause of the declining trend of correlation factors.
- Very strong growth of domestic energy sales is observed in relation to the growth of the overall GDP. The correlation factor was around 2.0.
- After 1993, many industrial consumers seem to have commenced use of self-generation due to inappropriateness of public power supply; in view of quantity, quality and reliability.

- The trend of commercial consumption completely changed between "up to 1991" and "after 1991" due to change in scope of the commercial demand. For demand forecast, only the correlation "after 1991" was referred to.

D4.4 Review of Government Demand Forecast by the JICA Team

The future energy sales of the country and of each category of Domestic, Industrial, Commercial, Agricultural and their sum, the total demand, were forecasted by JICA by extending the past trends taking into account the following:

- The correlation factor is generally high in low-income developing countries, and is mostly 1.2 to 1.5 and is near to 2.0 for high cases. This factor usually goes down with increase in GDP per capita exceeding 1,000 US$, and approach 1.0 in developed countries. The present per capita GDP of Pakistan is about 500 US$ and will not reach 1,000 US$ during the plan horizon.
- The recent trends suppressing the demand growth in Pakistan seem to be caused by insufficiency in power system capacity, and strong growth will be resumed if the supply insufficiency is lifted.
- There is a world-wide tendency to increase the share of electricity use in energy consumption as the electricity is the most convenient form of energy and used extensively in modern living.
- In view of future shortage of available energy foreseen in Pakistan, the movements for energy conservation and demand side management (DSM) are to be promoted.

The future demand was estimated for two scenarios of the Normal Growth Assumption (6% GDP growth) and the Low Growth Assumption (5% GDP growth). For the category-wise GDP growths, the reallocated growth rates mentioned in Clause D2 were applied. Assumed correlation factors for all the categories are mentioned below:

- Overall energy sales: The factor is assumed at 1.1 in initial years and increase to 1.5 in five years with improvement of power system and remain same thereafter.
- Domestic energy sales: The factor is assumed to increase from initial 1.6 to the past 1.95 in five years, and then goes down to 1.5 gradually as it is not likely that such a very high factor will be maintained for a long time.
- Industrial energy sales: It will take a long time for present consumers with self generating facilities use public power in full swing. It is assumed that

the factor is 0.5 initially and become the past 1.3 in 10 years and remain same thereafter.

- Commercial energy sales: The factor is assumed to be 1.2 initially and increase to the past 1.58 in five years, and remain same thereafter.
- Agricultural energy sales: The factor is assumed to be 1.1 initially and increase to the past 1.22 in five years, and remain same thereafter.
- The total energy sales is assumed to be 1.12 times the sum of the four items of Domestic, Industrial, Commercial and Agricultural sales to cover the other small items.

The forecast results are presented in Table D4.5 (1) for demand of the Country, (2) for the Domestic demand, (3) for the Industrial Demand, (4) for the Commercial demand, (5) for the Agricultural demand, and (6) for the Sum of category-wise demands. The difference between the Country demand and the Sum of category-wise demands is within several percent.

D4.5 Overall Evaluation of Load Forecast of the Revised 9-th Plan

The obtained forecast results of JICA do not much differ from the revised forecast of the 9th Plan of GOP. Thus, the revised forecast of the government is judged to be reasonable, and this forecast will be used for the execution of study.

D5 Existing Power System

D5.1 General

The generation system of Pakistan comprises hydroelectric and thermal power stations. The historical transition of the share of hydro and thermal generation energy is shown in Table 4.4.1. Though the maximum hydro share of 78.7% was recorded in 1979, the share has been declining thereafter due to delay of hydroelectric power development caused by financial constraints, and is just over 40% recently. After 1997, the IPP generation emerged and has exceeded 30% in energy in 1999.

As for the regional distribution of the generating capacity, the share of Punjab, the largest load center, is largest and followed by NWFP as shown below:

Province-Wise Installed Generation Capacity

Province	Hydro	Thermal	Total
Punjab	63	4,590	4,653
Sindh	-	2,909	2,909
N.W.F.P.	3,762	-	3,762
Balochistan	-	1,392	1,392
A.J.K.	1,000	-	1,000

The installed capacity of NWFP is very large compared with its consumption, as the Tarbela power station is located in this province. NWFP and AJK have only hydroelectric plants, while the thermal installations are predominant in the other 3 provinces.

D5.2 Generating Facilities

1) Hydroelectric Power Generation

The total installed capacity of the existing hydroelectric power stations is 4,826 MW as tabulated in Table D6.1, and the 3 major reservoir type power stations, Tarbela (3,478 MW), Mangla (1,000 MW) and Warsak (240 MW) occupies 98% of the total of hydroelectric installation in the country. The largest Tarbela plant occupies 72%.

In Pakistan, the first priority for the water use of multi-purpose reservoir is the irrigation water supply. Therefore, a reservoir is to be operated based on irrigation requirement. Sources of water flow to rivers in the area are the snow melt and monsoon rain. The river flow is high from May to August, while the irrigation requirement is high from April to June and the release from reservoir is closed in winter. Under such situation, the peak power shortage appears in April, May and June due to the low reservoir level and the energy shortage in December and January due to decrease in release from reservoir.

In Pakistan, the repairing of generating equipment can be performed when the river flow is little in the dry season. Therefore, troubled equipment can be repaired before being heavily damaged and the chance of fault breakdown of equipment is generally low.

The rated power factor of hydro generator is 0.85 to 0.8 and the overload factor or water turbine under high head condition is usually set at 110 (for instance Tarbela) to 115% (Mangla).

2) Thermal Power Generation

The total installed capacity of existing thermal power plants in the WAPDA system consists of 4,281 MW of WAPDA plants and private facilities of 3,044 MW. That of the KESC system is 1,926 MW of KESC and 130 MW of private facilities as shown in Table D6.2.

In the WAPDA system, 52% in installed capacity is steam plants and the remaining 48% are gas turbine and combined cycle plants. The recent gas turbine and combined cycle plants are operated with natural gas, while old plants of this type are with oil. The main steam turbine plants completed after the 1980s are provided with 210 to 250 MW units; only one unit is over 300 MW. The recent major gas turbine units are of 100 to 135 MW capacity. Many thermal units are very old and have been operated for more than 30 years. In Pakistan, the standard life of thermal plant is 35 years for steam plant, 25 years for gas turbine plant and 30 years for combined cycle plant.

All the KESC's stations, consisting of 76% steam, 11% gas turbine and 13% diesel, are based on the oil and gas fuel. The oil generation occupies 78.2% of the total generation capacity and the remaining 21.8% by old gas turbines with gas. At present there is no pipeline installation plan to reinforce the present gas supply.

The annual periods of regular maintenance of thermal generating sets are:

Steam turbine generators (WAPDA & KESC)	45 days
Gas turbine/Combined cycle generators (WAPDA & KESC)	30 days
Private Projects	36 days

Annual forced outage rates are:

WAPDA hydel plants	3.0%
WAPDA & KESC thermal plants	13.3%
Private power plants	6.5%

Regular maintenance of thermal generating facilities is being carried out mainly in the monsoon season when the river flow is abundant. Annual maintenance schedule of entire power plants including hydroelectric plants is prepared by NPCC.

Hub Company commissioned the first large private sector oil-fired power station of 1,292 MW (4 x 323 MW) capacity in 1996-97 at Hub on the Balochistan coast. The Kot Addu power station with new gas turbine and combined cycle units of 1,621 MW in total installed capacity was sold and management was handed over to KAPCO in June 1996. WAPDA is at present buying power from KAPCO.

D5.3 Transmission System

The transmission network of Pakistan has spine 500 kV transmission lines in 2 to 3 circuits from the Tarbela power station in the north to the Hub power station facing the Arabian sea, 1,500 km in total length. The present configuration of the 500 kV transmission system is shown in Figure 4.4.1. These transmission lines interconnect seven 500/220 kV substations and 220/132 kV networks in the country. All major power stations and load centers in the country are integrated through this 500 kV system. The total length of transmission lines of various voltage classes in each province is presented in Table 4.4.2.

In actual transmission system operation, the 500 kV and 220 kV systems are operated in loop formation to attain high system reliability, while the 132 kV and 66 kV systems in radial formation to avoid misoperation of protective relays and spreading of fault, and to limit rupturing capacity of circuit breakers.

In NWFP, the 500 kV system was recently extended from Tarbela to Peshawar. Only two 220 kV transmission lines from Tarbela to Mardan and from Peshawar 500kV to Daud Khel are in operation at present. In the province, there are 2 kinds of secondary system of 132 kV and 66 kV. The 132 kV system is the major system to feed to grid substations for stepping down to the MV distribution voltage of 11 kV. Such transmission system covers only the southern part of the province, and the most of northern areas have not been electrified. The historical transition of substation capacity in NWFP is shown in Table 4.4.3. Many distribution system transformers (mostly of 132/11 kV) have been over-loaded covering all over the country including NWFP due to shortage in installed capacity.

WAPDA has already acquired technology for planning, designing and constructing all transmission lines up to 500 kV class. For transmission system planning, WAPDA determine various parameters after carrying out power system analysis including power flow, stability and fault calculation, using the PSS/E software of Power Technologies Inc. (PTI) of USA. Transmission facilities are designed and bidding documents are prepared by the Transmission and Grid Substations Directorate.

All 500 kV transmission lines are of single-circuit construction with four-bundled conductors. ACSR Drake (795 MCM) is the standard conductor, however AAAC (DERECK) is going to be used. The standard conductors of

220 kV lines are ACSR RAIL (954 MCM), LYNX (175 mm^2) for 132 kV lines and DOG (100 sq. mm) for 66 kV lines. 2-bundled conductors are going to be applied for heavily loaded 220 kV lines. A double circuit line is usually planned to secure 70 to 80% of power under one circuit operation to satisfy the 'N-1' criteria for reliability as far as possible.

Lightning damage is not significant in Pakistan, and only one overhead earthwire is installed on a double-circuit line of 220 kV or 132 kV. To avoid troubles of insulator contamination due to dust and salt in desert lands, fog insulator discs are sometimes installed. The standard number of insulator discs in one string is 15 for 220 kV lines on both suspension and tension strings.

For line protection including 500 kV lines, the distance protection combined with transfer tripping with the help of PLC channels is used as the standard practice.

For a 220 kV switchyard with four generator circuits, planned for the Munda power station, the 1.5 circuit breaker double bus arrangement is the standard practice. However, the double bus system with a bustie circuit breaker will also be accepted.

D5.4 Load Dispatching System

In the present Pakistan power system, there are four load dispatching centers in operation as mentioned below:

- National Power Control Center (NPCC) of WAPDA in Islamabad for generation system and 500/220 kV transmission system covering the whole country.
- Regional Control Center (RCC) (North) of WAPDA in Islamabad for the northern 132/66 kV transmission system, from Peshawar to Multan.
- Regional Control Center (RCC) (South) of WAPDA at Jamshoro for the southern 132/66 kV transmission system, south of Multan.
- Load Dispatching Center of the KESC system at Karachi.

The existing NPCC's main facilities are of SCADA system from ABB supplied in 1990. This system has already been out-dated and requires renewal at an early time.

The location of NPCC was selected in Islamabad instead of Lahore as Islamabad is nearer to the largest power station of Tarbela and also to many future hydro power stations to be constructed in the northern area. Utmost attention is required to the operation of hydropower stations from effective utilization of water resources, and management and control of hydropower system. Moreover, Lahore is very close to the Indian border.

The daily generation plan of the next day covering whole the country is prepared by NPCC and operating instructions for the next day are sent to WAPDA's power stations and as well as to private power producers. Annual generation plan and generating equipment maintenance schedule of the whole power stations are prepared by NPCC. For a private producer, a 3-month notice is informed on both peak power and energy, and month to month notices are also provided.

The operating power output of hydropower station is to be determined referring to the government plans for irrigation water supply and available river flow.

The power system frequency is controlled using four generators each of the Tarbela and Mangla power stations.

The 220 kV sending out voltage of the Tarbela power station, etc. is usually set high, near to 240 kV during the peak load time to maintain system voltage and to minimize power loss, and is slightly lower during the off-peak time.

The power system operation records including fault data are compiled and databased in NPCC. NPCC has off-line computers for power system analysis to review and determine system operating conditions.

The KESC Load Dispatching Center is operated for control of the KESC system. The both WAPDA and KESC dispatching centers cooperate each other to attain an overall coordination of the two systems. The record of energy interchange between WAPDA and KESC in recent years is given below:

Energy Interchange Between WAPDA and KESC

Fiscal Year to 30 June	Export to KESC (GWh)	Import from KESC (GWh)
1983-84	6.00	37.00
1984-85	0.97	674.00
1985-86	0.55	470.03
1986-87	6.00	191.00
1987-88	86.22	116.00
1988-89	82.00	32.00
1989-90	171.16	264.46
1990-91	193.55	41.50
1991-92	292.21	463.02
1992-93	93.90	517.27
1993-94	367.74	350.71
1994-95	884.04	207.58
1995-96	794.61	298.47
1996-97	1,232.80	90.56
1997-98		

For long time, WAPDA was receiving power from KESC, but recently from 1993-94 WAPDA is exporting power to KESC and the exporting energy has been increasing rapidly.

D5.5 Communication System

The power line carrier (PLC) system is the main communication means of the transmission network and provided on all the existing transmission lines of up to 500 kV. Only 1-channel sets are used in Pakistan with formation of; 1+1+1+1 ....

For standby and maintenance communication, both VHF simplex and UHF duplex radio links are in use. In addition, the public telephone is also utilized for voice communication. However, the data communication and protection signal exchange are being performed using only PLC channels.

The power system administrative telephone system consists of the central exchange (PABX) at NPCC in Islamabad and about 100 local exchanges.

In Pakistan, there is only one microwave link of 2 GHz, 60 CH capacity between Islamabad and Jamshoro in the south to meet increased communication needs in recent years. Multi-channel UHF links are also in use in heavy traffic sections, for instance between Tarbela and Peshawar.

At present, optical communication is not applied for power system operation. OPGWs were once installed on a 500 kV line in, however this system was damaged and is being recommissioned after repairing. WAPDA has a plan to use the optical communication on the 500 kV system and on important and heavy traffic sections, and installation of OPGW is now ongoing on several lines and is to be commissioned in near future.

D5.6 Distribution System

The main system voltage of the high voltage distribution (MV) network is 11 kV. In many other countries, a higher voltage of 33 kV or 22 kV is preferred for long distance power distribution (say up to around 50 km) in rural areas. Therefore, power supply area around grid substation is limited to relatively narrow area in Pakistan. The 33 kV distribution is employed in certain remote areas including NWFP for long distance transfer of relatively small power.

The low voltage (LV) distribution voltage in the country is 400/230 V, 3-phase, 4-wire system. The standard secondary voltage of distribution transformers is 415/240 V.

To reduce T&D system losses, fundamental improvements of the distribution system with highest attention to LV system (especially use of insulated wires and improvement of consumer receiving facilities) are urgently needed.

D5.7 Rural Electrification

In Pakistan, the concept of rural electrification is the extension of power lines to unelectrified villages and does not mean the electrification of individual households, and rural electrification is assessed by the number of villages that have newly received power from the national power grid system. Up to 1997-98, 65,951 villages were electrified out of the total of 125,083 villages, the village electrification ratio was 52.7%. It is generally considered that villages within 20 km from the national grid are adequate for electrification by extending power lines. Priority should be given to electrification of villages within this limit.

The rural electrification activities are being basically carried out with the government fund. Loans from international institutions such as World Bank and ADB, and as well as from bilateral sources such as Japan, Germany, etc., are also allocated for this purpose.

In the draft 9th 5-Year Plan, 15,000 villages are planned to be electrified in the plan period at a rate of 3,000 villages per annum. Every year, the government announces available fund for rural electrification, and each provincial government submits an application stating particulars of its plan. The GOP selects projects to be executed in the year taking into account various factors. The electrification program shall be prepared with priority to villages in which many households can be electrified with relatively short line extension, say within 2 km to villages for Punjab and Sindh and longer (4 km) for Balochistan and NWFP.

D5.8 Transport

The transporting distance of equipment and materials from the landing port of Karachi to the Munda site is very long, around 1,700 km, and therefore the inland transport of the project is an important subject, especially the transportation time and cost.

For heavy cargo transport, two alternative ideas, the land transport with either rail or trailer over entire route and the barge transport on the Indus river combined with short distance transport with trailer are conceived. The land transport is generally preferred to the river transport due to its shorter transportation period. The river transport is usually chosen only when the land transport is not appropriate. The heavy items of the Tarbela power station were transported mainly by ship. The 500/220 kV, 450 MVA transformers of the Peshawar 500 kV substation, consisting of three (3) single-phase units with transporting weight of about 90 tons, were transported with ship and trailer.

Formerly, the limit of land transport in Pakistan was around 90 tons. However, due to improvement of roads and bridges and use of multi-axle trailers, this limit for main road transportation has been much increased.

D6 Particulars of Existing Generating Facilities

Information on particulars of existing power stations of WAPDA and KESC was obtained from their annual reports and verbal information, etc. Lists of power stations were compiled as given below:

Table D6.1	List of Existing Hydel Power Stations
Table D6.2	List of Existing Thermal Power Stations

D7 Generation Development Program of the Government

In the revised 1999 5-year plan, GOP prepared Generation Development Programs based on two economic growth scenarios of Normal (6% growth) and Low (5% growth) as given below:

Table D7.1	Generation Development Program (May 1999), based on Normal Growth Scenario
Table D7.2	Generation Development Program (May 1999), based on Low Growth Scenario

D8 List of Identified Hydroelectric Projects

In Pakistan hydroelectric power project sites are investigated and studied by various parties. In 1997, WAPDA compiled lists of identified hydroelectric power projects in various categories as given below:

Table D8.1	Hydel Stations in Operation with WAPDA
Table D8.2	Hydel Projects at Implementation
Table D8.3	Hydro Projects at Feasibility/Pre-Feasibility Stage
Table D8.4	Identified Projects with WAPDA
Table D8.5	SHYDO Projects
Table D8.6	Medium Schemes Identified in Northern Areas
Table D8.7	List of Low Head Sites

D9 Transmission System Analysis

D9.1 Conditions of System Analysis

(1) Assumed transmission system

The Pakistan transmission system is interconnected with 500/220 kV transmission system covering the whole country, in which the Munda power station will be connected to the northern part of the entire network. In carrying out the transmission system analysis related to the Munda connection to the network, the following were assumed:

- The transmission network assumed for the system analysis is the northern system up to Gatti and Lahore substations as shown in Figure D9.1 for the 500 kV system and D9.2 for the 220 kV system. The recommended plan is to connect the Munda power station with the New Shahibagh substation with a 220 kV double circuit transmission line. For alternative plans the Munda power station is to connect to the Charsadda 500/220 kV substation. This substation will be connected with the Mansehra substation through a single circuit 500 kV line, and with the New Shahibagh substation through a 220 kV line with 2-bundled Rail conductors. The connecting plan with the Charsadda substation will be as shown below:

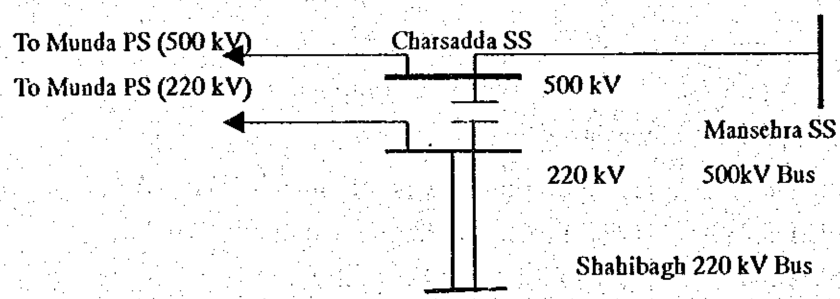

Figure D9.3 Alternative Configuration through the Charsadda Substation

- All the hydropower stations on the 500/220 kV system in the northern area, that are scheduled to be completed before the commissioning of the Munda power station, were taken into account including their associated transmission lines. Medium to small projects on the 132 kV systems can be taken into account by adjusting 220 kV substation loads.
- The influence of the connection of the Munda power station is great when the power system is small. Therefore, the transmission system just after the commissioning of the Munda project in the year 2010 was analyzed.
- Information on the power system was obtained from WAPDA, and the past transmission system analysis results of WAPDA for the year 2010 and 2005 were referred to.

(2) Assumptions for power system analysis

The following system conditions were assumed in carrying out the transmission system analysis:

- Equivalent phase spacing of transmission lines were assumed at 12.0 m for 500 kV lines (horizontal arrangement) and at 7.1 m for 220 kV lines (vertical arrangement) based on the data of the existing lines.
- Conductor spacing of bundled conductors, 2-bundle, 3-bundle and 4-bundle, is assumed at 45.7 cm (18 inches) for both the 500 kV and 220 kV systems based on the data of the existing lines.
- Particulars of 795 MCM ACSR (Drake) are assumed for all 400 sq. mm or 795 MCM class conductors.
- Conductor temperature was assumed at 60 °C.
- Impedance of the 500/220 kV auto-transformer is assumed at 12% for all transformers.
- 220 kV substation loads are assumed from the WAPDA's past power flow results of 2010 (used as it was) and 2005 (1.5 times figures were used). Loads of new substations were just assumed. All substation loads were connected to the 220 kV buses. The power factor of load is assumed at around 95%.
- The system loading conditions with and without the Munda output of 740 MW are prepared by adjusting the 500 kV side outgoing real power flow of the Gatti and Lahore substations.

D9.2 Items of Analysis

Power flow calculation was performed on the on the following 3 cases:

Alternative 1: Connection with the Shahibagh substation through 220 kV line

Alternative 2: Connection with the Charsadda substation through 220 kV line

Alternative 3: Connection with the Charsadda substation through 500 kV line

The power flow conditions were checked for the both cases of 'Munda full output' and 'Munda no output'. The cases 'Munda no output' is common to Alternatives 2 and 3, and five (5) cases in total were analyzed.

The fault level of the network around the Munda power station is far below the allowable fault level of the currently applied level (31.5 kA, 21.8 GVA at 220 kV) for 220 kV circuit breakers, as large power stations will be connected through long transmission lines. Therefore, the fault calculation to check fault level was not carried out.

D9.3 Results of Analysis

The results of power flow calculation for Alternative 1, with and without Munda output of 740 MW, are shown in Figures D9.4 (500 kV system) and D9.5 (220 kV system) for the case 'with the Munda output', and Figures D.9.6 (500 kV system) and D9.7 (220 kV system) for the case 'without Munda output'. With Munda 740 MW cases were analyzed for Alternatives 2 and 3, as shown in Figures D9.8 and D9.9 for Alternative 2 and in Figures D9.10 and D9.11 for Alternative 3. Without Munda case for Alternatives 2 and 3 is shown in Figures D9.12 and D9.13.

According to these results, both the bus voltage and line power flow are within normal operating ranges at all points of the transmission system, and no technical problems are observed in the results for all the Alternatives. However, the following are noted:

- The most of Munda power will be consumed in the Peshawar area, at New Shahibagh and Nowshera substations. Compared with the case of the Munda output being zero, power to Peshawar from both Tarbela and Ghazi Barotha power station will decrease significantly by the power generation at Munda power station and the power flow from these power station toward Lahore and Gatti will increase.
- In case that the Munda power station is connected to the 500 kV bus of the Charsadda substation, almost all of Munda power is stepped down to 220 kV at Charsadda and then transmitted to New Shahibagh.
- For the Shahibagh connection case the overall transmission loss decrease by the connection of the Munda power. The transmission loss of the Shahibagh connection case is clearly smaller than the Charsadda connection

case due to difference in the transmission distance to the main consumption center of the New Shahibagh substation.

It can be concluded that from the viewpoint of the power flow conditions the case to connect with the New Shahibagh substation through a 220 kV line is most appropriate among all the 3 alternatives.

D10 Transmission System Study

D10.1 Transmission System for Sending Out Power From Power Station

According to purposes of use, the transmission lines can be classified into the following two categories:

a) Network transmission line to connect two points in a network.

b) Power source transmission line to transmit the generated power of a power station to the network.

The power flow on a former network line varies from time to time and it is usually not possible to accurately predict future power on the line. Then, a standard design is usually applied to lines of this category. On the other hand, the sending power on the latter power source line can be determined based on the power station output and power on the line does not change through the operation period. Therefore, it is a usual practice to design a power source line case by case (design other than standard design is applied in many cases) so as to attain maximum economy based on the sending power. The transmission line connecting the Munda power station and adjacent substation belongs to the latter category and is to be designed based on the specific requirements so as to attain the maximum economy.

D10.2 Reliability Criteria of 'N-1'

The 'N-1' criteria require the continuity of power supply to load in the event of single fault event, i.e. separation of any one system element either line, transformer, generator, etc. Under these criteria, a 2-circuit transmission line to supply power to load needs to have power transfer capacity to send 100% power even in the event of one circuit being separated. However, in case of power source line for power supply to the national network like the Munda transmission line, transmission of 100% power under one circuit operation is not 'must' if the power supply to load from the network is not affected due to the separation of one circuit of the line.

In this case, the loss of power to the national network (not more than 150 MW) due to separation of one line circuit is smaller than the loss of one generator or transformer (185 MW at maximum). The national network can absorb such small variation of power with connected generators. The present WAPDA network must have capacity to meet the sudden loss of the largest Tarbela unit of 432 MW. In 2010, the network will have a larger capacity, more than double of the present installation.

Moreover, the chance of one circuit separation of the line will be around once in 10 years on the assumptions of line fault rate of 1-fault/100 km/year and 2/3 success rate of high speed reclosing. The possibility of loss of one circuit under full output operation under high temperature is very small.

Under such considerations, it is concluded that one circuit separation of the planned 220 kV line will not seriously affect the power supply to load from the Pakistan network. Any additional cost to further improve line reliability will not be justified on the reason of 'N-1' criteria.

D10.3 Transmission Capacity of 220 kV Line

It was told that in Pakistan there has been no past record to transmit more than 600 MW with a 220 kV line. However, there are a lot of examples in southeast Asian countries sending more than 740 MW with 220 kV class transmission line, by using lager conductors (Thailand) or by increasing number of conductors in bundle (Malaysia). In Japan, the standard transmission capacity of a 275 kV line is 750 and 1,500 MW per circuit with 2- and 4-bundled thermo-resistant 795 MCM ACSR. There are no technical problems in sending 740 MW power with a double circuit 220 kV line.

The 500 kV transmission will not be required technically. The Munda power will mainly be consumed in Peshawar and its surrounding areas according to the results of power flow studies in Appendix D9. In case that the Munda power station is connected to the Charsadda substation with a 500 kV line, the most of power will be stepped down to 220 kV at Charsadda and transferred to Shahibagh for consumption in the Peshawar area. Thus the 500 kV transmission will increase not only cost but also power loss due to unnecessary voltage step up and down.

The large cost for 500 kV transmission can be economically justified for a long distance transmission of large power for instance the transmission of the Tarbela power to Lahore and Gatti. For short distance (only 30 km) transmission of medium power (740 MW) of the Munda case, the 220 kV transmission will be most preferable from the technical and economic viewpoints.

D10.4 Difficulty in 220 kV Line Connection to Shahibagh Substation

Through site reconnaissance it was found that the site of Shahibagh substation, the main substation for power supply to Peshawar, is close to the city area, and there will be some difficulties in aligning many routes for many 220 kV lines. In the present design, at least 3 lines from the Peshawar 500 kV, Nowshera and Charsadda substations are to be connected to this substation. It is considered that there will not be much problem in connection of additional one more line from the Munda power station. However, relocation of some small houses or crossing over brick walls may be necessary. In Japan there are many examples to lay underground cables in several kilometer sections approaching to substations if a substation is surrounded with houses.

In case that the route selection is not possible, it will be obliged to construct a 220 kV line to the Charsadda substation or to construct a 220 kV line to Shahibagh via the Charsadda site to connect with the Charsadda substation later.

D10.5 Construction of Charsadda Substation

There is a plan to construct a 500 kV line from Mansehra to a 500/220 kV substation at Charsadda to interconnect with the Peshawar system. This 500 kV line will further be extended in future to the Peshawar 500 kV substation. This plan will surely be required after the commissioning of the Basha hydroelectric power station. However, according to the result of the 2010 power flow study based on WAPDA's load forecast in Appendix D9, the power flow on this 500 kV line is too small in 2010 to justify necessity of this 500 kV system.

The construction cost of this system is large, however this system is not essential for the operation of the Munda power station. Therefore, this system was assumed to be constructed under another transmission project when the necessity of the system is justified. Thus, the construction cost of this system is not included in the project cost of the Munda project.

D10.6 Technical Particulars of the Planned Transmission Line

The technical particulars of the planned 220 kV transmission line are as given blow:

Type: The transmission line will be a double-circuit tower line of vertical conductor arrangement with one overhead earthwire on the top of tower.

Conductors: Conductors will be 2-bundled ACSR, Rail (954 MCM), the standard conductor size for 220 kV lines in Pakistan. This conductor size is same as that of the Ghazi Barotha–Nowshera–Shahibagh–Peshawar line. This line can send about 700 MVA with one circuit based on the current capacity of the conductors.

Overhead earthwires: The overhead earthwire on the top of tower will be Composite Fiber Optic Overhead Ground Wire (OPGW) with at least five SM mode optic fibers of not smaller than 70 sq. mm in sectional area. In case that the optical communication is not adopted to the transmission line, stranded aluminum-covered steel wire of 70 sq-mm will be installed.

Line insulation: Insulator discs will be normal suspension insulators made from porcelain or toughened glass, 254 mm in diameter and 146 mm in spacing. The number of insulator discs in one insulator string will be 15 for both suspension and tension strings.

Wind velocity: Wind velocity to be applied to design of the transmission line is 160 km/hr.

D10.7 Comparison of Alternatives

Specific features and rough construction costs of conceivable alternative plans that were raised by WAPDA are compared below.

(1) 220 kV connection to Shahibagh substation

This is the plan proposed and recommended by the JICA team. The total estimated construction cost of power station main transformers, 220 kV switchyard, 220 kV line and extension of receiving substation is 26.3 Million US Dollars. This alternative will be the least cost plan and comparative costs of other alternatives are expressed by additional costs to this plan.

In case that 3-bundled conductors (3 x 795 MCM) enough to carry full load current with one circuit are installed, the additional cost for line will be 0.8 Million US Dollars, and the additional cost for the line with 3-bundled Rail conductors will be 1.8 Million US Dollars.

The additional cost for adding one more single circuit line with 2-bundled Rail conductor line is estimated at 5.6 Million US Dollars including 220 kV switchgear at the both ends.

(2) 220 kV connection to Charsadda substation

The power from Munda to Shahibagh, the main consuming station, flows on the 220 kV line from Charsadda to Shahibagh. Therefore, some increase of power loss is inevitable and the sending power from Mansehra to Peshawar may be restricted. The sectional area of conductors of Charsadda-Shahibagh line needs to be increased in case that power from Mansehra must be increased.

The overall construction cost is same as the above Case (1) as the line length from Munda to Shahibagh and to Charsadda is almost equal.

(3) 220 kV connection to Shahibagh substation through Charsadda site

Technical comments are same as the above Case (2). Additional cost of 7.5 Million US Dollars is required for approximately 30 km longer 220 kV line between Charsadda and Shahibagh.

(4) 500 kV connection to Charsadda substation with unit connection of power station transformers

The 500 kV circuit connection of power station is assumed to be similar to that of the 220 kV case, i.e. double bus with a bustie.

Construction of very wide switchyard for the 500 kV open outdoor switchgear is not possible. Therefore, the 500 kV switchgear must be of the very high cost GIS type and be arranged at the backside of the powerhouse.

The 500 kV line is assumed to be of single circuit construction, as the loss of entire Munda power will be allowed for the 2010 Pakistan network with more than 2-times the present capacity. The conductor size is assumed to be 4-bundled 477 MCM, which is same as the standard design for small power in Japan. The assumed additional cost on the 220 kV proposed design is 46.1 Million US Dollars, 2.75 times of the proposed plan is required.

The additional cost of 0.8 Million US Dollars (2.78 times the proposed) will be required in case that a 500 kV line of the standard design (conductors of 4-bundled 795 MCM) is adopted.

The addition of 16.3 Million US Dollars (3.37 times the proposed) is required on the cost of the above single circuit economic design in case that 2-circuit line of the standard design are adopted for line and switchgear on the both ends.

(5) 500 kV connection to Charsadda substation with double-secondary connection of power station transformers

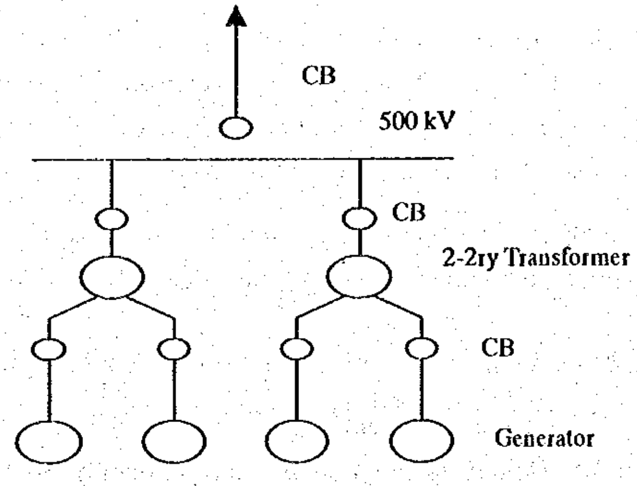

Figure D10.1 500 kV Connection with Double-secondary Connection of Transformers

The unit capacity of 220 MVA is relatively small for 2-winding 500 kV transformer and the quantity of 500 kV switchgear can be reduced by adopting 440 MVA, double-secondary transformers. In this case, two generators are connected to one transformer, and the single bus arrangement was assumed as the number of 500 kV circuits is only three. Circuit breakers are required on the generator circuits. The 500 kV line is single circuit with 4 x 477 MCM. The overall additional cost over the proposed 220 kV plan is 36.9 Million US Dollars (2.4 times the proposed).

The necessary additional costs for an additional line, for use of standard conductors, etc. are similar to the above Case (4).

D10.8 Conclusion

As mentioned above, the 220 kV connection to the Shahibagh substation with a 220 kV line with 2-bundled Rail conductors will be the least cost alternative that satisfies technical requirements, and its operating power loss will be low.

In case 500 kV transmission is adopted, the cost of transmission will increase significantly. The most of Munda power will be consumed in the Peshawar area, and unnecessary step up at Munda and step down to 220 kV again at Charsadda for local supply is not technically reasonable and requires large additional cost.

The network calculation of JICA team is based on WAPDA's past power flow calculation for 2010. The JICA team found connection to the load center substation, Shahibagh, was the most appropriate station. However, situations of surrounding circumstances will change from time to time, and the connection plan needs to be reviewed again based on the situation at that time during the detailed design stage.