CHAPTER 7

PRELIMINARY DESIGN OF PLANNED TRANSMISSION SYSTEMS

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7.1 Currently Applied Standards

(1) Standard Specifications

In the initial stage of development of the Sri Lankan power system the British Standards (BS) were introduced to Sri Lanka by British consultants and have been applied to various transmission system equipment and materials. At present, based on the tendency toward the worldwide application of the IEC standards, CEB is on the way to converting the standards of electrical facilities from BS to IEC. It is the world-wide consensus to apply the IEC standards as common standards. Particulars of the BS standards have already become similar to those of the IEC standards, and the recent Japanese standards are also formulated basically so as not to contradict with the IEC standards. However, the BS standards are still applied in Sri Lanka to the steel materials and hot-dip zinc galvanizing.

The CCITT recommendations are applied to communication facilities according to worldwide practices.

(2) Technical Standards

There are no Sri Lanka's own established technical standards or safety codes for the power system facilities. Design criteria established by British consultants in the early days have been applied for design of electrical facilities. The same criteria have been adopted also for electrical facilities designed by consultants from other countries. So far, no problems have occurred due to application of the above technical specifications.

7.2 Preliminary Design of Transmission System Facilities

7.2.1 Basic Principles

The power supply utility is a public enterprise to provide the electric energy essential to the human lives and economical activities to all the nation through power supply facilities as basic infrastructure. Therefore, the power supply facilities shall be designed so as to attain stable supply of power without affecting the social lives and safety of human bodies and also power facilities themselves. Coordination with the natural and social environment is a most important factor in designing power facilities.

Based on standard service criteria in the government regulation, power facilities shall be designed so as to supply sufficient quantity of electricity to satisfy the public requirement at a high quality (normal supply voltage and frequency) with minimum of interruption.

To meet such requirements, system component facilities shall be well coordinated in an efficient manner.

The technology of electrical engineering especially those based on semiconductors are improving rapidly and equipment are being modified with short interval. The transmission system plan in this Study are prepared based on currently available technology, and every time when the plan is realized in future the design is required to be reviewed referring to technical practices at the time.

7.2.2 Transmission System

(1) Transmission System Voltage

The current standard voltage of 132 kV for power supply to grid substations is not adequate for transmission of large power to meet growing demand in the future. The substantial portion of future system extensions will be by 220 kV, which is currently applied partly, to secure a larger transmission capacity.

For the purpose of bulk power transmission toward the end of the plan period of 2015, selection of a voltage higher than 220 kV was taken into account subject to situation. In such case, the land size of Sri Lanka is not wide and the introduction of 500 kV system which is widely applied in the southeast Asian countries will not be justified. The appropriate higher system voltage for Sri Lanka next to 220 kV will be either 330 kV or 400 kV. 400 kV is currently applied widely in Europe, Middle East, India, etc., while 330 kV is applied in the USA, Korea, Taiwan and African countries.

Among power stations planned in the long-term generation expansion plan, the installed capacity of the largest Trincomalee coal thermal plant is 1,200 MW. The power flow on the main line to Habarana is about 800 MW after deducting station service power and 132 kV supply to Trincomalee, Anuradhapura and Kilinochchi, and a 220 kV line of double circuit construction with quadruple Zebra conductors was proved to have enough transmission capacity by the power system analysis in Chapter 6.

(2) Review of System Capacity

The planned transmission system shall be reviewed at first from the viewpoints of system transmission capacity; long duration current capacity and short time capacity under short circuit under normal operation, and then under single contingency conditions.

The transformer has large thermal capacity and can withstand a certain amount of overload under an abnormal system condition by sacrificing its service life. According to practices in Japan, the transformer was assumed to withstand 110% overloading for relatively long duration and 130% for relatively short duration necessary for switching over of some loads.

(3) Redundancy Arrangement

Major transmission lines shall be of double circuit construction so that there is no serious impact on the entire power system even under absence of one circuit with support by other lines if available.

The grid substations shall basically be connected with two transmission lines to secure power supply even under failure of any one circuit.

In design of substations, consideration must be paid to separation of one transformer. Even when one transformer is out of service, full power supply shall be able to be maintained and system voltage shall be kept within an acceptable range with the help of redundant facilities in the same substation and support from adjoining substations.

(4) Parallel Operation with Cogeneration

The cogeneration is the generation means with dual output, heat and electric power, and higher overall efficiency can be attained. This type of generation is usually operated as self-generation, mostly with interconnection with public system. There are cases that power utilities does not purchase power from such self-generation to avoid technical troubles to the public power supply. However, from the viewpoint of overall efficiency of energy utilization of the country power utilities should purchase surplus energy from such self generation.

There are following three kinds of cogeneration conceived in Sri Lanka:

(a) Synchronous generators operated by steam turbines, diesel engines, gas turbines, etc. This is the normal form of generation of self generation.

(b) Asynchronous generators like induction generators, operated by wind mills, etc. Induction generators are used to curtail equipment cost. For operating induction generators without problems stable power system of ample capacity is required.

(c) AC power converted from DC source of solar cells, etc. The generated power is in DC, but for use of normal apparatus and interconnection with the public system DC power needs to be converted to AC with inverter.

There are two types of operation modes of self generation, independent operation and parallel operation with the public power supply system. For users with self generation, the interconnected operation is much preferable as the generator operation becomes much more stale by the operation dependent to the public system and generators can be operated with high load factor and at a high efficiency. In this case, two watt-hour meters are required for measuring the both of receiving and sending out power. In order to avoid bad affect to the public supply due to a fault on the self-generation side and to avoid influence of a fault in the public system to self-generation, proper protective devices shall be provided at the interconnection point for necessary separation of interconnection by detecting abnormality on either side. In Japan, provision of proper protective devices by user is requested in the supply contract to perform such parallel operation.

7.2.3 Transmission Lines

(1) Current Design Practice

CEB transmission line designs are currently based on a deterministic approach, that is, ultimate loads on towers and foundations are derived using factors of safety on working loads which are determined from the applied maximum wind speed. The following design values are used:

- Maximum wind speed (3 second gust): 145 km/hour (40 m/sec)
- Wind pressure on conductors, earthwires and insulators: 970 N/m^2
- Wind pressure on tower steelwork (1.5 x one face): 1640 N/m^2
- Factors of safety:
  Conductors and earthwires, UTS / MWT: 2.5
  Conductors and earthwires, UTS / EDT: 4.5
  Insulator strings and fittings, UTS / MWT: 3.0
  Suspension towers under normal working loads: 2.0

Tension towers under normal working loads: 2.5
Foundations under normal working loads: 2.5
All towers under broken wire loading: 1.25
All foundations under broken wire loading: 1.5

- Conductor sag / tension basis is MWT at 7°C with maximum wind, EDT at 32°C with no wind.
- Maximum conductor temperature: 75°C
- Basic span for 220 kV line: 350 m
- Basic span for 132 kV line: 305 m
- Electrical insulation :

	132 kV	220 kV
Minimum creepage distance (mm):	3500	4900
Specific creepage (mm/kV):	24	20
Impulse withstand voltage (kV):	750	1050
Power frequency withstand voltage (kV):	275	395
Arc horn gap (mm):	1500	2000
Live metal to earth clearance (0 - 10 degree):	1650	2200
Live metal to earth clearance (10 - 40 degree):	1550	2050
Minimum clearance to ground (m):	6.71	7.01

Note : UTS : Ultimate Tensile Strength
MWT : Maximum Wind Tension
EDT : Every Day Tension

The frequency of thunderstorms is high, the Isokeraunic level is quoted in CEB specifications as 60 days per annum on average but much higher values (up to 120) have been recorded at some meteorological stations. All new transmission lines are of double circuit construction with two 7/3.25 mm galvanized steel earthwires directly above the phase conductors (zero degree shielding angle). The maximum tower footing resistance is specified as 10 ohms for both 132 kV and 220 kV lines.

The current carrying capacity of the existing conductors is calculated for the following three cases of

Daytime rating: 8:00 am to 16:00 pm
Evening rating: 17:00 pm to 7:00 am
Emergency rating: Duration of 1 hour

The following are the conditions considered appropriate for each period of time.

	Day	Evening	Emergency
Solar radiation (W/m^2)	1200	0	0
Ambient temperature (°C)	35	30	30
Wind speed (m/sec)	0.6	0.6	0.6
Max. conductor temperature (°C)	75	75	90

The results of conductor current capacity calculation are presented in Table 7.2.3-1. It should be noted that operation of the overhead line conductor at 90°C will result in increased sag of approximately 0.6 m compared with the 75 °C case on the basic span such that minimum ground clearance may be infringed.

It should also be noted that many of the old lines, those constructed before 1975, were designed for a maximum conductor temperature of 54°C (130°F) as indicated in Table 7.2.3-2. Operating these lines is therefore equivalent to an emergency rating which will result in additional sag of approximately 0.75 m on the basic span. The current rating of these lines should therefore be restricted to the values shown for 54°C operation and the 75°C Evening Rating used as the Emergency condition.

(2) Design of Future Transmission Lines

CEB tower loadings are based on deterministic design principles using factors of safety and a maximum design wind speed of 145 km/hour. It will be worth reviewing these design values and comparing them to probabilistic design methods. These may result in savings in tower design or the possibility of the use of larger conductors on existing towers. A detailed study by a meteorological expert of all the available wind data for the whole of Sri Lanka would be necessary to establish the basis for probabilistic designs. The data records should be available for a minimum of 30 years and must be consistent, that is recorded with reliable instruments using the same recording regime.

CEB continue to use ACSR conductors though it is well known that ACSR is particularly prone to corrosion in coastal areas. AAAC conductors have higher current carrying capacity and lower losses than ACSR for the same overall diameter, and are not prone to corrosion. It may be more appropriate to use AAAC to replace existing ACSR when uprating old lines.

Conductor	ACSR "Lynx"	AAAC "Elm"	ACSR "Zebra"	AAAC "Yew"
Overall diameter (mm)	19.53	18.8	28.62	28.42
Aluminium area (mm^2)	183.4	211.0	428.9	479.9

In Japan the maximum operating temperature of conductors is generally considered to be 80°C and it is proposed that future transmission lines are designed for 80°C operation. Table 7.2.3-3 of proposed conductors shows the current ratings based on both 75°C and 80°C operation.

All the conductors proposed are ACSR with some additional sizes to increase the current capacity. In coastal areas it is recommended that ACSR with an aluminum-clad steel (AS) core is used instead of the normal galvanized steel core. AAAC conductors of similar sizes could also be used.

The major transmission lines and other lines which constitute important communication paths are recommended to be provided with OPGW (Composite Optical Fiber Ground-Wire) to attain the optical communication for line protection and voice and data communication. In this case, the OPGW is installed as one of two overhead earthwires.

(3) Underground Cable Lines

In the municipal area of Colombo, necessity to construct underground cable lines, 132 kV cables and also 220 kV cables in future, will increase with growth in power demand in the city center area. It is recommended to use CV (cross-linked polyethylene insulated and PVC sheathed) cables instead of currently used OF cables. This type of cables do not require oil supply facilities as for the OF cables, and are much easier in construction and as well as maintenance. Recently, use of CV cables is a world-wide tendency.

(4) Selected Line Routes

Routes of selected transmission line routes selected as the result of transmission system studies in Chapter 6 were reviewed through map study and site investigation with CEB counterparts and the selected route maps are compiled in Appendix A7.1.

7.2.4 Transmission Line Protection Systems

(1) Basic Principles of Line Protection Design

(a) Application of current practices

Till now, the application of distance relaying schemes with the help of PLC communication channels for overhead transmission lines and the pilot-wire relaying schemes for underground cables and short overhead lines have been the standard practices of CEB. These practices are still being applied widely for line protection of the medium class transmission systems in the world, though minor improvements like application of digital relays have been made from time to time.

There are no reasons to change these practices at the present stage and relaying practices similar to those of the current system are planned to be applied on the planned transmission system.

(b) Basic principles of relaying system design

The general functions to be provided with the line relaying system are mentioned below:

1. When a fault occurred on a line, the fault shall be cleared at high speed without failure so as to limit impacts by the fault to the minimum.
2. In addition to the main protection, the backup protection shall also be provided.
3. Protection coordination with adjacent sections shall be maintained and the relaying system shall be reviewed so that there is no unprotected portion.
4. Relays shall not operate by a fault outside the protected section, transient oscillation of voltage and current, electromagnetic and static induction, etc.
5. For major transmission lines of 220 kV and higher voltage, the main protection relays shall be duplicated, and relaying components such as CT windings, CB tripping circuits, communication channels, etc. shall also be duplicated.
6. T-branched substations must be provided with proper protection relays for rapid separation in case that a fault occurred on the connected transmission system.
7. Autoreclosing functions shall be provided for quick and automatic restoration of power supply after a fault and succeeding tripping. Applied autoreclosing shall be rapid reclosing for major systems and slow speed for radial feeders.
8. Important overhead lines shall basically be provided with fault locating functions associated with digital (distance) relays and.
9. In the Colombo area, many short section of overhead lines are anticipated and the pilot-wire protection will be applied to such sections.

(2) Application of New Protection Scheme

(a) Current differential protection for trunk lines

For major transmission lines it is a recent tendency in the world to apply the digital current differential practice, which detect a fault in the protected section by comparing the current values of each phase at the both ends of the protecting section with microprocessor-based digital relays at a sampling rate of 12 times (there are cases of 8 times) in one cycle. This protection is acknowledged as the most reliable based on the current technology, and applied worldwidely to major transmission lines. For this purpose, the current value information of three phases at one end must be sent to the other end 12 times in one cycle, and for this data sending a high speed and reliable digital communication link which can be attained by the optic or micro wave channels are required.

Highly reliable three-terminal protection is possible by applying this current differential practice for major lines. In Japan, there are many three-terminal sections with T-branching in the 500 and 275 kV systems with the current differential protection.

(b) Quick separation of T-branched substations

In case there is a fault on a transmission system protected by the distance relays involving T-branched substations, it is essential to rapidly separate the branched substations by detecting a fault to enable autoreclosing of the main line. For this purpose, undervoltage relays with current elements to detect direction of fault on inter-phase and phase-to-ground circuits are used in Japan. These relays activate circuit breakers for rapid separation.

(c) Overload protection of transformers

When one of parallel operated two or more transformers is failed, the remaining transformer may be overloaded for some duration before shifting of some load to other substations or shedding loads. The transformer has large thermal capacity to withstand 50% larger load for about 30 minutes before reaching the allowable limit of temperature. However, the overcurrent protection by IDMT type over-current relays operate in relatively short time, being several seconds to utmost say 10 seconds, and are not suitable for overload protection of transformer.

The overload protection is a system to protect a transformer based on its thermal capacity with the help of microprocessor and save the connected load from total failure. In Japan, this protection is provided to most of transformers. In this case, the current setting of overcurrent relays is selected high for short circuit detection.

7.2.5 Substations

(1) Current Design Practices

The applied standards on substation equipment have almost been converted from old BS to world-wide IEC. Recent transformers are based on the IEC standards.

Different figures are used as BIL (Basic Insulation Level) of major equipment, transformers (lower values) and switchgear (higher values) as given below:

	132 kV	220 kV
- Transformers	550 kV	850 kV
- Switchgear	650 kV	950 kV

The adopted standard capacity of transformers of grid substation is 31.5 MVA replacing the former capacity value of 30 MVA based on the IEC standard capacity value. The 30 MVA class is widely applied in the world and is considered to be appropriate for transformers of distribution use. Larger capacity ones of 60 MVA (63 MVA by IEC) are operated at the Kelanitissa power station with large load. As for 220/132 kV tie transformers, the unit capacity of existing transformers at Biyagama and Kotugoda is 250 MVA consisting of three single phase units. This capacity is considered as the standard capacity and smaller capacity of 150 MVA is going to be adopted for relatively small substations.

At present, the standard quantity of transformers at one grid substations is two sets and in many cases one T-branched substation is connected to two circuits but normally operated with connection to one circuit of the transmission line. Though this practice is acceptable when substation load is relatively small, with increase in substation load imbalance of line loading will create problems. In such a case, it is recommended to connect the two divided transformers to two circuits and operate the substation in two groups with circuit separation.

The arrangement of the 132 kV circuits of grid substations especially T-off substations is not suitable for extension of the 132 kV system. The substations seem to be designed not taking into account future line extension therefrom.

(2) Preliminary Design of Planned Substations

Outline of substation design, quantity of transformers and their capacity, number of connected feeders, is determined according to the results of the transmission system planning mentioned in Chapter 6. Regarding design of particulars of substations the followings are assumed:

(a) For 132 kV substations, the double bus system with a bustie circuit is assumed for major substations, single bus with bus section arrangement for a normal grid substation. The bus section circuit breaker is required when the quantity of transformers in one substation becomes three or four.

(b) For a substation only to receive power with two transformers, two circuit breakers on either of line or transformer circuit will be assumed to be omitted and one circuit breaker is planned to be operated for both line and transformer faults.

(c) The idea of constructing low cost substations to utilize replaced 16 and 10 MVA transformers to the fullest extent, in the Medium Voltage Distribution Development Plan, 1995 - 2005, of CEB is supported. However, in designing such a substation to be connected in tee with a major 132 kV line the protection system to separate the substation from the major line rapidly when a fault occurs on transmission line is essential to minimize influence to the major line. The automatic rapid reclosing can also be applicable to major lines with T-branchings.

(d) Substantial portion of static capacitors will be connected to the 33 kV tertiary windings of 220/132 kV tie transformers. In case that additional capacitors are required at 132/33 kV grid substations, 33 kV capacitors will be connected to the 33 kV buses of the grid substations.

(e) 33 kV switchgear are of GIS cubicle type and the standard number of feeders is assumed to be three per one 31.5 MVA transformer.

(f) In selecting sites for new substations, the following factors shall be taken into account:

    i) Access road for transportation of heavy items

    ii) Easiness in connection of transmission lines and outgoing distribution feeders

    iii) Environmental considerations:
        - Influence to general public
        - Commercial institutions
        - Industrial activities
        - Flood

    iv) Separation from populated areas

v) Geological check such as soil bearing capacities, soil resistance, well water, etc.

vi) Construction cost

The JICA study team is not familiar with current problems of the distribution systems, land problems and other related site information. Therefore, locations of new substations were determined under cooperation with CEB engineers.

(g) Results of preliminary design

Location maps and connection diagrams of the planned substations are prepared and included in Appendix A7.2.

7.2.6 System Control and Load Dispatching Facilities

For proper functioning of the system control operation, the present load dispatching facilities are not adequate. Though the equipment was commissioned 12 years ago, the technological progress of this kind of equipment is very rapid and the existing equipment have already become out-of-dated and are not provided with functions which this type of facilities should have as mentioned in Clause 3.5.5. It is required to replace the existing equipment with facilities provided with full SCADA functions.

The upgrading of the existing SCADA system was planned by CEB and an international tender was called with the World Bank finance in 1994, but its contract has not yet been concluded.

Particulars of the planned SCADA system remodeling are explained below:

(a) Master station

The existing master station equipment of SCC, computers, peripherals and operator consoles not including the mimic board will be replaced with new SCADA system equipment.

The main computers (processors) must be arranged in a redundant configuration to satisfy the 99.95% availability requirement. The SCADA system must cope with a transmission speed of minimum 200 baud per outstation for maximum of 70 outstations. Three operator consoles, two printers for the purpose of data logging, network event recorders, digital display of frequency at the Kolonnawa substation and interface with three guest computers will be provided.

Alarms and events signals are required to be transmitted within 5 to 10 seconds under the normal system conditions (more than 30 seconds at present) and energy production values of every 30 minutes are transmitted within 30 seconds from a power station to SCC. In order to attain the response time required above, the 600 baud transmission speed via the digital micro-wave network is proposed.

The existing mimic board will be retained. With this board, approximately 250 nodes will be connected and indicated. However, the obsolete drivers have to be replaced by a new driver system which can cope with the expansion requirements of CEB to the year 2005. On this occasion, CEB has planned addition of the following nine stations for the period from 1995 to 2005.

i) Sri Jaya'pura
ii) Broadlands
iii) Mawella Coal
iv) Trincomalee Coal
v) Upper Kotmale
vi) Kukule
vii) BOO/BOT Diesel
viii) Ginganga
ix) New Anuradhapura

(b) Outstations

Old seven sets of existing RTUs will be replaced with new equipment and the remaining 13 RTUs may be retained if the new SCADA system can integrate them without technical problems. For other stations, new RTUs with transducers and interface relays will be supplied by the new system.

(c) Operation philosophy

The following functions will be provided for proper energy management.

- Short-term load forecast by a program in hot line.
- Short-time hydro optimization program
- Generator control

(d) Network management

A network management software package to monitor and control the system will be incorporated into the SCADA system. The network system should include the following applications:

- Status estimation of current power system
- Load flow situation study
- Optimal power flow to minimize transmission system loss
- Contingency analysis
- On-line short circuit application

This helps operators to determine circuit breaker fault ratings against three-phase fault and single-phase-to-earth fault.

This load dispatching system improvement plan is expected to be realized in near future. The expected practical life time of a load dispatching facilities is estimated not exceed around 10 years. Replacement of the currently planned central system will be required in the period of 2005 to 2010.

In future, when the power system is extended further it is usual practice to provide two separate load dispatching systems; one is for generation system planning and control to attain the balance of demand and supply and the other for management and control of the transmission system. The latter will be regionalized and/or stratified with extension of the transmission system. In addition, control centers for the Colombo system and several regionalized systems will be required to control MV distribution systems. The system control functions of the 33 kV systems had better be regionalized.

Currently the PLC system is used for transmission of data and signal. However, available number of channels of the PLC system is limited due to limitation in channel allocating capacity. In future when many stations are connected to the system, it will be required to install microwave systems between SCC and major substations around Colombo to increase the channel capacity. This method is applied in most of countries in South-East Asia.

7.2.7 Communications Systems

(1) Current Design Practice

(a) Current Practice

Present CEB standard and practice for PLC circuit is of the phase-to-phase coupling. In this case two each of line traps and CC/CVTs are required at each coupling point, and the cost of the coupling facilities is approximately twice compared with that of the phase-to-earth coupling. The phase-to-phase coupling however provides a number of important advantages, which include lower attenuation and greater security against a communication failure due to line faults. As approximately 80% of faults are of single-line to earth, communication is possible even under this fault and this arrangement is expected to provide a high security. Therefore, this practice is to be based on an adequate design philosophy.

(b) Standard specifications

The present PLC system fully complies with the IEC standards.

Digital micro-wave system is designed based on the CCITT and CCIR recommendations (ITU-T and -R now), and BSI.

(2) Design of Future Communication Facilities

(a) General

The communication system for power network use has been developed to achieve requirements from the power system operation and control. The communication system functions for the two major purposes, one is for protection and control of the power system including the load dispatching use, and other is for telephone system for administrative use and automation of administrative works like the electricity billing system and an organization of power company or board. The communication system has became similar to a neuron network and an essential sector for operation of the power system.

In Japan, the major communication means for line protection, in association with technical progress of the protection relays and power supply systems, has already been converted from PLC to the combination of digital micro-wave and optical fiber systems as shown in Fig. 7.2.7-1. This is the result of study on up-to-date technology and of practical use. Design of the communication system for CEB in the future thus shall take into account not only already established technologies but also advanced new technologies. Outline of the conceived communication system for the CEB power system is shown in Table 7.2.7-1.

(b) Design of communication system up to the year 2000

The PLC system will be applied even in future up to 2000 to the extension of 132 kV transmission system.. The output power of the PLC terminals is basically required to overcome signal attenuation and noise due to corona on an overhead line. The line attenuation and corona noise level mainly depend on the transmission line design, thus the performances of the PLC system can be worked out after the detailed design of the transmission line is completed.

It is not possible to apply the present method of PLC system for the T branching to teleprotection in view of low reliability of signal transmission. According to available theory for the PLC circuit, a high cost is required to establish a reliable communication circuit to the T branched circuit by PLC. Telephone communication is possible by the T branching circuit.

For planning a PLC system, procedures shown in Fig. 7.2.7-2 are to be followed. Information and data necessary for planning are as given below:

i) Line length and line voltage provided from power system planning data.

ii) Design data of transmission line.

iii) Design criteria of PLC system by communication engineer.

The performance of PLC system basically depends on transmitting power of PLC terminals, signal attenuation and noise level at receiver input points of PLC terminals. The signal attenuation on high voltage lines and noise at the receiver input points can be calculated accurately if all relevant parameters as shown in Tables 7.2.7-2 and 7.2.7-3, which are required for the planning process shown in Fig. 7.2.7-2, are available.

If non-homogenous transmission line having transposition, T-branching and so on is designed, careful study on PLC system is necessary.

(3) Tendency to Apply Digital Communication

The digital communication is at present widely applied to power systems from reasons as given below:

- Digital signal are used for the SCADA system for sending telemetering and supervisory signals.
- The digital communication system is superior in properties against distortion and noise on signal to the analogue system.
- Cost of equipment like the multiplex sets are being decreased owing to mass production of parts.
- The same digital channel can be used for both data transmission and voice communication.

(4) Ideas for Utilization of High Speed Communication Means

(a) General

Requirements for digital communication traffic have increased remarkably with recent progress in technologies for power system control and protection. Concentration of traffic will become severe especially in the vicinity of SCC. In reply to the tendency toward increase in communication requirements for high speed and high reliability, the digital communication system with micro-wave and/or optical circuit is required to be established. After establishment of such high speed communication system, the existing PLC system shall be used for back-up service.

Actually such digital communication systems have already been installed for power systems of many South-East Asian countries.

In the existing CEB system, the communication channel requirements for the Kolonnawa - Polpitiya - Laxapana section and the Victoria - Kotmale - Biyagama section shall be reviewed. For the CEB system, there is a plan to upgrade the SCADA communication system to the duplicate route system with digital micro-wave/optical and PLC at 600 Bauds speed for handling 12 hydro and two thermal power stations, and over 40 substations. This system has enough channel capacity to assumed future communication.
It is recommend to gradually extend this practice to all power stations and grid substations in future. This practice can at first be applied to connect with some RTUs in grid substations near to the digital micro-wave stations.

(b) Redundancy of communication system

For the recent SCADA systems in many Asian countries, the duplicate route/path systems are employed for redundancy for communication; one is for normal use and the other for back-up. The most preferable combination will consist of micro-wave and optical path, but the micro/PLC or optical/PLC combinations with the latter as standby are also applicable.

(c) Use of power system communication facilities for public communication

In case that high speed and large capacity communication system is established on the transmission system, there are many cases that all available channels are not required for the power system use and in such case spare channels are diverted to use by the public system. Though the public communication system has already installed the micro-wave system, they may wish to acquire spare channels of the power system for standby use. In such case some of construction cost can be allocated to the public communication utility.

In Japan, a many number of optic cores are encased in OPGWs on transmission lines and some cores of them are used for public communication. Some power companies participate in public communication business and lend some cores to communication companies. There are similar examples also in other Asian countries.

Table 7.2.3 - 1 Existing Conductor Data

Code Name Type		Tiger ACSR	Coyote ACSR	Oriole ACSR	Lynx ACSR	Goat ACSR	Zebra ACSR
Steel Stranding		7/2.36	7/1.91	7/2.69	7/2.79	7/3.71	7/3.18
Steel Area (mm^2)		30.59	20.09	39.78	42.77	75.67	55.59
Steel core Diameter (mm)		7.08	5.73	8.07	8.37	11.13	9.54
Aluminium Stranding		30/2.36	26/2.54	30/2.69	30/2.79	30/3.71	54/3.18
Aluminium Area (mm^2)		131.1	132.1	170.5	183.4	324.3	428.9
Total Area (mm^2)		161.7	152.2	210.3	226.2	400.0	484.5
Overall Diameter (mm)		16.52	15.89	18.83	19.53	25.97	28.62
Greased Weight (kg/m)		0.602	0.522	0.782	0.842	1.489	1.621
Ultimate Tensile Strength (kg)		5914	4732	7730	8137	13838	13450
Modulus of Elasticity (kg/mm^2)		8200	7700	8200	8200	8200	7000
Temperature Coefficient (per deg C)		17.8x10-6	18.9x10-6	17.8x10-6	17.8x10-6	17.8x10-6	19.3x10-6
DC Resistance (ohms/km)		0.2204	0.2187	0.1694	0.1576	0.0891	0.0674
Current Rating at 54 °C	Day (A)	178	180	199	204	244	253
	Evening(A)	365	361	432	453	658	750
Current Rating at 75 °C	Day (A)	379	377	444	464	656	726
	Evening(A)	487	483	578	607	882	987
Current Rating at 90 °C	Emergency (A)	554	550	658	690	1005	1112
Fault Current 1sec (kA)		12.7	11.9	16.5	17.8	31.5	34.3

Table 7.2.3 - 2 Existing Transmission Lines Operating Temperature

Ref.	Section	Voltage (kV)	Circuits	Conductors	Max Design Temperature	Length (km)
2L1.	Biyagama - Kotugoda	220	2	Zebra	75	19.6
2L2.	Biyagama - Kotmale	220	2	2 x Zebra	75	70.5
2L3.	Kotmale - Victoria	220	2	2 x Zebra	75	30.1
2L4.	Victoria - Randenigala	220	1	2 x Zebra	75	16.4
2L5.	Randenigala - Rantembe	220	1	2 x Zebra	75	3.1
1U1.	Kelanitissa - Fort	132	1	UG. (Cu 500)		4.9
1U2.	Fort - Kollupitiya	132	1	UG. (Cu 350)		2.7
1U3.	Kollupitiya - Kolonnawa	132	1	UG. (Cu 500)		5.4
1L1.	Biyagama - Pannipitiya	132	2	Zebra	75	15.5
1L2.	Biyagama - Kelanitissa	132	2	2 x Goat	75	12.5
1L3.	Biyagama - Sapugaskanda PS	132	2	Lynx	54	2.1
1L4.	Kolonnawa - Kelanitissa	132	2	Zebra	54	2.2
1L5.	Kolonnawa - Pannipitiya	132	2	Lynx	54	12.9
1L6.	Kolonnawa -Sapugaskanda(T)	132	2	Coyote	54	6.6
1L7.	Sapugaskanda (T) - Kotugoda	132	2	Coyote	54	16.7
1L8.	Sapugaskanda (T) - SS	132	2	Coyote	54	4.6
1L9.	Kotugoda - Bolawatta	132	2	Coyote	54	21.0
1L10.	Bolawatta - Chilaw (T)	132	2	Lynx	54	22.6
1L11.	Chilaw (T) - Puttalam	132	2	Lynx	54	61.4
1L12.	Chilaw (T) - SS	132	2	Lynx	75	6.8
1L13.	Kolonnawa - Oruwala (T)	132	2	Lynx	54	14.0
1L14.	Oruwala (T) - SS	132	2	Lynx	54	3.4
1L15.	Oruwala (T) - Thulhiriya (T)	132	2	Lynx	54	36.0
1L16.	Thulhiriya (T) - SS	132	2	Lynx	54	23.9
1L17.	Thulhiriya (T) - Polpitiya	132	2	Lynx	54	28.0
1L18.	Kolonnawa - Avissawella (T)	132	2	Lynx	54	31.9
1L19.	Avissawella (T) - SS	132	2	Lynx	75	0.5
1L20.	Avissawella (T) - Polpitiya	132	2	Lynx	54	34.4
1L21.	Pannipitiya - Ratmalana	132	2	Lynx	54	6.9
1L22.	Pannipitiya - Panadura (T)	132	2	Goat	75	12.3
1L23.	Panadura (T) - Matugama	132	2	Goat	75	29.1
1L24.	Panadura (T) - SS	132	2	Lynx	75	4.7
1L25.	Polpitiya - Laxapana	132	2	Lynx	54	8.3
1L26.	Laxapana - Wimalasurendra	132	2	Lynx	54	5.1
1L27.	Laxapana - New Laxapana	132	2	Lynx	54	0.6
1L28.	New Laxapana - Polpitiya	132	2	Lynx	54	8.0
1L29.	New Laxapana - Canyon	132	1	Lynx	54	10.0
1L30.	Polpitiya - Kotmale	132	1	Lynx	54	29.5
1L31.	Kotmale - Kiribatkumbura	132	1	Lynx	54	22.5
1L32.	Kiribatkumbura - Anuradhapura	132	1	Lynx	54	143.9
1L33.	Polpitiya - Ukuwela	132	1	Lynx	54	59.3
1L34.	Ukuwela - Habarana	132	1	Lynx	54	82.3
1L35.	Habarana - Anuradhapura	132	1	Lynx	54	48.9
1L36.	Ukuwela - Bowatenna	132	1	Lynx	54	30.0
1L37.	Kiribathkumbra - Kurunegala	132	2	Lynx	54	34.6
1L38.	Habarana - Valaichchenai	132	1	Lynx	75	99.7
1L39.	Anuradhapura - Trincomalee	132	2	Lynx	54	103.3
1L40.	New Laxapana - Balangoda	132	2	Lynx	54	43.9
1L41.	Balangoda - Samanalawewa	132	2	Zebra	75	19.0
1L42.	Samanalawewa - Embilipitiya	132	2	Lynx	75	38.0
1L43.	Balangoda - Deniyaya (T)	132	2	Tiger	54	44.2
1L44.	Deniyaya (T) - Galle	132	2	Tiger	54	57.3
1L45.	Rantembe - Badulla	132	1	Lynx	75	37.0
1L46.	Badulla - Inginiyagala	132	1	Oriole	54	79.9
1L47.	Anuradhapura - Kilinochchi(T)	132	2	Lynx	54	128.8
1L48.	Kilinochchi (T) - Chunnakam	132	2	Lynx	54	67.2

Table 7.2.3 - 3 Proposed Conductor Data

Code Name		Lynx	Bear	Goat	Zebra	Grackle	Pheasant	Parrot
Type		ACSR	ACSR	ACSR	ACSR	ACSR	ACSR	ACSR
Steel Stranding		7/2.79	7/3.35	7/3.71	7/3.18	19/2.27	19/2.34	19/2.55
Steel Area (mm²)		42.77	61.60	75.67	55.59	76.9	81.71	96.88
Steel core Diameter (mm)		8.37	10.05	11.13	9.54	11.33	11.7	12.74
Aluminium Stranding		30/2.97	30/3.35	30/3.71	54/3.18	54/3.77	54/3.90	54/4.25
Aluminium Area (mm²)		183.4	264	324.4	428.9	604.2	644.5	765.4
Total Area (mm²)		226.2	325.6	400.0	484.5	681.1	726.4	862.1
Overall Diameter (mm)		19.53	23.45	25.97	28.62	33.97	35.09	38.22
Greased Weight (kg/m)		0.842	1.213	1.489	1.621	2.282	2.434	2.888
Ultimate Tensile Strength (kg)		8137	11329	13838	13450	19000	19800	22500
Modulus of Elasticity (kg/mm²)		8200	8200	8200	7000			
Temperature Coefficient (per deg C)		17.8x10-6	17.8x10-6	17.8x10-6	19.3x10-6			
DC Resistance (ohms/km)		0.1576	0.1095	0.0891	0.0674	0.0480	0.04501	0.03794
Current Rating at 54 °C	Day (A)	204		244	253			
	Evening(A)	453		658	750			
Current Rating at 75 °C	Day (A)	464	579	656	726	891	928	1029
	Evening(A)	607	771	882	987	1236	1292	1447
Current Rating at 80 °C	Day (A)	505	632	717	793	977	1081	1131
	Evening(A)	636	809	925	1032	1292	1350	1513
Current Rating at 90 °C	Emergency (A)	690	878	1005	1112	1394	1457	1633
Fault Current Isec (kA)		17.8	23.3	31.5	34.3	48.3	51.5	61.1

Table 7.2.7 - 1 Outline of communication system for power system

System	Capacity	Reliability	Cost	Features	Purpose
Micro-wave.	Analogue (FDM) : 60 ~ 960 CH Digital (PCM) : 24 ~ 480 CH	Most reliable.	High but unit cost is cheep	• Can transmit more than 50 km distance without repeater. • Suitable for where cable laying is difficult such as mountain area. • Frequency is controlled by an authority.	• System protection. • System control. • Management control.
Optical fiber.	24 ~ 6000 CH	High reliability.	High but unit cost is cheep	• Maximum 40 km distance without repeater. • Can transmit visual data.	• System protection • System control. • Management control. • Visual transmission.
Cable carrier.	Analogue: 12 CH Digital : 24 CH	• Weak in natural disaster. • Affected by induction and noise.	Cheap.	New cable laying for the system is necessary.	• System control.
PLC.	1 ~ 4 CH	• Strong in natural disaster.	Cheap but unit cost is high.	Channel capacity is limited but over-head line can be used as communication path.	• System protection. • System control. • Management control.

Table 7.2.7 - 2 Line Data for PLC Plan.

Name of Staion :

Name of Staion :

Nominal line voltage :

Coupling mode :

Section No.	1	2	3	4	5	6
Section length (km)						
Geometry No.						
Type of tower configuration						
Kind of section termination						
Average ground resistivity (Ohm/m)						
Average altitude above sea level (m)						
Designation fo phase conductor						
Designnation of groundwire						

Designation of phase conductor.

1. Conductor designation :
2. Number of conductors in the bundle:
3. Conductor distance within the bundle (cm) :
4. Conductor diameter (mm) :
5. Number of outer strands :
6. Diameter of outer strands (mm) :
7. Material of conductors :
8. Thickness of ice layer (mm) :
9. Horizontal displacement (m) of conductor No. :
10. Suspension height (m) :
11. Maximum sag (m) :

Designation of groundwire conductor.

1. Conductor designation :
2. Conductor diameter (mm) :
3. Number of outer strands :
4. Material of conductor :
5. Thickness of ice layer (mm) :
6. Horizontal displacement (m):
7. Suspension height (m) :
8. Maximum sag (m) :

Table 7.2.7 - 3 PLC Data for PLC Plan.

1. Channel requirment.

Item	Data
Speech channel	
Telephone signaling channel	
Data signaling channels	

2. Basic data of PLC terminal.

Item	Data
Nominal carrier (c.f.) band	
Type of modulation	
Nominal c.f. power	
Reduced carrier	
Carrier frequencies	

3. Line attenuation

Item	Data
Attenuation conversion loss	
Model conversion loss	
Additional attenuation	
Line attenuation	

4. Noise level

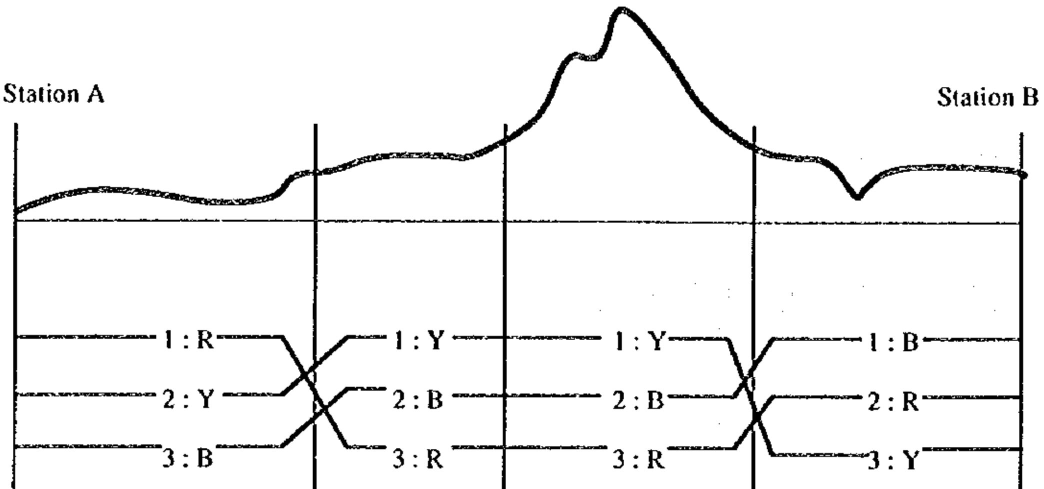
Item	Data
Noise level under adverse weather conditions	

5. S/N ratio

Item	Data
S/N ratios without compandor	

EXAMPLE

TRANSMISSION LINE WITH 2 TRANSPOSTIONS



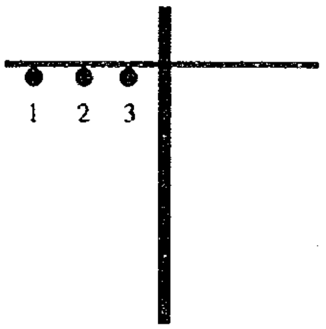
	Section 1	Section 2	Section 3	Section 4
Section length (km)	72.6	34.4	42.8	74.2
Geometry No.	1	1	2	1
Type of tower	H12	H12	H12	H12
Section termination	TR	NG	TR	CE
Ground resistivity (Ohm/m)	30	100	1000	300
Altitude above sea level (m)	150	200	2000	300

NOTES:

The line consists of 4 differnet sections, all with same tower type H12, single circuit horizontal.

Two differnt geometries are used on this line.

TR denotes Transposition, NG denotes New geometry and CE denotes Coupling equipment.



Type : H12

Example Line Data for PLC Plan (Line).

Name of Staion : A

Name of Staion : B

Nominal line voltage : 220 kV

Coupling mode : Phase-to-phase

Section No.	1	2	3	4	5	6
Section length (km)	72.6	34.4	42.8	74.2		
Geometry No.	1	1	2	1		
Type of tower configuration	H12	H12	H12	H12		
Kind of section termination	TR	NG	TR	CE		
Average ground resistivity (Ohm/m)	30	100	1000	300		
Average altitude above sea level (m)	150	200	2000	300		
Designation fo phase conductor	See Below					
Designation of groundwire	See Below					

Designation of phase conductor.

1. Conductor designation : LOTUS
2. Number of conductors in the bundle: 2
3. Conductor distance within the bundle (cm) : 45.7
4. Conductor diameter (mm) : 22.6
5. Number of outer strands : 24
6. Diameter of outer strands (mm) : 2.5
7. Material of conductors : ACSR
8. Thickness of ice layer (mm) : 0.0
9. Horizontal displacement (m) of conductor No. :0
10. Suspension height (m) : 24.3
11. Maximum sag (m) : 15.0

Designation of groundwire conductor.

1. Conductor designation : GJ-71A
2. Conductor diameter (mm) : 11.0
3. Number of outer strands : 12
4. Material of conductor : ST
5. Thickness of ice layer (mm) : 0.0
6. Horizontal displacement (m): 3.2
7. Suspension height (m) : 28.0
8. Maximum sag (m) : 12.5

Exapmle Data for PLC Plan.

1. Channel requirment.

Item	Data
Speech channel	300 to 2400 Hz
Telephone signaling channel	80 Hz
Data signaling channels	two x 50 bauds & one x 200 bauds

2. Basic data of PLC terminal.

Item	Data
Nominal carrier (c.f.) band	4 kHz
Type of modulation	SSB, reduced carrier
Nominal c.f. power	43 dBm, P.E.P.
Reduced carrier	200 Hz
Carrier frequencies	96-100 kHz

3. Line attenuation

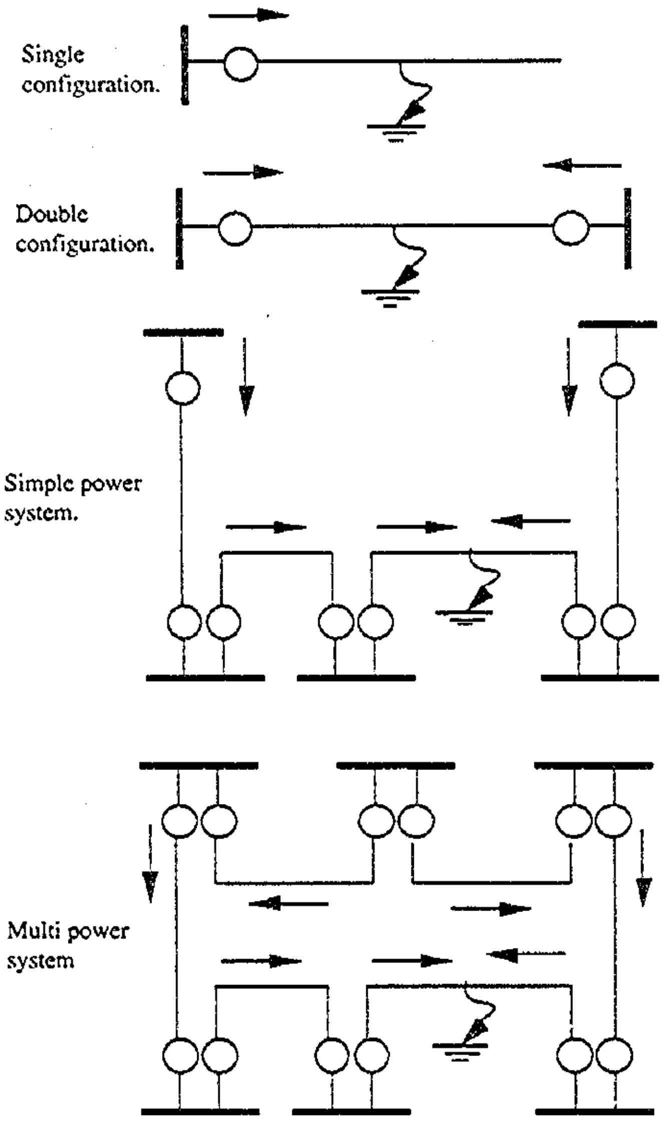
Item	Data
Attenuation conversion loss	
Model conversion loss	
Additional attenuation	
Line attenuation	Criteria <43 dB

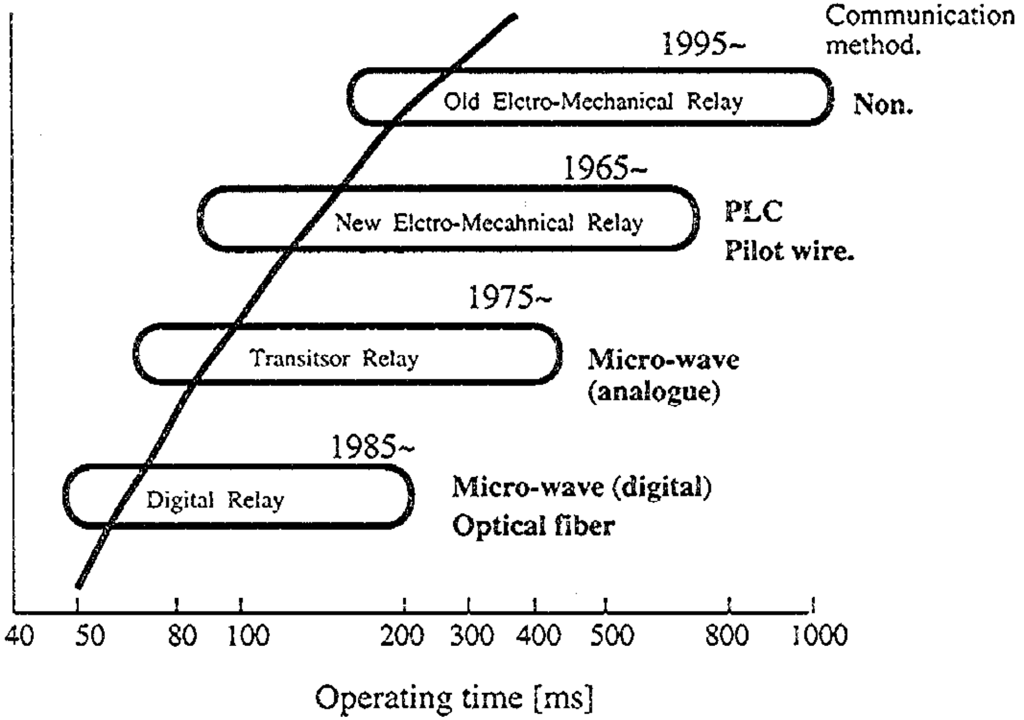
4. Noise level

Item	Data
Noise level under adverse weather conditions	

5. S/N ratio

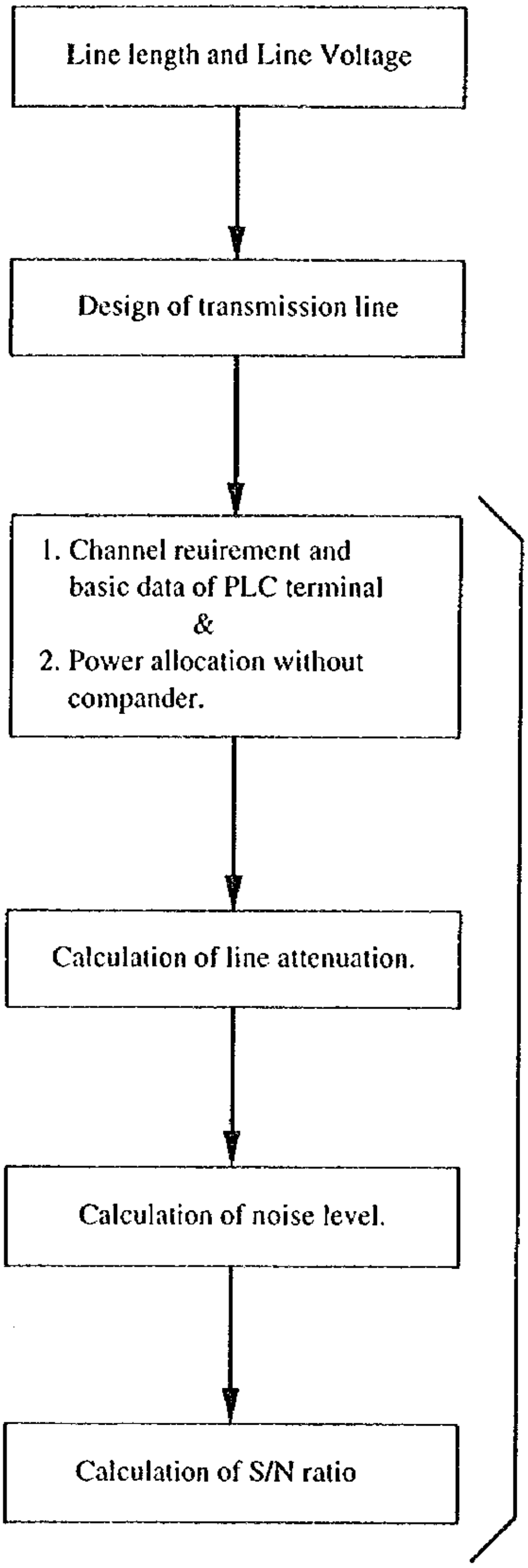
Item	Data
S/N ratios without compandor	Criteria >25 dB





In relation to progress of power system as shown in the left side, high speed operation and reliability are rquired for the protection relay.
In order to acheive the rquirments, type of realy have changed from the electro-mechanical to the digital as shown in the above.

CEYLON ELECTRICITY BOARD	JAPAN INTERNATIONAL COOPERATION AGENCY NIPPON KOEI CO., LTD. Consulting Engineer	MASTER PLAN STUDY FOR DEVELOPMENT OF THE TRANSMISSION SYSTEM OF THE CEYLON ELECTRICITY BOARD IN THE DEMOCRATIC SOCIALIST REPUBRIC OF SRI LANKA	TITLE Fig. 7. 2. 7 - 1 General Changes of Protection Relay and Power System



This will be provided from power system planning data.

This works will be designed by transsmission enginner and data as shown in Table 7.2.7-2 is required.

These wroks shall be carried out by PLC enginner referring to IEC-663 and data as shown in Table 7.2.7-3 is required.

CEYLON ELECTRICITY BOARD	JAPAN INTERNATIONAL COOPERATION AGENCY NIPPON KOEI CO., LTD. Consulting Engineer	MASTER PLAN STUDY FOR DEVELOPMENT OF THE TRANSMISSION SYSTEM OF THE CEYLON ELECTRICITY BOARD IN THE DEMOCRATIC SOCIALIST REPUBRIC OF SRI LANKA	TITLE Fig. 7. 2. 7 - 2 Flow of Planning PLC System

CHAPTER 8

EXECUTION PLANS AND PROJECT COSTS

CHAPTER 8

EXECUTION PLANS AND PROJECT COSTS

8.1 List of Projects for Execution

Transmission system projects to be implemented during the 20 year period from 1996 to 2015 comprise the following two categories:

1. Ongoing projects now under execution and projects to which fund arrangement has already been made as referred to in Clause 4.6.2.
2. Projects identified through the long-term transmission system planning studies in Chapter 6.

The transmission system studies in Chapter 6 have been carried out for each of five year periods of 1996 - 2000, 2001 - 2005, 2006 - 2010 and 2011 to 2015. These five-year plans have been allocated to each year as seen in Tables 6.1.5-1 for Ongoing Projects, 6.3.1-2 for Projects up to 2000, 6.4.1-3 up to 2005, 6.5.1-3 up to 2010 and 6.6.1-2 up to 2015. In the tables the names of sub-projects, their component lines and substations and target year of completion of each sub-project are mentioned.

For the period of 2011 to 2015, the number of required grid substations for new construction and extension with associated transmission lines, which comprise new construction of 16 stations, transformer addition at 25 stations and transformer replacement at one station, has been identified in the system planning studies. However their individual sites and development timing can not be determined due to inability of estimating situation of each of individual sites.

8.2 Preliminary Design

Route maps of the selected major transmission lines were prepared based on map study and site reconnaissance taking into account the associated land problems. Among them route maps of selected lines are included in Appendix A7.1.

For the planned 40 substations and switching stations, location maps and single line connection diagrams of main circuits were prepared and included in Appendix A7.2.

8.3 Execution Schedule and Necessary Costs

To meet the forecast demand up to 2015, transmission lines and substations need to be constructed as shown in the project lists mentioned in Clause 8.1.

The required quantity of project components (transmission lines, substations and communication facilities) is obtained from the results of preliminary design in Clause 8.2 above. Rough project cost of each subproject was calculated by multiplying the required quantity and rough unit costs mentioned in Chapter 9; i.e. Clause 9.2.1 for transmission lines, Clause 9.2.2 for substations and Clause 9.2.3 for communication facilities. Various assumptions used for preparation of project cost schedule are mentioned below:

1. For the ongoing and finance arranged projects, the same unit costs as assumed in Chapter 9 were applied to evaluate all the projects on the same basis.
2. In the period of 2011 to 2015, there are many tentative grid substation and associated transmission line projects whose requirement was identified but its schedule can not be determined. The total costs of these projects were distributed to five years equally.
3. The construction period was assumed to be two years for all the projects and the project costs were allocated to two years, 40% for the first year and 60% for the second year for the foreign currency portion and 50% each for two years for the local currency portion.

Summary of required fund for each 5-year period is given below:

SUMMARY OF PROJECT COSTS

Unit: Million US$

Period	FC Portion	LC Portion	Total
1995 - 2000	214.2	54.7	268.9
2001 - 2005	186.8	50.9	237.7
2006 - 2010	369.0	96.5	465.5
2011 - 2015	279.8	67.2	347.0
Total	1,048.5	269.0	1,319.1

The calculated total project costs is 1,319.1 Million US Dollars equivalent and the yearly disbursement is shown in Table 8.3-1.

8.4 Future Execution of Transmission System Planning

From its subordinate nature of transmission system, to be subject to generation plan and demand, the transmission system plan is to be remodeled according to changes in the generation plan (location of power stations and their output), or loads (substation locations and loads). A transmission system reinforcement and extension plan must be reviewed every time when preconditions for system planning, either generation or load, have been revised. These conditions are usually reviewed and revised very often. Under such situation, it is a usual practice to review the transmission system plan every year together with demand forecast and generation plan as a revolving plan. The planning term of such transmission system plan needs not to be very long, say 20 years, and usually is short- or mid-term of around 10 years. Transmission system plan for execution is usually for a period of around three years, which shall be prepared as a short plan based on actual situation that time.

It is recommended to carry out such transmission system planning by CEB mainly by power flow analysis. To carry out such studies by CEB, the number of capable engineers in the current Planning Division in charge of the studies seems not enough. It is necessary to train some more engineers who can handle the PSS/E program including the TPLAN program.

Table 8.3 - 1 Scedule of Required Fund

(Unit : Mil. $)

	Foreign Component			Local Component			Total
Year	Ongoing	Planned	Total	Ongoing	Planned	Total	FC + LC
1995	7.9		7.9	2.4		2.4	10.3
1996	19.6		19.6	5.0		5	24.6
1997	30.3	16.6	46.9	8.5	5.6	14.1	61
1998	36.9	24.8	61.7	8.7	5.6	14.3	76
1999	13.6	21.3	34.9	2.7	6.0	8.7	43.6
2000		43.2	43.2		10.2	10.2	53.4
Subtotal	**108.3**	**105.9**	**214.2**	**27.3**	**27.4**	**54.7**	**268.9**
2001		44.7	44.7		13.2	13.2	57.9
2002		55.9	55.9		12.7	12.7	68.6
2003		22.4	22.4		5.3	5.3	27.7
2004		26.6	26.6		8.8	8.8	35.4
2005		37.2	37.2		10.9	10.9	48.1
Subtotal	**0**	**186.8**	**186.8**	**0**	**50.9**	**50.9**	**237.7**
2006		103.8	103.8		33.7	33.7	137.5
2007		146.3	146.3		34.1	34.1	180.4
2008		47.4	47.4		12.2	12.2	59.6
2009		50.4	50.4		11.4	11.4	61.8
2010		21.1	21.1		5.1	5.1	26.2
Subtotal	**0**	**369**	**369**	**0**	**96.5**	**96.5**	**465.5**
2011		43.2	43.2		10.7	10.7	53.9
2012		76.1	76.1		20.9	20.9	97.0
2013		91.6	91.6		19.9	19.9	111.5
2014		36.1	36.1		8.1	8.1	44.2
2015		32.8	32.8		7.6	7.6	40.4
Subtotal	**0**	**279.8**	**279.8**	**0**	**67.2**	**67.2**	**347.0**
Total	**108.3**	**941.5**	**1049.8**	**27.3**	**242**	**269.3**	**1319.1**

CHAPTER 9

ECONOMIC AND FINANCIAL EVALUATIONS

CHAPTER 9

ECONOMIC AND FINANCIAL EVALUATIONS

9.1 Economic Evaluation Criteria

The benefit of an electrical power supply system accrues by selling power to consumers. The transmission system consists a part of the overall power system, which includes generation, transmission and distribution, and the transmission system itself does not accrue benefit. In evaluation of a generation project which occupies around 65% of the total power system cost, the total cost of power system is generally estimated by adding assumed costs for the transmission and distribution systems on the cost for the generation project. An internal rate of return (IRR) is calculated based on the benefit from estimated power sales and this overall cost. The transmission system occupies only 10 to 15% of the total cost of the overall power system, and therefore it is not appropriate to apply a similar method, to a transmission system to calculate IRR based on estimated benefit and cost.

Such being the case, for economic evaluation of a transmission system the benefit-cost analysis same as a generation project is not practical. Execution of a project can be justified through the following two processes:

(1) Justification of technical necessity of the project.

(2) Selection of least-cost plan among conceived technically sound alternatives.

The normal overhead transmission line is acknowledged as the most economical means to transmit the electric power for a long distance in the presently available technology. The high cost underground cable line is justified only for special cases like city center installation. In determining plans for future development, the least cost solution among various alternatives must be selected, and such selection process has been followed in the transmission system planning in Chapter 6. In this chapter, economic and financial evaluations are carried out on the selected plans.

The price level for economic and financial evaluations is based on the CEB Asset Revaluation Index at the end of 1995.

9.2 Unit Costs for Estimation of Project Costs

In many countries, standard unit costs of transmission system facilities for calculating rough project cost which are arranged by electricity utility are available. However such standard unit costs have not yet been prepared for the CEB system. Therefore, the JICA team prepared the standard unit costs based on recent contract prices in Sri Lanka and available information for similar developing countries. As the project cost tends to increase somewhat due to variation orders and additional works during construction, some addition is required as allowance or contingency for fund.

For the CEB system, development projects are generally being executed on a turn-key basis by foreign contractors. Foreign contractors normally do not wish to remain any surplus local money, while foreign money is convertible to local money. Therefore, it is a usual practice that they increase foreign component larger than actual requirements in their tender as well as contract, and reduce local components, keeping the total as required. Clearly some local costs were shifted to foreign portion willfully. In preparing standard costs for estimation purpose of this Study, actual contract prices are referred to accepting some imbalance in the foreign and local allocation as mentioned above as the present situation is considered to continue in the plan period.

9.2.1 Transmission Lines

In order to establish the end-1995 construction costs, the two most recent transmission line projects were reviewed.

One is the Laxapana - Badulla 132 kV double circuit line of 74 km with single Lynx conductors (175 mm^2) and two GS earthwires of 7/3.25 mm. This line is constructed by a Thai contractor in a hilly area with mainly normal foundations at a tender price in equivalent US$ 4.75 million, which corresponds to US$ 64,000 per km.

The other example is for two 132 kV transmission lines, Anuradhapura - Puttalam, 81 km, and Matara - Embilipitiya , 62 km, with the same particulars as the above. The contract for these lines was made with a Korean contractor. The tendered prices for these two lines are US$ 3.83 million and US$ 2.94 million respectively. This is equivalent to US$ 47,000 per km.

The latter price per km seems to be exceptionally low and the JICA team therefore based the end-1995 construction cost estimates on the former prices with an escalation rate to take account of the fact that this project was tendered in 1991.

End-1995 transmission line construction costs based on approximate line length of 50 to 100 km in hilly area with tree clearing and 10% piled foundations, and insulation level of 25 mm/kV are shown in Table 9.2.1-1 in US Dollars per km. These figures include wayleave and compensation payments and the cost of engineering and supervision by consultants and/or CEB staff.

Wayleave costs and compensation payments can vary considerably from low level padi areas where compensation is quite low, to higher level tea and tree areas where compensation is higher. CEB do not purchase the land for tower sites and do not pay any compensation for land usage, they only pay compensation for crop damage during construction and cutting of trees, etc. The compensation payments are fixed by local authorities. Wayleave costs will tend to be fixed per kilometer of line route regardless of the line voltage or conductor size, a typical average would be US$ 3,000 per km.

The cost of engineering and site supervision of construction by consultants and/or CEB staff will generally be related to the project duration regardless of line voltage or conductor size. These costs can be calculated per kilometer of line route by assuming a typical project of 150 km being completed in 2 years. On this basis, consultants costs would be approximately US$ 2,500 per km, and CEB costs approximately US$ 3,500 per km.

The estimated overhead line ratings and construction costs are shown in Table 9.2.1-1.

It is generally accepted that single circuit line construction costs are approximately 67% of double circuit line construction costs for the same voltage and conductor size. If double circuit towers are used but only one circuit is installed, the initial cost would be approximately 85% of the double circuit cost. However, the cost to string the second circuit will be approximately 25% of the double circuit cost making the total 10% higher than if both circuits were installed initially.

The breakdown of transmission line construction costs are generally in the following components:

Earthwires	3 %
Conductors	32 %
Insulator sets	9 %
Towers	36 %
Foundations	20 %

The typical split of materials and erection costs is 65/35. However in the two latest contracts for CEB, the foreign/local split was 85/15 probably due to that the main contractors were foreign parties from Thailand and Korea.

9.2.2 Substations

The substation works of this Study include not only new constructions but also line circuit additions and upgrading of the existing substations, and comprise various kinds of work items. To work out rough estimates of substation works, the work items will be broken down to the followings:

1. Common facilities for substation
2. Main transformers
3. kV circuit bays for line feeders
4. kV circuit bays for transformers
5. kV circuit bays for bus couplers
6. kV bays for transformer secondary circuits, feeders and bus couplers
7. kV static capacitors
8. PLC facilities
9. Overhead including consultant fees

Cost items included in the above major items are as follows:

- Item 1 includes land preparation, peripheral fencing, control building, mesh earthing, low voltage AC and DC power supply facilities, ancillary equipment, SCADA facilities, etc.
- Item 2 includes transformers and associated foundations.
- Item 3 includes not only switchgear but also relays and control apparatus, outdoor steelworks, conductors and insulator sets, foundations, cable trenches etc.
- Items 4 and 5 include similar cost items as Item above.
- Item 6 includes similar cost items as Items 3, 4 and 5 above. In spite of some difference in particulars, the same cost will be used for transformer secondary, feeder and bus coupler circuits.
- Item 7 includes not only static capacitors but also necessary switchgear, control and protection equipment, miscellaneous materials, foundations, etc.
- Item 8 includes PLC facilities reference is made to Clause 9.2.3.

- Item 9 includes general expenses such as consultant services which is roughly estimated to be about 10% of the construction cost, CEB's general expenditures such as land and compensation, and overhead.

The grid substations in Sri Lanka were designed based on standard ideas and this concept is assumed to be applied for future installations. The above prices for 132 kV and 33 kV facilities were estimated based on the contract prices of the ongoing Transmission System Augmentation and Development Project. For 220 kV facilities, CEB's data were not available, and international prices obtained in south-east Asian countries were used for cost estimation.

The estimated standard unit costs of substation facilities are shown in Table 9.2.2-1, and its back data are included in Appendix 9.

9.2.3 Load Dispatching and Communication Facilities

The costs of SCADA system is not reviewed as the system extension plan of the existing system has been prepared and tender was called already with World Bank financing.

Economic life of a load dispatching facilities is estimated to be approximately 10 years. Therefore, the existing facilities are renewed as planned the next renewal will be required in the period of 2005 to 2010. Renewal of 33 kV regional systems will also be required this time.

In order to establish the end-1995 standard construction costs, actual prices of two communication projects were reviewed. The first project is the PLC and SCADA system under the Transmission System Augmentation and Development Project (TSADP). The project comprises the PLC and SCADA system extension on the 132 kV power system, which is under execution by a Thai Contractor.

The tendered price of 1993 for the PLC system consisting of 1 link arrangement with 2 channels of 40 W output between two stations is US$ 305,456-. This total price seems to be around 20 to 30% higher compared with general tender prices in other Asian countries. It is however understood that communication facilities such as PLC terminals must be compatible with the existing ones to keep up the operation and maintenance procedure and purchase of spare parts.

The other is newly built digital micro-wave system under TSADP, lot II, by a Japanese contractor. The total tendered price including site survey, equipment supply, installation, training, maintenance apparatus and provision of spare parts was US$ 11.44 million in 1992. Typical tendered prices of out-stations are as follows:

1. Station with 19.2 kB/s data transmission and telephone (12 stations)
   The cost is US$ 79,161 for Negombo A/O, but the costs range from US$ 74,982 at the lowest to US$ 205,613 at the highest. The station cost is much influenced by geometrical conditions of the site.
2. Station with 64 kB/s data transmission and telephone (19 stations)
   The cost is US$ 82,901 for Rantembe P/S ranging from US$ 72,514 at the lowest to US$ 98,544 at the highest.
3. 1.5G repeater station (9 stations)
   The cost is US$ 96,839 for Avissawella ranging from US$ 88,482 at the lowest to US$ 100,539 at the highest.

The estimated end-1995 standard cost of PLC system consisting of one link of 2-channel sets with 40 W is US$ 340,000 with particulars given below:

1. Line coupling equipment	US$ 43,000
2. PLC terminal equipment	148,000
3. Telephone equipment	108,000
4. DC power supply equipment	41,000
Total	US$ 340,000

The local cost component is 3% of the above and the remaining is the foreign cost. The cost of 80 W unit is estimated to be 4% higher.

Regarding the cost for digital micro-wave system, it is very difficult to make a standard cost for a out-station, because height and type of antenna tower, and type of antenna depend on site conditions.

9.2.4 Distribution Facilities

The future investment for addition of distribution system is estimated from the forecast growth in energy sales and the total cost of distribution facilities per GWh energy sales. Necessary addition of facilities for distribution per GWh sales is estimated from the total installations in 1995, and costs of facilities are taken from the beginning-1996 standard costs of CEB.

9.2.5 Operation and Maintenance Cost

Annual cost for operation and maintenance of transmission system facilities, covering transmission lines and substations, was assumed from the actual expenditures of CEB in recent years to be 1.5% of the construction costs of corresponding facilities. The rate of 2.0% was assumed for the distribution system.

9.3 Capacity and Energy Values

For the purpose of carrying out economic evaluation of loss values in the Study, the capacity and energy values of thermal projects were calculated based on the average thermal power cost in 2015 referring to the Long-Term Generation Expansion Plan of CEB and the Thermal Generation Options Study, Final Report (Draft) of March 1996. The available thermal plant capacity was obtained from the Generation Expansion Plan and the cost data are taken from the Thermal Generation Options Study report. The average annual fixed cost of available thermal plants was calculated as the sum of capital costs and fixed O&M costs, and energy costs were obtained as the sum of fuel costs and variable O&M costs. The results are given below:

Capacity (kW) cost (annual cost)	US$ 131 per kW
Energy (kWh) cost	US$ 2.392 per kWh

These figures are used for economic evaluation of the transmission line loss.

9.4 Transmission Cost on LRMC Base

The transmission cost of the CEB power system which is planned to be developed during the period from 1995 up to 2015 was calculated on the long-run-marginal-cost (LRMC) bases. Here the long-run marginal transmission cost was obtained as 1.4 cents/kWh of electricity sales. This was calculated by dividing the net present value of transmission cost stream (capital and O&M costs) by the net present value of electricity expressed in the end-December 1995 market (financial) price.

9.5 Economic Analysis

A transmission system can not be readily evaluated for economic and financial performance on an isolated bases, but must be considered as a part of CEB's integrated power system expansion program. An economic evaluation of CEB's total investment program was therefore done additional power supply over the 20-year study period from 1996 to 2015 (see Table 9.5 - 2). As discussed in Clause 4.5.2 of Chapter 4, CEB's generation plan as given in Table 4.5 - 1 will be the basis for this analysis. The total capital costs for generation expansion (Table 9.5 - 1) and transmission (Table 8.3 - 1)[1] and distribution (Table 9.5 - 2) system development were determined, as well as the incremental costs for fuel and operation and maintenance. Here O&M costs for transmission and distribution are assumed to be 1.5% and 2.0% of accumulated investment amounts of completed facilities, respectively. These incremental costs at economic prices are compared with the incremental economic benefits of electricity consumption. Here the economic benefits were calculated, taking into account the consumer surplus, which represents economic benefits to consumers in excess of the tariff level, as follows referring to the ADB study[2].

Consumer Category	Share of Sales	Average Economic Benefit (Rs./kWh)
Residential	26%	12.60
Commercial	17%	8.90
Industrial	40%	5.20
LECO Bulk Supply	17%	5.52
Weighted Average		7.81 Rs./kWh or 0.156 $/kWh

The resulting EIRR for the 20-year expansion program against consumer's willingness to pay is estimated to be 26.3%, and the benefit-cost ratio is estimated to be 1.50 at 10% discount rate. The CEB's integrated power expansion program is economically highly rated.

9.6 Financial Analysis

The FIRR for the CEB's integrated power system expansion program should be close to 8.0% since CEB are obliged under IBRD and ADB loan covenants to earn an 8.0% rate of return on revalued net fixed assets in service. The actual rate of return on revalued assets of CEB in 1995 was 7.6%.

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[1] In the economic analysis, all costs are economic costs expressed in constant 1995 price to match the planning conditions of the CEB's generation expansion plan adopted. Therefore, the capital costs for transmission system given in Table 8.3 - 1 were adjusted for inputting in Table 9.5 - 2.

[2] ADB's Report and Recommendation for the Second Power System Expansion Project, November 1995.

Table 9.2.1 - 1 Overhead Line Ratings and Costs

Voltage (kV)	No. of Circuit	Conductor	Circuit Rating (MVA/circuit)	Const. Cost (US$/km)
132	2	1 x Lynx	145	90,000
	2	1 x Bear	185	100,000
	2	1 x Zebra	236	117,000
	2	1 x Grackle	295	134,000
	2	1 x Pheasant	308	138,000
	4	1 x Zebra	236	250,000
220/132	4	2 x Zebra	786/472	388,000
220	2	1 x Zebra	393	130,000
	2	2 x Zebra	786	199,000
	2	2 x Pheasant	1029	242,000
	2	2 x Parrot	1153	266,000
	2	3 x Zebra	1180	260,000
	2	4 x Zebra	1573	311,000
	4	2 x Zebra	786	445,000
330	2	2 x Zebra	1180	232,000
	2	2 x Pheasant	1543	282,000
	2	2 x Parrot	1730	310,000
	2	3 x Zebra	1770	302,000
400	2	2 x Zebra	1430	254,000
	2	2 x Pheasant	1870	308,000
	2	2 x Parrot	2096	340,000
	2	3 x Zebra	2145	330,000
	2	4 x Zebra	2860	396,000

Note: 1. Circuit rating is based on conductor temperature of 80°C under the evening condition.

Table 9.2.2 - 1 Standard Unit Costs of Substation Facilities (1995 prices)

(Unit: 1000 US$)

1. 220 / 132 kV Substations

			FC Portion	LC Portion
(a)	Substation common facilities (open type)		1,751	785
	About 30,000 m^2 land space is assumed.			
		(GIS type)	796	838
(b)	Transformers:	150 MVA	1,955	125
		250 MVA	3,005	185

Price is 10% higher in case that special design is applied to GIS substation.

(c) 220 kV switchgear and circuit components

	Open Type		GIS Type	
	FC	LC	FC	LC
1. Line circuit	498	60	867	46.5
2. Transformer primary circuit	410	51	867	46.5
3. Bus coupler circuit	449	52	---	–

2. 132 kV Grid Substations

			FC Portion	LC Portion
(a)	Substation common facilities (open type)		727	348
	Normal grid substation design is taken into account.			
		(GIS type)	522	422
(b)	Transformers:	31.5 MVA	555	38
		63 MVA	1,055	65

10% higher prices are to be used if special design is applied to GIS substation.

(c) 132 kV switchgear and circuit components

	Open Type		GIS Type	
	FC	LC	FC	LC
1. Line circuit	294	36	587	31
2. Transformer primary circuit	253	32	587	31
3. Bus coupler circuit	296	33	---	–

(d) 33 kV facilities

	FC	LC
1. 33 kV switchgear and others	104	12
2. Static capacitor (US$/kVA)		
20 MVA unit	10	1
5 MVA unit	12	1.2

Table 9.5 - 1 Generation Plant Capital Cost Stream (for JICA Study)

Unit: Mil. $

Item / Year	1996		1997		1998		1999		2000		2001		2002		2003		2004		2005		2006		2007		2008		2009		2010		2011		2012		2013		2014		2015		Total
Commissioning Year/Plant/Capacity	LC	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	FC	LC	FC	
1996&97 Diesel Refurbish 36MW x 2	0.5	3.9	0.8	6.2	0.2	1.8																																			13.4
1997 Diesel Extension 40MW	3.9	35.8	2.7	26.1																																					68.5
1998 Diesel 90MW	3.0	29.2	6.7	63.7																																					102.6
1998 Gas Turbine 140MW	2.9	19.7	6.4	43.0																																					72.0
1999 Combined Cycle 150MW	2.4	8.5	14.3	50.7	7.7	27.3																																			110.9
2000 Combined Cycle 150MW			2.4	8.5	14.3	50.7	7.7	27.3																																	110.9
2001 Gas Turbine 70MW							1.5	9.8	3.2	21.5																															36.0
2002 Hydro (Kukule) 70MW					8.6	20.0	12.8	29.9	12.8	29.9	8.6	20.0																													142.6
2002 Coal 150MW					1.4	7.0	7.0	35.1	12.8	64.5	5.4	27.4																													160.6
2003 Coal 150MW							1.4	7.0	7.0	35.1	12.8	64.5	5.4	27.4																											160.6
2003 Gas Turbine Refurbish 60MW													1.0	7.3																											8.3
2004 Coal 300MW									2.5	11.9	12.4	59.6	22.7	109.7	9.6	46.5																									274.9
2004 Gas Turbine Refurbish 60MW															1.0	7.3																									8.3
2005 Coal 300MW											2.5	11.9	12.4	59.6	22.7	109.7	9.6	46.5																							274.9
2007 Coal 300MW															2.5	11.9	12.4	59.6	22.7	109.7	9.6	46.5																			274.9
2008 Combined Cycle 300MW																			4.0	13.7	23.9	82.1	12.9	44.3																	180.9
2009 Coal 300MW																			2.5	11.9	12.4	59.6	22.7	109.7	9.6	46.5															274.9
2010 Coal 300MW																					2.5	11.9	12.4	59.6	22.7	109.7	9.6	46.5													274.9
2011 Combined Cycle 300MW																									4.0	13.7	23.9	82.1	12.9	44.3											180.9
2012 Combined Cycle 300MW																											4.0	13.7	23.9	82.1	12.9	44.3									180.9
2012 Coal 300MW																									2.5	11.9	12.4	59.6	22.7	109.6	9.6	46.5									274.8
2013 Coal 300MW																											2.5	11.9	12.4	59.6	22.7	109.7	9.6	46.5							274.9
2014 Coal 300MW																													2.5	11.9	12.4	59.6	22.7	109.7	9.6	46.5					274.9
2014 Gas Turbine 35MW																																	0.7	4.9	1.6	10.8					18.0
2015 Combined Cycle 300MW																																	4.0	13.7	23.9	82.1	12.9	44.3			180.9
2015 Gas Turbine 175MW																																			3.7	24.1	8.0	53.8			89.6
Total	12.7	97.1	33.3	198.2	32.2	106.8	30.4	109.1	38.3	162.9	41.7	183.4	41.5	204.0	35.8	175.4	22.0	106.1	29.2	135.3	48.4	200.1	48.0	213.6	38.8	181.8	52.4	213.8	74.4	307.5	57.6	260.1	37.0	174.8	38.8	163.5	20.9	98.1	0.0	0.0	4,025.0
Total of LC and FC	109.8		231.5		139.0		139.5		201.2		225.1		245.5		211.2		128.1		164.5		248.5		261.6		220.6		266.2		381.9		317.7		211.8		202.3		119.0		0.0		4,025.0

Notes :

1. Costs are economic costs expressed in constant January 1995 US $.
2. Taxes and duties not included.
3. Local market costs are converted to economic costs by a factor of 0.9 (standard coversion factor).
4. LC: Local Cost, FC: Foreign Cost, 1US$=50 Rs.

Table 9.5 - 2 Economic Evaluation of CEB's Power System Expansion Program (for JICA Study)

No	Item / Year	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Total
1	Load Forecast																						
	Generation Required (GWh)	4,806	5,242	5,718	6,238	6,805	7,407	8,017	8,659	9,373	10,194	11,111	12,111	13,201	14,389	15,684	17,096	18,635	20,312	22,140	24,132	26,304	
	Sales (GWh)	3,946	4,341	4,775	5,252	5,777	6,355	6,927	7,550	8,230	8,971	9,778	10,658	11,617	12,663	13,802	15,044	16,398	17,874	19,483	21,236	23,148	
	Peak Load (MW)	996	1,071	1,161	1,256	1,365	1,481	1,597	1,719	1,854	2,010	2,187	2,384	2,598	2,832	3,087	3,365	3,668	3,998	4,358	4,750	5,177	
2	Expansion Program																						
	Net Capacity Commissioned (MW)	0	-36	40	266	150	150	26	166	156	324	300	0	300	264	300	300	300	600	300	335	475	4,716
	Total CEB Generation Capacity (MW)	1,339	1,303	1,343	1,609	1,759	1,909	1,935	2,105	2,257	2,581	2,881	2,881	3,181	3,445	3,745	4,045	4,345	4,945	5,245	5,580	6,055	
	Reserve Margin (% of Peak Load)	25.6%	17.8%	13.6%	21.9%	22.4%	22.4%	17.5%	15.4%	15.2%	20.0%	22.2%	15.2%	16.5%	16.1%	16.0%	15.3%	14.2%	18.0%	15.8%	13.8%	13.5%	
3	Capital Costs (Million $)	144.7	183.5	343.0	270.0	247.3	324.7	351.7	388.7	324.5	256.2	312.7	486.9	549.9	410.4	470.2	566.9	542.4	491.3	512.5	386.7	284.8	7,849.0
	CEB Power Plant	85.4	109.8	231.5	139.0	139.5	201.2	225.1	245.5	211.2	128.1	164.5	248.5	261.6	220.6	266.2	381.9	317.7	211.8	202.3	119.0	0.0	4,110.4
	Transmission	9.3	22.4	55.2	69.1	39.7	48.5	52.3	62.4	25.1	31.9	43.5	124.2	163.9	54.1	56.2	23.8	49.0	87.9	101.4	40.2	36.7	1,196.8
	Distribution	50.0	51.3	56.3	61.9	68.1	75.0	74.3	80.8	88.2	96.2	104.7	114.2	124.4	135.7	147.8	161.2	175.7	191.6	208.8	227.5	248.1	2,541.8
4	Fuel and O&M Costs (Million $)	29.0	56.0	68.8	98.5	114.1	131.5	160.5	157.0	172.3	180.5	194.2	227.0	248.3	286.7	313.4	345.8	394.7	435.1	479.8	529.9	603.0	5,226.2
	Fuel Costs	17.8	44.4	52.9	70.3	81.0	93.7	118.3	109.5	117.9	119.3	125.6	151.8	163.3	193.5	209.8	231.6	270.9	298.1	329.2	364.2	424.3	3,587.4
	O&M Costs (Thermal)	4.1	3.4	6.3	16.6	19.3	22.0	24.1	26.9	31.3	35.9	40.9	44.8	50.4	53.7	60.6	67.4	73.4	82.3	90.8	100.2	108.0	962.4
	O&M Costs (Hydro)	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	4.6	94.5
	O&M Costs (Transmission)	0.8	0.9	1.3	2.1	3.1	3.7	4.5	5.2	6.2	6.6	7.0	7.7	9.6	12.0	12.8	13.7	14.0	14.8	16.1	17.6	18.2	177.9
	O&M Costs (Distribution)	2.0	3.0	4.0	5.2	6.4	7.8	9.3	10.7	12.4	14.1	16.0	18.1	20.4	22.9	25.6	28.6	31.8	35.3	39.1	43.3	47.9	404.0
5	Incremental Fuel and O&M Costs (1995 base) (M$)	0.0	27.0	39.8	69.5	85.1	102.5	131.5	128.0	143.3	151.5	165.2	198.0	219.3	257.7	284.4	316.8	365.7	406.1	450.8	500.9	574.0	4,617.2
	Generation	0.0	25.9	37.3	65.0	78.4	93.8	120.5	114.8	127.6	133.6	144.9	175.0	192.1	225.6	248.8	277.4	322.7	358.8	398.4	442.8	510.7	4,094.1
	Transmission	0.0	0.1	0.5	1.3	2.3	2.9	3.7	4.4	5.4	5.8	6.2	6.9	8.8	11.2	12.0	12.9	13.2	14.0	15.3	16.8	17.4	161.1
	Distribution	0.0	1.0	2.0	3.2	4.4	5.8	7.3	8.7	10.4	12.1	14.0	16.1	18.4	20.9	23.6	26.6	29.8	33.3	37.1	41.3	45.9	362.0
6	Total of 3 and 5 (Million $)	0.0	210.5	382.8	339.5	332.4	427.2	483.2	516.7	467.8	407.7	477.9	684.9	769.2	668.1	754.6	883.7	908.1	897.4	963.3	887.6	858.8	12,321.5
	Generation	85.4	135.7	268.8	204.0	217.9	295.0	345.6	360.3	338.8	261.7	309.4	423.5	453.7	446.2	515.0	659.3	640.4	570.6	600.7	561.8	510.7	8,204.5
	Transmission	9.3	22.5	55.7	70.4	42.0	51.4	56.0	66.8	30.5	37.7	49.7	131.1	172.7	65.3	68.2	36.7	62.2	101.9	116.7	57.0	54.1	1,357.9
	Distribution	50.0	52.3	58.3	65.1	72.5	80.8	81.6	89.5	98.6	108.3	118.7	130.3	142.8	156.6	171.4	187.8	205.5	224.9	245.9	268.8	294.0	2,903.8
7	Total Incremental Energy Sales (1995 base) (GWh)	0	395	829	1,306	1,831	2,409	2,981	3,604	4,284	5,025	5,832	6,712	7,671	8,717	9,856	11,098	12,452	13,928	15,537	17,290	19,202	150,959.0
8	Economic Benefit due to Incremental Energy Sales (M$)	0.0	61.6	129.3	203.7	285.6	375.8	465.0	562.2	668.3	783.9	909.8	1,047.1	1,196.7	1,359.9	1,537.5	1,731.3	1,942.5	2,172.8	2,423.8	2,697.2	2,995.5	23,549.6
9	Net Incremental Benefits - Costs (Million $)	0.0	-148.9	-253.5	-135.7	-46.8	-51.4	-18.1	45.5	200.5	376.2	431.9	362.1	427.5	691.7	782.9	847.5	1,034.4	1,275.4	1,460.4	1,809.6	2,136.7	11,228.1

Note: Costs are economic costs expressed in constant January 1995 US$. Exchange rate is 1US$=Rs.50.

Basic Results

1. Average economic benefit of electricity sales:	0.156 $/kWh (refer to the right)
2. Average incremental cost of electricity sales: (Economic cost at Jan. 1995 price, 10% discount rate)	0.104 $/kWh
3. Long term average incremental generation cost: (Economic cost at Jan. 1995 price, 10% discount rate)	0.069 $/kWh
4. Long term average incremental transmission cost: (Economic cost at Jan. 1995 price, 10% discount rate)	0.012 $/kWh
5. Long term average incremental distribution cost: (Economic cost at Jan. 1995 price, 10% discount rate)	0.022 $/kWh
6. Economic internal rate of return system as a whole:	26.3%
7. Benefit/cost ratio for expansion program, 1996-2015: (at 10% discount rate)	1.502

Consumer Category	Share of Sales	Average Economic Benefit (Rs/kWh)
Residential	26%	12.60
Commercial	17%	8.90
Industrial	40%	5.20
LECO Bulk Supply	17%	5.52
Weighted Average		7.81 Rs/kWh
	or	0.156 $/kWh

CHAPTER 10

URGENT PLANS FOR IMMEDIATE REALISATION

CHAPTER 10

URGENT PLANS FOR IMMEDIATE REALISATION

10.1 General

As mentioned in Clause 4.6, the 1995 - 1997 Transmission System Extension Plan which consists of four projects is now under construction utilizing various fund sources, CEB's own fund, OECF fund from Japan and the World Bank, and as of mid-1996 certain lines and substations have been completed. In addition, development finances for the next series of projects have already been allocated by ADB, IDA, Korean and Norwegian fund and preparatory works have already been commenced with target completion in 1998 to 1999.

As the results of this Study, several additional projects, other than those for which fund has already been allocated, have been identified for realization up to the 2000. In addition, some more projects which are to be constructed by the beginning of the next period, year 2001, were raised by CEB also as urgent requirements. The both projects have been taken up as the projects for urgent implementation in this Study.

In the past, execution of transmission system development projects, typically the Transmission and Grid Substations Development Project (TGDP) under OECF finance, has delayed much due to insufficiency in preconstruction preparation. So as cause no serious troubles after starting construction activities, more studies on selection of line routes and substation sites, identification of expected land problems, site investigations, environmental impact assessment and official approval for project execution shall be carried out prior to starting construction.

10.2 List of Urgently Required Transmission System Projects

Sub-projects which have been identified and require urgent implementation are summarized below:

(1) Transmission lines

(a) New constructions

<u>220 kV Line</u> : 8 km (16 circuit-km)

- Pannipitiya - Dehiwala	2-cct	2 x Zebra	8 km

This line planned to be operated at 132 kV for the time being.

<u>132 kV Line</u> : 152 km (276 circuit-km)

- Balangoda - Ratnapura	2-cct	Zebra	40 km
- Matugama - New Galle	2-cct	Zebra	64 km
- Branching to Kuliyapitiya	2-cct	Zebra	18 km
- Embilipitiya - Hambantota	1-cct on DC towers	Bear	28 km
- Connections to substations	2-cct	—	2 km

(b) Voltage upgrading from 132 kV to 220 kV : 15.5 km (31 cct-km)

- Biyagama - Pannipitiya	2-cct	Zebra	15.5 km

This line was originally constructed with 220 kV design. However, some addition of insulators is required.

(c) Reconductoring of 132 kV line : 13 km (26 cct-km)

- Kolonnawa - Pannipitiya 2-cct Lynx to Zebra 13 km

(2) Substations

(a) New construction of 132/33 kV grid substations : 11 substations (756 MVA in total)

- Ratnapura	2 x 31.5 MVA
- Aniyakanda	2 x 31.5 MVA
- Athurugiriya	2 x 31.5 MVA
- Sri Jaya'pura	2 x 63 MVA
- New Galle	2 x 31.5 MVA
- Kelaniya	2 x 63 MVA
- Dehiwala	2 x 63 MVA
- Kuliyapitiya	2 x 31.5 MVA
- Polonnaruwa	2 x 16 MVA * 1
- Ambalangoda	2 x 31.5 MVA
- Hambantota	2 x 10 MVA * 1

* 1 : Transformers replaced from other stations are planned to be installed.

(b) Extension of existing substations : 5 substations

Biyagama, Pannipitiya, Balangoda, Matugama and Embilipitiya

The required extensions at the Pannipitiya substation includes 220/132 kV, 2 x 250 MVA transformers, and other substations comprise line bay addition only.

The detailed list of sub-projects for urgent implementation is presented in Table 10.2-1 and location map in Fig. 10.2-1.

The implementation cost of urgent projects is roughly estimated to be US$ 116.8 Million in total, which consists of US$ 93.2 Million in foreign component and US$ 23.6 Million equivalent in local component, in the end-1995 price level as shown in Table 10.2-2.

10.3 Expected Financial Source and Immediate Actions to be Taken

The own fund of CEB will not be sufficient to carry out all the projects mentioned above. As financial institutions which are expected to extend financial assistance to the implementation of the planned projects, OECF of Japan, IBRD, ADB and other institutions are conceived. At the present stage it will be difficult to find out a financial source soon for immediate implementation of the sub-projects.

Under such a circumstance, it is recommended to carry out studies at an earliest convenience to prepare for future smooth execution of the sub-projects when a project finance is granted. Such studies shall include for instance the following items:

(a) Basic design of sub-projects to determine basic criteria of design and selection of substation sites and transmission line routes including the center line survey and soil tests for transmission line routes, and topographic survey and soil investigation for substation sites.

(b) Detailed design and preparation of tender documents for international competitive tendering.

(c) Environmental impact assessment studies (EIA) on sub-projects.

These studies had better be completed prior to application of loan for implementation. For certain institutions, the execution and clearance of the EIA studies is a condition for granting a loan.

10.4 Terms of Reference for Consulting Services

Proposed terms of reference for consulting services to preparatory studies for the development projects which require urgent implementation are given below.

A proposal for financial assistance from a bilateral source or an international institution is to be submitted together with the result of this study.

Terms of Reference for Studies on Preparation for Urgent Implementation of Transmission System Extension Projects

1. General

The consultant services for the studies on preparation for Urgent Implementation of the Augmentation and Extension of Transmission System of CEB is proposed to consist of the following two categories:

Part A : Basic design and detailed design of transmission system facilities
Part B : EIA (Environmental Impact Assessment) studies

and will be carried out in the following two stages:

Stage I : Basic design stage (Part A)
Stage II : Detailed design stage (Part A and Part B)

2. Basic Design

During the basic design stage, the consultant shall carry out the following services:

(1) Assistance in selection of substation sites and transmission line routes which will be carried out by CEB.

(2) Investigation of the existing transmission system facilities related to required extensions.

(3) Basic design of transmission lines and substations which includes connection design and general layout.

(4) Assistance in topographic survey and investigation of soil properties (boring, bearing strength and resistivity) of substations by CEB.

(5) Preparation of design drawings (to be inked by CEB) and basic design report (to be printed by CEB).

3. Detailed Design

During the detailed design stage, the consultant shall carry out the following services:

Part A : Detailed design and preparation of tender documents for international competitive tendering for transmission facilities

(1) Transmission lines

  (a) Assistance in center line survey and soil investigation for the transmission line routes.

  (b) Detailed design of transmission line facilities.

  (c) Assistance in preparation of tender drawings (to be inked by CEB).

  (d) Preparation of tender documents (to be printed by CEB).

(2) Substations

  (a) Detailed design of substation facilities including PLC communication facilities and line protection system.

  (b) Detailed design of control buildings.

  (c) Preparation of tender drawings (to be inked by CEB).

  (d) Preparation of tender documents (to be printed by CEB).

Part B : EIA studies

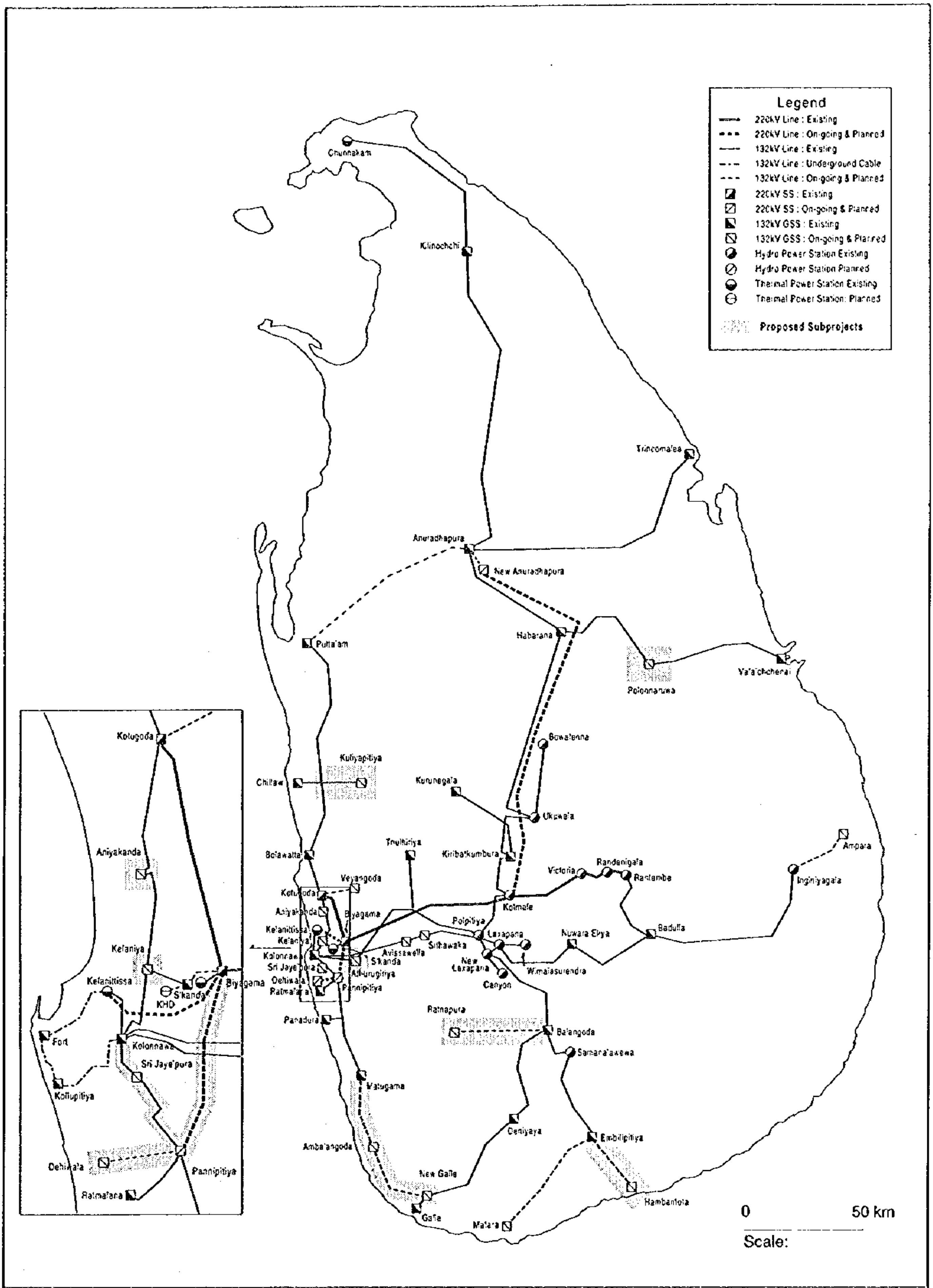
  (a) EIA studies on the planned transmission facilities.

Table 10.2 - 1 List of Proposed Subprojects

Augmentation and Extension of Substations	Proposed Commiss. Year
(1) Upgrading of 132kV Biyagama - Panipitiya Line to 220kV	2000
a) Upgrading of Biyagama - Panipitiya 132kV line to 220kV (220kV construction)	
b) Biyagama (two 220kV T/L bays for Panipitiya line)	
c) Panipitiya (2x250MVA, two 220kV T/L bays for Biyagama line)	
(2) Reconductoring of Kolonnawa - Panipitiya 132kV Line	2000
a) Kolonnawa - Panipitiya 132kV line (2cct, 13km, Lynx to Zebra)	
(3) Construction of Ratnapura 132 kV Substation	1998
a) Ratnapura (2x31.5MVA)	
b) Balangoda - Ratnapura 132kV line (2cct, 40km, Zebra)	
c) Balangoda (two 132kV T/L bays for Ratnapura line)	
(4) Construction of Aniyakanda 132 kV Grid Substation	1998
a) Aniyakanda (2x31.5MVA)	
b) Double pi-connection for Aniyakanda (2x2cct, 0.2km, Zebra)	
(5) Construction of Athurugiriya 132 kV Grid Substation	1998
a) Athurugiriya (2x31.5MVA)	
b) Triple pi-connection for Athurugiriya (3x2cct, 0.1km, Lynx)	
(6) Construction of Sri Jayawardenapura 132 kV Grid Substation	1998
a) Sri Jaya'pura (2x63MVA)	
b) Double pi-connection for Sri Jaya'pura (2x2cct, 0.1km, Zebra)	
(7) Construction of New Galle 132 kV Grid Substation	2000
a) New Galle (2x31.5MVA)	
b) Double pi-connection of New Galle (2x2cct, 0.1km, Tiger)	
(8) Construction of Matugama - New Galle 132kV Line	2000
a) Matugama - New Galle 132kV line (2cct, 64km, Zebra)	
b) Matugama (two 132kV T/L bays for New Galle line)	
c) New Galle (two 132kV T/L bays for Matugama line)	
(9) Construction of Kelaniya 132kV GIS Grid Substation	2000
a) Kelaniya (2x63MVA)	
b) Triple pi-connection for Kelaniya (3x2cct, 0.1km, Zebra)	
(10) Construction of 132kV Dehiwala Grid Substation	2000
a) Panipitiya - Dehiwala 132kV line (220kV construction, 2cct, 8km, 2xZebra)	
b) Dehiwala (132/33kV:2x63MVA)	
c) Panipitiya (two 132kV T/L bays : existing bus for Biyagama line are available)	
(11) Construction of Kuliyapitiya 132 kV Grid Substation	2001
a) Double T-connection for Kuliyapitiya (2cct, 18km, Zebra)	
b) Kuliyapitiya (2 x 31.5MVA)	
(12) Construction of Polonnaruwa 132 kV Grid Substation	2001
a) Polonnaruwa (2 x 16MVA) : (replaced transformer)	
b) Single pi-connection for Polonnaruwa (2cct, 0.5km, Lynx)	
(13) Construction of Ambalangoda 132 kV Grid Substation	2001
a) Ambalangoda (2 x 31.5MVA)	
b) Single pi-connection for Ambalangoda (2x2cct, 0.1km, Zebra)	
(14) Construction of Hambantota 132 kV Grid Substation	2001
a) Embilipitiya - Hambantota 132kV line (1cct on 2cct towers, 28km, Bear)	
b) Hambantota (2 x 10MVA) : (replaced transformer)	
c) Embilipitiya (one 132kV T/L bays for Hambantota line)	

Table 10.2 - 2 Cost of Proposed Subprojects

Augmentation and Extension of Substations	Cost (1,000 US$)		Proposed Commiss. Year
	FC	LC	
(1) Upgrading of 132kV Biyagama - Pannipitiya Line to 220kV	11,597	2,370	2000
(2) Reconductoring of Kolonnawa - Pannipitiya 132kV Line	1,338	471	2000
(3) Construction of Ratnapura 132 kV Substation	8,907	2,316	1998
(4) Construction of Aniyakanda 132 kV Grid Substation	5,748	1,453	1998
(5) Construction of Athurugiriya 132 kV Grid Substation	6,549	1,629	1998
(6) Construction of Sri Jayawardenapura 132 kV Grid Substation	5,727	1,448	1998
(7) Construction of New Galle 132 kV Grid Substation	5,858	1,482	2000
(8) Construction of Matugama - New Galle 132kV Line	6,886	1,783	2000
(9) Construction of Kelaniya 132kV GIS Grid Substation	11,528	2,336	2000
(10) Construction of 132kV Dehiwala Grid Substation	8,551	2,053	2000
(11) Construction of Kuliyapitiya 132 kV Grid Substation	6,368	1,687	2001
(12) Construction of Polonnaruwa 132 kV Grid Substation	3,352	1,143	2001
(13) Construction of Ambalangoda 132 kV Grid Substation	4,882	1,275	2001
(14) Construction of Hambantota 132 kV Grid Substation	6,458	2,475	2001
Total	93,749	23,921	



CEYLON ELECTRICITY BOARD

JAPAN INTERNATIONAL COOPERATION AGENCY

NIPPON KOEI CO., LTD.
Consulting Engineer

MASTER PLAN STUDY
FOR DEVELOPMENT OF THE TRANSMISSION SYSTEM
OF THE CEYLON ELECTRICITY BOARD
IN THE DEMOCRATIC SOCIALIST REPUBLIC OF SRI LANKA

TITLE

Fig. 10.2 - 1

Location of Proposed Subprojects

CHAPTER 11

DATA BASE PREPARATION

CHAPTER 11

DATA BASE PREPARATION

11.1 Purpose of Data Base Preparation

Due to recent growth in power demand and progress in manufacturing technologies, total capacities of power system facilities have much increased and sophisticated recent equipment have been introduced. In order to carry out the power supply activities of a power utility in most efficient and economic manners, the sound management organization and efficient operation of facilities, and importance of rationalization and modernization of maintenance operation have been increasingly recognized. To promote effective planning and designing of system facilities, and their efficient operation and maintenance, not only hardware but also software must be well established. The database is a tool to support effective fulfillment of the activities of power utility from the software view point.

In Japan, the importance of systematic preparation of the database system covering major facilities data for hydropower stations, thermal power plants, overhead lines, underground cables, substations, distribution systems, etc., which include not only major facilities but also auxiliary facilities, consumer information, etc. has been acknowledged and systematic establishment of database is being in study and progress.

The database system contemplated in Japan comprises a wide range of information and requires a large scale computer system for data handling.

In this Study, as the first step of database preparation for CEB the following basic database items were contemplated:

(a) Database for parameters necessary for power system analysis

(b) Database for major transmission system facilities

11.2 Parameters Necessary for Power System Analysis

Various parameters of the present power system necessary for performing power system analysis have already been stored utilizing various occasions in the PSS/E computer software, the major power system analysis software of CEB.

11.2.1 Transmission Lines

Transmission line information necessary for power system analysis is impedance (resistance and reactance) and capacitance of each section of transmission lines. For calculating these figures, conductor type and size, number of conductors in one phase, line length and tower configuration data are required. CEB already had database of the present power system parameters necessary for carrying out power system analysis, though not complete. However, in this Study the data have been partly revised according to the results of investigation of actual status of the existing facilities as mentioned in Clause 11.3.1.

Actual figures of a line section can be confirmed by site measurement, but theoretically calculated parameters based on tower configuration and conductor height have enough accuracy.

For steady state and three-phase fault analysis, only the positive-phase figures are used. However, for system analysis under earth fault conditions negative-phase and zero-phase figures are additionally required. The negative-phase values of the transmission lines can be taken same as those of the positive phase values. However, the zero-phase values are influenced by the specific resistance of the ground where the line is passing, and can be confirmed only as a result of actual measurement. It is possible to analyze theoretically if necessary data are available. As systematic site measurement data are not available for the CEB system, assumed figures are used for the Study. For determination of zero phase values with enough accuracy, it is required to collect site measurement data for impedance and capacitance and specific soil resistance. In Japan, the zero-phase values a new line can be estimated if line route is fixed based on past data of the area and theoretical calculations.

11.2.2 Substation Facilities

Parameters of substation equipment necessary for power system analysis are data of transformers; reactance values (primary to secondary, including primary to tertiary and secondary to tertiary in case of tree-winding transformers) and adjusting ranges of tap ratios.

11.2.3 Generating Equipment

For analyzing behavior of generating equipment in the power system including transient phenomena, various parameters are required.

Only positive-phase sequence values are required for analyzing three-phase balanced circuits, and negative- and zero-sequence values are also required for analyzing unbalanced circuits such as earthing fault and line to line short circuit conditions. Working reactances under steady state are synchronous values. These values are not fixed values and varies under disturbance, and for analysis under fault and disturbance transient (within 1 second) and subtransient values (up to 0.3 second) are also required.

To carry out dynamic stability analysis of a power system using computer, various parameters to represent dynamic behaviors of turbine governors and the generator excitation system which include AVR are required.

In case of relatively new machines necessary information for computer analysis are available on request, however for old equipment such data were not prepared; the analytical technology had not been established and equipment were designed and manufactured without ideas of recent technologies. In such cases, parameters necessary for system analysis are usually be assumed from statistical records and representative values were used.

11.3 Information Necessary for Planning and O & M

Preparation of database for major power system components is required as technical information and as well as a list of asset of power utility. These constitute prime items of the database. These database need to be modified and renewed periodically.

In future, with progress in database utilization it is required that the facilities data, together with patrol and inspection data, environmental data, etc., can be searched, processed and edited to provide timely information.

11.3.1 Transmission Lines

The intention of the overhead line (OHL) database was primarily to identify and confirm all the information necessary for the calculation of the OHL impedance and capacitance values; the line length; the number, type and size of conductors and earthwires; the geometric spacing of conductors and earthwires above ground level. The average height of the conductors above ground level (Y_{AV}) was based on the suspension tower dimensions minus the suspension insulator length and two thirds of the conductor sag at maximum operating temperature on the basic span length. Some additional information not relevant to the calculation of impedance and capacitance values was also recorded. In future the database information could also be useful for planning, design, maintenance and evaluation of OHL fault statistics.

Initial information on the existing transmission system provided by CEB was given on the CEB Primary Power System Diagram, TD/95/7706 dated 6 July, 1995. Much of the information on this drawing was found to be incorrect. Reference is made to Table 11.3.1-1.

In order to confirm all the information it was necessary to find out the original overhead line records, the Drawing Office and the Library were the main sources of these. Line schedules gave the tower types and the overall route length of the line. Once the basic suspension tower type had been identified from the line schedule the detailed drawings could be located for the dimensions of conductor and earthwire attachment points. The Contract Documents or Technical Specifications gave type, size and number in one phase of the conductors and earthwires and the insulator type, number of discs in string and material, also the basic span, sag and maximum operating temperature.

Many of the OHL circuits, particularly those with T-connections were constructed at different stages by different contractors using different tower designs. Where possible each of these pieces of OHL have been identified separately.

It has not been possible to confirm all the database information, suspension insulator set lengths were particularly difficult to confirm, where this occurs the information has been marked with * in Table 11.3.1-1. It is hoped that when the database information is handed to CEB that this information can be checked and maintained by the Maintenance Branch, and when OHL modifications are made or new circuits are added that the database can be modified accordingly to keep it up to date and as accurate as possible.

The database for each of the existing transmission line has been prepared, though not complete, based on available information. The collected data and information are compiled in Appendix A11.

11.3.2 Substation Facilities

In planning and design of new substation and maintenance of substations, information of existing facilities in detail is required to be referred to.

Data and information for preparing the database were collected mainly from the Transmission Planning Branch of the Planning Division, with assistance of Drawing Office and Library in the head office, and Complex Offices and Area Offices. Up to now, most of data have been collected, but these include a lot of doubtful items. The remaining data are hoped to be collected by CEB staff. As to parts of them which are doubtful, reinvestigation and correction were requested to the Planning Division.

Equipment selected as the initial items of database are transformers and circuit breakers.

Database based on available information is included in Appendix 11.

11.3.3 Fault Records

To improve the reliability of power supply to consumers, faults of the electric power system must be reduced to the minimum. For this purpose, it is required to collect fault data in a systematic manner and analyze properly to identify causes of faults and find out measures to reduce occurrence of faults.

The items of fault records to be prepared for each occurrence of fault are for instance as given below:

(a) Reports of electrical faults (immediate and final reports)

Reports are required for all faults

(b) Reports of designated faults (immediate reports)

For serious fault which affects much the consumer power supply, immediate reports shall be prepared and submitted to the authority. In Japan, the first report is submitted in about 5 minutes after fault, second one about 25 minutes, third one 60 minutes, and succeeding ones as required. The first report shall be prepared by SCC.

(c) Protective relay maloperation reports

A report shall be submitted for each maloperation of protective relay against electrical fault.

Examples of reporting items are presented in Tables 11.3.3-1, 2 and 3 with notes for filling in.

11.3.4 Relay Settings

Relay setting data are essential to confirm coordination of the power system protection. However, an overall relay setting table has not been prepared for the CEB system as settings have been decided substation wise or section wise without overall coordination. Wide variety of relays, operation principles, old and new, characteristics, etc., from various manufacturers in the system makes difficult preparation of a standard form for setting table.

The Protection Branch of the Generation Division has a plan to formulate an overall relay setting standard to be applied to all relays in the CEB power system by compiling recommendations from consultants and manufacturers.

11.3.5 Communications Facilities

Data and information necessary for the operation and maintenance are shown in database of the PLC system in Tables 11.3.5-1 and 11.3.5-2. The intention of this database is to identify and recognize the existing PLC system, and to be referred to in planning, designing, and as well as for operation and maintenance. This list is to be utilized for extension planning of the existing PLC circuit because the blocking frequency band of line traps and the passing frequency band of HF coupling device can be obtained easily. And necessary replacement time can also be estimated from this list.

All the data and information in the list were obtained from the Communication Branch of the Generation Division. The tables of collected data and information are included in Appendix A11.3. There are many blank columns in the tables and these are required to be filled in later by CEB.

In addition to the CEB's general drawing (No. CEM/CMN/PLC 001), a drawing showing line coupling mode of all PLC circuits shall be prepared to refer to in future planning and designing works. Regarding carrier frequency allocation, it is recommended to renew the drawing in CEB's hand to make the frequency use more clear.

Table 11.3.1 - 1 Comparsion of actual circuit data with original information

(from CEB Primary Power System Diagram TD / 95 / 7706 dated 6 / 7/ 95)

Ref.	Section	Voltage (kV)	Circuits	Conductors	Original Length (km)	Actual Length (km)	Note
2L1.	Biyagama - Kotugoda	220	2	Zebra	23.0	19.6	-15 %
2L2.	Biyagama - Kotmale	220	2	2 x Zebra	71.0	70.5	
2L3.	Kotmale - Victoria	220	2	2 x Zebra	32.0	30.1	- 6 %
2L4.	Victoria - Randenigala	220	1	2 x Zebra	16.0	16.4	
2L5.	Randenigala - Rantembe	220	1	2 x Zebra	2.4	3.1	+ 29 %
1U1.	Kelanitissa - Fort	132	1	UG, (Cu 500)	4.9	4.9	
1U2.	Fort - Kollupitiya	132	1	UG, (Cu 350)	2.7	2.7	
1U3.	Kollupitiya - Kolonnawa	132	1	UG, (Cu 500)	5.8	5.4	- 7 %
1L1.	Biyagama - Pannipitiya	132	2	Zebra	17.0	15.5	- 9 % (1)
1L2.	Biyagama - Kelanitissa	132	2	2 x Goat	16.0	12.5	-22 %
1L3.	Biyagama - Sapugaskanda PS	132	2	Lynx	2.1	2.1	
1L4.	Kolonnawa - Kelanitissa	132	2	Zebra	2.2	2.2	*
1L5.	Kolonnawa - Pannipitiya	132	2	Lynx	13.0	12.9	
1L6.	Kolonnawa -Sapugaskanda(T)	132	2	Coyote	6.6	6.6	*
1L7.	Sapugaskanda (T) - Kotugoda	132	2	Coyote	16.7	16.7	*
1L8.	Sapugaskanda (T) - SS	132	2	Coyote	7.3	4.6	-37 %
1L9.	Kotugoda - Bolawatta	132	2	Coyote	21.0	21.0	*
1L10.	Bolawatta - Chilaw (T)	132	2	Lynx	42.0	22.6	- 46 %
1L11.	Chilaw (T) - Puttalam	132	2	Lynx	42.0	61.4	+ 46 %
1L12.	Chilaw (T) - SS	132	2	Lynx	8.0	6.8	- 15 %
1L13.	Kolonnawa - Oruwala	132	2	Lynx	14.0	14.0	*
1L14.	Oruwala (T) - SS	132	2	Lynx	0.1	3.4	*
1L15.	Oruwala (T) - Thulhiriya (T)	132	2	Lynx	36.0	36.0	*
1L16.	Thulhiriya (T) - SS	132	2	Lynx	24.0	23.9	
1L17.	Thulhiriya (T) - Polpitiya	132	2	Lynx	28.0	28.0	*
1L18.	Kolonnawa - Avissawella (T)	132	2	Lynx	33.1	31.9	
1L19.	Avissawella (T) - SS	132	2	Lynx	0.5	0.5	*
1L20.	Avissawella (T) - Polpitiya	132	2	Lynx	33.0	34.4	
1L21.	Pannipitiya - Ratmalana	132	2	Lynx	6.0	6.9	+ 15 %
1L22.	Pannipitiya - Panadura (T)	132	2	Goat	12.0	12.3	(2)
1L23.	Panadura (T) - Matugama	132	2	Goat	36.0	29.1	- 19 % (2)
1L24.	Panadura (T) - SS	132	2	Lynx	7.0	4.7	- 33 %
1L25.	Polpitiya - Laxapana	132	2	Lynx	8.1	8.3	
1L26.	Laxapana - Wimalasurendra	132	2	Lynx	5.1	5.1	
1L27.	Laxapana - New Laxapana	132	2	Lynx	0.6	0.6	*
1L28.	New Laxapana - Polpitiya	132	2	Lynx	8.0	8.0	*
1L29.	New Laxapana - Canyon	132	1	Lynx	10.0	10.0	*
1L30.	Polpitiya - Kotmale	132	1	Lynx	35.0	29.5	- 16 %
1L31.	Kotmale - Kiribatkumbura	132	1	Lynx	27.0	22.5	- 17 %
1L32.	Kiribatkumbura - Anuradhapura	132	1	Lynx	159.0	143.9	- 9 %
1L33.	Polpitiya - Ukuwela	132	1	Lynx	69.0	59.3	- 14 %
1L34.	Ukuwela - Habarana	132	1	Lynx	89.0	82.3	- 7 %
1L35.	Habarana - Anuradhapura	132	1	Lynx	51.0	48.9	
1L36.	Ukuwela - Bowatenna	132	1	Lynx	32.0	30.0	- 6 %
1L37.	Kiribathkumbra - Kurunegala	132	2	Lynx	34.6	34.6	*
1L38.	Habarana - Valaichchenai	132	1	Lynx	96.0	99.7	*
1L39.	Anuradhapura - Trincomalee	132	2	Lynx	110.0	103.3	- 6 %
1L40.	New Laxapana - Balangoda	132	2	Lynx	44.0	43.9	
1L41.	Balangoda - Samanalawewa	132	2	Zebra	19.0	19.0	
1L42.	Samanalawewa - Embilipitiya	132	2	Lynx	38.0	38.0	
1L43.	Balangoda - Deniyaya (T)	132	2	Tiger	44.0	44.2	
1L44.	Deniyaya (T) - Galle	132	2	Tiger	55.0	57.3	
1L45.	Rantembe - Badulla	132	1	Lynx	37.0	37.0	*
1L46.	Badulla - Inginiyagala	132	1	Oriole	79.9	79.9	*
1L47.	Anuradhapura - Kilinochchi(T)	132	2	Lynx	131.0	128.8	
1L48.	Kilinochchi (T) - Chunnakam	132	2	Lynx	67.0	67.2	

* Length not confirmed.

(1) Original Conductor 2 x Zebra

(2) Original Conductor Lynx

Table 11.3.3-1 Report of Electrical Fault

(1) Fault number

(2) Date and time of fault with weather

(3) Particulars of fault with system diagram, sketch, etc.

(4) Cause of Fault

(5) Protection operation

(6) Date and time of restoration

First restoration

Complete restoration

(7) Interrupted power (MW)

(8) Relieved interruption by automatic apparatus (MW)

(9) Interrupted generation power (MW)

(10) Restricted generation power (MW)

(11) Duration of interruption

Minimum duration (hours, minutes)

Maximum duration (hours, minutes)

(12) Location of supply interruption

Grid substation ________________, ______ MW

HV consumer ________________, ______ MW

(13) Location of power failure

Grid substation ________________, ______ MW

HV consumer ________________, ______ MW

(14) Rough number of consumers of power failure

(15) Process of restoration

(16) Other information

Notes for Filling the Form

Notes for filling in each item are mentioned below:

(1) Fault number: For each of all faults in one year, series number shall be provided. A number of faults occurred due to one cause (for instance same lightning stroke, tree touching line, etc.) shall be treated as one fault.

(2) Date and time of fault: Time of occurring or detecting a fault. Weather at the fault, fine, cloudy, rain (with strong wind or not), lightning (accompanied by rain or not), strong wind, etc. with surrounding situations.

(3) Particulars of fault: With specific description.

Location:

Line:	Section, 1L or 2L, Phase red, yellow or blue
Substation:	Name, Voltage level, Line, Bus or Main transformer, (generator)
Reclosing:	1-phase, 3-phase, High speed, Low speed
Protective relays:	Normal or Abnormal
Electric shock of human:	If any, reason for fault

(4) Cause of fault: As specific as possible.

1. Not identified Defective equipment
2. Weather including lightning attack
3. External interference
4. Maintenance error such as touching of tree or bamboo
5. Human element
6. Protection maloperation
7. Fault spreading

(5) Protection operation:

1. 1-phase-to-earth fault
2. Phase-to-phase fault
3. 2-phase-to-earth fault
4. 3-phase short circuit
5. Overload
6. Breaker fail open/close
7. False relay operation
8. Manual operation
9. Generator or transformer unit protection operated

(6) Date and time of restoration: When power supply situation returned to normal. Resumption of partial supply and complete restoration. Expected time in case of immediate report.

(7) Interrupted power: Amount of power in MW interrupted by fault (not include restored supply by auto-reclosing or operation of automatic controlling apparatus), to be identified as the balance of power just before and after the supply interruption.

(8) Relieved interruption by automatic apparatus: Amount of power relieved from the supply interruption by automatic apparatus such as autorecloser, automatic controllers, etc.

(9) Interrupted generation power: Amount of generation power interrupted by fault at the power station, to be identified as the balance of generated power just before and after the generation interruption.

(10) Restricted generation power: In case that shutdown or restriction of generation occurred due to faults outside the power station, fault of transmission line connected to the power station, overloading of line or transformer, system over- or under-frequency, system separation, etc., balance of generated power just before and after fault.

(11) Duration of interruption: Duration of supply interruption or generation restriction. Minimum duration to first restoration and maximum duration to final restoration shall be entered.

(12) Location of supply interruption and power: Names of grid substations and HV consumers affected by supply interruption and individual interrupted power in MW.

(13) Location of power failure and power: Names of grid substations and HV consumers affected by power failure and individual failed power in MW.

(14) Number of consumers of power failure: Roughly estimated number of consumers affected by power failure.

(15) Process of restoration: Time and action of each process shall be shown.

(16) Other information: Miscellaneous information related to fault and its restoration such as:

- Conditions of damaged facilities
- Influence to communities and important consumers
- Instructions of SCC related to restoration
- Considerations for restoration activities

Table 11.3.3-2 Immediate Report for Designated Fault

(1) Particulars of fault in brief related to designated fault

(2) Location of fault occurrence

(3) Location of power failure

(4) Date and time of occurrence or discovery of fault

(5) Failed power in MW and number of failed houses

(6) Area where power is failed

(7) Impacts to community

(8) Restored faults and prospect for restoration: Particulars of restoration such as name of line, area of restoration, restored power, number of restored houses, etc.

(9) Location and facilities of fault

(10) Cause of fault

(11) Special remarks
Brief connection, restoration process, weather conditions, etc.

Note: Based on importance, faults are classified to A and B.

Table 11.3.3-3 Report of Relay Maloperation

(1) Particulars of maloperation

Contents of relay maloperation shall be described briefly.

(2) Date and time with weather

Time of relay maloperation. Weather shall include thunder, strong wind and other special remarks shall also be clarified.

(3) Location

(4) Classification of maloperation

Primary cause

1. Maloperation of relay itself, mechanism or operation characteristics
2. Improper setting
3. Inadequacy of system
4. Improper design, sequence or relay selection
5. Improper installation, wiring, polarity, workmanship
6. Equipment fault, CB, CT, VT, and other equipment
7. No good maintenance
8. Maloperation
9. Vibration
10. Not identified

Secondary cause

1. Technical limitation
2. Incidental accident of equipment
3. Unavoidable economically
4. Improper planning, manufacturing, installation, setting, maintenance, operation, inspection, etc.
5. Not identified

(5) Kind of relay

(6) System voltage

(7) Operating situation at the time of relay maloperation. System connection, relay operation, etc. shall be clarified.

(8) Contents of investigation

(9) Supposed cause of maloperation

(10) Proposed countermeasures

(11) Particulars of relay impropriety, manufacturer, type, year of manufacture, etc.

(12) Impacts of maloperation, supply interruption caused by relay maloperation

Table 11.3.5- 1 Data Base Data for PLC System

Voltage/	Transmission Line		Power Line Carrier (PLC)						Teleprotection				PLTS			PAX			Line trap						CVT/CC	HF Coupling device		
Line No.	Station from/to station	Distance (km)	Type	TX/RX (kHz)	CH	Watt	Serial No.	Operation Year	Type/Scheme	CH in PLC	Q'ty	Operation Year	Q'ty	CH in PLC	Operation Year	Q'ty	CH in PLC	Operation Year	Current (A)	Inductance (mH)	Blocking freq. (kHz)	Phase	Q'ty	Operation Year	Capacitance	Type	Passing freq. (kHz)	Remarks

Table 11.3.5 - 2 Data Base Data for PLC System of d.c. power

No.	Name of station	Battery			Battery charger			Distribution board/circuits				Load data		Required capacity	
		Type	Capacity	Operation year	Type	Capacity	Operation year	Used circuits	Rating (A/AF)	Equipped circuits	Rating (A/AF)	Existing [A]	Additional [A]	Battery	Charger
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
12															
13															
14															
15															
16															
17															
18															
19															
20															

CHAPTER 12

TRANSMISSION AND DISTRIBUTION SYSTEM LOSS STUDIES

CHAPTER 12

TRANSMISSION AND DISTRIBUTION SYSTEM LOSS STUDIES

12.1 Transmission and Distribution System Loss

(1) Transmission and Distribution Loss of the CEB System

The T&D loss factor of the CEB system was 17.8% in 1995. The loss factor has been in an increasing trend after the 1970s; the average loss factor was 13.5% in the 1970s, 16.9% in the 1980s and 17.9% after 1990. These loss values are for the CEB system only and do not include the distribution losses in the systems of LECO and LAs. The entire T&D loss rate including the non-CEB systems is estimated to be around 20%.

Though exact analysis of the system loss is not possible without thorough study, the breakdown of the entire T&D loss factor is roughly estimated based on information from CEB as follows:

220/132 kV system	3.5%
33/11 kV system	4.5%
230/400V system	12.0%
Total	20.0%

The above estimates for the transmission and MV distribution systems are based on results of computer calculations by CEB, power flow calculation under full load conditions by the PSS/E software for the transmission system and analysis by the Scott and Scott software for the MV distribution system. It is difficult to accurately estimate the energy loss of the system under actual varying operating conditions.

The transmission system loss values based on the site measurement in the monthly review reports for system control and operations of CEB is close to 7% and much larger than the above calculation-based value. The measured data involve a lot of discrepancies and seem to be caused by inaccuracies in reading of old meters.

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

The Distribution and Consumer Service Division presented their estimation for technical loss of the 1995 distribution system as follows:

33/11 kV lines	2.5%
Distribution transformers	1.5%
LV lines	6.0%
Total	10.0%

Note: All of the above figures are based on calculation and not measurements.

It is a fact that there is about 20% difference in energy meter readings between the generation ends and consumer ends. However, it is not possible to confirm its breakdown as considerable error is presumed in energy meters especially relatively old ones. It can be assumed that the balance of about 6% constitutes nontechnical loss, i.e. illegal use and metering and billing loss.

Reduction of the loss factor in the T&D system is equivalent to the construction of costly power stations and the loss reduction is a great concern to the Sri Lankan Government and CEB.

(2) Comparison with Situation of Other Countries

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

T&D Loss Factors of Asian Countries

Country	T&D Loss Factor (%)
Sri Lanka (1994)	20.0
Japan (1994)	5.5
Korea (1991)	5.6
China (1991)	8.2
Thailand (1993)	9.2
Indonesia (1991/92)	14.8
Vietnam (1993)	19.9
India (1993)	22.0
Nepal (1993/94)	24.9

The 1994 T&D loss factor of the Japanese power companies was 5.5%. The loss factor is generally high in developing South-East Asian countries; less than 10% in China and Thailand, around 15% in Indonesia, around 20% in Vietnam, and exceeding 20% in India and Nepal according to available 1991 to 1993 records. There are certain countries with loss factor of exceeding 30%. The loss factor is generally low in relatively rich countries. For reducing loss, actually a lot of investment is required. It is judged that the loss factor of Sri Lanka is fairly high, however is not in an extreme level in international comparison taking into account of 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 eight power companies had fallen down from 25.3% to 11.4%, less than a half, 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.

12.2 Review of Loss Behaviors

The T&D loss energy of the CEB system is normally obtained by deducting the sales energy and station service energy of CEB's stations 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 meter readings which include estimation for non-metered consumers. The sent out energy from the grid substations was measured by watt-hour meters on the secondary sides of distribution use transformers.

A considerable difference of the transmission system loss is noted between the computer calculation and site measurements. Regarding this difference, the followings are noted:

(a) Due to the lack of proper metering facilities, accurate measurement of loss is not possible. Relatively large metering discrepancies are noted among various meter readings including those of the LDC system.

(b) Basically, transmission system characteristics must well conform to theoretical calculations as have been confirmed through actual site measurements. There shall be no inaccuracy in the computer calculation; the CEB's estimated loss factor of 3.5% seems to be reasonable considering from data of other countries.

(c) Confirmation is required whether station uses in power stations and substations and unmetered consumers are properly included or not.

(d) Watt-hour meters tend to show large error due to friction under very light loading especially in case of old meters. This causes a high side loss factor.

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 33 kV at grid substations. The transmission system loss is estimated at 3.5% and the smallest among the three categories.

(b) The MV distribution system loss comprises the ohmic loss in 33 kV and 11 kV line conductors and the loss in stepping down transformers, 33/11 kV, 33 kV/240-415 V and 11 kV/240-415 V. The loss is estimated at 4.5% including non-CEB systems and is slightly larger than the transmission system loss.

(c) Amount of LV distribution system loss can not be physically confirmed due to the lack of proper metering arrangement. Actually, the total T&D loss deducted by the estimated transmission and MV distribution system losses was merely defined as the LV distribution system loss.

According to Clause 3.6, the total length of LV distribution lines is 2.7 times that of MV lines. Though actual line loss is affected by conductor sizes, loading of lines, etc., the ohmic loss in the LV system would be much larger than that 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 long time studies on the actual situation, exact quantification of these losses is not possible.

12.3 Loss Reduction Measures

12.3.1 Transmission System

The 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 the 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 the same 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 economic efficiency. Reference is made to Clause 6.1.4 (3). It is judged that the CEB's present transmission system consisting of 220 and 132 kV lines is of proper voltage level taking into account the present power transfer requirement.

The keeping transmission system voltage high results in smaller line current and reduces the ohmic loss in line. In principle actual operating voltage shall be selected high within the limit in the technical standard, 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 CEB system, though the upper limit of bus operating voltage is plus 5% the actual operating voltage seems to be selected 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, the power flow calculation computer program for transmission system has a function to calculate the sum of ohmic loss in all the connected transmission lines and indicate in the calculation result. Also the MV system loss can be calculated by the computer program.

(2) Transformers

In purchasing transformers on tender basis, it is a widely applied practice to award contract to a tenderer who offered the lowest price including evaluated loss values for load and no-load losses.

(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, shall be collected and edited 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 at the load dispatching centers with the help of computer. To accurately quantify loss values, measuring meters must have high accuracy. Small error of measured values result in relatively large error of loss as the balance of two indications.

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. Exact loss values had better be obtained from calculated results using computer.

12.3.2 MV and LV Distribution Systems

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

(a) By adopting higher voltage, the distribution loss can be reduced. For the CEB MV system, the 33 kV system shall be extended as far as possible instead of the 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 is not practical.

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 shall be taken that a higher operating voltage in the LV system results in increase of power consumption.

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

(c) The most economic conductor sizes shall be selected. The relation of appropriate conductor size vs. sending power, which shows the most economic conductor size for a certain sending power, shall 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 fault due to touching of vegetation and other items and to reduce pilferage.

(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 for loss reduction. The reactive current in line decreases, and as a result power loss and voltage drop in the line decreases significantly. It will be the most effective measure to request large consumers to install static capacitors in the power supply regulation. There is an idea to decrease power tariff against the power factor improvement (this practice is applied in Japan).

(g) Installation of static capacitors at 33 kV switching gantries and along 33 kV and 11 kV feeders shall be planned as required. 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 CEB with the help of the Scott and Scott Network Analysis Software.

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

12.3.3 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. It is required to design consumer service facilities so as to prevent attempts for power pilferage. Careful considerations are required in selecting wiring materials and watt-hour meters, and their fixing locations 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 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 the houses. The outdoor installation of watt-hour meters is beneficial also to the monthly meter reading. Security of installation shall also be taken into account. Stout cables installed at easily visible points connect the dropwires and watt-hour meters. All these facilities are usually installed on the outdoor walls easily visible from the road including trial for illegal use.

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 type watt-hour meters to reduce influence of illegal use by avoiding rotation in the reverse direction.

12.3.4 Relation with Voltage Maintenance Measures

In Sri Lanka, according to the regulation the consumer supply voltage is required to be kept within the range of the rated value ± 6%. As on-load tap changers are provided with the substation transformers, the 33 kV bus voltage is 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

All measures to limit variation of the consumer supply voltage result in reduction of line loss. In Japan's case, 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 is determined based on criteria of the maximum economy taking into account construction and O&M costs, and loss evaluation.

12.3.5 Nontechnical Approaches

The followings are conceived measures to reduce nontechnical losses.

(a) The public campaign for loss reduction and prevention of illegal use will be effective in making the general public fully aware of intention of CEB and consequence 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.

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

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

12.4 Conclusions

(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 lines
- Sold energy

In principle, the measured loss must coincide with theoretically calculated values. However, in the CEB transmission system there are considerable difference between the computer calculation results and the measured results. It is necessary to check the accuracy of all metering apparatus and identify causes of discrepancies.

Actually, accurate meters to measure loss values with practical accuracy cost much, and there is technical difficulties to maintain their accuracy under the present situation of CEB. 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 (220 kV and 132 kV) and MV distribution lines (33 kV and 11 kV), the relation of the most appropriate conductor size vs. sending power shall be obtained based on economic calculations. Economically most appropriate conductor size is that gives the lowest economic cost including construction cost, O&M cost and evaluated cost of loss.

(3) Control of System Operating Voltages

The current upper limit of transmission voltage in CEB 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. CEB is recommended to carry out proper studies on this point.

At grid substations, the secondary sending out voltage is set at the rated 33 kV. To raise the sending end voltage around 5% higher will contribute to reduction of distribution loss and as well as improvement of voltage profile.

(4) Thorough Studies for Loss Reduction

At first a thorough loss study covering all voltage classes of the system, 220 and 132 kV transmission, MV (33 and 11 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 CEB's transmission and distribution systems.
- Establishment of selecting procedure 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, 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 are limited to 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 is generally not high in the CEB's power system; mostly 85 to 90% at the secondary buses of grid substations and generally low for substations with factory loads. 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 be able to be achieved only by improving the LV distribution system, which is the largest source of T&D loss, including the consumer service facilities. Usual loss reduction studies focus on the LV system especially on the reduction of illegal uses, which is considered to be the most cost effective measures obtaining effects with 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 CEB, and other measurers.

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

CEB'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.

CHAPTER 13

ENVIRONMENTAL PROBLEMS ASSOCIATED WITH CONSTRUCTION OF TRANSMISSION SYSTEM FACILITIES

CHAPTER 13

ENVIRONMENTAL PROBLEMS ASSOCIATED WITH CONSTRUCTION OF TRANSMISSION SYSTEM FACILITIES

13.1 General

Transmission lines run through various types of land; flat plain and mountainous land, forest, cultivated field and grassland, inhabited and deserted area, etc., and grid substations are located near load centers, mostly cities and industrial areas. In planning, selecting line route and substation site, designing, constructing and operating and maintaining transmission system facilities, utmost cares shall be taken to conservation of natural environment and prevention of damage to communities and as well as natural, physical and ecological resources.

(1) Coordination with Environment

It is required to study carefully about coordination of the transmission system facilities, transmission lines and substations, with the natural environment. Impact on human life, fauna and flora, and wild life shall be limited to the minimum, and damage to the natural environment and public properties shall be avoided.

(2) Prevention of Damage to Public

It is required to design power transmission system facilities so as to avoid any accident of the public during operation of the system. Utmost care shall be taken and necessary measures be executed to prevent damage to the general public during construction.

13.2 Institutional Arrangement for Environmental Protection

Economic activities including industry, commerce and others, tend to accrue aggravation of environmental atmospheres and harm comfortable social lives. The environmental protection measures in economic activities usually need a certain investment. So as to protect the environment and to maintain comfortable social lives, it is required to prepare a certain standards for environmental criteria and to enforce laws and regulations for protection of environment.

The institutional arrangements for environmental protection related to development projects in Japan and Sri Lanka are summarized below:

<u>In Japan</u>

In the environmental protection laws and regulations, the environmental pollution is classified to seven categories of air pollution, water pollution, soil pollution, noise, vibration, ground subsidence and bad smell. For the four items of air, water, noise and vibration, there are individual government regulations which prescribe required environmental criteria. The responsive governmental organization in charge of the environmental protection activities is the Environmental Agencies (EA). Various laws and regulations are being enforced by the national government and also by local authorities; they are Laws for Environment Protection, Preservation of Nature, Prevention from Disasters, Prevention of Air Pollution, Prevention of Water Pollution, Noise Restriction, Vibration Restriction, etc. In addition, specific rules, criteria, guidelines, etc. are enforced by various organizations.

Prior to commencing actual execution of a development project, an environmental impact investigation report shall be prepared based on the government guideline and submitted to the Ministry of International Trade and Industry (MITI) with copies to concerned local authorities. For each of the above seven environmental categories, present conditions shall be investigated and estimated impacts after completion and during construction shall be evaluated. The report shall also include other aspects such as impacts on natural scenery, historical and cultural assets, fauna and flora, radio interference, etc. The report is reviewed in joint meetings of concerned ministries, and some revisions of environmental protection measures may be ordered as required. Public hearings are required for important projects to disseminate information to the public.

In various stages of a execution, planning, designing, constructing, and operating and maintaining, environmental protection measures must be taken so as to satisfy concerned laws and regulations.

In Sri Lanka

The purposes of environmental impact assessment (EIA) are to ensure that development options under consideration are environmentally sound and sustainable, and that environmental consequences are recognized and taken into account early in project design.

The governmental agency in charge of institutional matters for the environmental protection is the Central Environmental Authority (CEA). The National Environmental Act (NEA) was promulgated in 1980 and amended in 1988. According to a Gazette of June 1993 under the NEA, for overhead transmission lines of length exceeding 10 km and voltage above 50 kV and substations which require environmental considerations an EIA must be carried out and a report be submitted to the Project Approving Agencies (PAA). Approval to the planned environmental protection measures is given after passing an EIA Inter-Agency Committee held by CEA and public consent is obtained.

13.3 Problems Related to Construction of Transmission Lines

13.3.1 Selection of Line Route

The transmission line must be aligned in the natural environment and in social activity areas. Major environmental considerations to be taken into account in route selection are enumerated below:

(a) Related to natural environment

- To evade national park and natural forest.
- Not to affect temples (religious installations), historical installations, cultural monuments, etc.
- To evade mining area and lands with buried precious items.
- In view of coordination with the natural scenery, alignment on mountain ridges or in wide plains is to be evaded as far as possible so that the transmission line is not too much conspicuous in the natural scenery. A line route had better be selected along the mountain side; this seems to contribute to reduction of the chance of fault due to lightning hits.

- There are cases to paint towers in brown or green so that the towers may be melted in the natural colors. There are examples to select insulator color, brown or sky blue. Non-glossy conductors are sometimes selected to avoid shining surface. Such practices are tried especially in the national park areas or in urban areas.
- There are examples of applying specially designed supports in and around urban areas from aesthetic viewpoints.

It is a recent tendency in developed countries to pay utmost attention to coordination with the natural environment.

(b) Interference with human lives

- At first, land use along the line route shall be investigated. Consideration shall be paid to change in land value by construction of transmission line.
- To evade highly inhabited land. There are examples to design special supports like pole construction, sometimes with insulator arms, along large roads in urban areas to minimize width of right of way.
- To study on inhabitant relocation and resettlement problems.
- To evade as far as possible to align line route in cultivated fields, orchards and other human affected lands.
- Interference to traffic and blockage of access way
- Influence to an aviation route, and restricted areas according to aviation acts.
- Pipe lines, underground burials like gas facilities, etc.
- Influence to radio wave paths, television, etc.

(c) Impact on fauna and flora

- Influence to natural lives of animals and vegetation shall be avoided to the minimum after completion and during construction.
- Current conditions of general lives of animals and vegetation, especially those of important species shall be investigated and impacts of construction be evaluated.
- Cutting of trees shall be limited to the minimum and small precious vegetation, orchards, teas, coffees, etc. shall be kept not cleared by installing conductors high to keep enough clearance.

13.3.2 Land Problems and Compensation

In Japan, the width of right of way for a transmission line is limited in the 3 m space from the line of outer conductors. To further reduce the width of right of way (land cost is extremely high in Japan), the following three special design practices are applied widely:

(a) Erection of 4-circuit towers. In city areas in and around Tokyo, most of major lines up to 275 kV are of 4-circuit construction. Also in Southeast Asian countries, this practice has been applied.

(b) Application of the V-string to suspension insulator sets, for 500 kV and 275 kV lines, to curtail the spacing between two phases by preventing conductor swing.

(c) Application of narrow phase spacing towers by erecting tension towers for all supports and jumpering at towers.

No inhabited buildings are allowed in the right of way under extra high voltage (EHV) lines of 500 kV and 275 kV, but construction of buildings is allowed under line conductors of up to 154 kV. Within or in the vicinity of urban areas and where future construction of houses is expected, line conductors are strung high, not lower than 12 to 21 m, so that 2 to 4 story houses can be constructed under the line conductors with necessary clearance.

13.3.3 Tower Site Finishing and Soil Problems

To avoid troubles with land owners and the public, it is the basic principle to reinstate the tower site disturbed during construction works to the original state before the construction commenced. Residual soil after foundation backfilling shall be disposed by spreading within the tower site or by throwing to borrow areas without disturbing the original land. Sodding is required in case that long time is expected to growing of natural weeds and land erosion is anticipated.

Site finishing shall be proper such as to avoid erosion of land, disturbance of land drainage, etc.

13.3.4 Electromagnetic Induction

(1) Electromagnetic Induction Phenomena

A certain amount of voltage is induced on the communication line running in parallel with a transmission line due to the electromagnetic induction phenomena when unbalanced current flows in the transmission line. High induction voltage under an earth fault on the transmission line endangers human bodies and connected communication facilities when the induced voltage exceeded a certain limit.

Influence of the electromagnetic field to human body has not been identified.

The limits of induction voltage under the normal operation and under the earth fault condition are prescribed in the CCITT recommendations as given below:

(a) Under normal operation

- Power frequency dangerous voltage -------------------- 60 V r.m.s
- HF noise voltage on cable line -------------------- 1 mV
- HF noise voltage on bare conductor line -------------- 2.5 mV

Note: HF represents "High Frequency".

(b) Under earthing fault condition

- 430V for normal lines constructed with normal criteria.
- 650V for highly stable lines whose duration of flowing earth fault current is short, mostly within 2 seconds and never exceeds 5 seconds.

(2) Calculation of Electromagnetic Induction Voltage

The electromagnetic induction voltage on a communication line under the earth fault is calculated based on the zero-phase current of the transmission line and the relative location of the transmission line and communication line. A formula to calculate the electromagnetic induction voltage on communication lines is included in Appendix A13, Clause A13.1.

To calculate the electromagnetic induction voltage, the geographic relation of the transmission line and communication line must be known through available map and supplemental survey.

(3) Countermeasures Against Electromagnetic Induction Problems

Of conceived countermeasures, proper and most economical measures shall be selected to limit the electromagnetic induction voltage on communication lines after consultation with the communication authority and other concerned authorities. Usually applied countermeasures are enumerated below:

(a) To reduce earth fault current:

In Japan, the neutral point resistance earthing system is employed to the 66 and 154 kV transmission systems to curtail earthing fault current. The maximum earthing current through the neutral resistors is selected at 100 A. While, the neutral points of the 500 and 275 kV systems are directly earthed as the merit of graded insulation of transformers is significant for such EHV systems.

(b) To suppress electromagnetic induction voltage:

(b-1) Countermeasures on transmission line side

- To reduce earthing fault current of the transmission system.
- To increase separation between power and communication lines.
- To string (a) shield wire(s) between power and communication lines.
- To select overhead earthwires and/or shield wires with high conductivity for instance by using aluminum-clad steel wires instead of normal steel wires.
- To screen underground cables.
- To lay three single phase cables properly.

(b-2) Countermeasures on communication system

- To replace communication lines with non-metallic lines like optic fibers
- To shift route of communication line.
- To install shielded cables for communication lines.
- To reduce earthing resistance of the shield wires.
- To install repeater coils at intermediate points of communication lines to reduce induction voltage and lightning arresters at communication terminals to protect communication equipment.

13.3.5 Electrostatic Induction

The electrostatic voltage gradient is induced in the air due to existence of electrical field caused by the potential difference between line conductors and the ground. This causes potential difference between a certain point in the air and the ground In Japan, the strength of electric field at 1 m above the ground where is frequently approached by the public is required to be within 30 V/cm in the government regulation to avoid electrical shock to a human body. Higher electric field strength can be allowed on the condition that such electric field does not affect the health of human being. Even in developed countries, USA, Russia, etc. where line is long in scarcely populated areas, higher limits are applied to electric field strength to curtail the cost for construction of transmission line.

The present highest transmission system voltage in Sri Lanka is 220 kV. Therefore, there will not be serious electrostatic induction voltage problems if line conductors are strung at a height of not less than 8 m above the ground. This problem shall be reviewed when a higher transmission voltage of 400 kV is to be introduced.

In Japan, the electrostatic induction current on a communication line is required to be within 3 μA in the government regulation for the communication line length of 40 km for the line voltage of 66 kV and higher.

The problem of electrostatic induction to a communication line can be completely removed by replacing air-insulated communication lines with shielded cables. The reverse phasing arrangement of two circuits on double circuit towers decreases the electrostatic induction voltage.

Influence of the electric field to human health has not yet been clearly identified from a medical viewpoint..

13.3.6 Interference to Radio Wave, Television, etc.

High structures in open field sometimes have influences on propagation of radio wave and affects televisions.

The radio interference problem can be prevented by properly selecting the relative location. Therefore, transmission line route shall be selected properly and care shall be taken in selecting conductor size and type.

Countermeasures shall be designed so as not to cause any trouble to the public. For televisions, the common antenna system with CATV (CAble TeleVision) is applied in case that the radio interference problem can not be solved completely.

In selecting line route, care shall also be taken to the existing and planned microwave communication routes, radar location and other important radio communication paths.

13.3.7 Noise Problems

Generally, not so serious problems from noise exist for the completed transmission lines. However, the corona noise and conductor wind noise problems are two major subjects for noise prevention.

Relatively large discharging noise is generated under normal operation in case that insulator surface is contaminated by salt carried by strong seasonal wind from the sea not accompanying rain. Also in Sri Lanka, similar problem may arise in case that a transmission line is aligned near to the sea coast.

Strong wind exceeding 20 to 25 m/sec on conductors causes a flute-like sound of conductors. In Japan, such conductor wind noise problem is serious at a certain topography where strong wind blows. In case that blowing of such strong wind is expected, the line route is usually selected to avoid the area with strong wind. Special design of conductors to avoid severe noise is also taken into account. Such wind noise can be weakened by stringing conductors with projections instead of normal smooth conductors.

This problem will not be serious in Sri Lanka as wind is generally not so strong.

13.4 Problems Related to Construction of Substations

13.4.1 Land Problems

For construction of a large outdoor substation, a considerable area of land is required. In developed countries with large population, the acquisition of necessary land for a large substation, especially for EHV, is becoming very difficult. In Japan, due to the steady increase in electric power consumption there is a strong need to increase the overall substation capacity especially near urban areas and in industrial zones. From growing difficulties in obtaining lands wide enough for locating large substations near urban areas, the GIS equipment are installed widely to reduce necessary land area not only in indoor and underground substations but also in outdoor substations. The GIS are preferred also from the operation viewpoint as this type of switchgear has no exposed portions and is preferable in safety of operation and maintenance.

Even in developing countries, it is a recent tendency to construct indoor or underground substations with GIS in the city areas and connect with major substations with underground cables. The power demand of Colombo is growing rapidly, and two indoor GIS substations have been constructed at Fort and Kollupitiya. Application of several substations with GIS in the Colombo area is planned in the Study.

13.4.2 Noise and Vibration

In Japan, there is a government regulation to limit noise level according to the classification of lands and time of the day as given below:

Allowable Noise Level at Various Locations

Area Classification	Day Time	Morning/Evening	Night Time
Special residence area	45 - 50 dB	40 - 45 dB	40 - 45 dB
Residence area	50 - 60 dB	45 - 50 dB	40 - 50 dB
Commerce & residence area	60 - 65 dB	55 - 65 dB	50 - 55 dB
Industry area	65 - 70 dB	60 - 70 dB	55 - 65 dB

This level must be secured at the peripheral boundary of substation.

There are also restrictions for area-specific noise level under regulations of local authorities. According to these regulations, substations need to be designed so as to satisfy the required criteria.

The largest sources of continuous noise from the substation in operation are main transformers. Noise from other sources such as compressors, large circuit breakers, etc. is usually for short duration.

Examples of countermeasures against the noise problems are mentioned below:

(a) To keep maximum possible separation between noise sources and substation boundaries.

(b) To surround the substation with high walls or high trees.

(c) To provide noise reduction measures to transformers for instance:

- To cover transformers with steel plate or concrete muffled with noise absorbing materials.
- To provide special design to air blast type oil coolers.

Usually there is no serious vibration problem as substation has no large moving machine.

13.4.3 Soil Pollution by Oil

There are various oil-filled equipment in a substation such as transformers, oil circuit breakers, current transformers, etc. and oil leakage from these equipment causes pollution of soil and resultant intrusion of oil into the ground water system.

The largest equipment impregnated with oil in a substation are main transformers and oil leakage from the transformers is serious in view of environmental aspect. It is a usual practice to provide a reservoir tank with a capacity to retain leaked oil from the transformer together with fire fighting water for each main transformer. In Japan, such reservoir tank is a concrete structure cast together with the transformer foundation and filled with cobble stone, and normally has a capacity of not less than the sum of a half quantity of the transformer oil and 30 minutes spraying water for fire fighting.

The reservoir tank needs to be provided with a drain and a pump to drain oil and water in the tank except the case that natural drain is available.

13.4.4 Fire Protection

In a substation, there are several kinds of oil-filled equipment, the largest of which are main transformers. A fire of such oil filled equipment causes serious consequence to the substation.

In Japan, it is a standard practice to provide water spraying fire fighting system to an outdoor substation and carbon dioxide or other chemical fire extinguisher for an indoor substation with oil-filled transformers.

(1) Water Spraying Fire Extinguisher

The water spraying fire extinguishing facility normally consists of a large water tank, 2 sets of water pumps (each pump having sufficient capacity for the fire fighting operation), embedded piping system, fixed nozzles around main transformers, fire fighting taps for movable nozzles, movable hand nozzles, etc.

Water is sprayed by manual operation and by automatic operation on detecting heavy fault of the transformer by protective relays, or on detecting smoke or abnormally high temperature (or its gradient).

Capability of such fire fighting system is to be designed sufficient to avoid spreading of fire before arrival of public fire fighting teams, and usually has no capability for extinguishing the transformer fire. The final fire extinction of transformers is to be attained by the public fire fighting teams. However, the fire fighting operation during the initial stage is very important to suppress spreading of fire.

Such fire fighting systems are in many cases used jointly with insulator washing to prevent heavy salt contamination on the insulator surface.

(2) Separation Walls Between Transformers

In case plural number of main transformers are aligned outdoors side by side each other, a concrete wall of proper size is required each between transformers to prevent spreading of fire to the adjacent transformers.

(3) Fire Extinguishing of Indoor Substations

In case of an indoor substation, installation of inflammable oil-filled equipment must be avoided as far as applicable. Main transformers are installed outdoors as far as possible and the dry type transformers are used for small capacity transformers, like those for station service. Recently, there is a tendency to adopt

SF6 gas filled main transformers for indoor installation. Chemical fire extinguishers with carbon dioxide, etc. are provided for indoor fire extinguishing. In case that oil-filled transformers or oil circuit breakers are installed indoors, separating walls and fire-fighting doors shall be arranged to shut up these equipment from others and stationary fire-fighting equipment with carbon dioxide, halogen compound or chemical powder need to be provided.

(4) Avoiding Use of Oil-filled Switchgear

So far as inflammable oil is used for insulation, it is not possible to perfectly avoid explosion of switchgear and causing fire though its chance of occurrence is low. Firing of any oil-filled switchgear equipment causes serious damage to the substation. Firing of distribution switches on distribution poles may cause damage to the public. In Japan, oil-filled equipment are no more used by power companies for small station service transformers, and switching apparatuses such as circuit breakers, distribution switches, etc.

13.4.5 Rise of Earth Voltage under Earthing Fault

The earthing system of a large outdoor substation usually consists of the earthing mesh buried into the ground which covers whole the substation area. The potential of the earthing mesh rises considerably against surrounding land when large earthing current flows in to the earth due to an earthing fault in the substation or surrounding power system. The existence of potential difference of the earth surface causes the step-voltage and touch-voltage problems; voltage difference between two feet in one step of walk and when a man touches metal. A pedestrian outside the substation feels electrical shock if he touches the peripheral fencing which is connected with the substation earthing mesh or by walking along the peripheral area. These voltages appear very short duration during continuation of the earthing fault.

At the present moment, the short circuit capacity of the CEB power system is relatively small, and therefore its earthing fault current is not large and the substation mesh voltage does not rise high if its earthing resistance is low. The problem will need to be studied with enlargement of the power system.

The potential difference between the peripheral fencing and the outside ground and in one step distance of the adjacent ground can be decreased by the following measures:

- To lower earthing resistance of substation earthing mesh.
- To provide earthing to the peripheral fence separately from the substation earthing mesh system.
- To bury the periphery of the substation mesh deeper than the other parts.

13.5 Environmental Problems During Construction Works

The construction works of transmission lines and substations shall be carried out so as to avoid trouble with surrounding communities and general public, and to take utmost cares to health and safety of workers. Various measures to be taken in view of the environmental protection and accident prevention are mentioned below.

(1) Access and Transport

(a) Requirement for access to the line route and tower sites for construction is of temporary nature and access is to be secured during the construction period only, and to be ceased on completion of construction. Public roads shall be utilized as far as possible, however passing of private land or land occupied by public is required. For use of such access, negotiation on conditions of use and payment of compensation money will be required. Construction of an unnecessary access road or unnecessarily large access shall be avoided. Care shall be taken to avoid damage to surrounding lands and damages during construction shall be reinstated to the original conditions. Interference with other uses of affected land shall be avoided as far as possible.

(b) Interference to the public traffic, and blockage of public accesses, wildlife, etc. shall be avoided by all means.

(c) Regarding transport of heavy items and short time blockage of public road for construction purposes, permission shall be obtained from concerned authorities and in actual execution utmost care shall be taken to reduce influence to the public to the minimum and to keep the safety of the public.

(2) Environmental Protection During Actual Construction

(a) In Japan, acquisition of access all along the line route and cutting of trees are extremely difficult. Usually, trees in valleys, precious orchard, etc. under line conductors are not cleared for the purpose of conductor stringing. For the purpose of conductor stringing, light weight small nylon ropes are usually paid out initially using helicopter. The small nylon ropes are replaced with small steel ropes or larger nylon ropes of enough strength under tension and then with steel messenger wires for conductor pulling. Conductors are paid out under tension to keep clearance from the ground.

(b) In preparing working spaces for stringing, foundation construction, etc., land size and number of trees to be cut in forest shall be minimized and trunks of cut trees shall be remained to promote regrow after the work finished.

(c) In carrying out foundation works like piling, care shall be taken to generation of noise and vibration. In city area, use of percussion type piling rigs is restricted and the cast-in-place piling or repulsion type piling rig must be used. For the transmission line works, only cat-in-place piling is applied. In this case, care shall be taken to uncontrolled runoff of silt and bentonite to avoid contamination of ground water.

(d) Pumping up of ground water shall be minimized to avoid ground subsidence problem.

(e) To avoid public nuisance by execution of construction works, care shall be taken to minimize generation of noise and various kinds of vibration, and emission of hazardous matters and solutions.

(f) On completion of construction works, the surface disturbed during construction shall be finished adequately and borrow areas be disposed properly. Natural drainage shall not be impeded and flooding shall be avoided.

(3) Safety of the Public

(a) During the period of the construction in progress, safety of the public shall be monitored all the time by a safety inspector and proper sign boards to indicate the construction work is in progress with danger warnings must be provided.

(b) Adequate buffer zone shall be provided around the work site to avoid approaching of public.

(c) While construction is in pose, fences shall be provided to avoid entering of public and causes of danger like excavations shall be protected.

(4) Safety of Workmen

(a) To secure safety of workers of high location works like tower superstructure erection and conductor stringing, all workmen shall wear helmet and proper safety apparatus shall be used. To keep safety of workers on the ground, wire nets shall be provided to avoid direct hit of falling matters.

(b) Adequate provisions are required to prevent fire and explosion at work site and in workers' lodgings.

(c) Proper housing, water supply, sanitation, etc. shall be provided to maintain health of workers. Adequate provisions are required to control communicable diseases, especially malaria in tropical areas.

13.6 Environmental Monitoring after Completion

Conditions of environmental protections and also health and safety of workers shall be monitored all the time during the operation and maintenance of the transmission system based on government regulations and appropriate guidelines.

So as to maintain the skills of workmen, care shall be taken to their living conditions.