CHAPTER 3

CURRENT STATUS OF ELECTRIC POWER SECTOR

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CURRENT SITUATION OF ELECTRIC POWER SYSTEM

3.1 Organization of Electric Power Sector

The electric power supply activities in Sri Lanka are under the control of the Ministry of Irrigation, Power and Energy (MIPE). The organization chart of MIPE is presented in Fig. 3.1-1. Based on the Electricity Act and the Ceylon Electricity Board Act, CEB, Lanka Electricity Company (LECO) and Local Authorities (LA) are executing the activities to supply electric power to all consumers in the country. Under the laws, these enterprises must supply electric power to all people in the country in impartial manners taking into account safety of the public.

CEB is responsible for designing, constructing, operating and maintaining the generation, transmission and a substantial portion of distribution facilities in efficient, coordinated and economical manners covering the whole area of Sri Lanka. In addition to CEB's own direct power sales to consumers, CEB is also wholesaling a certain portion of power (17.4% of the whole in 1995) to power distribution utilities, LECO and LAs, for further retailing to consumers. Formerly, a considerable portion of power sales to consumers had been undertaken by LAs which own distribution facilities, receive electric power from CEB on the wholesale basis and retail it to consumers in their concession areas. However, their quality of power supply has been far from satisfactory. According to a government policy to provide more safe and efficient services to consumers, the power distribution business of LAs has been and is gradually being handed over to CEB and LECO.

In executing development projects of power generation and transmission systems, CEB is required to obtain approval of the MIPE. The finance for development is arranged from its own source or by borrowing from domestic and foreign sources. However, it is the recent tendency that external borrowing from international agencies and bilateral sources is decreasing, and CEB is obliged to consider utilization of foreign private investments. CEB is allowed to purchase electric energy in bulk from private power suppliers for distribution through their network. For borrowing from foreign sources such as international and bilateral organizations for power development, approval must be obtained from the Government. Then the Government guarantee the loan instead of the recipient.

(1) Ceylon Electricity Board (CEB)

CEB is a statutory corporation under the MIPE established under the Ceylon Electricity Board Act in 1969, by taking over the undertakings of the former Department of Government Electricity Undertakings (DGEU). The organization chart of CEB is shown in Fig. 3.1-2. The board members of CEB are composed of seven persons; four members from the MIPE each in charge of engineering, commerce, administration and accountancy respectively, one member representing local authorities, one member representing the field of industry and one member from the Ministry of Finance (MOF) in charge of the subject of finance. Board meetings are held by these seven members with attendance of the Chairman and Vice Chairman of CEB. The Executive Meeting of CEB attended by the General Managers and seven Additional Managers determines top operating policies of CEB. Seven Additional General Managers (AGM); Head Quarter, Generation, Distribution and Consumer Services, Transmission, Generation

Projects, Planning, and Finance, are managing the actual execution of the board as the chiefs of respective divisions. The Planning Division which is in charge of the Study has six branches of Generation Planning, Transmission Planning, Pre-Electrification, Demand Forecast and Tariffs, Electronic Data Processing, and Demand Side Management. The Generation Planning and Transmission Planning Branches manage the development planning of the hydro and thermal power stations and the transmission system respectively. Actual implementation of generation and transmission system projects is undertaken by the Generation Projects Division and Transmission Division respectively.

The number of employees of CEB as of September, 1995 was about 14,000 and its particulars are included in Table 3.1-1.

The total number of engineering executive staff is only 508 (3.6%) and seems not sufficient to carry out all technical activities of the board. More than 90% of these staff are electrical engineers, and there are not sufficient staff for civil and mechanical engineering works related to hydro and thermal generation projects. All engineering works of these projects are as a rule being performed by CEB, but sometimes with assistance of the Central Engineering Consultancy Bureau (CECB).

Resignation of trained technical staff of the board to seek for higher salary is a serious problem. To fill up deficiency in technical staff, CEB is obliged to train new engineers again from the starting point.

(2) Lanka Electricity Company (Private) Limited (LECO)

LECO was established in 1983 as a private power distribution company backed by the Government and CEB, both of them own 50% each of LECO's share. Though LECO is at present operated as an independent organization, the company received financial assistance from CEB in the past and its repayment is a burden to LECO. Many directors of LECO are concurrent staff with positions in CEB and retired staff from CEB. There is an idea to privatize the LECO's operation by selling its share owned by the Government to a private party.

LECO is now distributing electric power received from CEB to the urban areas around Colombo, not including its municipal areas, and many towns and villages along the coast line between Negombo and Galle. These areas constitute the most preferable regions to operate the distribution business. LECO occupied 15.0% of total energy sales and its total number of consumers was 14.6% of the total of Sri Lanka in 1994.

(3) Local Authorities (LA)

Local government authorities have long time been operating the power distribution activities by retailing electric power received from CEB on the wholesale basis. However, in accordance with a government policy their operations have gradually been diminishing by handing over their facilities and concession areas to CEB and LECO, and it is supposed that all facilities will be taken over by CEB and LECO under the Local Authority Taking Over Project and terminate their operation in near future.

Currently, a limited number of LAs are in operation only in the Ratnapura area. Their energy sales was 2.1% of the total of Sri Lanka in 1994.

(4) Independent Power Producers (IPP)

As explained in Clause 3.4, several foreign private investors have submitted proposals for power development and are now carrying out investigation and studies for construction of several power generation projects in Sri Lanka under the BOO or BOT schemes. CEB has, within the Generation

Projects Division, established the Private Power Projects Branch and review of their proposals and negotiation are progressing. Till now, contract has been concluded only for the KHD diesel plant of 51 MW capacity at Sapugaskanda. There are some examples of development of mini hydro plants.

3.2 Power Demand and Supply

Historical data of power demand and supply of CEB for the recent 22 years, 1974 to 1995, are tabulated in Table 3.2-1. In 1995, the generated energy was 4,786 GWh with peak generation of 981 MW and annual load factor of 55.7%. The sold energy was 3,912 GWh and its average annual growth rate was 7.2% for the recent 20 years, 6.6% for 10 years and 8.4% for 5 years after 1990. The high growth after 1990 is remarked. The transmission and distribution loss factor was 17.8% and station service ratio was less than one percent as the station service power consumption of hydropower station is minimal.

As seen in Fig. 3.2-1, the reserve margin of installed capacity of generating facilities to the peak demand has been decreasing gradually after 1992. A strong correlation is noted to growth in energy consumption and number of consumers as seen in Fig. 3.2-2. As for the relations with GDP and national output of the country, larger growth of power consumption compared to general growth of economy is noted as seen Figs. 3.2-6 and 3.2-7. Regarding the elasticity of growth of power consumption and GDP, Clause 4.2.1 is referred to.

Colombo is the largest load center of Sri Lanka and its energy sales occupied 17.5% of the total in 1995. Industries and other large power consuming activities are concentrated in the Western Province with its center at Colombo. The sold energy of this province including Western North and Western South areas occupied 61.0% of that in the whole country in 1995.

The electrified population of the county not including the Northern Province, now being separated from the interconnected system, was 45% of the whole country in 1995. The present electrification ratio of the whole country if the northern system is included is estimated to be near to 50%. The 1994 ratio was highest in Colombo (79.2%), and generally high in the Colombo area and other large cities and low in rural areas, exceptionally low in the Northern Region not including Jaffna (less than 5%). The 1994 share of distribution utilities in the number of consumers was 81.5% for CEB, 14.6% for LECO and 3.9% for LAs.

In category wise, out of the CEB's total 1995 sales of 3,912 GWh the largest share was occupied by the Industrial Sector, 39.0%, the second by the Domestic Sector , 25.9%, and followed by Bulk Sales, 17.4%, Commercial, 16.1%, and minor portion by the Street Lighting and Hotels. Reference is made to Fig. 3.2-3. Large consumption by the industrial sector seems to reflect the government policy, however recent sector wise growth rate is highest for the domestic sector due to the recent progress in rural electrification activities.

A typical weekly load curve as the continuation of seven daily load curves and a weekly duration curve for the period of 24th to 30th March, 1996 are shown in Fig. 3.2-5. The daily load curves are of the typical evening peak pattern and the duration of peak load is very short, being around 3 hours. No clear difference in load curves is noted according to days of week, except that the peak demand and day time demand are slightly smaller in weekend; Saturday and Sunday. The estimated category wise daily load curve is presented in Fig. 3.2-4. The evening peak load pattern is derived from the domestic consumption.

There is almost no temperature difference throughout an year, therefore no significant monthly variation according to months of year. The demand gradually increase from January toward December according to an increasing trend of power demand, though slight decrease in demand is observed in rainy season due to supposed minor decrease in ambient temperature and air conditioning load.

3.3 Power Tariff System

(1) Tariff Decision

The complete monopoly system was established according to government regulations for the electric power supply activities of CEB as a sole organization to provide basic infrastructure to the nation. Under such a system, the power tariffs are required to be determined on a fair basis. The power tariff from time to time (basically in each year) is determined based on the estimated annual expenditure of the electricity supply utility plus eight percent return which is acknowledged by the World Bank and ADB as fair and reasonable. The annual expenditure for tariff decision includes depreciation of facilities, all operating and maintaining costs, repayment to borrowed loans and interest payment to them for generation and transmission projects, construction costs of distribution facilities, etc. The necessary expected income from power sales is allocated to all categories of consumption group based on assigned tariffs and estimated sales. Thus, the actual tariffs are determined according to the government pricing policy and actual costs for power supply of each category are not well reflected. Under an ADB loan a tariff study to calculate tariffs based on actual costs was commenced by a Swiss consultant in July 1996.

(2) Current Tariff System

The current tariff system effective from 1 January 1996 is shown in Table 3.3-1. The overall average tariff is Rs 4.15 per kWh. The electricity consumption charge is billed as the sum of monthly fixed charge and energy charge based on monthly consumption in kWh. The country-wide uniform tariffs are applied covering whole the country including supplies by CEB, LECO and LAs.

Specific features of the current tariff system are mentioned below:

(a) It is normal practice to determine each category of tariff based on the cost for supplying energy to each category of consumers. However, the current tariffs have been determined by allocating the total estimated expenditures of CEB to all categories of consumption according to the government pricing policy without due regard to actual costs of supply to each category.

(b) Cross subsidy is applied in the tariff decision. The domestic sector is subsidized by the commercial and industrial sectors. The power tariffs of small consumers are generally lower than those of large consumers regardless of higher costs incurred. The tariff of MV receiving industries is slightly higher than that of LV consumers. This tendency is conspicuous for the domestic category. The energy tariff of domestic consumers of up to 30 kWh per month (smallest category) is only 21% of that of consumption exceeding 180 kWh per month (largest category).

(c) In many countries (including Japan), relatively low tariffs are applied to the agricultural consumption. However, in Sri Lanka such tariffs preferential to agricultural consumption are not applied.

(d) Time-of-day different tariffs are applied only to the industrial consumers. There is no differential tariff according to season. However for dry season, there is a rule to purchase surplus power from self generations to curtail supply by CEB.

(e) Cost for constructing consumer service lines for new connections must entirely be borne by consumers. This practice makes service connections of low income consumers difficult.

(f) Watt-hour meters to measure energy consumption for tariff charging are arranged and installed by the power utilities, and their costs are charged to consumers on the rental basis.

The electricity consumption charge is collected based on monthly reading of watt-hour meters installed at consumers. Two-month allowance against delay of payment is granted and in case that the tariff is not received within this period, power supply may be cut. There is also a fine payment regulation against illegal use like pilferage.

Ideas to improve the current tariff structures are enumerated below:

(a) Tariff reduction against consumer's efforts to curtail expenditures of CEB:

The maintenance of high supply power factor is a very important factor to minimize variation of supply voltage and to reduce distribution loss. In Japan, the power supply regulation of a power company requests consumers to keep high receiving power factor, higher than 90% for domestic consumers and 85% for large consumers. Large consumers are requested to install static capacitors in the supply contract. In return, there is a tariff reduction arrangement against consumers with power factor improvement exceeding 85% at peak load time, and vice versa penalty is applied to consumers with lower power factor. A certain amount is reduced or added against each percentage of power factor value to the monthly basic capacity charge.

The tariff reduction can also be applied to various consumer's cooperation to reduce power supplier's expenditure on fixed basis or on negotiation basis.

(b) Promotion of DSM:

In view of growing difficulty in obtaining fuel for power generation in future and avoiding excessive installation of generating facilities by peak shift, it is required to promote the demand side management (DSM) activities such as energy conservation, peak shift, etc. by providing subsidies to the peak shift measures or by applying time-of-day different power tariffs.

(c) Seasonal variation of tariff:

In Japan, the annual peak demand appears in the hot summer season due to the increase in air conditioning demand. Higher tariffs are applied to large consumers during the summer season, 1 July to 30 September. A similar idea can also be applied to the hydro-dominant Sri Lankan system by charging high rates in the dry season when consumption of imported fossil fuel increases and low rates in the rainy season.

(d) Supply contract with large consumers:

In Japan, with large consumers an individual supply contract is made with each of consumers including tariff adjustment clauses to suit the case according to individual supply conditions. In case of difficulties in sufficient supply to all consumers, power companies request various cooperation to large consumers such as connecting and disconnecting static capacitors, allocating higher priority against load shedding in the case of system disturbance, allocating holiday shifts during the summer high demand season, etc.

It will be required that power tariffs of large consumers are not considered as fixed ones based on the basic tariffs and can be adjusted according to conditions of each supply after due negotiation.

3.4 Power Generating Facilities

As seen in the historical generation record in Table 3.4-2, during the recent 20 year period a predominant portion of energy (more than 90% in most of the years) has been supplied by the hydropower stations. The generation means of CEB is mainly hydro power and thermal power has been generated only for supplementing deficiencies in the hydro power generation when available river flow and storage in reservoirs is not enough to meet the demand.

Till now, the thermal power stations have been operated only to fill up the deficiencies in the hydropower generation. However, with the anticipated rate of growth of demand, CEB power system will be badly in need of additional thermal generating capacities in the near future.

The available total generation capability of the CEB system as of the end of 1995 is summarized as given below:

Hydro generation	1,125 MW
Thermal generation	224 MW
Total	1,349 MW

The lists of the existing hydro and thermal power stations are shown in Table 3.4-1. 1,135 MW is the total installed capacity of hydropower stations including mini-hydro stations, and the total installed capacity of the thermal plants being 250 MW has been derated to 224 MW in spite of recent rehabilitation efforts. However, available output of hydro generation is 1,125 MW as mentioned in (1) below.

The possible annual hydro generation energy in 1996 under different weather conditions is estimated as follows:

Under very wet hydro conditions	4,370 GWh
Under wet hydro conditions	4,259 GWh
Under medium hydro conditions	3,890 GWh
Under dry hydro conditions	3,289 GWh
Under very dry hydro conditions	2,689 GWh

The average annual energy output is 3,773 GWh.

Note: Probability of occurrence of the hydrological conditions is 10% for very wet, 20% for wet, 40% for medium, 20% for dry and 10% for very dry conditions.

The available output of the thermal power stations is 224 MW and their medium annual generation energy in 1996 is estimated to be 1,186 GWh in total, comprising Kelanitissa steam being 274 GWh, Kelanitissa gas 558 GWh and Sapugaskanda diesel 354 GWh respectively.

(1) Hydropower Stations

The past hydropower development has been concentrated on the two major river basins of Mahaweli and Kelani. These cascades of power stations are called the Mahaweli Complex and the Laxapana Complex respectively. The Mahaweli development is of multi-purpose with a higher priority to irrigation water supply, and power generation is governed by the downstream irrigation requirements with a certain seasonal pattern. While, the Laxapana complex has no significant other water requirements restricting their operation in meeting the power requirements of the country. Owing to the water leakage from the right bank of the reservoir, the Samanalawewa power station is now operated basically as a run-of-river plant with a minimum amount of storage.

The installed capacity of the existing power stations is summarized below:

Mahaweli Complex	660 MW
Laxapana Complex	335 MW
Samanalawewa PS	120 MW
Small hydros	20 MW
Grand-Total	1,135 MW

The installed capacity of the Canyon power station in the Laxapana Complex is two units of 30 MW, however its total output is limited to 50 MW when two units are operated together due to a constraint of the water way. Therefore, the total available output of the Laxapana complex is 325 MW.

(2) Thermal Power Stations

The installed and available capacities of the currently operating thermal power stations are as given below:

	Installed	Available
Kelanitissa Steam	2 x 25 MW	2 x 22 MW
Kelanitissa Gas	6 x 20	6 x 18 MW
Sapugaskanda Diesel	4 x 20	4 x 18 MW
Total	250 MW	224 MW

All of these three power stations are located in the urban area of Colombo. The small thermal plants of 14 MW diesel at Chunnakam and 7 MW gas turbine at Kankesanturai, both in the Jaffna peninsula are not presently in operation and not counted in the existing plants.

(3) Problems of the Existing Power Generating Facilities

The past efforts for power development of Sri Lanka has been concentrated on the exploitation of the hydropower potential for the purpose of utilizing only available indigenous, clean and renewable energy resources. As the result, the present hydro-dominant generation system has been formulated. The total available capacity of hydro plants (1,125 MW) has been larger than the maximum demand of the country (980 MW in 1995) so far. In years with abundant rainfall, almost all of the energy demand can be met by the hydro energy; 99.8 to 99.9% has been recorded four times during the past 20 years. However, the minimum of 57.6% was recorded in 1983 due to the world-wide extremely dry weather. The average share of the hydro generation during the recent 10 years up to 1994 was 93.0%. In the former half of 1996, CEB has experienced a severe electric power shortage due to unexpected little rain in the season.

To ensure power demand is met even in very dry years, considerable amount of contingency thermal capacity is required. For relatively cheap thermal generation with very short annual operation hours, diesel and gas turbine generators with relatively low construction cost and short starting time are suitable. However, when demand grows further base-load thermal stations of larger capacity like coal thermal would become appropriate economically.

Among the estimated total hydro potential of 2,000 MW in the country, 1,135 MW (57% of the total) has been exploited. As relatively large and economically favorable sites have been developed with priority, economically attractive sites are near to depletion. Even in the Master Plan Study for the

Electricity Supply of Sri Lanka in 1989 by a German consultant and others, the proposed number of attractive sites is not many.

Environmental problems and compensation for resettlement associated with large hydro developments are becoming serious in the recent years. The development of the Upper Kotmale hydropower project (150 MW) is being suspended due to associated environmental concerns.

Since 1992, new addition of generating capacity has not been performed and the total installed capacity of generating facilities has been unchanged. Then the peak demand of 1995 became 86.3% of the total hydro installations. The lack of generating capacity during dry season is becoming serious though some urgent developments are progressing and the power shortage in dry season is unavoidable after 1996 as experienced in April to July of the year.

3.5 Transmission System Facilities

3.5.1 Transmission System

The CEB's present transmission system involves 220 kV, 132 kV and 66 kV transmission lines, and their total lengths as of the end of 1995 are as given below:

220 kV lines	270 circuit-km
132 kV lines	2,517 circuit-km
66 kV lines	314 circuit-km

Particulars of the existing 220 kV and 132 kV transmission lines are shown in Table 3.5.1-1.

Formerly, up to the beginning of the 1980s the CEB's transmission system was composed of 132 kV and 66 kV lines, which had been developed in coordination with the growth in demand and development of hydroelectric power projects for delivering power to the Colombo area and other regions. The major hydropower stations of the Mahaweli and Laxapana Complexes are in the central mountains and a number of transmission lines have been constructed toward the Colombo area. Initially, 132 kV transmission lines were constructed as the major systems to transmit large power for long distances and 66 kV systems for local power transmission. In 1984, the first 220 kV transmission line with duplex Zebra conductors (400 mm^2), Victoria - Kotmale - Biyagama (suburb of Colombo), commenced its operation to transmit the large generated power of the newly constructed two major hydro power stations of Victoria and Kotmale (approximately 410 MW in total) to Colombo. Later, this system was extended from Victoria to Rantembe via Randenigala, and from Biyagama to Kotugoda. Two 132 kV lines, Biyagama - Kelanitissa and Biyagama - Pannipitiya, were constructed with the 220 kV design and have been operated at 132 kV for conversion to 220 kV operation when required. For other areas, the 132 kV systems have been extended so as to meet the area demand.

Many grid substations are T-connected with main transmission lines to minimize the cost for construction in spite of less reliability compared with pi-connected stations. Such grid substations are not provided with proper line protection relays, and this causes protection problems to the transmission lines provided with distance relays.

The 132 kV system is still operated as the major transmission system covering the wide areas of the country.

Except the Colombo area, the most of the 132 kV transmission systems are of radial formation, not forming ring. Therefore, a shutdown of one transmission line causes a total failure of power supply to its supply area. The most serious fault for the present CEB system is a two-circuit outage of the Kotmale - Biyagama 220 kV line, which leads to an entire collapse of power supply to the Colombo area. Though this line is of double circuit construction with an advanced protection practice, it is not possible to completely avoid two-circuit failure. During the past 11 year operation period, there have been total failures at an average rate of once in an year.

The current 220/132 kV transmission system diagram is presented in Fig. 3.5.1-1 and the transmission system map in Fig. 3.5.1-2. In the CEB system, there are 37 grid substations in operation at the end of 1995, the list of which is shown in Table 3.5.1-2.

At present, the 132 kV double circuit transmission line from Anuradhapura to Chunnakam in the Jaffna peninsula via Kilinochchi is disconnected at the outgoing point of the Anuradhapura substation. The transmission system facilities in the northern area have been severely damaged during the recent civil disturbance and a certain period will be required for their restoration and resumption of power supply. Some part of the 132 kV line to the north up to Vavuniya is at present operated as a 33 kV line for power supply to this area. Even after the restoration of 132 kV supply, some time will be required to normalize the power consumption in the northern area. At the latest the normal power supply to this area is expected to be resumed by the year 2000.

The 132 kV Habarana - Valaichchenai line has been constructed, but this line is at present used as a 33 kV line for power supply to the Eastern Province waiting commissioning of the 132 kV Valaichchenai substation.

The 66 kV system has been operated for major transmission initially and for secondary transmission later till now. However, CEB has decided to upgrade all the 66 kV transmission voltage to 132 kV to meet future increasing power demand. The present application of the 66 kV system is limited to the section of Kolonnawa - Old Laxapana, and this system is planned to cease its operation in near future after the completion of the Avissawella substation which is under construction.

3.5.2 Transmission Lines

The existing major transmission lines of CEB comprise 220 kV and 132 kV lines, and their major features are enumerated below.

(1) Supports

All the transmission lines are of steel tower construction and there are no pole support lines of 66 kV and higher voltage.

Most of transmission line towers are of double circuit construction, and single circuit towers are constructed for local lines only; Victoria - Randenigala - Rantembe section of 220 kV line and Rantembe - Badulla - Inginiyagala and Habarana - Valaichchenai sections and branch lines to relatively small power stations of 132 kV lines.

As Sri Lanka is located in the tropical region and transmission lines are frequently hit by thunderstorms, major lines are provided with two overhead earthwires. There are several 132 kV lines of rather old design with one earthwire, but lines of recent design are provided with two earthwires to improve the efficiency of lightning protection.

(2) Line Conductors

For overhead lines, only ACSR are used and the standard conductor sizes of the existing 220 kV and 132 kV lines are as follows:

(a) The BS series of conductor sizes were introduced by British consultants during the initial stage of development and this practice has been followed till now. Thus the BS sizes are employed for most of lines.

(b) For 220 kV lines, only ACSR Zebra conductors (400 mm^2) are used; duplex conductors for bulk power transmission for the Victoria - Kotmale - Biyagama section and the extension of Victoria - Rantembe, and single conductors for the Biyagama - Kotugoda section. The two 132 kV lines, Biyagama - Kelanitissa and Biyagama - Pannipitiya, are of 220 kV construction with twin Goat (320 mm^2) and single Zebra conductors respectively.

(c) For 132 kV lines, ACSR Lynx (175 mm^2) is the standard conductor size which is used for most of the existing lines. Larger conductors (Zebra and Goat) have been installed where larger power flow was anticipated. Coyote (130 mm^2) and Tiger (125 mm^2) were installed in the Colombo area for initial stage installations. The future power flow will be large in these sections and conversion to larger conductors is now under execution or going to be executed in near future to increase power transfer capacity.

(d) CEB specify only the steel core of ACSR conductors to be greased, and the aluminium layers are not greased. CEB have not experienced significant corrosion of ACSR, however this may be due to lack of detailed investigation. It is suggested that during routine maintenance of older exposed lines such as Bolawatta - Puttalam that some jumpers are removed (and replaced with new conductors). The old jumpers can then be examined in detail and if necessary subjected to mechanical testing to establish the extent of internal corrosion. In UK all ACSR has now been replaced with AAAC due to corrosion problems of ACSR and better performance, higher current rating and less losses of AAAC.

(3) Overhead Earthwires

Galvanized steel wires of 58 mm^2 (7/3.25 mm) and 83 mm^2 (19/2.36 mm) are used as overhead earthwires for most of the existing lines. Aluminum-clad steel wires have also been used on some 220 kV lines.

(4) Insulators

Both porcelain and glass suspension insulators typically of 254 mm diameter and 140 mm spacing based on the BS standard are used for all the existing lines. Specific creepage values of 20 to 24 mm/kV under the highest system voltage are used without incurring pollution problems. Insulators are not usually washed although some insulators may be removed and cleaned during routine maintenance every three years.

There is no example of taking any countermeasures against the salt contamination as the existing lines are separated from the sea coast with enough distance. It is told by CEB engineers that the salt contamination on the insulator surface causes problem only in areas within around 1 or 2 km from the sea coast. Necessary measures are taken to the distribution systems as mentioned in Clause 3.6. Therefore, the salt contamination problem on transmission system can be avoided by separating the high voltage facilities from the sea coast by enough distance. All new insulator discs are provided with sacrificial zinc sleeves to protect against pin corrosion.

(5) Underground Cable Circuits

There are three 132 kV underground cable circuits all in the Colombo city area, Kelanitissa - Fort - Kollupitiya - Kolonnawa. They are paper insulated OF (oil filled) cables generally directly buried along the central reservation of main roads. There is pressure drop problem for the cables between Kolonnawa and Kollupitiya.

3.5.3 Transmission Line Protection System

The current line protection arrangement of the CEB transmission system has basically been formulated based on the UK practices.

(1) Distance Protection

The distance protection has been applied as the main protection practice to most of the existing 220 kV and 132 kV transmission lines in the CEB's transmission network.

(a) 220 kV transmission lines

Two series of PUTT (permissive underreach transfer tripping) scheme with two kinds of distance relays from different manufacturers, provided with 1 plus 3 rapid autoreclosing function (1-phase autoreclosing against 1-phase faults and 3-phase autoreclosing against 2-phase faults), are applied to major 220 kV lines. No autoreclosing is attempted against 3-phase faults from the reason that most of 3-phase faults are of permanent nature. The no-voltage time of single-phase autoreclosing is around 0.4 second (high speed autoreclosing) and a longer time is applied for 3-phase autoreclosing (delayed autoreclosing of several seconds). Analogue solid state relays are employed for these systems.

In this system, distance relays, CT windings and CB trip coils are duplicated to improve reliability of protection. For the PLC circuits, two channels are used without physical separation, and no duplication practice is applied to the DC power sources consisting of storage batteries and chargers.

(b) 132 kV transmission lines

The PUTT relaying system is being applied only to several major lines, and most of lines are operated with plain 3-stage distance protection without signal exchange through the PLC channels. However, the existing relaying sets are mainly from top-ranked European manufacturers and provided with functions for application of the PLC aided protection, transfer tripping, autoreclosing, etc. as standard accessories of relay sets.

The distance protection is applied also to lines with T-branching. On the branched substations, no protective relays for line faults are provided and some stations have not even circuit breakers. This causes line protection problems and results in frequent system interruptions.

(c) Distance settings

At present CEB has no established policy for relay setting, however they are planning to adopt the following principles for distance setting:

- First zone : 85% of protected line
- Second zone : 100% of protected line plus 50% of the shortest second section
- Third zone : 100% of protected line plus the longest second section

(2) Pilot-Wire Protection

The pilot-wire relaying practice is applied to the underground cable lines, Kelanitissa - Fort - Kollupitiya - Kolonnawa, and the four short distance overhead lines of up to a few kilo-meters; Biyagama - Sapugaskanda PS, Kelanitissa - Kolonnawa, Laxapana - Wimalasurendra and Randenigala - Rantembe. CEB's own telephone cable lines are installed to constitute communication paths of the pilot-wire relaying and public lines are not utilized due to their low reliability. Pilot cables are in common use with those for communication, and basically buried in the ground but overhead cables are installed for the Kelanitissa - Kolonnawa section.

(3) Automatic Fault Location

The automatic fault location of overhead lines is applied widely in many countries. But, this function is not provided with the traditional electromagnetic relays and separate fault locators have been provided for important lines. The fault locating function is provided with recent microprocessor-based digital distance relays of leading manufacturers as a standard accessory. Thus, this function will become prevalent also in Sri Lanka after replacing the existing relays with advanced digital relays.

(4) Backup Protection

Overcurrent relays (mostly of inverse definite minimum time pattern) and directional earth fault relays (non-directional relays are also used at some locations) are provided for backup protection.

(5) Breaker Failure Protection

The breaker failure protection is provided only to 220 kV lines and major 132 kV lines.

(6) Under-Frequency Relays

To save the power system from entire collapse even in the case of system disturbances, under-frequency relays for shedding a certain amount of loads when system frequency drops are provided at the most of grid substations. The relays are usually provided with five frequency settings and automatically cut off assigned 33 kV feeders when the system frequency drops exceeding the set frequencies, typically 49, 48.5 and 48 Hz.

(7) Application of Microprocessor-Based Digital Relays

Traditional protective relays are mainly of induction disc or cup type. However, the microprocessor-based digital relays are generally provided worldwidely for recent supplies. The characteristics of these digital relays are flexible and the operation times are adjustable in a wide range so as to coordinate with operation of old induction relays. So far, no operation coordination problems with old relays have been raised due to application of digital relays.

It is a recent tendency that major relay suppliers manufacture only solid-state digital relays and stop manufacture of old electromagnetic relays. In near future, spare parts of old relays will run out and all relaying system will be obliged to be replaced with the digital relays.

(8) Typical Operating Times

The typical operating times of the protection systems including relays and circuit breakers are given below:

Operating time of Protection System

	Operating Times in Second		
	Relays	CB	Total
a) Main protection			
a.1) First zone			
• Major 220 kV lines	0.04	0.05	0.09
• 132 kV lines	0.05	0.10	0.15
a.2) Second zone			
• Major 220 kV lines	0.25	0.05	0.30
• 132 kV lines	0.5	0.1	0.6
b) Third zone and backup	1.0	0.1	1.1

(9) Protection Coordination

In the existing system, various kinds of relay from various manufacturers with different characteristics are in use for line protection. This makes coordination of operations difficult, sometimes impossible.

From the Monthly Review Reports on System Control and Operations of 1995, many cases of spreading of system faults are noted. Among the transformer trippings, many faults were associated with line faults and many generator trippings were associated with faults of transformers and transmission lines.

When a fault occurred on certain electrical facility, it is preferable that the circuit breaker tripping is limited to those for the fault section only. However, the T-branched grid substations have no proper line protective relays or in many cases no such relays are provided. Therefore, it is not possible to detect line faults at such grid substations. Except for major stations, circuit breakers are provided for common use or omitted for tripping at the sending ends. These cause protection mismatching.

(10) Problems of the Current Relaying System

(a) Till the present, relay settings have been decided according to recommendations of consultants and manufacturers without established policy of CEB. Each of four protection engineers in charge of the Protection Branch of the Generation Division looks after about four power stations and nine substations and actual settings of relays have been determined by them without established criteria. In the branch, two Chief Engineers for Protection Development and Protection Maintenance have recently been appointed and CEB has a plan to prepare standard practice for setting.

(b) The present transmission line protective relaying system seems to have been formulated paying attention to saving cost, and installation of relays has been minimized. The up-to-date design was adopted for the recent 220 kV lines and distance relays are provided on 132 kV lines, however proper relays necessary for system protection are not installed on the transmission systems with T-branches. This causes increase in line faults which resulted in supply interruptions as seen in the monthly review reports on system control and operations.

At present CEB is promoting improvement of the relaying system for T-branching one by one, and a work is progressing at the Bolawatta substation.

(c) The Protection Branch has no computer software for power system analysis. Relay setting values are determined according to power system analysis results of the Planning Division and supplemental hand calculation.

(d) At present various kinds of relays, including recent digital relays and old electromagnetic type, are applied without proper coordination among each other. The old relays will gradually be replaced by recent relays. To establish an overall coordinated relaying system throughout the country, systematic relaying system investigation and preparation of detailed improvement plan will be required.

(e) To adopt the high speed autoreclosing practice, review of technical specifications and replacement of certain circuit breakers is also required.

3.5.4 Substation Facilities

(1) General

In the CEB transmission system, there are three kinds of substations. They are grid substations furnished with step-down transformers to deliver power to distribution systems, 220/132 kV substations for interconnection of two voltage systems, and outdoor switchyards of power stations for transmission system interconnection.

The major transmission system voltage of the existing CEB transmission system is 132 kV, and the grid substations (GSS) step down the transmission system voltage of 132 kV to the distribution voltage of 33 kV to connect with the distribution systems. Two 220/132 kV substations of Biyagama and Kotugoda were constructed to deliver 220 kV power from the Victoria and Kotmale power stations the to the 132 kV Colombo system, and to extend 132 kV lines therefrom.

Some power stations and substations are configured for multi-purposes. Several power stations, like the Kelanitissa, Ukuwela and Rantembe power stations, are used not only generation but also for 33 kV distribution, and many transmission lines are connected to certain power stations, like the Laxapana and Polpitiya power stations. 33 kV distribution feeders are connected to the 33 kV tertiary windings of the 220/132 kV transformers of the Biyagama and Kotugoda substations. Though these tertiary windings are suitable for connection of static capacitors for system voltage control, the capacity of connecting capacitors is limited to avoid excessive voltage variation of 33 kV distribution voltage.

In this Study, the existing 66 kV facilities are not investigated as their operation is planned to be ceased in near future on completion of the Avissawella substations now under construction. 33/11 kV substations (called primary substation, PSS) are also not investigated as these substations are not directly related to the development of the transmission system.

(2) Types of Substations

Most of the existing substations are of open surface type and only two substations, the Fort and Kollupitiya substations in the Colombo city center, are of indoor compact type with gas insulated switchgear (GIS). The Fort substation is of semi-underground installation and the Kollupitiya substation is of surface installation.

The double bus system is applied to important substations with a number of feeders, and the grid substations are normally designed to receive from two-circuit lines and provided with bus section arrangement for connecting two or up to four transformers. The 220 kV bus arrangement of the Victoria and Kotmale power station outdoor switchyards are of one and a half breaker type. The bus conductors are mostly aluminum pipes. Copper pipes are also used at some old substations.

The most of grid substations of standard design have the initial installation of two transformers at present, but there are spaces for addition of transformers up to four units in total.

(3) Major Equipment

The present conditions of major substation equipment are mentioned below:

(a) Transformers

The current standard capacity of grid transformers for the distribution circuits is 31.5 MVA based on the IEC standard. Formerly, smaller capacity ones, typically of 10 MVA, were installed at many local substations, but these sets are being gradually replaced with the 31.5 MVA ones due to the recent increase in substation load.

An on-load tap changer is provided on each grid substation transformer and operated automatically to adjust the 33 kV bus voltage. The time interval setting of tap changing operation is 30 seconds, which is relatively long to avoid unnecessary tap changing actions. However, some old on-load tap changers have been deteriorated and parts are not available any more and transformers are operated without tap changing. On the 220/132/33 kV three-winding transformers at Biyagama and Kotugoda, two tap changers are provided to control both 132 kV and 33 kV side voltages separately.

Current transformers for operation of line drop compensators are normally provided with the tap changers of recent transformers, as standard accessories, for regulation of sending out voltage to compensate the voltage drop in long distribution lines. Till now, such line drop compensation practice has not been applied in the CEB system, however its trial operation is scheduled to be commenced in near future.

(b) Circuit breakers

Old circuit breakers are of the bulk and minimum oil type and recent ones are of the SF6 gas type according to the worldwide tendency. Old bulk oil circuit breakers are slow in operation and not suitable to high speed autoreclosing duty.

The rated current of the circuit breakers is mostly 1250 A, but CBs of up to the maximum of 3000 A are used actually. The rupturing capacity of old circuit breakers is up to 25 kA and increased to 31.5 or 40 kA for recent ones.

(c) Disconnecting switches

Old disconnecting switches are of manual operation type and new equipments at important stations are of motor operated type to enable the remote control through the load dispatching system. The rated currents of disconnecting switches are same as those of circuit breakers.

(d) Current transformers

The rated secondary current of old current transformers is 5 A and that of recent ones is 1 A in view of its technical superiority.

(e) Static capacitors and shunt reactors

The static capacitors (SC) and shunt reactors (SR) are necessary to minimize voltage variation of the bus voltage regardless of voltage drop (or rise) in long transmission lines. At present, only three static capacitors of 20 MVA each have been installed on the 33 kV buses of the Kotugoda, Anuradhapura and Galle substations. At the Galle substation an additional static var compensator

(SVC), +20MVA and -20 MVA, is also in operation for smooth adjustment of 132 kV system voltage.

The low power factor of the Colombo power system is a serious problem to keep the operating voltage of the 132 kV system. Though idle gas turbine generators are used for the condenser operation, their available capacity is not enough and shortage of reactive power is a serious problem at present.

(f) Protective relays

Majority of protective relays currently used in the substations are of electromagnetic type, but digital relays are applied for recent supplies. The replacement of the electromagnetic relays with the digital relays is progressing as recent supplies from major manufacturers are mostly based on the digital technology.

Transformers are protected by the differential relays and backup overcurrent relays of inverse definite minimum time (IDMT). Clause 3.5.3 is referred to regarding the transmission line protection. Distribution feeder circuits are provided with IDMT overcurrent relays for short circuit fault protection and earth fault relays for earth fault protection.

Formerly before 1980, no bus protection relays had been applied to substations, but has been provided with substations constructed thereafter.

(g) 33 kV switchgear

Formerly, outdoor switchyard type installation had been adopted for arranging 33 kV switchgear. However, compact GIS type cubicles are adopted for recent applications. The GIS has superiority in view of less maintenance requirement.

(h) DC control sources

A lead acid battery set and a charger are installed at each substation to supply DC control source. Recently, the nickel-cadmium type battery is also used as DC power source for small substations.

The standard voltage of the battery set is 50 V for relatively old substations and 110 V for relatively new substations. There are a few substations which adopted 220 V as the DC control voltage.

(4) Current Problems of the Existing Substations

Current problems of the existing substations are enumerated below:

(a) Considerations for system extension

Cost saving design seems to have been adopted in construction of the existing grid substations at the sacrifice of operational convenience. The current standard grid substation design may be suitable for less important small substations at line ends. No considerations were made for future system extensions, and additional installation of line feeders is quite difficult. Strength of bus section or bus conductors against large force due to short circuit current seems to be weak and many buses seem to have not enough strength.

(b) Multi-purpose use of major substations

In order to improve overall reliability of power supply, multi-purpose use of major substations had better be avoided. There is possibility of power system troubles in minor systems spread to the major system.

The connection of distribution lines to the tertiary windings of main 220/132/33 kV transformers like those at the Biyagama and Kotugoda substations is not recommendable. The tertiary windings of these tie transformers are most appropriate positions to connect reactive power equipment to regulate system voltage, and it is noted that the tertiary voltage varies much by connection of large static capacitors and shunt reactors and these windings become not suitable for connection of distribution feeders for public supply.

(c) Frequent occurrence of faults

According to the 1995 Monthly Review Reports on System Control and Operations of CEB, the number of faults in certain substations is very large and the records include serious faults like operations of transformer differential relays. When a serious fault occurred on a transformer, causes of the fault shall be identified, and maintenance and repairing works shall be carried out soon to keep its normal life of equipment.

(d) Operation problems of SF6 gas circuit breakers

There are many examples of gas leakage from SF6 circuit breakers and there are examples of explosion of relatively new breakers under normal operation. Review of technical specifications for purchase and strict acceptance tests at factory and at site will be essential.

3.5.5 System Control and Load Dispatching System

(1) General

The System Control Center (SCC) for the CEB power system is located at Dematagoda in Colombo, which is adjacent to the Kolonnawa substation. Therefore, connection between SCC and the PLC communication network is easy.

This SCC manages the operation of power generation, the 220/132 kV transmission system (at present includes 66 kV system) and the 33 kV subtransmission system of CEB in the whole country. SCC must from its nature have authority to issue operation instructions and such authority is bestowed from the CEB authority.

(2) Major Functions

Major functions currently executed by SCC are as follows:

<u>Planning and Management Operations</u>

(a) Generation planning:

- Medium-term generation plan for the period of one year is prepared and reviewed every month to check optimal operation plan to effectively utilize available generators including new installations, and two times an year to check seasonal operation patterns for the periods of October - March and April - September taking into account availability of water. The reservoir operation planning to utilize available water in reservoirs to the fullest extent is most important. This plan is reported to the CEB authority.

- Daily generation plan is prepared every day for the next day based on the estimated load curve of the day.

(b) Transmission system operation planning:

The transmission system operation plan including new additions and retirements, preparation of operation manuals, decision of target bus voltage, etc. is prepared by the Planning Division and necessary operation instructions are issued from SCC.

(c) Maintenance scheduling:

An annual maintenance schedule of power stations in the country is prepared taking into account availability of water resources, wet and dry seasons, new additions, etc.

(d) Management of transmission system protection:

Decision of transmission system protection relay settings, setting operation, commissioning and their maintenance, and suggestion on 33 kV relay settings are performed by the Protection Branch of the same Generation Division, and are out of control by SCC.

(e) Management and operation of SCC system facilities:

Load Dispatching System Operation

(a) Power system supervision and monitoring:

Supervision of power system operating conditions and important items, collection of operation and fault records and dispatch of information. System operation records are taken manually with half-hour interval by SCC operators.

(b) Instructions for adjustment:

Adjusting items managed by SCC include power station output (real and reactive) and AVR setting voltage, system frequency and bus voltage of power station and substations, and so on. The system frequency control is being undertaken with one governor-free operated hydro generator of the Victoria or New Laxapana Power Station. The power station sending out voltage is adjusted by changing setting of AVRs of generators. The 33 kV bus voltage of a grid substation is adjusted by changing voltage setting of on-load tap changers of transformers. Static capacitors are required to be connected and separated according to variation of system voltage and reactive power flow.

(c) Instructions for major switching:

Instructions on operation of major switches for transmission system operation, for fault restoration and for maintenance.

(3) Load Dispatching Facilities

All the existing load dispatching system facilities including one for the power stations and 220/132 kV transmission network, and the other for the 33 kV subtransmission systems were supplied by BBC. System diagrams are shown in Figs. 3.5.5-1 and 3.5.5-2.

The main systems for major power stations and 220/132 kV network are provided with remote indicating functions associated with computer data processing. The master station computer system comprises duplicated PDP 11/34 mini-computer (8 bits) of DEC, one is for normal duty and the other is of standby-mode. The PDP 11/34 software communicates with the existing 20 RTUs using ABB's telecontrol protocol (BECOS-20 system). The PDP 11/34 computers process on-line data for display on-line data, and for display on the VDUs and on the mimic diagram, and also printing on loggers. However, RTUs are installed at selected major stations (20 RTUs) only due to limitations of both hardware and software, and information from other minor stations are collected over telephone.

A mimic diagram board to indicate switching status only by manual operation is provided for the 33 kV system, and switching information from 33 kV stations is collected over PLC, VHF, telephone or other communication means.

The CEB system has no satellite radio standard time receiving facilities and time signals from the standard clock in SCC are used as the standard time.

SCC has a DC power supply system with dual 48V, 300 A chargers and lead-acid battery, but not provided with uninterrupted power supply equipment (UPS). The low voltage AC power is normally supplied from the adjacent Kolonnawa substation, and a standby diesel generator of 125 kVA is also installed in this substation for common use with the substation.

With regard to off-line calculation, the medium-term scheduling of generation is being undertaken using a hydro-thermal optimization computer program which is run on a personal computer (PC). The short-term dispatch of generators is a manual procedure which takes into account the medium-term schedule, daily load forecast, actual reservoir levels and actual generator unit availability.

Though the system facilities were commissioned in 1984, the equipment design was prepared around 15 years ago. Therefore, the system has already become old fashioned and has not the following important functions:

- Remote control function.
- Automatic recording of essential data and records such as station operation data, fault records, operation records, etc. Most of data and records are being prepared with manpower.
- Automatic collection of data through RTU is limited to major stations and supplemented by telephone.
- Off-line power system calculations for power flow, fault analysis, dynamic stability analysis, etc.

The circuit breaker operation records of selected stations with RTUs are automatically typed out.

(4) Problems of the Present Facilities

The existing SCC facilities have already become very old-fashioned in view of hardware functions and moreover have not essential functions such as remote control, automatic data logging, off-line calculation software, etc. and computers are fully loaded and either addition of functions or connection of new RTUs is not possible. These make efficient operation of the entire power system difficult. There are also difficulties in obtaining spare parts for the old system. Renewal of the existing system is essential in near future.

Non availability of spare parts due to old equipment makes maintenance of the present performances to future difficult. Model change of this type of equipment is very quick and manufacturers stop manufacturing of old parts.

Under such situation, it is recommended to purchase a new load dispatching facilities with full SCADA functions with capacities to cater for power system expansion for about 10 years time at an earliest time.

3.5.6 Communications Facilities

(1) General

The two kinds of communication system, PLC and radio, are in operation at present on the power system and the third system, micro-wave, is under installation to be commissioned soon. The principal aim of them is to establish a major communication network to link the CEB head office (H/O), SCC and Complex Offices with power stations, 220 kV, 132 kV and 33 kV substations, and provincial and area offices.

In the CEB power system, the major communication system consists of Power Line Carrier (PLC) which transmit the following data and information for operation of the CEB power system:

- Telephone: Communication for load dispatching use and for general communication purpose.
- Teleprotection: Signal interchanges for transmission line protection.
- Telex: System control and administrative purposes.
- Data transmission: Telemetering and supervising information of the major power stations and substations.

400 MHz band UHF radio system is used for communication between SCC and some area offices. In addition, the cable carrier system is applied to Biyagama - Sapugaskanda PS for which underground communication cable is laid. For the Randenigala - Rantembe section, both the PLC and cable carrier systems are used. For the Fort and Kollupitiya substations, 2-wire extensions are connected directly to the telephone exchange of Kolonnawa via pilot wire cables commonly with those for the pilot-wire relaying purpose.

The VHF radio is used for back-up of the PLC communication system, and for communication on the 33 kV system.

New digital micro-wave system which is now ready for commissioning test is planned to supplement the above communication network except the VHF radio. After completion of the digital micro-wave system, the following new technology-based network can be achieved covering the Colombo head office, the major power stations through complex offices and most of the area offices in the power supply area:

- Digital telephone.
- High-speed facsimile.
- Computerized data exchange.

At the present stage CEB have no idea to utilize this micro-wave system for power system control and transmission line protection. For this system, the Communication Control Center (CCC) was newly constructed in the Kelanitissa power station.

(2) PLC System

The existing major equipment were supplied by selected manufacturers (formerly BBC and now ABB) and their technical particulars are mentioned below:

(a) Line traps

Rated current of the old line traps was 400 A and that of the recent ones is 800 A. Rated short-time current is 25 kA and coil inductance is 0.2 mH. Minimum impedance in the working band is 600 ohms (resistive) and attenuation loss is less than 2.6 dB. These comply with the IEC recommendations.

(b) Coupling capacitors (CC)/capacitor voltage transformers (CVT)

The capacitance value of the existing CC/CVTs that have been procured as parts of substation contracts are not obtained in this Study. Minimum 4000 pF is required to ensure proper operation of the PLC system, and around 6000 pF is required to achieve performance of HF coupling device mentioned below.

(c) HF coupling devices

The phase to phase coupling mode is applied to single circuit overhead line to maintain reliability of signal transmission. For double circuit overhead lines, inter-circuit coupling mode which uses one phase each of two circuits of the overhead line is applied.

Carrier frequency of coupling filter unit is adjusted in the range of 70 - 500 kHz at site.

Composite loss is less than 1.5 dB and is a much better figure than the IEC's requirement (not greater than 2 dB). Return loss is not less than 12 dB, which complies with the IEC.

Indication of "on" and "off" position of earthling switch is clearly visible for safety purpose.

(d) PLC terminals

PLC terminals are designed for Single Side Band (SSB) of 4 kHz band width for simultaneous transmission of speech, telex, data and the teleprotection signals with band allocation of 300 - 2000 Hz for speech, 2000 - 3600 Hz for telex (50 bps), data (200 Bauds) and the teleprotection signaling and 3600 - 4000 Hz for pilot signal.

Carrier frequencies can be selected in the range of 40 - 500 kHz, but use of 368 - 400 and 492 - 500 kHz bands is prohibited due to the use of these bands for radio beacons for airplane.

The following three models of the PLC terminal are in use in the CEB system at present:

i) Old ones: 1 CH and 2 CH sets of 15 W
ii) Widely used: 1 CH and 2 CH sets of 20/100 W
iii) Recent ones: 1 CH and 2 CH sets of 40/80 W

Note: 100 W sets are used for long lines with section length of over 100 km.

The PLC system diagram is presented in Fig. 3.5.6-1 and 3.5.6-2.

Carrier frequencies of old PLC terminals (i and ii above) are governed by the crystal synthesizer and frequencies once set by supplier are fixed and their modification is not possible without changing crystal, but frequencies of recent terminals are freely programmable at site with a personal computer. Therefore, assigned frequencies can be revised easily. Thus, frequency allocation becomes flexible and available frequency band can be utilized effectively.

The carrier frequency allocation of the present system to assign different carrier frequencies of 4 kHz bands without spacing at the same station with the help of discriminating capability of equipment does not conform to the requirement of the IEC recommendations to allocate frequencies with spacing to avoid crosstalk.

(c) Teleprotection signaling equipment

Teleprotection signaling equipment transmit circuit breaker tripping or blocking commands from a station to the opposite station via PLC terminals. The teleprotection signals are sent out at full power in the speech band of PLC channel. Speech and any other data transmission are momentarily interrupted while the protection signals are being sent out.

The equipment is designed to be suitable also to transfer tripping and blocking signals in the blocking, and permissive and direct transfer tripping schemes.

(3) Telephone System

There are two types of telephone system, one is automatic dialing (PAX) system for general communication purpose and the other is Party Line Telephone System (PLTS) for load dispatching use. The four-digit numbering plan, two digits for stations and the remaining two digits for extensions, is applied.

The existing PAX is of stored program controlled trunk switching system and has an electronic 4-wire switching matrix. Subscriber extensions and 4-wire connections can be mixed as intended by using plug interface circuits. The transfer and inquiry, and call diversion functions are not furnished with the existing PAX.

The PLTS consists of 4-way bridging amplifier and DTMF (Dial Tone Multi Frequency) decoder modules that are installed within a PLC terminal, and 4-wire DTMF telephone sets having 10 keys and special key-pads.

The telex system is used for administrative use connecting SCC with power stations and the Mahaweli Complex Office in Kandy. The telex signal has five directions and of 50 bps speed on PLC channels. The system itself has already become out-of-dated, and therefore replacement work is being performed gradually.

The public telephone system is basically not used for supplemental communication among stations because the system in urban areas does not function satisfactorily and no facilities are available in rural areas.

(4) Radio Communication System

(a) VHF and UHF radio

There are about 1,000 sets of VHF radio including mobile sets in use, and 40 and 80 MHz frequency bands are allocated.

Twelve (12) UHF links through the PAX trunks at grid substations have been established to connect SCC and the CEB head quarter, area offices and the Mahaweli Complex Office in Kandy where subscriber sets are installed.

(b) Digital micro-wave system

New digital micro-wave system has been designed with operational philosophy which is considered appropriate to future needs of the CEB power system for digital telephone, high-speed facsimile, computerized data exchange, digital Private Automatic Branch Exchange (PABX) system, etc. System configuration with 99.7% availability is required for performing necessary functions and its system diagram is shown in Fig. 3.5.6-3. Three kinds of data communication, 9.6, 19.2 and 64 kbps, recommended in CCITT can be accommodated.

For the section, Weywella (repeater) - Inginiyagala Hydro power station - Ampara area office in the Eastern Province, communication equipment have been purchased but their installation is suspended due to security reason.

All radio frequency allocation in Sri Lanka is controlled by the Authority of Director General of Telecommunication, a government agency of the Ministry of Posts and Telecommunication. Any users including army have to make application in writing to this authority. Permission of frequency allocation is obtained within one week to one month. In many cases, an applicant has to find out available frequencies himself.

(5) Communication System for Load Dispatching

Six (6) part systems connecting 20 RTUs are shown in the Fig. 3.5.5-1. The present system is at a bit rate of 200 bps using the recommended frequencies in the CCITT in the PLC VFT (Voice Frequency Telegraph) band.

After completion of the planned new upgrading of SCADA system mentioned in Clause 7.2.6 and integration of the digital micro-wave system, 600 bps rate of data transmission, dual communication with the PLC system and the digital micro-wave connecting major power station and substations will become available.

(6) DC Power System

A lead-acid battery and a charger are installed at about 27 stations, and a nickel cadmium battery and a charger are installed at 7 stations. The standard voltage of the battery set for communication use is 48 V.

(7) Problems of the Present System

Current problems of the existing communication system are enumerated below:

(a) Old model (ETB and ETBB) PLC terminals

More than 20 years has passed since the old model equipments were manufactured. Spare parts including vacuum tubes are no more available at present.

(b) Inductance of line traps

The inductance value of the existing line traps is 0.2 mH, but its blocking frequency band is narrow and can block a limited number of channels only, thus new 0.315 or 0.5 mH one will be necessary when an additional PLC terminals are required on the existing lines.

(c) Channel capacity of PLC system

Traffic will increase after completion of the upgraded SCADA system, in which RTUs are planned to be installed at all power stations and substations. In particular, the channel capacity of Kolonnawa - Polpitiya - Laxapana shall be raised to cope with expected increase in communication traffic. Therefore, line trap problems and interference problems will be inevitable as many PLC terminals have already been installed on the above lines.

(d) PLC systems for protection of T-branched substations

As mentioned in Item (10) (Problems of the Current Relaying System), in Clause 3.5.3 (Transmission System Protection) and (4) (a) (Considerations for System Extension) in Clause 3.5.4 (Substations), many of the existing 132 kV grid substations are T-connected to main lines by. Application of PLC audio teleprotection to a T-branched system causes difficult technical problems, such as mismatch at the tee-off point, standing wave effects on the un-trapped line, etc. Technical coordination works between protection relays and PLC system seems to have not been carried out previously.

(e) Mutual interference and substation attenuation

No interference caused by crosstalk from other operating PLC carrier frequencies is reported but it may be serious problems in particular for the following PLC systems which are achieved by multi-connections of T-branching form.

- Kotugoda - Bolawatta (T) - Chilaw (T) - Puttalam
- Kolonnawa - Oruwala (T) - Thulhiriya (T) - Polpitiya
- Kolonnawa - Avissawella (T) - Polpitiya (HF coupling bypass) - Laxapana

In addition, the present carrier frequency allocation (to allocate next frequency without spacing) as stated in (2) (d) (PLC Terminals) in this clause may cause interference among each other.

Substation attenuation (more than 15 dB is required in general) data to get rid of the interference is not available at present.

3.6 Distribution System Facilities

(1) General

The distribution system in Sri Lanka is owned by the three categories of organization, CEB, LECO and LAs, and the total length of distribution lines including overhead and underground lines in Sri Lanka as of the end of 1995 is about 61,000 km as summarized below:

Total Length of Distribution lines

	CEB	LECO	LA	Total
33 kV line, overhead	13,000	---	---	13, 000
underground	55	---	---	55
11 kV line, overhead	2,000	1,100	---	3,100
underground	417	---	---	417
3.3 kV line, underground *1	18	---	---	18
LV line, OH and UG	40,000	4,300	150	44,450
Total	55,490	5,400	150	61,040

*1: Exceptional case in Kandy.

(2) Medium Voltage (MV) Distribution System

The standard secondary system voltage of transformers at grid substations is 33 kV (11 kV is adopted only to the Fort and Kollupitiya substations), and the following kinds of feeders are connected to the 33 kV buses of grid substations:

(a) 33 kV distribution feeders with Raccoon conductors (75 mm^2): In rural areas, 33 kV MV line voltage is directly stepped down to low voltage for supply to consumers.

(b) 33 kV subtransmission feeders with Lynx conductors (175 mm^2) to 33/11 kV substations for MV distribution at 11 kV: In major cities like Colombo and Kandy, and coastal areas, the MV distribution voltage is 11 kV.

(c) 33 kV backbone feeders with single or double circuit of Lynx conductors to switching gantries (functions are similar to switching stations) near large load centers or at important points of the distribution systems.

(d) 33 kV feeders from many grid substations are basically interconnected each other through section switches, though they are normally operated as radial feeders. Therefore, modification of load sharing among substations is possible by connection changes with section switches.

Bare aluminum conductors, ACSR and AAAC, are used for MV overhead distribution lines.

The switching gantries are usually of outdoor installation without attended operators. The gantry receives power from a grid substation through a backbone feeder and distribute power through a number of 33 kV radial feeders with Raccoon conductors. The distribution feeders originating from the gantry are normally provided with low speed autoreclosers for automatic supply restoration. No voltage adjusting facilities, like step voltage regulators and/or static capacitors, are provided at the switching gantries. In many cases, such gantries are interconnected among each other taking into account mutual connection under line fault or maintenance.

In the coastal areas, 33 kV pin insulators sometimes cause flashover due to salt contamination when operated under the rated voltage of 33 kV. In the coastal areas, the 33 kV distribution lines are used for 11 kV distribution without modification and 33 kV pin insulators are used for 11 kV service.

Underground cables are laid for the MV distribution lines in Colombo city and overhead lines are constructed in all the other areas.

The designed maximum route lengths of MV feeders are as follows:

(a)	33 kV feeders	
	- Backbone feeders:	40 km
	- Raccoon feeders for distribution:	20 to 25 km
(b)	11 kV feeders (Racoon conductors)	20 to 25 km

The standard capacity of 33/11 kV transformers is 5 and 10 MVA in the urban areas and 2 and 5 MVA in the rural areas.

(3) Low Voltage (LV) Distribution System

The LV distribution system in Sri Lanka is of 230/400 V, 3-phase, 4-wire. The rated voltage of the secondary windings of distribution transformers is 240/415 V.

Bare aluminum conductors are widely used also for LV lines. However, insulated wires are also used especially in highly vegetated areas to improve reliability of supply and in city areas to prevent illegal use. Bundled insulated conductors are used widely.

The normal maximum length of LV lines is decided so as to keep the consumer supply voltage within an allowable range, depending on the load density of the area, and is short in city areas and long in rural areas.

(4) Distribution Voltage Control

The 33 kV and 11 kV MV distribution voltage must be kept within a control level. At the line ends of the 33 kV system especially in remote rural areas a considerable voltage drop is reported; lower than 90% voltage at many locations and less than 80% in northern and eastern regions. To minimize variation of the MV system voltage, the following measures are being taken:

(a) The control level of voltage variation at the HV substation bus is ± 5% of the standard voltage and the allowable voltage variations at the consumer ends is ± 6% according to the regulation.

(b) Automatic on-load tap changers are provided on the 132/33 kV transformers to adjust the secondary side voltage automatically. On-load tap changers are provided also on main 33/11 kV transformers, while only off-load tap changers are provided on small transformers.

(c) Arrangement to operate line drop compensators to compensate voltage drop in distribution lines under service conditions is provided on on-load tap changers of transformers as their standard accessories, but these have not been operated in the CEB system. The first trial operation of line drop compensator is planned at the Deniyaya substation.

(d) Installation of static capacitors by bulk supply consumers is promoted. For such capacitor installation, CEB provides funding with a low interest rate, 12% instead of 20% in the market, and the monthly fixed charge based on the kVA contract is lowered due to decrease in kVA by power factor improvement.

(e) Necessity of static capacitors at the switching gantries and at the ends of MV lines has been identified as the results of computer studies by CEB. No static capacitors have been installed at the switching gantries and for the Colombo system, however for rural systems with long lines static capacitors have been installed to mitigate excessive voltage drop.

(f) Step voltage regulators to compensate voltage drop in long distribution lines are not installed in the 33 kV system. This type of equipment will be effective for the CEB system with a lot of extremely long 33 kV lines and suffering from excessive voltage drop. The step voltage regulator is the apparatus consisting of an autotransformer and a tap changing apparatus of either manual or automatic operation.

(5) Improvement of Supply Reliability

The mean annual duration of power supply interruption in the CEB system is told to be seven hours in Colombo. This figure is considered to be in a reasonable range if the economic situation of the country is taken into account. This figure is fairly good compared with other developing Asian countries.

For each of MV distribution feeders, slow speed autoreclosers are provided for automatic restoration of power supply after occurrence of momentary faults. In addition to circuit breakers at the outgoing points of feeders at substations, additional circuit breakers with the autoreclosing function are provided at switching gantries and at branching points on the main lines together with overcurrent and earth fault relays. The time differential protection with the help of the IDMT overcurrent relays is applied and the breakers near to the line ends operate quicker than those on the supply sides at the time of line fault.

CEB is strongly wishing to improve the supply reliability of their power system particularly in the Colombo area.

(6) Distribution System Study

The planning of distribution network (33 kV and below) is the responsibility of the Distribution Development Branch of the Distribution and Consumer Service Division. The distribution system analysis and loss reduction studies of the MV systems are being carried out with the help of the Scott and Scott Mapping and Network Analysis Software developed in the USA. The systematic distribution system studies were performed in 1995 on the MV distribution system of each province covering the whole country by the Distribution Development Branch, and the results were compiled as Medium Voltage Distribution Development Plan, 1995 - 2005.

(7) Consumer Metering Facilities

A normal induction disc type watt-hour meter is installed at each consumer service point. However, due to shortage in quantity of watt-hour meters electricity is being supplied to newly connected consumers on a monthly charging based on estimation basis even before installation of meters. Precision meters for metering of bulk supplies are of electronic type.

Accuracy of the watt-hour meters is not properly controlled. Though CEB has two meter calibrating apparatus (movable type), these are used for calibration of newly purchased and repaired meters. Calibration of installed meters is performed at the installed sites. Available handling capability of these meters is not sufficient, and for regular calibration of all used watt-hour meters additional laboratories are required. The regular meter calibration after every predetermined period of service and replacement with calibrated meters are not carried out. Watt-hour meters are replaced only when meter readers or consumers claimed inaccuracy of meters.

There is no assembling plant of watt-hour meters in Sri Lanka and all meters in use are being imported from abroad.

(8) Rural Electrification

Normally, the rural electrification is not profitable to an electricity supply utility due to its necessity of long distribution lines to sell relatively small amount of power at very low rates (Refer to Clause 3.3). Same like other developing countries, funds necessary for extension of rural distribution system is arranged by the Government.

(9) Recommendation for Improvement

Recommended measures for improvement of the existing distribution system are enumerated below:

(a) The present 33 kV bus voltage at grid substations is set at the rated 33 kV. But, it is recommended to set the sending end voltage higher, at around 5% higher by line drop compensation or by selecting higher setting voltage of tap changers.

(b) System voltage at the switching gantries is recommended to be controlled with step voltage regulators and/or static capacitors.

(c) Installation of static capacitors for power factor improvement by large consumers is recommended to be promoted to improve the voltage profile in the distribution system. Such capacitor installation is compulsory in Japan under a supply contract of power company.

(d) The plan to construct low cost grid substations using replaced 10 MVA and 16 MVA transformers of 132/33 kV is supported in view of effective utilization of available assets. This measure will contribute to reduce length of 33 kV feeders and to improve supply reliability in certain rural areas.

Actually, construction of low-cost substations using replaced 10 MVA transformers at five locations was proposed by the Distribution and Consumer Service Division in the Medium Voltage Distribution Development Plan, 1995 - 2005.

3.7 Operation and Maintenance of Transmission System

3.7.1 General

(1) Basic Principles

The principal aim of the operation and maintenance (O&M) of electrical facilities is to operate and maintain available facilities in efficient and coordinated manners so as to attain stable supply of electric power of good quality (with minimum of variation of supply voltage and frequency) to all the nation in impartial manners.

SCC shall function well for most efficient operation of the transmission system. The maintenance of the working facilities shall be carried out so as to maintain effective functioning of the transmission system.

(2) Organizations for Operation and Maintenance

The O&M of transmission lines and substations are under the control of the Transmission Division of CEB. While O&M of the relaying systems, system control center and communication facilities are under the Generation Division.

(3) Quality of Power Supply to Consumers

The target quality of power supply to consumers in the CEB power system is as follows:

- Voltage: $\pm$ 5% at the HV substation bus
  $\pm$ 6% at the consumer ends
- Frequency: $\pm$ 1% (50 $\pm$ 0.5 Hz)

According to the results of power system analysis of the 1995 system, there are cases that the bus voltage goes down exceeding the above control level even under normal operation.

The voltage level of the Colombo MV distribution system is relatively kept well due to short line length. However, according to the results of computer analysis by CEB system voltage drops considerably in long 33 kV lines to remote centers. Assuming rated voltage being kept at the substation secondary side, MV voltage drops more than 6% at a 40 different selected locations in provinces according the MV Distribution Development Plan, 1995 - 2005. In extreme cases, receiving voltage is just over 70% at east coast centers, Baticaloa and others. At present, the MV voltage of grid substations of CEB is basically set at the rated 33 kV. The actual supply voltage to consumers must further drop from the above MV system voltage.

There is no automatic frequency control (AFC) apparatus in the CEB system, and the system frequency is adjusted by manually controlling setting values of turbine governors at the Victoria and New Laxapana power stations. According to the 1995 Monthly Review Reports on System Control and Operations of CEB, the number of monthly violations of the above frequency range is between 50 and 200 with mean value of around 120 (4 times a day), and this figure is generally low in the rainy season and high in the dry season. There are cases of operation of underfrequency load shedding relays, which means frequency drops to lower than 49 Hz, a few times a month. The operating system frequency shall be watched carefully.

(4) Supply Interruption

It was told by CEB that the average duration of power supply interruption to all the consumers in Colombo is approximately 7 hours in a year. The total breakdown of the Colombo system occurs at an average rate of once an year due to the two-circuit failures of 220 kV Kotmale - Biyagama line and other causes. In 1995 serious failures which affect the Colombo power system occurred at an average rate of once a month. Frequent faults on the 132 kV Kolonnawa - Polpitiya lines are noted.

The 132 kV radial transmission systems, especially in the Polpitiya - Anuradhapura, Anuradhapura - Trincomalee and Badulla - Inginiyagala sections, are causing a lot of problems as mentioned in Clause 3.7.2. High probability of faults of the T-branched sections is also noted. Many times of supply trouble are recorded in the above mentioned monthly review reports on system control and operations of CEB.

According to fault records, there are a lot of power failure due to short circuit and earthing faults and duration of supply failure is long. These seem to be caused by old facilities, improper conductor connection, frequent lightning, touching of trees, improper maintenance, overloading during peak load time, improper system configuration, techniques of operator and maintenance staff, and other causes.

(5) Faults of Generating Facilities

Monthly average of 24 generator trippings were recorded. However, according to the records more than half seem to be associated with faults in other facilities, transformers and transmission lines. Among them, very high rate of faults is noted for the Old Laxapana and Inginiyagala power stations.

(6) Noted Problems

Problems noted for improvement are mentioned below:

(a) Installed capacity of static capacitor especially in the Colombo system shall be significantly increased to improve the voltage profile of the system and to reduce reactive power flow on the power supply line, especially of the Victoria - Kotmale - Biyagama line.

(b) The 33 kV bus voltage of the grid substations had better be set higher than the rated value under the heavy load condition, and for long lines use of line drop compensators and step voltage regulators shall be reviewed.

(c) Thorough studies on the voltage management measures including the following items for the distribution system are recommended.

   i) Control of switching gantry voltage by installing step voltage regulators at the receiving point from a grid substation and static capacitors.

ii) Installation of step voltage regulators on long feeders.
iii) Installation of static capacitors at line ends.
iv) Promotion of installation of static capacitors by large consumers.

For all improvement measures, cost - benefit relations shall be clarified and measures shall be executed based on economic priority.

(d) For stability of system frequency, installation of automatic frequency controller (AFC) at one or two relatively new major hydro power stations like Victoria, Kotmale, New Laxapana and Samanarawewa will be required.

(e) To improve dynamic system stability under disturbance, provision of high speed excitation devices with power system stabilizers (PSS) on large generators will be required.

(f) Improvement of T-branching connections is required especially for line protection and PLC communication.

(g) Overall review of relaying system to remove unprotected sections and to attain coordination among each other will be essential.

(h) To ensure efficient working of available transmission facilities improvement of the load dispatching system is essential.

(i) Maintenance manuals and/or check lists shall be prepared for all items.

3.7.2 Transmission Lines

(1) General

According to the Monthly Review Reports on System Control and Operations of CEB for the period of January 1994 to November 1995, the annual rates of forced outages of the existing transmission lines are as shown below:

	220 kV Lines	132 kV Lines
Forced outages, 1994	3	154
Forced outages, 1995	8	184
Total circuit lengths (km)	260	2187
Outage/100 km/year	2.1	7.7

The number of outages per 100 km in one year of the 132 kV lines is fairly high compared with values of other Asian countries. The figure for the 220 kV lines is in a reasonable range. It should be noted that successful automatic reclosings are not recorded as faults in these statistics. It is apparent that some lines experienced numerous faults whereas others are relatively fault free. However, a lot of anomalies which are caused by untraceable and need clarification appear in the recorded fault data.

The majority of the faults recorded were only temporary, caused by lightning or trees touching the line, and were successfully restored by reclosing after a short while. The number of permanent faults or breakdowns requiring repair were relatively few, three in 1994 and five in 1995.

The lines with T-connections given below seem to cause a lot of operation problems:

- Kolonnawa - Sapugaskanda - Kotugoda
- Kotugoda - Bolawatta - Chilaw - Puttalam
- Kolonnawa - Oruwala - Thulhiriya - Polpitiya, No. 1 and 2
- Kolonnawa - (Avissawella) - Polpitiya, No. 3 and 4

The two 132 kV northern lines between Polpitiya and Anuradhapura are heavily loaded and cause successive trip as a result of overload. The other line with excessive number of faults is the 132 kV Badulla - Inginiyagala line.

(2) Organization

The CEB's organization in charge of transmission line maintenance is the Transmission Line and Grid Substation Maintenance Branch of the Transmission Division. The maintenance activities of all transmission lines for the whole country is being undertaken by five gangs with their main offices in Colombo. The gangs are assigned to work in whichever area is required. The total number of maintenance staff is 55.

(3) Maintenance Procedures

The first maintenance inspection of a new transmission line is carried out within five years after handing over and energizing. Thereafter, the maintenance is expected to be carried out every 2.5 to 3 years. The maintenance consists of a ground patrol and a climbing inspection of all towers. Insulators and fittings are inspected from the tower. Any defects are noted and reported, and they are rectified as soon as possible within the same inspection period. Insulator replacement on single conductor lines can be undertaken using "hot line" techniques. However, equipment is not available for "hot line" working on twin conductor lines. Actually, suspension insulator sets can be changed but tension sets can not due to the design of the crossarm end and lack of maintenance provisions also the use of a single attachment point for the twin tension set allows the complete set to swivel.

CEB staff are trained and confident in hot line working at 132 kV but have had no training and little experience on hot line working at 220 kV.

The maintenance gangs report where tree cutting is required but do not carry out this work. Actual cutting is undertaken by the area engineer in conjunction with wayleave officers. The wayleave officers are required to negotiate with landowners for permission to cut trees. It would seem that one reason for the high number of faults recorded is the lack of effective tree cutting and long time interval between patrols. Although the Area Engineers are supposed to carry out routine tree cutting on a regular basis independent of the Maintenance Branch, it appears that this is not done regularly and tree cutting is only undertaken when a number of faults occur indicating a problem.

There is no specific manual of maintenance procedures for overhead transmission lines. At the start of each line inspection the maintenance gang is provided with a "Transmission Line Information Sheet" giving the line name, single or double circuit and indicating for each tower number, the tower type, span length, angle of deviation, the conductor size, earthwire size and whether single or double, the number of insulator discs per phase and the type and make for each circuit, the number of vibration dampers, and whether earth tape is installed. The information sheet also shows the tower location, CEB Depot and Area Engineer responsible. The maintenance gangs are also provided with blank "Inspection Report Forms" on which to record for each tower number the condition of the tower foundation, steelworks, earthing, insulator strings and insulator hardware, phase conductors, earthwires, dampers and arcing horns.

The maintenance gang records any defects and then if possible rectify the defects during the same inspection period. Painting of tower steelworks is carried out when the maintenance gangs note the appearance of rust on towers. A record of all work carried out at each tower is kept at the Maintenance Office.

(4) Recommendations

The vast majority of transmission line faults are temporary caused by lightning or trees touching the line. Generally the line is re-energized within a very short time without any inspection or repair necessary. However the numbers of these faults is excessive and some attempt should be made to reduce the number of outages.

In the case of outages caused by lightning the first remedial action would be to reduce the tower footing resistance. The specified requirement for tower footing resistance for 132 kV towers is generally less than 10 ohms. A program of checking the tower footing resistance should be undertaken starting with lines that exhibit particularly poor performance such as:

- Kolonnawa - Polpitiya, No. 1 and 2
- Kolonnawa - Polpitiya, No. 3 and 4
- Kolonnawa - Kotugoda
- Kotmale - Kiribatkumbra

Particular attention should be paid to towers exposed to air, i.e. towers on hill tops. Where tower footing resistance is found to be high, installation of additional counterpoises should be carried out initially using 4 x 30 meters galvanized steel wire 7/4.0 mm. In severe cases earth rods 25 mm diameter can be installed in drilled holes 150 mm diameter and 25 m deep filled with bentonite and sodium carbonate solution.

It is recommended to commence systematic collection of lightning phenomena, number of lightning days in each year, measurement of lightning current with recorders and records of lightning damage with location and degree of damage.

With regard to tree clearing, obviously more frequent patrols and more severe cutting of trees would help. Particular attention should be paid to mid-span locations where the conductors are lowest but also where maximum conductor swing can occur.

3.7.3 Transmission System Protection Systems

(1) Organization

The Protection Branch of the Generation Division is in charge of protection matters of the CEB power system covering power stations, transmission lines, substations and MV distribution systems. In the branch, under a Deputy General Manager there are two Chief Engineers for Protection Development and Protection Maintenance. The former is in charge of system design and decision of relay setting and the latter is in charge of relay maintenance. For relay maintenance, this division has four test engineers who looks after all power stations and substations assigned to each engineer. Each test gang consists of one test engineer, one superintendent and several laborers.

(2) Maintenance Procedures

General inspection, visual check and check of setting values, are performed at the time of periodical inspection of substation as mentioned in Clause 3.7.4. Operation check is carried out when maloperation of relay is reported or some doubts are raised regarding performance of relays. All such tests are carried out at site using available testing apparatus of movable type.

CEB has a Japan-made overall relay testing board, but this set is not used due to difficulty in transport to site. Only portable testing apparatus are used as all tests must be performed at site. Usually, the relay tests are carried out under the live conditions by inserting test plugs to relays to be tested. Duration of shutdown shall be minimized, in case that partial or entire shutdown is required for test purpose.

3.7.4 Substation Facilities

(1) General

According to the Monthly Review Reports on System Control and Operations of CEB of 1995, monthly number of power system faults, mostly detected at substations, was fairly large with around 70 per month. The causes of faults are classified as follows:

- Transformers: 10 to 80 per month with average of 36 times
- Transmission Lines:
  - 220 kV lines: 0 to 3 per month with average of one time.
  - 132 kV lines: 8 to 50 per month with average of 22.
  - 66 kV lines: 4 to 50 per month with average of 16.

From the fault records, the followings are noted:

(a) Though the rate of faults of the 220 kV system is not high, the rates are high for the 132 kV and 66 kV systems. It is noted that the 220 kV system equipment are relatively new and an advanced protection system is employed, while the system equipment are mostly old and inferior in quality for the 132 kV and 66 kV systems. The 66 kV system is very old and its equipment have already been deteriorated with age.

(b) It is a general tendency that many faults (5 to 10 times a month) occurred at the same substations by operation of same relays and the fault rate became normal again after some time after repairing. For the 132 kV lines, very high rate of faults was recorded for the Polpitiya - Anuradhapura and Anuradhapura - Trincomalee sections, and the fault rate of the Kolonnawa - Polpitiya 66 kV lines was extremely high.

(c) Many of transformer trippings were caused by feeder faults and overcurrent relay operation, and not faults of transformers themselves. However the transformer fault records include serious faults such as differential relay operation.

(d) A lot of overcurrent relay operations of transformers are noted. Many of them seem to be caused by over loading or insufficiency of transformer capacity compared to demand.

(2) Organization for Operation and Maintenance

(a) Organization for Operation

Grid substations are under control of Province DGM of the Distribution and Consumer Service Division, and the operation of substations is executed under guidance of the Area Electrical Engineers.

Operation organization is of 3-shift. Each shift consists of 2 to 3 members headed by an Electric Superintendent, who is at work day time only. Major duties of shift operators are equipment operation according to instructions from SCC, half-hourly collection of operation records, check of operating conditions of facilities by regular patrol and reporting of results, minor maintenance works of simple nature in control room, etc. Telephone for exclusive use is provided for hot-line communication of important topics with SCC.

Grid substations in power stations are under control of the Complex DGM of the Generation Division, and their operation is executed by power station operators together with power station facilities.

(b) Organization for Maintenance

The Transmission Line and Grid Substation (T&S) Maintenance Branch, headed by DGM, of the Transmission Division is in charge of the maintenance operations. The maintenance works are executed by maintenance staff of the Heavy Maintenance Section, and Instrumentation & Control Section each headed by a Chief Engineer of the T&S Maintenance Branch. Each of the both sections have four gangs controlled by an Electrical Engineer. Each site working gang is headed by an Electrical Superintendent and the total number of person is about 57 including Electrical Superintendent.

The maintenance works of grid substations in power stations are executed within the maintenance schedules of power stations.

Maintenance of relays and protective devices is carried out by the Protection Branch of the Generation Division.

For execution of a thorough maintenance operation, the substation must be shut down. Therefore, the maintenance schedule is determined through 3-party discussion among the Transmission Division, System Control Branch and Provincial Offices.

(3) Maintenance Procedures

Most of initial troubles come out during the one year warranty period of equipment supplied. Trouble shooting is carried out under attendance of the Project Engineers and sometimes with help of manufacturer's engineers. Through this process, members of the Heavy Maintenance, and Instrumentation and Control Sections acquire knowledge for equipment installation and maintenance process.

For a grid substation, periodical overall inspection and maintenance are conducted with a 6-month interval in principle. The routine inspection and maintenance are carried out according to the annual schedule at a rate of four substations a month. The works are carried out during day time from 8 am to 4 pm under the shutdown condition, and therefore power supply during evening peak can be secured.

Work items include visual inspection, equipment cleaning, additional tightening of bolts, touch painting, overhaul, inspection and check of auxiliary equipment, etc. with each days' work quantity which can be finished in a day. Planned repair and parts replacement of damaged equipment are also carried out at this occasion.

Inspection items for transformers are analysis of insulating oil, insulation check of windings with megger, visual inspection of portions easily visible from outside, bolt tightness, conditions of insulating materials, scars, etc. Major substations have apparatus for oil analysis.

Due to the limited available time, though contamination or deterioration of insulating oil is noted in inspection, purification or replacement of oil can not be carried out. Operation is continued watching oil temperature, voltage variation, etc. Only when severe fault occurs, power is cut off and dismantling, overhaul, detailed inspections, etc. are carried out.

For circuit breakers, only simple works such as dismantling and inspection of contact portions, some repairing and replacement of parts can be performed.

Cubicles for inspection and maintenance include those in SCC. For relays, protective devices, meters, small breakers, etc., cleaning, operation checks, parts and equipment replacement, etc. are carried out.

There is no instruction manual or check list for the 6-month regular maintenance, and the maintenance is carried out based on past experience of the maintenance gang. After each maintenance operation, a report for works is prepared containing inspection items, various measurement results (data), replaced parts, noted problems, pending matters, requirement for spare parts, etc.

(4) Problems of Maintenance Practice

(a) Management of drawings

Originals of completion drawings of grid substations are under custody of the Drawing Office of the Transmission Planning Branch of the Planning Division. While, drawings of augmented existing substations, new grid substations and power stations are kept at site.

For the Study collection of single line diagrams and layout drawings of the existing substations was tried. But due to poor management, a lot of difficulties were experienced in looking for drawings themselves and their up-to-date editions.

(b) Management of data, and operation and maintenance manuals

The Transmission Planning Branch has the Library which should keep data for the new construction of grid substations and power stations, and operation and maintenance manuals. However, stored items were limited and most of necessary information for transformers, circuit breakers, etc. were not available. It was obliged to refer to branch offices, grid substations, power stations, etc. looking for necessary data and information. Some data and information necessary for the Study could not be found out.

(c) Apparatus for test and maintenance

Hand tools necessary for general maintenance of substation are furnished with the grid substations. The T&S Maintenance Branch in charge of heavy maintenance has, in addition to ordinary hand tools, special tools such as torque wrenches, oil jacks, chain blocks, oil purifiers, etc., and store and manage them.

Measuring and testing apparatus necessary for inspection, such as meggers (5 kV dc), meters, a primary current injection test set, high voltage test apparatus, oil testers, earth testers (resistance value and specific resistance), etc. are owned and managed by the T&S Maintenance Branch. They do not have a meter calibrating equipment. Many of these apparatus are already old and operated long time without calibration, therefore their accuracy is doubtful.

(d) Spare parts

In case that spare parts at the time of new construction run out, parts are manufactured or recruited locally as far as possible and items which can not be manufactured or repaired locally must be ordered to the suppliers. But such foreign recruitment is not much and most of items are repaired and manufactured in local factories. There are also cases to utilize component parts or spare parts of abandoned equipment as spare parts.

Recruitment of printed circuit board (PCB) spare parts is very difficult. Damaged boards are repaired as far as possible, and sometimes similar boards of other substations are diverted. Only in case that local repair or recruitment is not possible, boards are ordered to suppliers. However there are many cases that desired boards can not be obtained from the original manufacturer due to model change or other reasons.

(e) Lack of technologies for maintenance of up-to-date facilities

For recent equipment like SF6 gas circuit breakers and GIS, maintenance technologies have not yet been established in CEB and there are difficulties in actual maintenance.

Training of engineers and technicians at manufacturer's works to acquire new technologies especially for the above two items, and purchase of required maintenance tools are urgently required in view of expected future increase in supply of these equipment.

As for PCBs for which model changes take place at short interval and recruitment of spares is difficult, establishment of repairing technologies including acquisition of detailed drawings and repairing technologies, etc. are important subjects for CEB.

(f) Lack of maintenance engineers

Due to existence of many decrepit substations and recent increase in number of substations, total quantity of maintenance works is increasing. Together with shortage of engineers and superintendents for maintenance works, there are cases that intervals of six monthly inspection and maintenance are prolonged and duration of works is extended.

Recruitment of maintenance staff and their education and training are required to be planned systematically according to expansion of the power system.

(g) Quality assurance

Among CEB facilities, some old transformers have been operated without major troubles, while some transformers with shorter service period cause a lot of troubles. Not only the problems of equipment reliability, there might be situation such as shortage of spare parts, shortage in time of overhaul, etc.

At the time of purchasing equipment, the quality tests are conducted by quality controllers of the Construction Office. However, attendance check of routine inspection, data check, necessary data corrections of the existing facilities, etc. are not being carried out systematically. Various organizations are conducting quality control arbitrarily without coordination among concerned parties.

With introduction of new technologies and augmentation of facilities, it is recommended to establish a Quality Control Branch so that the quality control can be carried out steadily in systematic manners.

3.7.5 Load Dispatching and Communications Facilities

(1) Organization

The System Control Branch of the Generation Division is in charge of the operation of SCC and, the prime function of SCC is to maintain a proper balance of demand and supply of the system all the time.

The transmission system operation function is assisted by the Transmission Line and Grid Substation Maintenance Branch of the Transmission Division, and the transmission system protection and communication problems by the Protection and Communication Branches of the same Generation Division.

(2) Operation

Each shift for operation of SCC consists of one engineer (specialist for generation operation) and two electrical superintendents. Major duty of superintendents is preparation of half-hourly operation records.

CEB seems to have no complaint to the performance of the existing communication system with backbone by PLC because of less failures. But replacement of PCBs of the PLC system, which are damaged due to induction current associated with a lightning stroke, and of the PAX, etc. is required sometimes.

(3) Maintenance Works

Maintenance of both of the SCC facilities and communication systems is being undertaken by the Communication Branch of the Generation Division.

Maintenance works are executed once a month by the six groups in five areas, two groups for the Colombo area and one group each for the Laxapana, Kandy, Samanalawewa and Anuradhapura areas.

Each group consists of one engineer, one superintendent, a driver and some laborers. The maintenance groups have a complete set of manuals and they are familiar with communication equipment. For example, an old condenser which has been in service more than 10 years is replaced by their judgment. Some engineers have experience of training in manufacturer's works for four months.

The working budget for the maintenance operations in 1996 is for instance Rs. 535,000 for batteries and chargers, and Rs. 4,300,000 for replacement of components and so on.

All maintenance operations are carried out by Sri Lankan staff and there is no special contract with manufacturers including SCC facilities.

The Monthly Review Report for System Control and Operations for all the CEB generation and transmission systems is prepared monthly by SCC.

(4) Maintenance Procedures

Voltage check of the battery is performed from time to time as an everyday checking item of substation operation. Inspection items in the maintenance works are enumerated below:

- For batteries and chargers
  - Specific gravity and voltage check.
  - Full discharge and re-charge of the batteries once a year.
- For PLC terminals
  - Cleaning.
  - Output power measurement.
  - Check of working voltage.
  - Check of modulation.

After every one year operation, the following specified items in manufacturer's manuals are tested:

- For PLC terminals
  - Frequency testing (once in two years)
  - Measurement of stabilized D.C. auxiliary voltage.
  - Measurements on selected AF and RF level.

- AGC operating level.

• For teleprotection signaling equipment

  - Checks during operation by loop test function.
  - Removing the equipment from receiving for testing.
  - Checking entire link.

(5) Problems of Maintenance Practice

CEB has some drawings that show system diagram but the following data on the existing equipment are poor:

- Blocking frequency bands of the line trap.
- Available frequency bands of the coupling device.
- Information on direction of PLC.
- Channel utilization of the teleprotection signaling equipment.
- Drawings showing line coupling mode.
- Exact operation year of equipment.
- Load of equipment.

From the above, the followings are noted:

(a) Name plates of line traps can not be identified from the ground with binocular. Thus, it is necessary to record the blocking frequency prior to its installation.

(b) On PLC terminals there is no indication plates denoting connected station name, carrier frequencies, etc. Therefore, it is very difficult to distinguish PLC connection at site.

(6) Recommendation

(a) Replacement of the old PLC terminals, ETB and ETBB, is required at an early time.

(b) Reinforcement of above data/drawing of equipment and a table/list of equipment such as a material list is required.

Table 3.1-1 Composition of CEB Employees

The number of employees of CEB as of September, 1995 was 13,971 and its composition was as summarized below:

Work Category	Number of Person	Percentage (%)
Additional general managers	6	–
Finance manager	1	–
Engineering executives	508	3.6
Accountants	38	0.3
Clerical executives	143	1.0
Middle level technical grades	777	5.6
Clerical and allied grades	2,253	16.1
Skilled technical services	3,043	21.8
Office employee services	430	3.1
Technical services	5,641	40.4
Other skilled grades	1,061	7.6
Other unskilled grades	70	0.5
Total	13,971	100.0

Table 3.2-1 Historical Data of Power Demand and Supply

	Generation			Sales		System	Load	Aux.
Year	GWh	Inc. %	MW	GWh	Inc. %	Loss (%)	Factor (%)	Use(%)
1974	1012	–	216	892	–	11.8	53.6	0.6
1975	1079	6.6219	965	8.2	10.5	56.3	0.5	
1976	1133	5.0240	997	3.3	12.0	53.7	0.6	
1977	1217	7.4261	1041	4.4	14.5	53.2	0.5	
1978	1385	13.9	291	1162	11.6	16.1	54.3	0.7
1979	1536	10.1	329	1298	11.8	14.9	53.0	0.6
1980	1686	9.4369	1392	7.2	16.6	51.5	1.0	
1981	1872	12.2	413	1503	8.0	19.7	51.7	0.9
1982	2066	10.4	431	1686	12.2	18.4	54.7	0.8
1983	2114	2.4437	1792	6.3	15.2	55.2	1.0	
1984	2261	6.9487	1877	4.7	17.0	52.9	0.5	
1985	2464	9.0515	2061	9.8	16.4	54.6	0.5	
1986	2652	7.6540	2232	8.3	15.8	56.0	0.4	
1987	2708	2.1570	2253	0.9	16.8	54.2	0.6	
1988	2799	3.4594	2371	5.2	15.3	53.7	0.5	
1989	2858	2.1618	2353	-0.8	17.7	52.8	0.5	
1990	3150	10.2	640	2608	10.8	17.2	56.2	0.5
1991	3377	7.2685	2742	5.2	18.8	56.3	0.7	
1992	3540	4.8742	2916	6.3	17.6	54.3	0.9	
1993	3979	12.4	812	3270	12.1	17.8	55.9	0.7
1994	4365	9.7911	3565	9.0	17.6	54.7	0.7	
1995	4786	9.6981	3912	9.7	17.8	55.7	0.5	

Table 3.3-1 Current Electricity Tariffs (Effective from 1st January, 1996)

Domestic			
Block 1 : First 30 kWh		Rs 1.20 per kWh	
Block 2 : 31 - 90 kWh		Rs 2.40 per kWh	
Block 3 : 91 -180 kWh		Rs 4.50 per kWh	
Block 4 : Above 180 kWh		Rs 5.60 per kWh	
Monthly fixed charge :		Rs 15.00 per month	
Religious Purpose			
Block 1 : First 90 kWh		Rs 1.20 per kWh	
Block 2 : 91 - 150 kWh		Rs 2.40 per kWh	
Block 3 : Above 140 kWh		Rs 4.50 per kWh	
Monthly fixed charge :		Rs 15.00 per month	
	General Purpose	Industrial	Industrial (Time of Day)
1) Supply at 400/230V (Contract Demand < 50 kVA)			
Energy Charge (Rs/kWh)	5.60	4.30	8.90 (peak) 3.20 (off peak)
Fixed charge (Rs/month)			
. Up to 10 kVA	15.00	15.00	15.00
. Above 10 kVA	205.00	205.00	205.00
2) Supply at 400/230V (Contract Demand >=50 kVA)			
Energy charge (Rs/kWh)	5.50	4.10	9.00 (peak) 3.80 (off peak)
Demand charge (Rs/kVA)	270.00	235.00	110.00
Fixed charge (Rs/month)	435.00	435.00	435.00
3) Supply at 11/33/132 kV			
Energy charge (Rs/kWh)	5.40	3.90	8.60 (peak) 3.60 (off peak)
Demand charge (Rs/kVA)	250.00	210.00	100.00
Fixed charge (Rs/month)	435.00	435.00	435.00
Bulk Supply to LECO/LA			
		Energy charge (Rs/kWh)	Demand charge (Rs/kVA)
L1 : Supply at 400/230V		2.60	65.00
L2 : Supply at 11 kV and above		2.25	47.50
Street Lighting		4.30 per kWh	

Note: 1) Adoption of fixed energy charge or time differential energy charge for industrial consumers is consumer's choice.

2) Peak time is 18 to 21 o'clock and off peak time is the rest of the day.

Table 3.4-1 List of Existing Power Stations

A. Hydropower Stations

No.	Power Station	River	Output Capa. N x MW		Voltage kV / kV	Operation Start Year	Fund Source
Laxapana Complex							
11	Canyon	Kelani	2 x 30	60.0	12.5 / 132	1983/88	ADB
15	Wimalasurendra	Kelani	2 x 25	50.0	11 / 132	1965	WB
6	New Laxapana	Kelani	2 x 50	100.0	12.5 / 132	1974	WB
2	Laxapana Stage 1	Kelani	3 x 8.33	25.0	11 / 66	1950	CEB
2	Laxapana Stage 2	Kelani	2 x 12.5	25.0	11 / 132	1958	WB
4	Polpitiya	Kelani	2 x 37.5	75.0	12.5 / 1132	1969	CEB
	Laxapana Complex			335.0			
Mahaweli Complex							
8	Victoria	Mahaweli	3 x 70	210.0	12.5 / 220	2 - 1984	UK
						1 - 1985	UK
7	Kotmale	Mahaweli	3 x 67	201.0	13.8/132/220	1 - 1985	Sweden
					13.8 / 220	2 - 1988	Sweden
13	Randenigala	Mahaweli	2 x 61	122.0	12.5 / 220	1986	W German
10	Bowatenna	Mahaweli	1 x 40	40.0	12.5 / 132	1981	ADB
9	Ukuwela	Mahaweli	2 x 19	38.0	12.5 / 132	1976	WB
17	Rantembe	Mahaweli	2 x 24.5	49.0	12.5 / 132	1990	W German
	Mahaweli Complex			660.0			
18	Samanarawewa	Walawe	2 x 60	120.0	10.5 / 132	1993	Japan, UK
Small Hydros							
14	Inginiyagala	Gal Oya	2 x 2.5	5.0	6.9 / 33	1963	CEB
			2 x 3.15	6.3			
15	Uda Walawe	Walawe	3 x 2	6.0	6.9 / 33	1969	CEB
16	Nilambe	Mahaweli	2 x 1.6	3.2	6.9 / 33	1988	China
	Small Hydros			20.5			

Hydro Total (Not including small hydros) 1,115.0

Hydro Total (Including small hydro) 1,135.5

Source: Long Term Generation Expansion Planning Studies, 1995 - 2009 Supply and Demand of Power Up to 2009, Strategy to Meet Expected Demand

B. Thermal Power Stations

No.	Power Station	Output Capacity (MW) Installed	Available		Voltage kV/kV	Start Year
3	Kelanitissa					
	Steam	2 x 25	2 x 22	44	11 / 132	1962, 3
	Gas Turbine	1 x 20	1 x 18	18	11.5 / 132	1980
		3 x 20	3 x 18	54	11/33/132	1981
		2 x 20	2 x 18	36	11/33/132	1982
12	Sapugaskanda					
	Diesel	4 x 20	4 x 18	72	11 / 132	1984
1	Chunnakam *1					
	Diesel	5 x 2, 4 x1	--	--	11 / 132	Stopped
	Kankesanturai *1	7	--	--		Stopped
Thermal Total *2		250.4	224			

Note: *1 Not operative at present.

*2 Excluding units not operative at present.

Source: Long Term Generation Expansion Planning Study, 1995 - 2009

Table 3.4-2 Historical Record of Hydro and Thermal Generation

Year	Hydro Generation GWh	Hydro Generation Share (%)	Thermal Generation GWh	Thermal Generation Share (%)	Gross Generation GWh	Gross Generation Inc. (%)
1974	997.4	98.6	14.3	1.4	1011.7	-
1975	1077.5	99.9	1.3	0.1	1078.8	6.6
1976	1108.5	97.9	24.3	2.1	1132.8	5.0
1977	1214.4	99.8	2.1	0.2	1216.6	7.4
1978	1365.8	98.6	19.3	1.4	1385.1	13.9
1979	1461.2	95.8	64.3	4.2	1525.6	10.1
1980	1479.4	88.7	188.9	11.3	1668.3	9.4
1981	1571.3	84.0	300.3	16.0	1871.6	12.2
1982	1608.1	77.8	457.6	22.2	2065.8	10.4
1983	1217.2	57.6	897.2	42.4	2114.4	2.4
1984	2090.7	92.5	170.0	7.5	2260.7	7.5
1985	2394.6	97.2	69.4	2.8	2394.6	9.0
1986	2645.3	99.8	6.5	0.2	2651.9	7.6
1987	2177.4	80.4	530.1	19.6	2707.5	2.1
1988	2597.0	92.8	201.7	7.2	2798.8	3.4
1989	2801.5	98.0	56.6	2.0	2858.1	2.1
1990	3144.6	99.8	5.1	0.2	3149.7	10.2
1991	3116.2	92.3	260.4	7.7	3376.7	7.2
1992	2900.1	81.9	639.8	18.1	3539.8	4.8
1993	3795.9	95.4	182.7	4.6	3978.6	12.4
1994	4089.2	93.7	275.4	6.3	4364.6	9.7

Table 3.5.1-1 Existing Transmission Circuits at December 1995

Ref.	Section	Voltage (kV)	No. of cct.	Conductors	Length (km)	Circuit-km (km)
2L1.	Biyagama - Kotugoda	220	2	Zebra	19.6	39.2
2L2.	Biyagama - Kotmale	220	2	2 x Zebra	70.5	141.0
2L3.	Kotmale - Victoria	220	2	2 x Zebra	30.1	60.2
2L4.	Victoria - Randenigala	220	1	2 x Zebra	16.4	16.4
2L5.	Randenigala - Rantembe	220	1	2 x Zebra	3.1	3.1
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)	5.4	5.4
1L1.	Biyagama - Pannipitiya *1	132	2	Zebra	15.5	31.0
1L2.	Biyagama - Kelanitissa *1	132	2	2 x Goat	12.5	25.0
1L3.	Biyagama - Sapugaskanda PS	132	2	Lynx	2.1	4.2
1L4.	Kolonnawa - Kelanitissa	132	2	Zebra	2.2	4.4
1L5.	Kolonnawa - Pannipitiya	132	2	Lynx	12.9	25.8
1L6.	Kolonnawa -Sapugaskanda(T)	132	2	Coyote	6.6	13.2
1L7.	Sapugaskanda (T) - Kotugoda	132	2	Coyote	16.7	33.4
1L8.	Sapugaskanda (T) - SS	132	2	Lynx	4.6	9.2
1L9.	Kotugoda - Bolawatta (T)	132	2	Coyote	21.0	42.0
1L10.	Bolawatta (T) - Chilaw (T)	132	2	Lynx	22.6	45.2
1L11.	Chilaw (T) - Puttalam	132	2	Lynx	61.4	122.8
1L12.	Chilaw (T) - SS	132	2	Lynx	6.8	13.6
1L13.	Kolonnawa - Oruwala (T)	132	2	Lynx	14.0	28.0
1L14.	Oruwala (T) - SS	132	2	Lynx	3.4	6.8
1L15.	Oruwala (T) - Thulhiriya (T)	132	2	Lynx	36.0	72.0
1L16.	Thulhiriya (T) - SS	132	2	Lynx	23.9	47.8
1L17.	Thulhiriya (T) - Polpitiya	132	2	Lynx	28.0	56.0
1L18.	Kolonnawa - Avissawella (T)	132	2	Lynx	31.9	63.8
1L19.	Avissawella (T) - SS	132	2	Lynx	0.5	1.0
1L20.	Avissawella (T) - Polpitiya	132	2	Lynx	34.4	68.8
1L21.	Pannipitiya - Ratmalana	132	2	Lynx	6.9	13.8
1L22.	Pannipitiya - Panadura (T)	132	2	Goat	12.3	24.6
1L23.	Panadura (T) - Matugama	132	2	Goat	29.1	58.2
1L24.	Panadura (T) - SS	132	2	Lynx	4.7	9.4
1L25.	Polpitiya - Laxapana	132	2	Lynx	8.3	16.6
1L26.	Laxapana - Wimalasurendra	132	2	Lynx	5.1	10.2
1L27.	Laxapana - New Laxapana	132	2	Lynx	0.6	1.2
1L28.	New Laxapana - Polpitiya	132	2	Lynx	8.0	16.0
1L29.	New Laxapana - Canyon	132	1	Lynx	10.0	10.0
1L30.	Polpitiya - Kotmale	132	1	Lynx	29.5	29.5
1L31.	Kotmale - Kiribatkumbura	132	1	Lynx	22.5	22.5
1L32.	Kiribatkumbura - Anuradhapura	132	1	Lynx	143.9	143.9
1L33.	Polpitiya - Ukuwela	132	1	Lynx	59.3	59.3

1L34.	Ukuwela - Habarana	132	1	Lynx	82.3	82.3
1L35.	Habarana - Anuradhapura	132	1	Lynx	48.9	48.9
1L36.	Ukuwela - Bowatenna	132	1	Lynx	30.0	30.0
1L37.	Kiribatkumbra - Kurunegala	132	2	Lynx	34.6	69.2
1L38.	Habarana - Valaichchenai	132	1	Lynx	99.7	99.7
1L39.	Anuradhapura - Trincomalee	132	2	Lynx	103.3	206.6
1L40.	New Laxapana - Balangoda	132	2	Lynx	43.9	87.8
1L41.	Balangoda - Samanalawewa	132	2	Zebra	19.0	38.0
1L42.	Samanalawewa - Embilipitiya	132	2	Lynx	38.0	76.0
1L43.	Balangoda - Deniyaya (T)	132	2	Tiger	44.2	88.4
1L44.	Deniyaya (T) - Galle	132	2	Tiger	57.3	114.6
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	128.8	257.6
1L48.	Kilinochchi (T) - Chunnakam	132	2	Lynx	67.2	134.4
	Total	220 kV OH lines			139.7	259.9
		132 kV OH lines			1,611.3	2,579.6
		132 kV UG lines			13.0	13.0

Note: ACSR conductor sizes for overhead lines are in BS and their sectional areas are as follows:

Zebra:	400 mm^2
Goat:	320 mm^2
Lynx:	175 mm^2
Oriole:	170 mm^2 (ASTM size)
Coyote:	130 mm^2
Tiger:	130 mm^2

*1 220 kV design currently operated at 132 kV.

Table 3.5.1-2 List of Substations

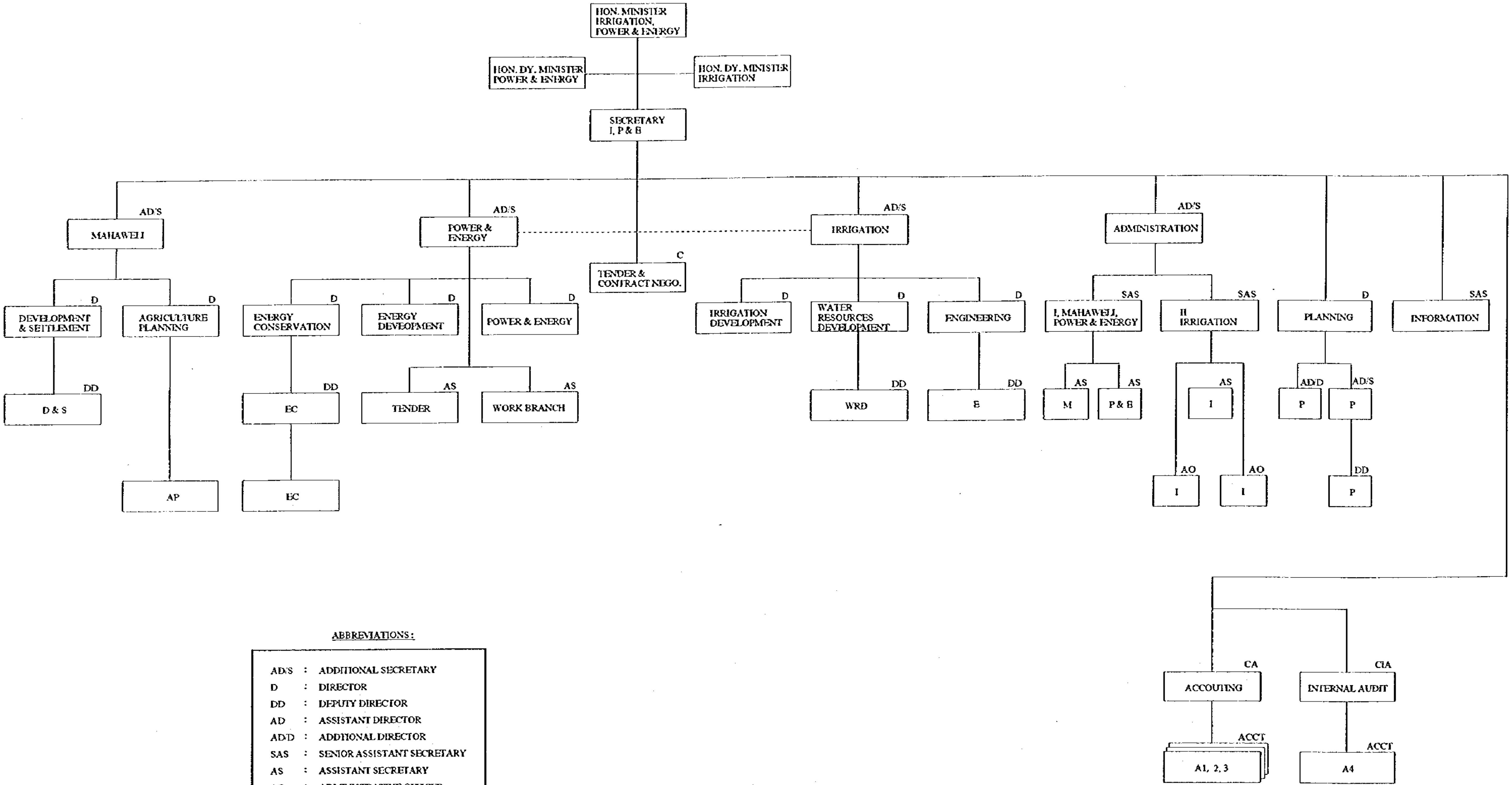
No.	Name	Voltage Class (kV)	Transformer Capacity (MVA)
Grid Substations			
1.	Biyagama	220/132/33	2 x 250/60
2.	Kotugoda	220/132/33	2 x 250/60
3.	Rantembe *1	220/132/33	1 x 105
		138/34.5/12.5	2 x 10
4.	Kotmale *2	220/132/13.8	1 x 90
5.	Bolawatta	132/33	2 x 31.5
6.	Sapugaskanda	132/33	3 x 30
7.	Chilaw	132/33	2 x 31.5
8.	Puttalam	132/33	2 x 31.5
9.	Anuradhapura	132/33	2 x 10
10.	Trincomalee	132/33	2 x 10
11.	Chunnakam *1	132/33	2 x 30, 1 x 10
12.	Kilinochchi	132/33	1 x 10
13.	Habarana	132/33	3 x 10
14.	Valaichchenai	132/33	2 x 10
15.	Kiribatkumbura	132/33	2 x 31.5
16.	Kurunegala	132/33	2 x 16
17.	Ukuwela *1	132/33	2 x 15
18.	Thulhiriya	132/33	2 x 31.5
19.	Kelanitissa *1	132/33	2 x 60
20.	Fort	132/33	2 x 30
21.	Kollupitiya	132/11	2 x 30
22.	Kolonnawa	132/33, 132/66/33	3 x 30, 1 x 30
23.	Ratmalana	132/33	2 x 30 + 31.5
24.	Oruwala	132/33	1 x 6.3
25.	Pannipitiya	132/33	2 x 30 + 31.5
26.	Panadura	132/33	2 x 31.5
27.	Matugama	132/33	2 x 31.5
28.	Galle	132/33	2 x 30, 1 x 20 *3
29.	Wimalasurendra *1	132/33	2 x 31.5
30.	Balangoda	132/33	2 x 10
31.	Deniyaya	132/33	3 x 10
32.	Embilipitiya	132/33	2 x 10
33.	Badulla	132/33, 66/33	2 x 31.5, 4 x 3
34.	Inginiyagala *1	132/33	2 x 15
35.	Norton Bridge	66/33	2 x 5
36.	Nuwara Eliya	66/33	4 x 3
37.	Avissawella	66/33	2 x 6
38.	Padukka	66/33	4 x 3
Power Station Switchyards			
1.	Victoria	220	
2.	Kotmale	220/132	
3.	Rantembe	220/132	
4.	Polpitiya	132	
5.	Laxapana	132	
6.	New Laxapana	132	

Note:

*1 These are power stations have function of grid substation.

*2 Kotmale power station is provided with a 3-winding transformer for power feeding to either of 220 kV or 132 kV system.

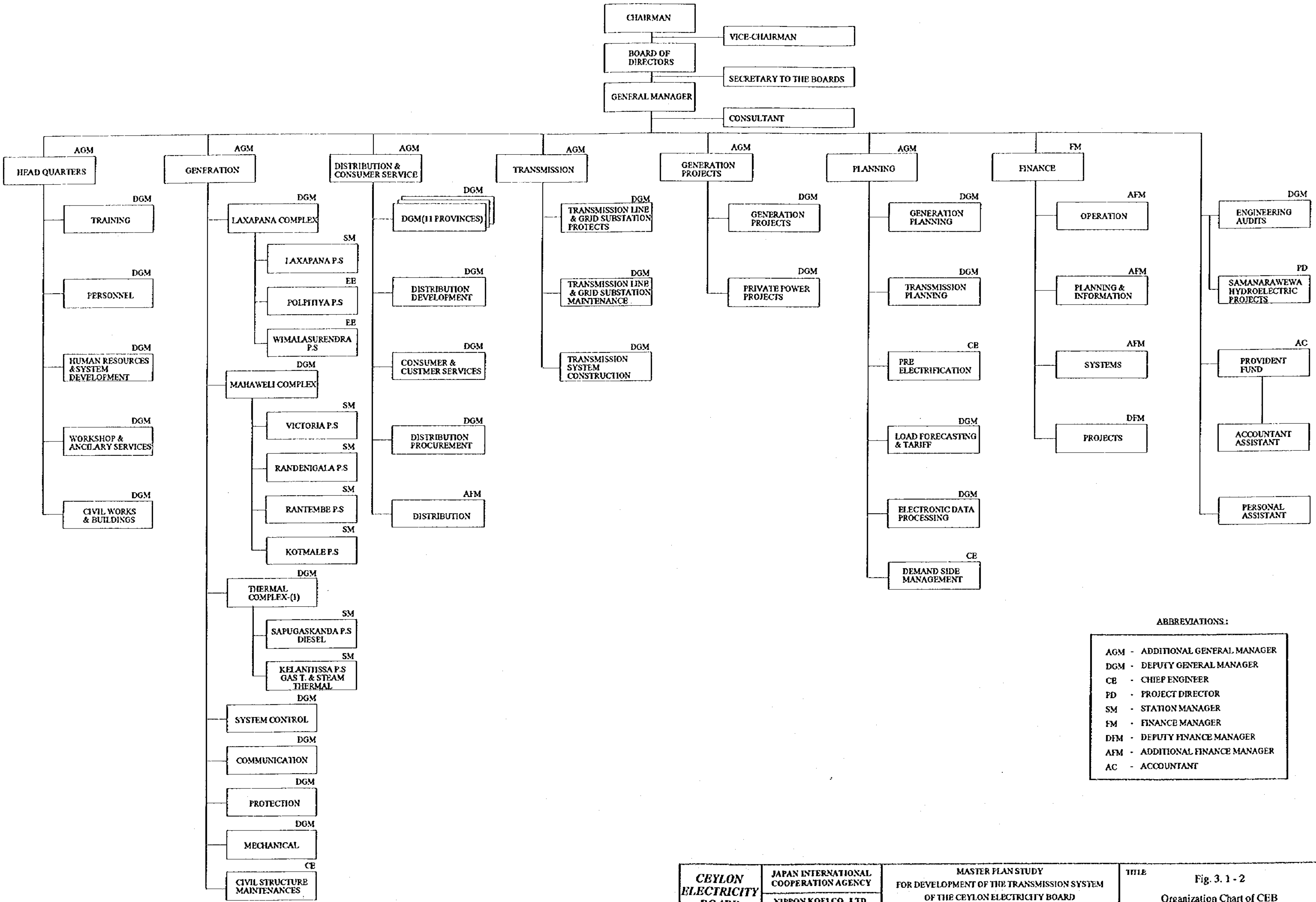
*3 1 x 20 MVA is for a SVC.



ABBREVIATIONS :

AD/S	:	ADDITIONAL SECRETARY
D	:	DIRECTOR
DD	:	DEPUTY DIRECTOR
AD	:	ASSISTANT DIRECTOR
AD/D	:	ADDITONAL DIRECTOR
SAS	:	SENIOR ASSISTANT SECRETARY
AS	:	ASSISTANT SECRETARY
AO	:	ADMINISTRATIVE OFFICER
CA	:	CHIEF ACCOUTANT
CIA	:	CHIEF INTERNAL AUDITOR
ACCT	:	ACCOUTANT
C	:	CONSULTANT

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. 3. 1 - 1 Organization Chart of Ministry of Irrigation, Power and Energy



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. 3. 1 - 2 Organization Chart of CEB

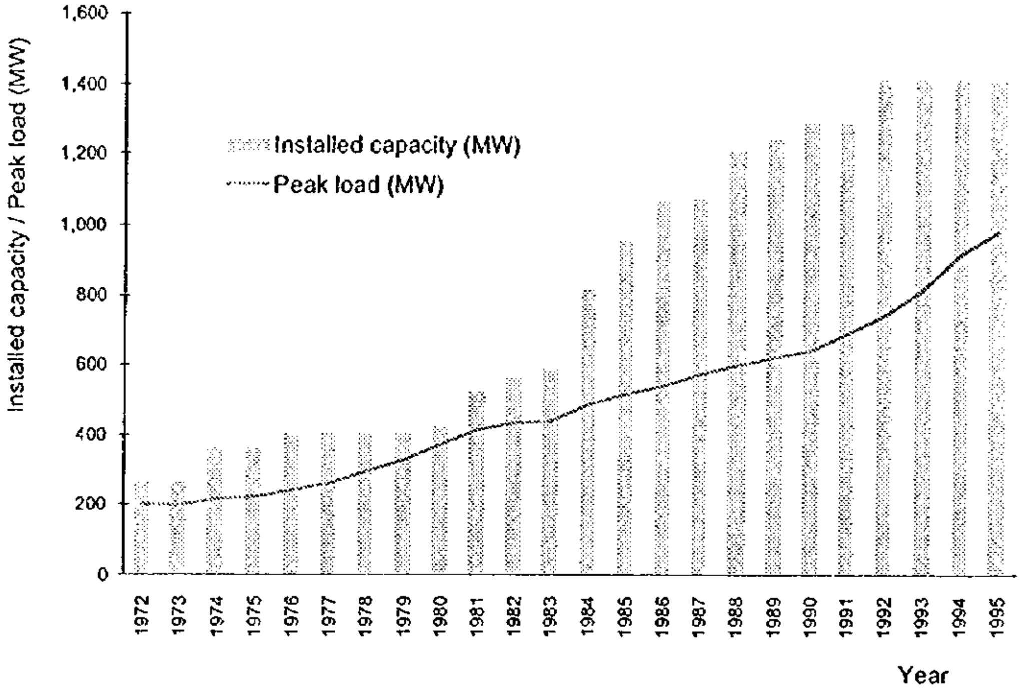


Fig. 3.2 - 1 Installed Capacity and Peak Demand Growth

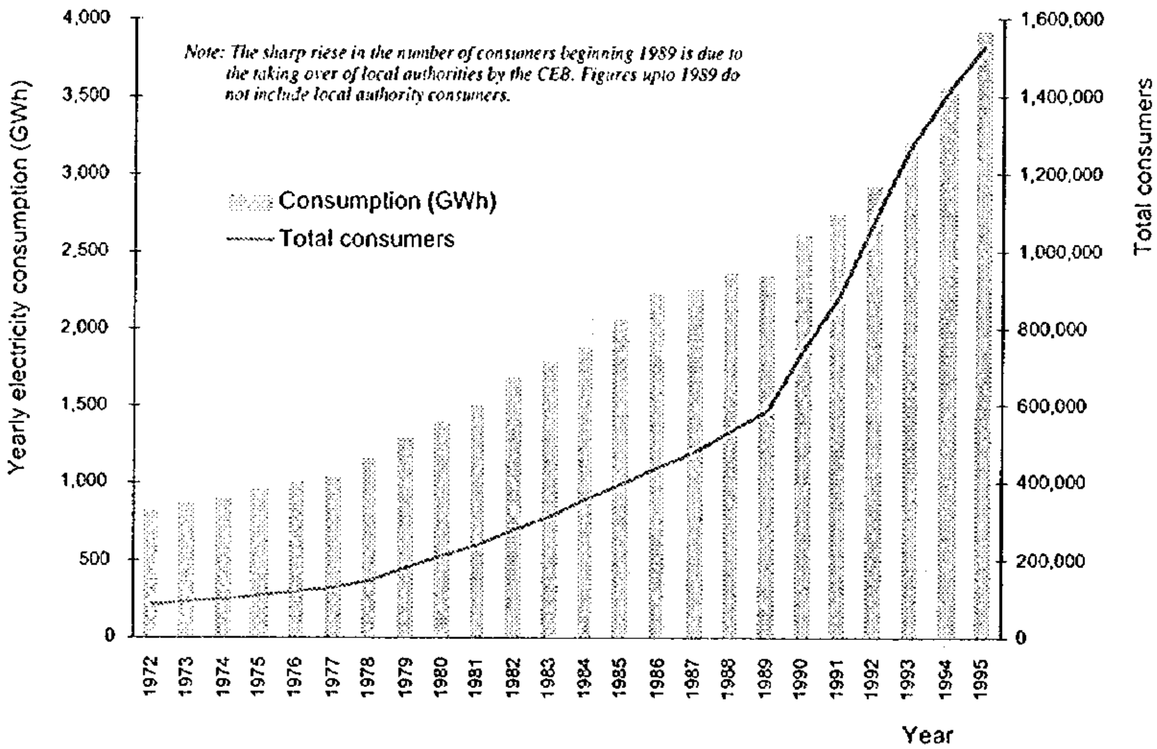


Fig. 3.2 - 2 Total Power Consumption and Number of Consumers

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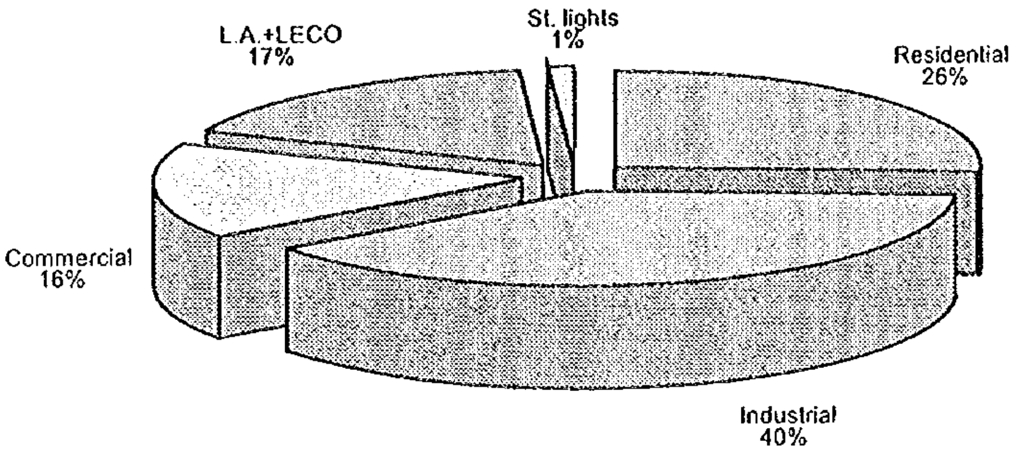


Fig. 3.2 - 3 Electricity Consumption Pattern in 1995

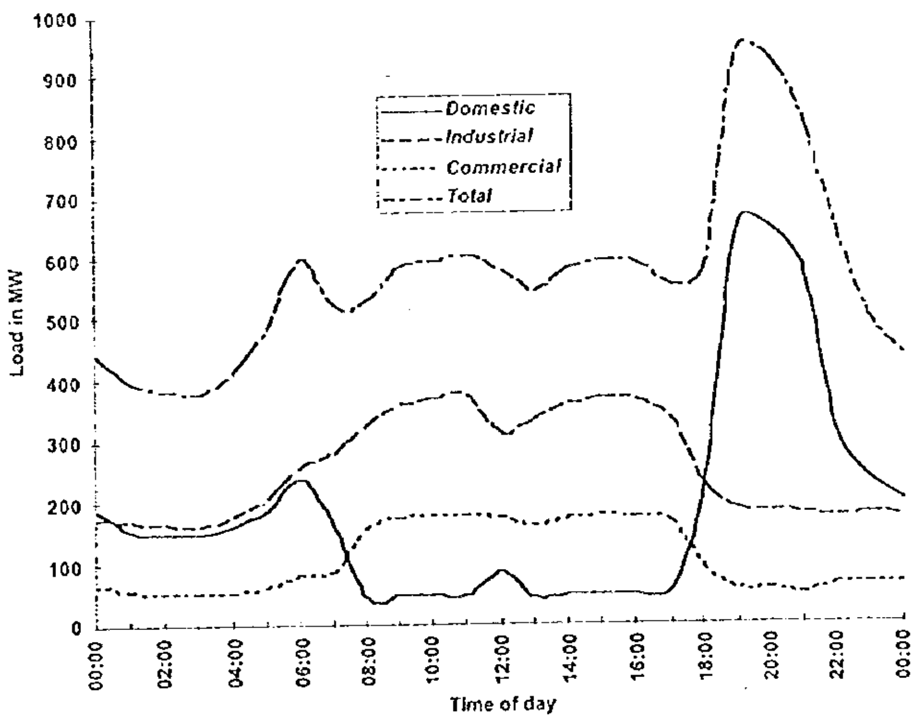


Fig. 3.2 - 4 Daily Load Curves of Typical Weekday

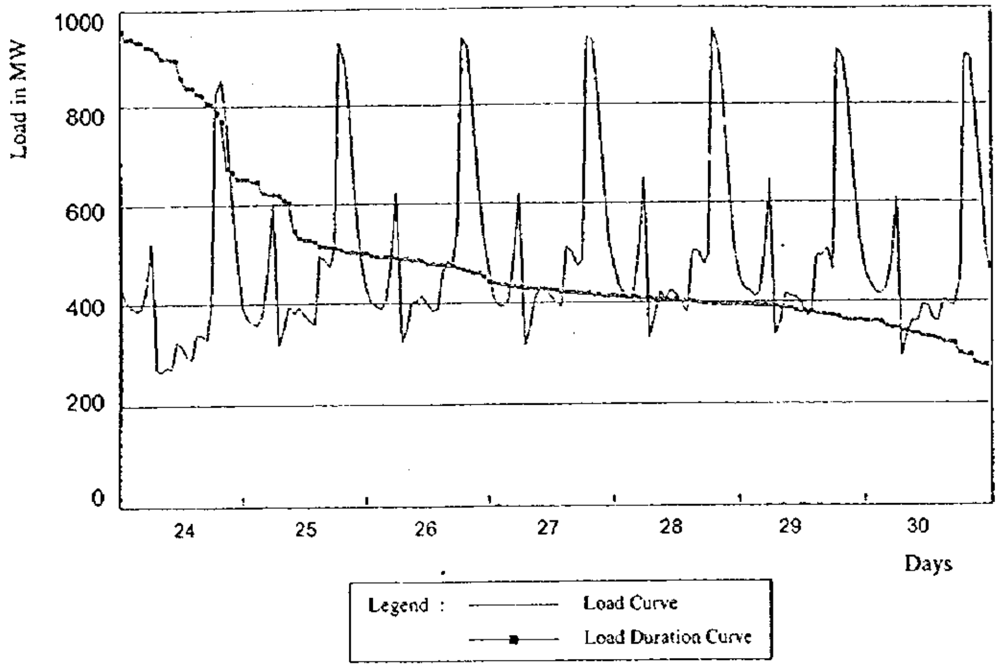


Fig. 3.2 - 5 Weekly Load and Load Duration Curves
(24th to 30th March 1996)

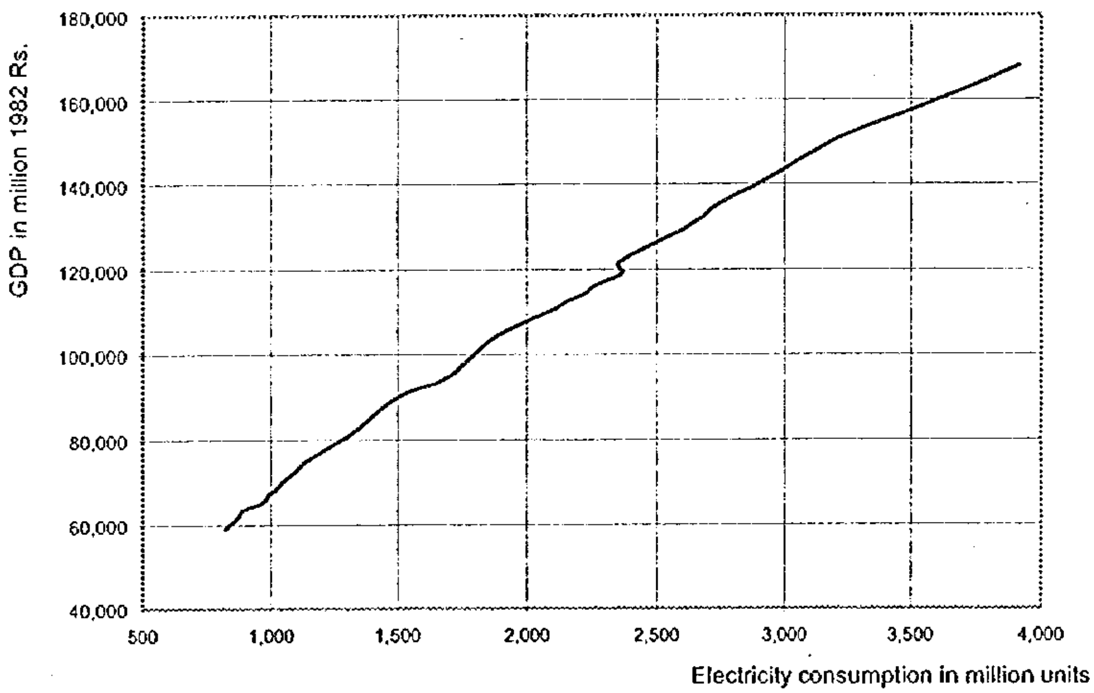


Fig. 3.2 - 6 GDP - Electricity Relationship for Sri Lanka

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

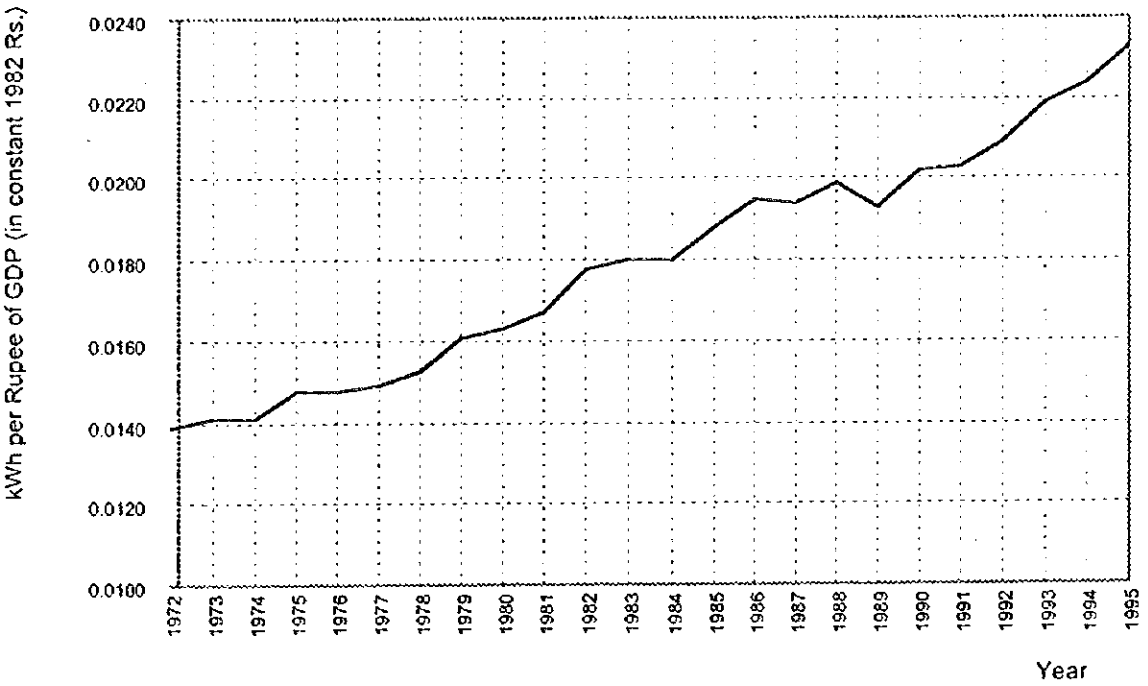
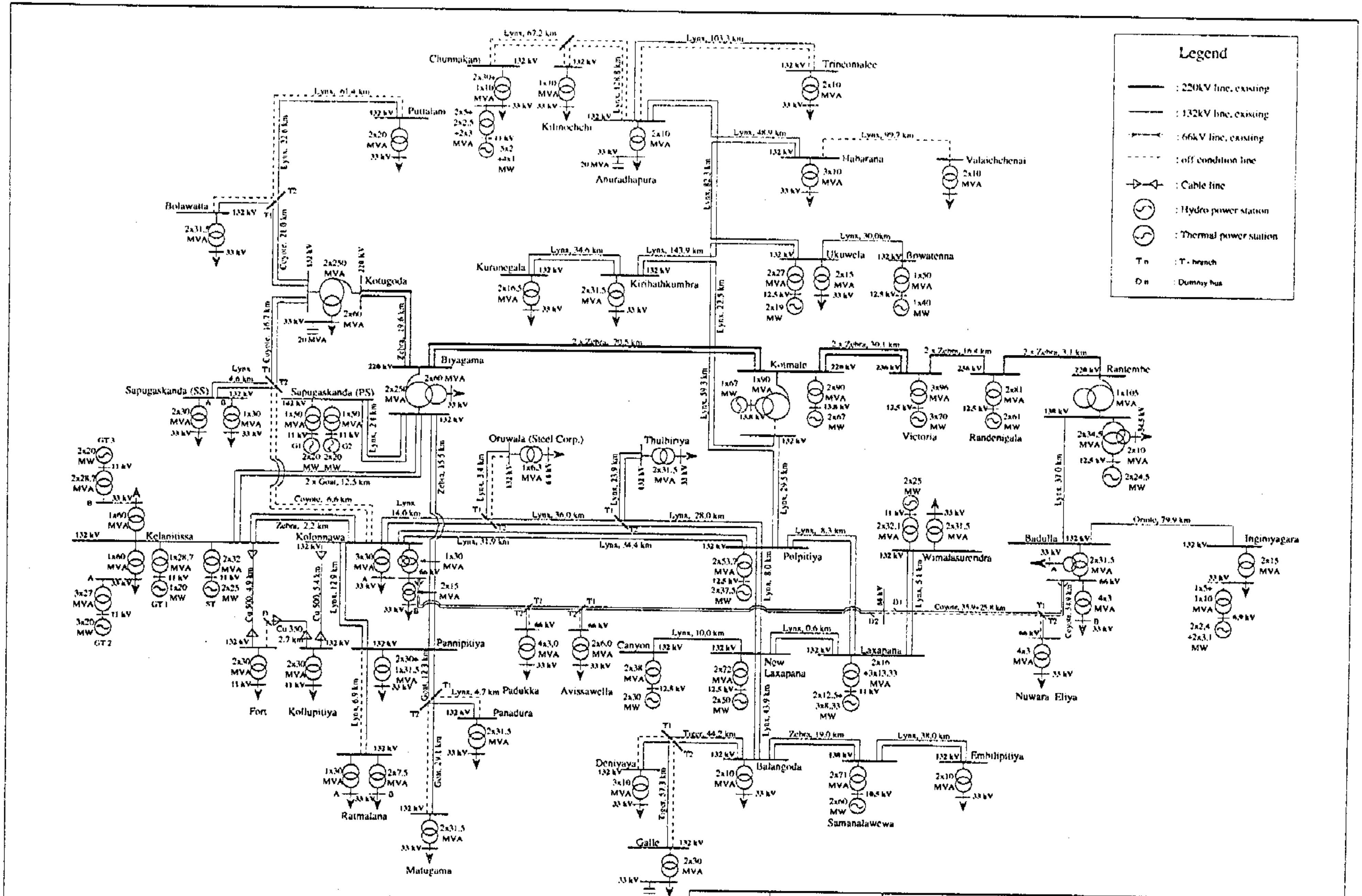
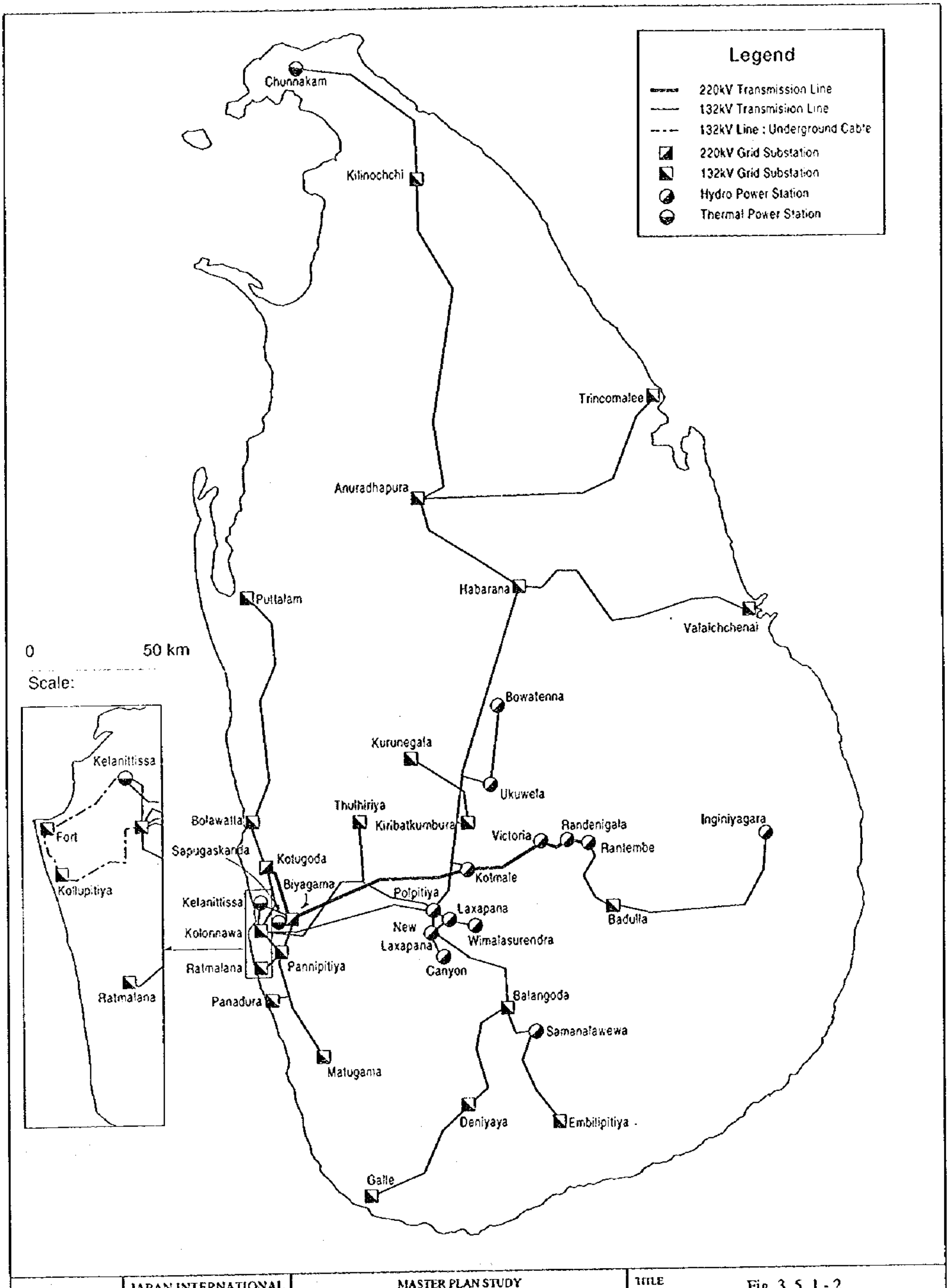


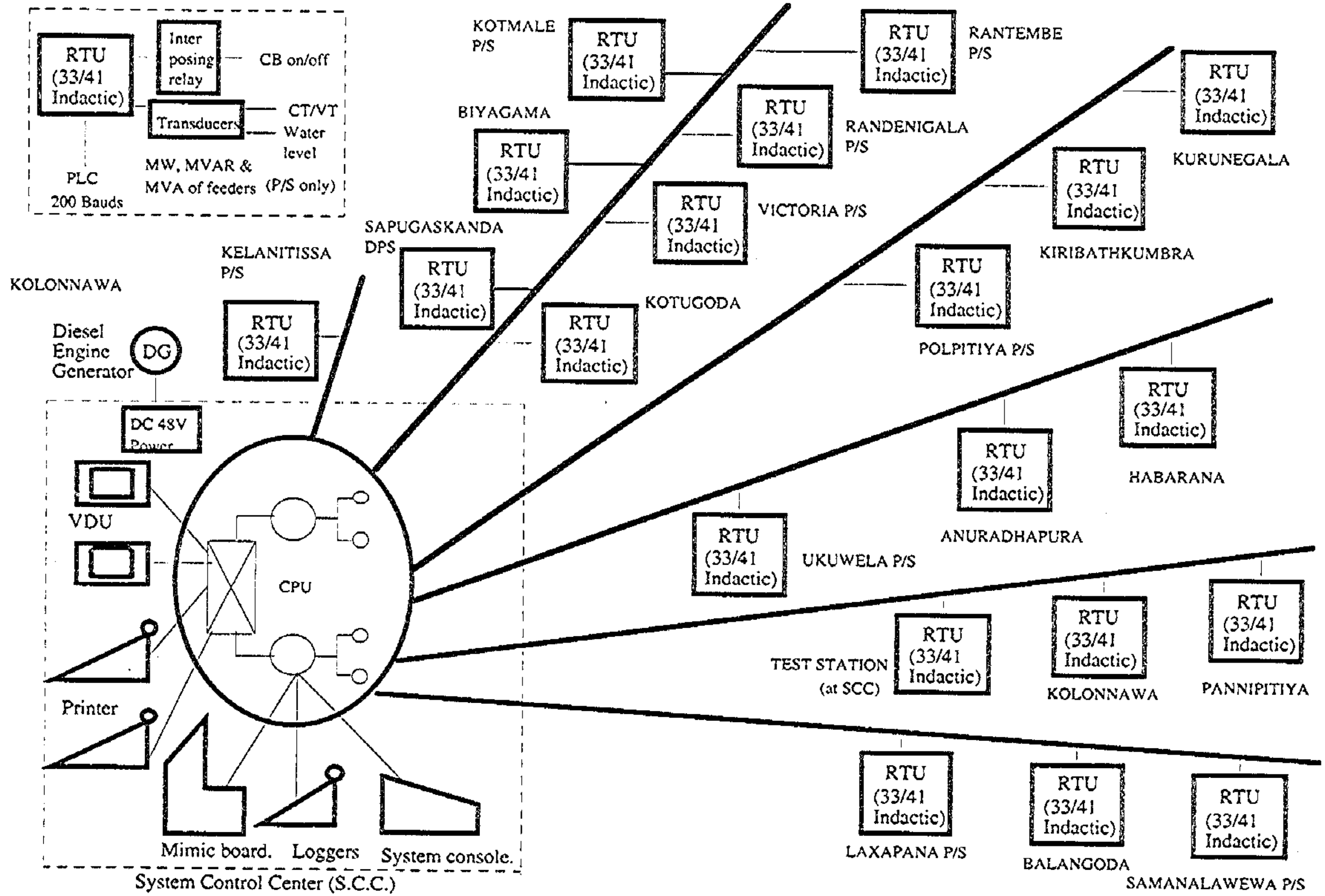
Fig. 3.2 - 7 Electricity Intency in the National Output



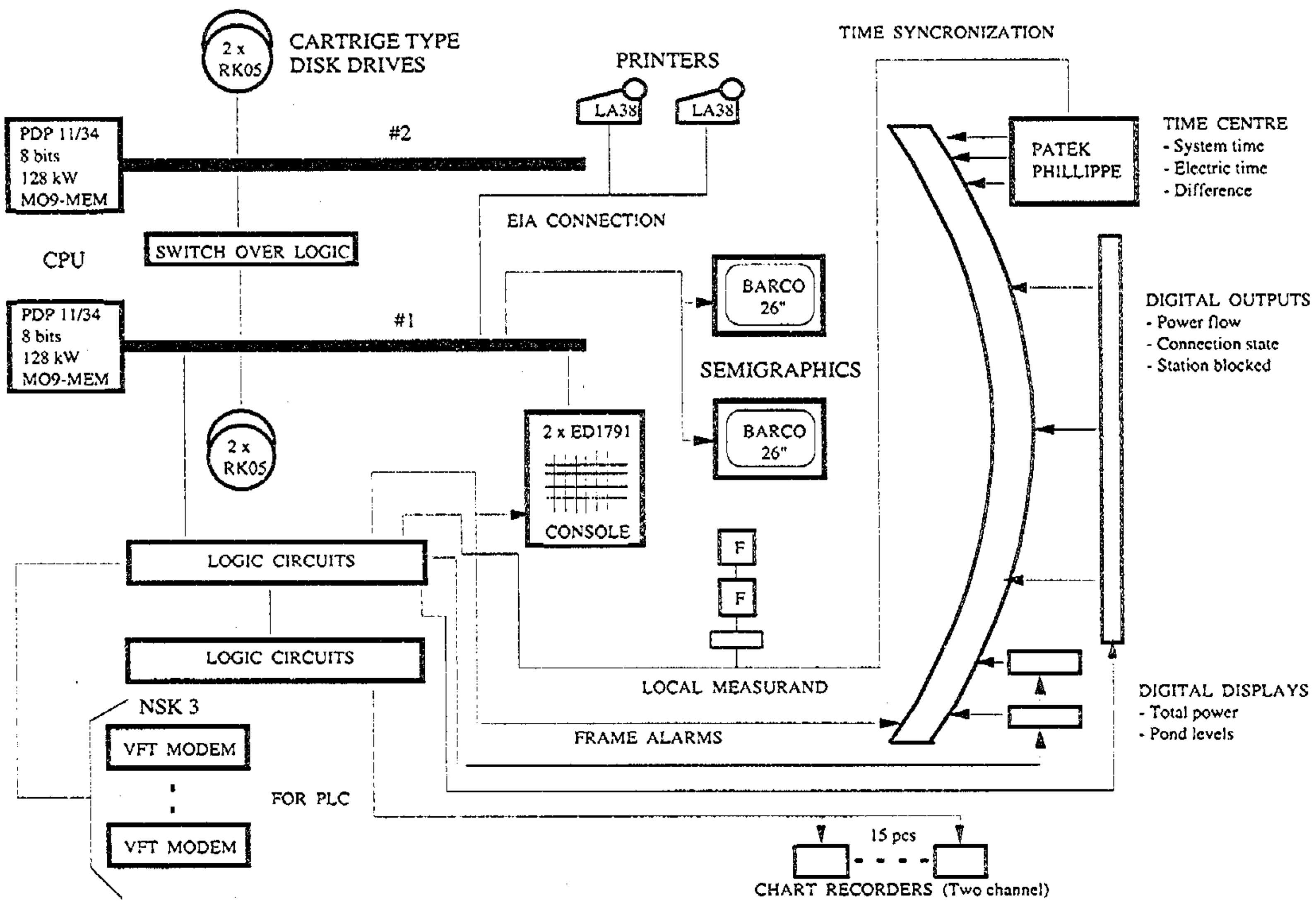
CEYLON ELECTRICITY BOARD	JAPAN INTERNATIONAL COOPERATION AGENCY NIPPON KOEI CO., LTD. Consulting Engineers	MASTER PLAN STUDY FOR DEVELOPMENT OF THE TRANSMISSION SYSTEM OF THE CEYLON ELECTRICITY BOARD IN THE DEMOCRATIC SOCIALIST REPUBLIC OF SRI LANKA	TITLE Fig. 3. 5. 1 - 1 End 1995 Power System Diagram



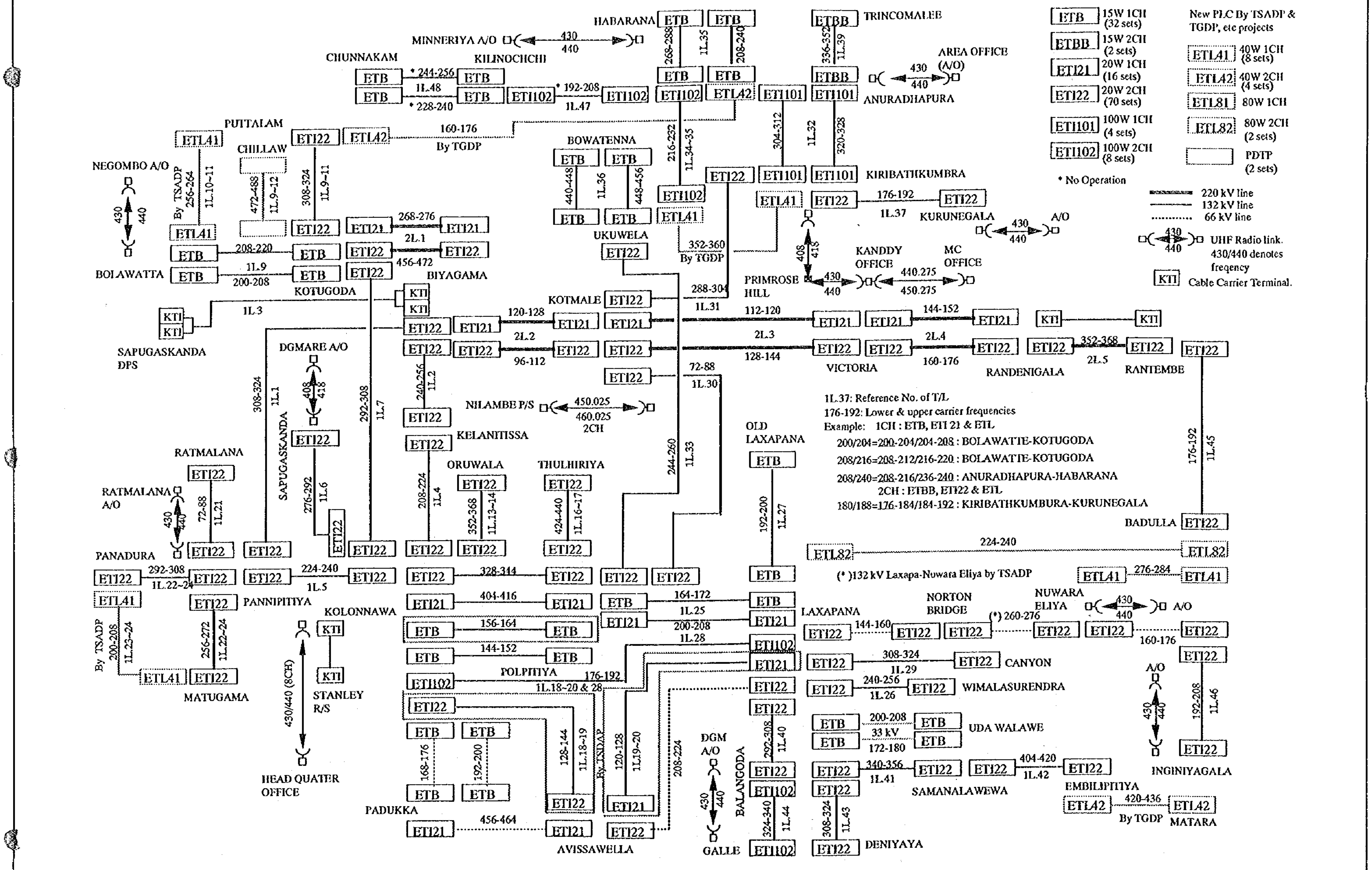
CEYLON ELECTRICITY BOARD	JAPAN INTERNATIONAL COOPERATION AGENCY NIPPON KOEI CO., LTD. Consulting Engineer	MASTER PLAN STUDY FOR DEVELOPMENT OF THE TRANSMISSION SYSTEM OF THE CEYLON ELECTRICITY BOARD IN THE DEMOCRATIC SOCIALIST REPUBLIC OF SRI LANKA	TITLE	Fig. 3. 5. 1 - 2 End - 1995 Power System Map



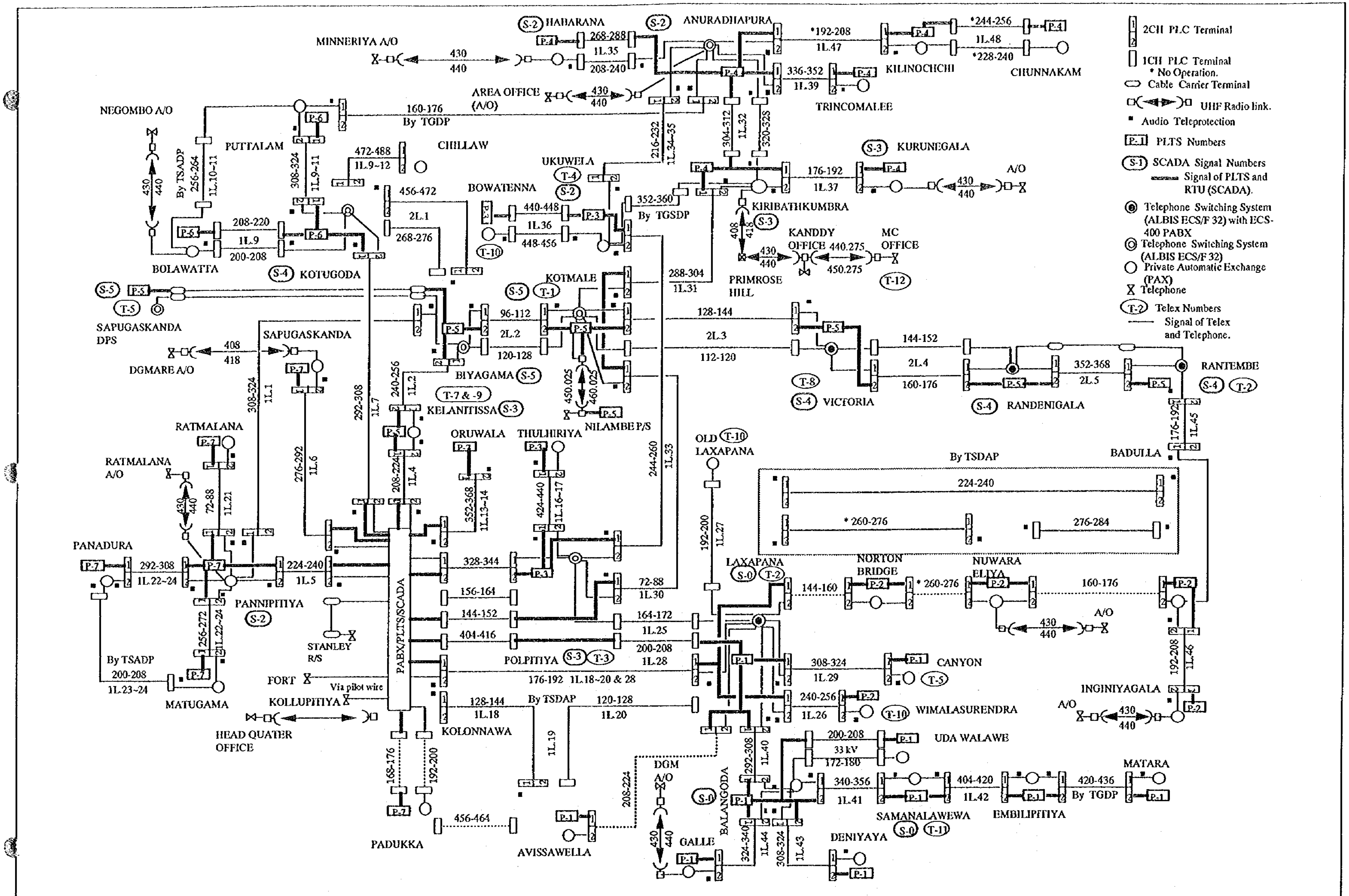
CEYLON ELECTRICITY BOARD	JAPAN INTERNATIONAL COOPERATION AGENCY NIPPON KOEI CO., LTD. Consulting Engineer, TOKYO JAPAN	MASTER PLAN STUDY FOR DEVELOPMENT OF THE TRANSMISSION SYSTEM OF THE CEYLON ELECTRICITY BOARD IN THE DEMOCRATIC SOCIALIST REPUBRIC OF SRI LANKA	TITLE Fig. 3. 5. 5 - 1 Diagram of SCADA System



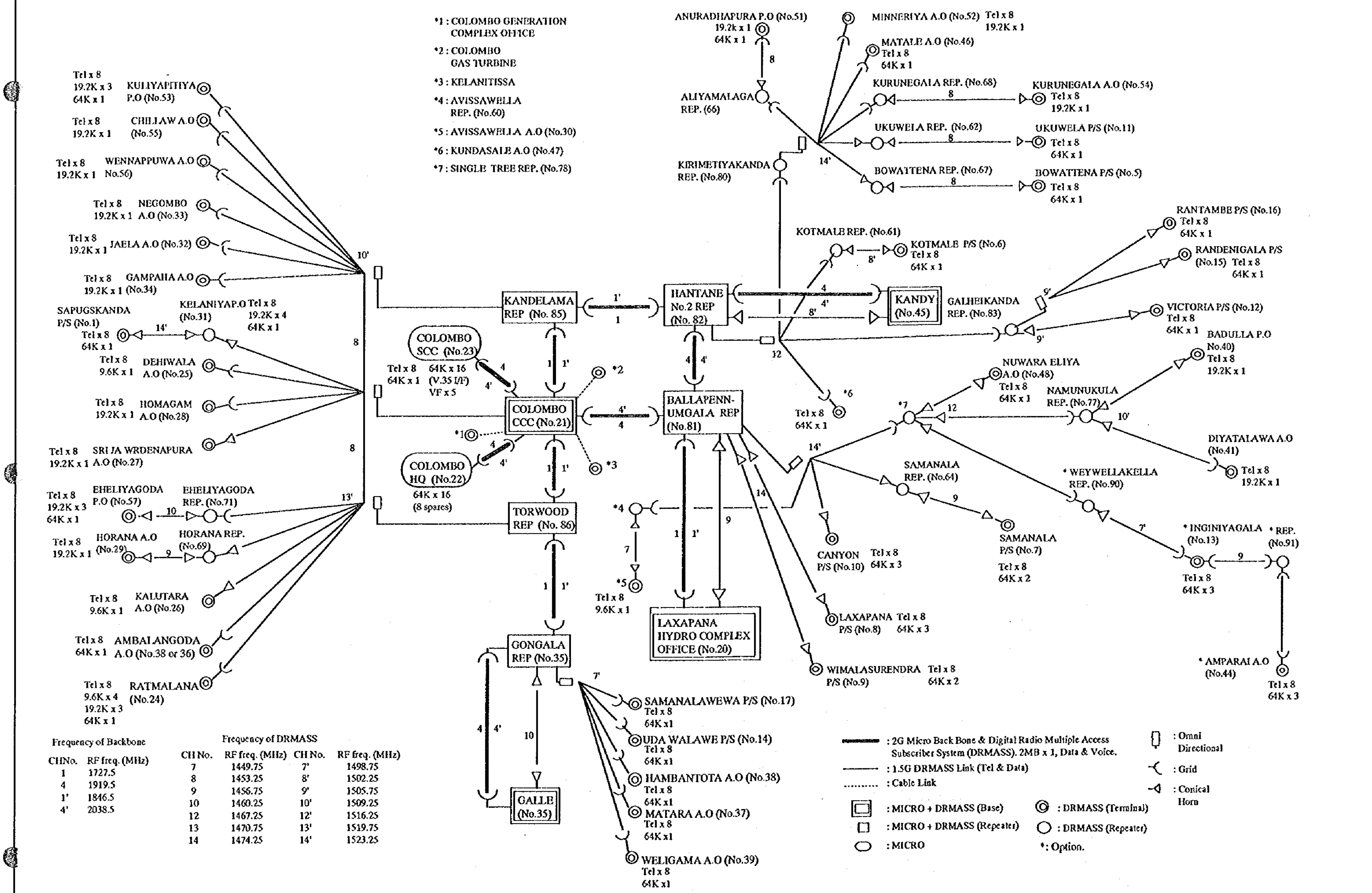
CEYLON ELECTRICITY BOARD	JAPAN INTERNATIONAL COOPERATION AGENCY NIPPON KOEI CO., LTD. Consulting Engineer, TOKYO JAPAN	MASTER PLAN STUDY FOR DEVELOPMENT OF THE TRANSMISSION SYSTEM OF THE CEYLON ELECTRICITY BOARD IN THE DEMOCRATIC SOCIALIST REPUBRIC OF SRI LANKA	TITLE Fig. 3. 5. 5 - 2 System Diagram of S.C.C



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. 3. 5. 6 - 1 PLC & UHF System at December 1995



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. 3. 5. 6 - 2 Channel Assignment



Frequency of Backbone

CH No.	RF freq. (MHz)
1	1727.5
4	1919.5
1'	1846.5
4'	2038.5

Frequency of DRMASS

CH No.	RF freq. (MHz)	CH No.	RF freq. (MHz)
7	1449.75	7'	1498.75
8	1453.25	8'	1502.25
9	1456.75	9'	1505.75
10	1460.25	10'	1509.25
12	1467.25	12'	1516.25
13	1470.75	13'	1519.75
14	1474.25	14'	1523.25

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