CHAPTER 5

RELIABILITY OF POWER SUPPLY

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5.1 Introduction

Supply reliability planning in Sri Lanka is in its infancy stages. CEB are adopting the WASP III software which is utilized around the world and adopt a probabilistic approach for long term reliability planning of the generating system. However, a generally applied analysis program has not yet been applied to the planning of the transmission system.

The descriptions in this chapter are summary information and their details are included in Appendix A5.

5.2 Review of Transmission System Planning Criteria

Transmission reliability indices fulfill a number of functions including providing a basis for planning systems and for communicating system performance history to management and consumers.

Indices may relate to the performance of the system as whole (interconnected power indices) or to the reliability of supplies at specific points on the network (load point indices). It is understood that CEB are interested in investigating both types of index to establish and define a set of indices that would be considered ideal for the present system as well as for an introductory application of the concept.

Reliability indices have two attributes :

- adequacy, essentially consideration of steady state reliability; and
- dynamic security, essentially consideration of critical dynamic conditions.

This study has concentrated on power system adequacy since the main interest of the study primarily relates to the degree of reliability (or resilience) which should be built into the network, rather than with the dynamics of generation and transmission system's post-fault response.

Transmission reliability criteria may either be deterministic or probabilistic. Deterministic criteria typically require that the system is able to withstand relatively frequent outage events without affecting service reliability. These are often expressed as 'N-1' (single outage contingency) or 'N-2' (double outage contingency) criteria which require that load can still be supplied in the event of either a single or a double outage event. However it is not necessarily the case that no supply interruptions occur for all contingencies considered, and indices can be defined which indicate the effect of the outages. Again these indices may be calculated for pre-determined single or multiple outage events.

Probabilistic criteria are intended to recognize the random nature of outage events and provide measures of system reliability on the basis of the outage statistics of the system components.

The 'N-1' and 'N-2' deterministic transmission criteria are based on the effect of the loss of network components, such as overhead lines, cables and transformers, possibly coupled with a stuck breaker. In some utilities more serious cases are considered such as the loss of a set of busbars, or cascade tripping. Utilities also classify parts of their network differently with major bulk interconnectors having perhaps a higher security standard (say 'N-2'), compared to a lower voltage feeder circuit which may only have a single contingency capability, or even just a single circuit supply. These criteria apply equally to the transmission interconnection elements as well as substation components.

Deterministic indices typically include :

- Maximum Load Not Supplied;
- Maximum Energy Not Supplied;
- Minimum Load Supplying Capability;
- Minimum Simultaneous Interchange Capability; and
- Maximum Line Flow.

There is no reason why these indices can not be calculated on both a system wide basis as well as for individual nodes. It should be noted that there are no frequency or duration information associated with these indices, and this is a key weakness in them.

Probabilistic reliability criteria overcome these difficulties and have three fundamental attributes :

- Frequency of events;
- Duration of events; and
- Severity of events.

Not all indices necessarily have all three attributes. Event severity may also be differentiated by whether the event gives rise to a problem, such as a line overload or an out of limits voltage, or whether load is actually curtailed.

Typical system problem indices include :

- Overload indices (frequency, duration, probability or amount of overload);and
- High or low voltage indices (frequency, duration, probability or average amount outside limits).

Load curtailment indices include :

- Loss of Load Probability;
- Frequency of Loss of Load;
- Power Curtailed;
- Hours Load Not Supplied;
- Expected Energy Not Supplied;
- Interconnected Power Interruption Index (MW/MW yr);
- Interconnected Power Supply Average Load Curtailment (MW/disturbance);
- Interconnected Power Energy Curtailment Index (MWh/MW); and
- Severity Index (system minutes).

5.3 Survey of Present Utility Practice

Recently, present transmission reliability planning practices of various utilities were investigated. This has been based around a questionnaire sent to 62 selected utilities worldwide. Replies have been received from the following:

Canada:	B.C. Hydro Manitoba Hydro
Australia:	SECWA QEC SEQEB
Brazil:	Centrais Electricas Brasileiras
Malaysia:	Sarawak Electricity Supply Corporation
Norway:	Oslo Lysverker
Barbados:	Caribbean Utilities Company
Cyprus :	Electricity Authority of Cyprus
Taiwan :	Taiwan Power Company
USA :	NERC American Electric Power
Germany:	Ueberlandwerk RWE Energie
Austria :	Tiroler Wasserkraftwerke
Sweden :	Vatenfall Transmission
Iceland :	Landsvirkjun

Data on the methodologies adopted in the United Kingdom, Belgium, Kenya, Western Malaysia, Malta, and other parts of Australia including the Electricity Commissions of Victoria and New South Wales are also in hand.

The majority of these utilities are using deterministic criteria for planning their transmission systems at present, and mostly on the basis of an 'N-1' criteria that ensures that supplies are not interrupted on single outage contingency basis.

The exceptions to this are Brazil, the American Electric Power Company, some NERC members, Manitoba Hydro and SECWA which have adopted both probabilistic and deterministic indices, although the probabilistic indices are generally limited in their application. The probabilistic indices used are :

SECWA :	average duration and frequency of failure
Brazil :	unsupplied energy , frequency and duration of failure
Manitoba :	not known
AEP :	not known (EHV only)
NERC:	LOLP, LOLE

A small number of utilities are evaluating and considering the development of probabilistic indices. The consensus view is that probabilistic indices are advantageous in that they provide a superior basis for evaluation, but the main drawback is the lack of appropriate analytical tools for actually calculating them. Indeed the thrust in utilities such as B.C. Hydro is to develop suitable computer programs for the purpose.

An aspect which was also evident from the survey is that some utilities are developing or starting to use composite generation and transmission indices. These are to an extent in their infancy as computational techniques are only now becoming available.

A survey of indices undertaken by CIGRE in the early 1980's was also reviewed, and this reinforces the findings of the above survey.

In Japan, the deterministic approach has been applied for reliability assessment of the transmission system. For a trunk system, there shall be actually no supply interruption by 'N-1' contingencies and there shall be minimum of interruptions even under 'N-2' contingencies. Looser conditions are applied to local systems. Details are enclosed in Attachment of Clause A5.3 of Appendix A5.

Probabilistic criteria are applied to generation planning; LOLP, LOLE, etc. Application of probabilistic approach to transmission systems was once studied, but was not taken up due to uncertainty of its effects.

5.4 Calculation of Probabilistic Indices

Deterministic indices may be simply calculated using a load flow program to simulate the effect of the chosen outage or outages and information derived and accumulated on line overloads and out of limit voltages. An experienced power system planner can most likely adapt conventional load flow programs for this purpose.

The calculation of probabilistic indices is considerably more complex, both computationally and because of the difficulty in obtaining suitable data on the reliability of the main system components.

Two distinct approaches exist for the calculations :

- State Enumeration (selective analysis); and
- Monte Carlo simulation.

With the <u>selective analysis</u> approach, it is recognized that many system outages do not have an adverse effect on system reliability. The approach consists of a systematic selection and evaluation of disturbances, the classification of each disturbance according to failure criteria, and the accumulation of reliability indices. The key is the contingency enumeration selection.

The overall pattern of analysis can be considered as a form of failure and effects analysis. For each contingency, a model (load flow) of the system is run, any corrective action initiated such as generation rescheduling, and the accumulation of the effects of the contingency into a reliability index. D.C. load flows are often used to speed up the computation, albeit with some loss of accuracy.

With the <u>Monte Carlo technique</u>, rather than selecting the outages, a random number of generator is used to randomly select disruptive events, and the effect simulated. This process is repeated a large number of times to ensure that all possible adverse events are captured. The need to carry out a large number of simulations is the main drawback to this approach.

The techniques described above implicitly assume a single set of loading conditions on the network, and consideration has to be given as to whether an annual index is to be calculated, or a point in time value. If an annual value is required, this may involve a significant number of sets of analysis.

The method for rescheduling generation following an outage is also computationally complex, and a linear programming formulation is appropriate for this.

5.5 Selection of Transmission Planning Criteria

In selecting appropriate transmission planning criteria, a number of factors must be taken into consideration including :

- what is the objective of the criteria?;
- can the criteria be calculated for planning purposes?;
- is suitable data available for its calculation?; and
- are there any constraints influencing the degree of reliability (financial, economic)?

Two aspects have to be considered in the selection of the type of index, and its value. The type of index is influenced by the objectives and the practicality considerations. The value is more influenced by economic and financial considerations.

Increasing the level of reliability costs money, and it is therefore necessary that this expenditure is justified by the planners. A number of approaches are possible:

- follow existing practice;
- determine level of reliability where additional investment gives maximal additional improvement;
- determine level of reliability which is optimized with respect to the consumers' valuation of unserved energy; and
- select a value based on an international practice.

The first of these, the "do nothing" option, is attractive if the majority of consumers are satisfied with the present security levels, but this may hide over investment in some parts of the network. The second one follows the practice increasingly being adopted by generation planners, but suffers from the need to estimate the value of unserved energy, which theoretically will vary between load points with different mixes of consumer types.

The third approach is a compromise between the two. It has the advantage of avoiding the need to value unserved energy, but its success relies on the cost/reliability function having a form which enable the point of diminishing return to be established.

The fourth approach is not necessarily sound because transmission systems vary between utilities, and particularly for probabilistic indices, there is very little precedent to go on.

The selection of an index or indices and its value(s) is, it is believed, a matter to be considered on a case by case basis, taking into account the issues raised above.

5.6 Course of Actions for CEB

It was concluded from analysis of the Study that reliability based planning will enable CEB to meet its objectives of setting an acceptable criteria.

As the Study represents the first application of its kind in Sri Lanka, it is therefore recommended that as part of the process of establishing a probabilistic planning capability in CEB, analysis is done using the new tools to test the effect on the relative reliability at different points in the network of including and excluding generation reliability.

In adopting probabilistic techniques it is therefore necessary to select points in time which will be used for the analysis. It is understood that there are at least two critical profiles, the first represents the wet season where hydro generation is at maximum, while the second represents the dry season with minimum hydro generation and maximum thermal output.

It is therefore recommended that the analysis is carried out on a typical day in each season of the year. For each of these seasons reliability indices can be calculated and then aggregated into an annual index for that year. The process can then be repeated for a number of years.

The establishment of an actual value for the index is not readily determined in advance. Indeed values need to be considered on both a system wide and a load point basis, and the values need not necessarily be the same.

The actual value in itself, as noted earlier, needs to be interpreted with care and its setting is a function of several factors such as the nature of the system itself, existing system performance, and the willingness of consumers or CEB to make and pay for extra investments.

It is therefore recommended that once the planning software is obtained, analysis is carried out on the existing system to better understand how it performs and to interpret the results obtained.

As this software can be run for a wide range of contingencies, it was also recommended that the sensitivity of the power system to different network running conditions was also analyzed and losses checked against the various system running arrangements.

Record of system faults

During the preliminary works, efforts were concentrated on data gathering using CEB's records of system faults.

Chief Engineer of System Control kindly answered numerous questions and supplied the JICA team with hard copies of the fault records and information recorded on a database using the standard commercial software DBASE III. These records have been reviewed within the overall context of the Study for the transmission master plan in Sri Lanka, with particular emphasis on quantification and qualification of reliability of supply.

The structure of the database was studied, and some minor modifications to this structure were strongly recommended as shown in Table 5.6-1. Since the CEB database is still in the early stages of its development, it was felt that modifying the structure at this stage would not present a significant task to undertake and would have its future benefits for CEB.

The original database structure was discussed with System Control and presented to them as a suggested guideline as shown in Table 5.6-1. This information is needed to enable the precise cause of the lost load or equipment erroneous operation to be identified.

5.7 TPLAN Modeling

The acquisition of the PTI TPLAN software under this Study by CEB, in conjunction with the existing PTI PSS/E software meant that the reliability data along with the projected system loading could be modeled on the computer to evaluate the reliability of the existing system and the proposed systems, under this master plan program.

The data collected from System Control Branch was used to model the reliability of the existing network. In addition contingency analysis was carried out using TPLAN's own state enumeration software. This performs ranking algorithms for overload, voltage collapse and islanding of the power system. From this, contingency analysis was carried out on the existing network and the proposed transmission network from 2000 to 2015. The results of this are reproduced in Chapter 6.

5.8 Future Works by CEB

It is recommended that CEB continue to collect the fault data shown above in order that they can monitor the performance of the power system. In addition it is recommended that the PSS/E model for the present system be revised to model individual generator units, rather than complete power stations. This will allow, with dispatch data, the loss of load probabilities to be calculated and will help with economic dispatch of the generator sets on a least cost basis.

It is further recommended that CEB's System Control Center have their own copy of PSS/E and TPLAN in order that they can model forthcoming planned outages on the power system. This is important for the security and reliability of the power system as without this information, coupled with the latest load flow data, they are always working at a disadvantage. Current good utility practice supports this recommendation.

Table 5.6-1 Recommended Form for Fault Recording

- LOCATION
- EQUIPMENT REFERENCE
- VOLTAGE
- EQUIPMENT TYPE
- CAUSE OF FAILURE

  I PRIMARY

  - A UNKNOWN
  - B DEFECTIVE EQUIPMENT
  - C WEATHER
  - D EXTERNAL INTERFERENCE
  - E MAINTENANCE ERROR
  - F HUMAN ELEMENT
  - G PROTECTION MISOPERATION

  II SECONDARY

  III COMMON MODE (COMMON CAUSE)

- PROTECTION OPERATION

  1. 1 PHASE TO EARTH FAULT
  2. PHASE TO PHASE FAULT
  3. 2 PHASE TO EARTH FAULT
  4. 3 PHASE SHORT CIRCUIT
  5. OVER LOAD
  6. BREAKER FAIL TO OPEN /CLOSE
  7. FALSE RELAY INDICATION
  8. MANUAL OPERATION
  9. GENERATOR OR TRANSFORMER UNIT PROTECTION OPERATED

- DATE & TIME OF OUTAGE
- DATE & TIME OF RESTORING SUPPLY
- DATE & TIME OF RESTORING FAILED COMPONENT(S)

Notes for Filling

(I) CAUSE OF FAILURE : the contents of this field would be one of three possibilities defined as follows:

1. PRIMARY : this is the independent failure of any element. The cause for such a failure should be attributed to one of the following reasons:

   A- Unknown.

   B- Defective equipment (defects that were due to intrinsic design or component-faults).

   C- Weather or Natural Environment (rain, fire, lightning, flooding, etc.).

D- External Interference(third party damage, damage by contractors, vandalism, trees contacting line, building construction work, etc., also vibration or mechanical shock).

E- Maintenance/Installation Error (failures that might have been prevented by correct installation or adequate maintenance).

F- Human Element (testing, system operations etc. by CEB staff).

G- Protection misoperation (cascade tripping, tripping caused by protection setting problems, etc.)

2. SECONDARY : these outages are dependent on the occurrence of one or more other outages, e.g. an independent outage of one line of a double circuit followed by the tripping of the second line due to overload.

3. COMMON MODE : a common mode or a common cause of an outage is an event having an external cause with multiple failure effects where the effects are not consequences of each other.

(2) MODE OF FAILURE : Failure modes describe either a type of fault or an equipment malfunction. Codes have been assigned to the following failure modes as follows:

1. 1 phase to earth fault (1 phase E/F[1] also sensitive earth fault SEF)
2. phase to phase fault (2 ph O/C[2])
3. 2 phase to earth fault (2 ph E/F and O/C)
4. 3 phase short circuit (and 3 phase short circuit to earth)
5. overload/over temperature (overloading of network or exceeding maximum permitted temperature of transformer)
6. breaker fail to open /close (this covers a stuck breaker or tripping battery failure)
7. false indication (which may result from protection misoperation or from flags not dropping on relays that have actually operated correctly).
8. manual operation.
9. generator or transformer unit protection operated (differential protection, restricted earth fault, etc.)

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[1] E/F means earth fault.
[2] O/C means overcurrent fault or short circuit.

CHAPTER 6

TRANSMISSION SYSTEM PLANNING

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6.1 Criteria and Procedures of Transmission System Planning

6.1.1 Planning Principles

For a large power system, locations of power stations and demand centers are separated each other and naturally scattered in the country, and the primary function of the transmission system is to deliver the generated power from the power stations to the demand centers satisfying necessary supply criteria.

The basic requirements to the power supply activities comprise the following three factors:

1. **Quantity** : The transmitting power shall be determined according to the demand and corresponding generating output, and each component of the transmission system must have sufficient capability to meet the transmission requirements.
2. **Quality** : Quality of power supply represented by supply voltage to consumers and system frequency must be kept within acceptable ranges as mentioned in Clause 3.7.1. The transmission system shall be planned so as to satisfy the required ranges of voltage variation under normal and contingency operating conditions. The system frequency is a factor determined by properties of generating equipment and is out of control for the transmission system.
3. **Security** : To promote benefit to consumers, the electricity supply shall be secured with minimum possible interruption. The reliability of power system shall be reviewed under the normal and contingency conditions. From an economic viewpoint, supply interruption caused by a fault in inevitable. However, to shorten the duration of supply interruption by system changeover the ring system was planned to be formed as far as possible. The entire power system needs to be planned so as to achieve a target annual duration of supply interruption to consumers.

Transmission system facilities need be planned systematically so as to satisfy the above requirements in coordinated manners. In planning, maximum utilization of available facilities and cost performance shall also be taken into account. The idea to select the least cost alternative satisfying the minimum requirements shall be followed in planning and succeeding design of system facilities.

A master plan study for long-term development, as studied by the JICA team, is prepared based on agreeable assumptions on demands and generation developments, which will be subject to modifications due to changes in situation from time to time. The power demand forecast and power generation expansion plan must be reviewed often when there are changes in situations. Under such circumstance, it is required to review around 10 year transmission system plan every year as a revolving plan and when any major portions of the premises for planning have been changed.

6.1.2 System Planning Criteria

The criteria for new construction and capacity addition of grid substations to feed distribution systems are mentioned in detail in Clause 6.1.5.

The power system analysis of the Study was carried out based on the following criteria:

1. In reviewing system reliability, the single contingency conditions (loss of one circuit of any line, or transformer) were taken into account. Power supply situation under various contingencies was reviewed with the TPLAN software.

2. Under the normal operating conditions, there shall be no overload exceeding the rated values of transmission lines and transformers. Under the single contingency conditions, there shall be no excessive current in line conductors but transformer overloading at the maximum of 10% can be granted for relatively long time and 30% for short time, normally necessary for circuit changeover.

   The rated currents of line conductors are as follows: (see Appendix A6.1.1)

   i) for existing lines; evening time current rating at maximum design sag temperature.

   ii) for future lines; evening time current rating at 80 degrees.

3. Even under the single contingency conditions, basically there shall be no loss of load. For instance, in case that one circuit of transmission line in one section is separated due to a fault there shall be no resultant separation of power source, imbalance of demand and supply, and forced segregation of certain loads from the system.

4. Allowable range of substation bus voltage under the normal and single contingency conditions shall be:

   i) Under normal operation: + 5% to - 5%

   ii) Under single contingency: + 5% to - 10%

   Though on-load tap changers of transformers at grid substations have an adjusting range of plus 10% to minus 15%, and the rated secondary voltage can be maintained at rated value if the primary voltage is within this range. Therefore, a larger variation of voltage was allowed for certain cases based on situation of calculation results. The sending end voltages of power stations are allowed to be higher than the above to maintain normal system voltage and to reduce power loss.

5. The power system shall be dynamically stable when 3-phase short circuit fault occurs at the most severest point of the power system, the power station end of a heavily loaded transmission line, which is followed by rapid reclosing of one line circuit out of two circuits and its separation by failure due to continuation of the fault status.

6.1.3 General Work Flow

Basically an overall transmission system is planned so as to connect conceived power plants and substations at load points, and to enable delivery of power from generation points (power stations) to demand centers. Therefore, the transmission system planning are dependent on a generation expansion plan and demand forecast.

The long-term generation expansion plan prepared by CEB mentioned in Clause 4.5.2 and the substation-wise demand forecast of the JICA team in Clause 4.4 are used as bases of the transmission system planning in this Study.

The transmission system development plan of this Study was prepared by the following steps:

(a) Review of power supply reliability criteria.

(b) Review of a series of Monthly Review Reports on System Control and Operations prepared by the System Control Branch. Investigation of system operation records including review, analysis and compilation of operation records of existing substations, sending out energy, real and reactive power, load power factor and facility utilization factors in the peak time, etc.

(c) Determination of the estimated load of each of existing and planned grid substations. Substation-wise demand forecast was worked out taking into account capacity addition to existing substations and construction of new substations.

(d) Selection of countermeasures to overcome problems of the existing transmission system.

(e) Preparation of preliminary transmission system plans taking into account the generation expansion plan, substation loads, criteria for supply reliability and various constraints of the existing system.

(f) Confirmation whether the selected plan is the least cost plan or not.

(g) Power flow calculation of the preliminarily selected transmission system and evaluation of results.

(h) Assessment of power system reliability with the TPLAN program on the selected transmission system.

(i) Analysis of dynamic stability and fault calculations on the selected transmission system.

(j) The preliminary transmission system plan shall be revised as required until all the above required criteria are satisfied.

(k) The transmission system plan become final by satisfying all the required criteria.

The overall work flow of the transmission system planning study is presented in Fig. 6.1.3-1.

6.1.4 Determination of Power Station Output

The output of each power station is determined so as to satisfy demand according to available capacities of the existing facilities and their operation records, power source composition, typical operation patterns of various power stations and fuel costs. The existing generation facilities in Sri Lanka consists predominantly of hydro plants. Though the share of thermal power will increase in future, the operation pattern of hydro plants much affects the generation planning. The output of hydropower station varies seasonally according to the availability of river water and water level of reservoirs; hydro output is high in rainy season and low in dry season.

Conditions of power supply of the transmission system become severe in case that major power sources are located far from the major load centers. For the present transmission system of CEB, the condition of power supply is severer in rainy season as the hydropower stations are located far from the major load center of the Colombo area. System voltage profile, required capacity of static capacitors and supply reliability were reviewed under the rainy season condition. While, the maximum power flow in the Colombo area must also be reviewed under the dry season condition when the share of thermal generation is large. This situation must be reviewed even after the major power sources of the system have been converted to the coal thermal power plants, located far from Colombo.

The maximum sending out power of a hydropower station, the output of power station minus station service power, has been taken to be same as the rated output of the power stations, as the requirement for station power of a hydropower station is minimal, normally less than 1%, and many hydro generators have a certain overload capability under high head. While, the coal thermal power plant consumes around 6% of the generated power for station service consumption, which is smaller for the gas turbine, combined cycle and diesel plants. In system analysis, the sending out power of thermal plant was assumed to be 90% of the rated output. For a diesel power station with a number of units, one unit is assumed to be out of service.

6.1.5 Capacity Addition to Existing Substations and Construction of New Substations

(1) General

Addition of new substations was, in general, planned for the following two situations:

(a) Even though a substation capacity is sufficient, voltage variation in the distribution system can not be maintained in a permissible range, or distribution line losses are excessively large due to power demand growth in the network.

(b) Augmentation of existing substation capacity is not possible due to design constraint of the original facilities, difficulties in enlarging the substation premises or site conditions of the surrounding areas to construct additional incoming/ outgoing transmission lines.

For the case of (a) above, the Distribution Development Branch reported in April 1996 "the Medium Voltage Distribution Development Plan, 1995-2005" with cooperation of system planning engineers of provincial offices. Proposals to construct new grid substations in the Plan has been approved by the board of directors of CEB, and financial arrangement for some substations is in progress. The construction plans up to the years 2000 and 2005 in this Study are similarly formulated on the basis of the approved plans so as to meet the necessity of the above (a) situation.

While, the above (b) corresponds to such a case that the overloaded condition of a grid substation can not be solved by rearrangement of distribution feeders and there is only a way to solve the overloading condition by installation of additional transformers or construction of new substations. Necessity and timing of the specific plan is analyzed by utilizing the Power Supply Matrix stated in Clause 4.4.2. Necessities of constructing new substations due to difficulties in augmenting existing substations are examined in this Study from the results of the site investigation of the areas, except the northern and eastern provinces.

In this Study, transformer addition to the existing substations or construction of new substations was planned in case that demand concerned was anticipated to exceed 90% of the total capacity of existing transformers in the substation.

(2) Ongoing and Committed Extension and Reinforcement of Transmission System

Table 6.1.5-1 is prepared through investigations through CEB to understand current situation related to the extension and reinforcement of transmission system and to formulate the extension and reinforcement plans of the system up to the year 2015. The extension and reinforcement program in this Study was formulated under the assumption that all the plans in the Table 6.1.5-1 would be completed as scheduled.

(3) Construction Plan of New Substations for Improvement of System Voltage Profile and Promotion of Rural Electrification

As for the construction of new substations to improve the system voltage profile mentioned in the foregoing item (1), it is rather hard to justify the same practices to urban or industrialized areas with relatively high demand density and to new substations in rural areas with low demand density from economic aspects. Taking into account such situation, the Distribution Development Branch planned to improve the system voltage profile by the following manners:

(a) Expansion of the existing 132 kV system and construction of new grid substations in the high demand density areas, and

(b) Reinforcement of the existing 33 kV distribution network or extension of new 33 kV subtransmission lines in the low demand density area.

The following are substations in the above category (a) to be newly constructed by 2005 proposed in the Medium Voltage Distribution Development Plan.

i)	Veyangoda substation	Western-North Province
ii)	Aniyakanda substation	Western-North Province
iii)	Katana substation	Western-North Province
iv)	Athurugiriya substation	Western-South Province
v)	Sri Jaya'pura substation	Western-South Province
vi)	Horana substation	Western-South Province
vii)	Palekelle substation	Central Province
viii)	Kuliyapitiya substation	North-Western Province
ix)	Ambalangoda substation	Southern Province
x)	Ratnapura substation	Sabaragamuwa Province

The above plans are judged to be appropriate from the results of area-wise demand forecast, site reconnaissance conducted by the Team and a series of discussions with the CEB's distribution engineers. Consequently, the substations listed above were selected as candidates for new substations in this Study.

The Distribution Development Branch carried out computer analysis to review the voltage level of the 33 kV system to formulate reinforcement plans, and prepared construction plans of subtransmission lines and upgrading plans of existing distribution systems for the program of the above category (b). Figs. 6.1.5-1 to 6.1.5-4 show the results of year 2000 voltage analysis in the areas except for the areas covered by the above-mentioned new substations.

The above-mentioned reinforcement plans of 33 kV system are considered to be tentative measures in case that demand growth is high, when rapid growth of demand and capacity limits of 33 kV systems are taken into account. Reinforcement plans of the 132 kV system will be economically justified in certain cases. As seen in Table 6.1.5-1, a number of the existing 10 MVA transformers will be replaced with new 31.5

MVA transformers. Utilization of these removed 10 MVA transformers will result in economical advantage to substation construction plans in rural areas. In this Study, construction of the following new low-cost substations is planned in low load density areas where excessive voltage drop is anticipated as given below:

i)	Vavunia substation	Northern Province
ii)	Polonnaruwa substation	North-Central Province
iii)	Hambantota substation	Southern Province
iv)	Tissamarama substation	Southern Province
v)	Medagama substation	Uva Province
vi)	Bowatenna substation	Central Province

(Addition of transformer in the switchyard of the existing power station)

In addition to the above, the JICA team, according to outcomes of discussions with distribution planning engineers of branch offices of CEB, studied on other new substations in the areas where excessive voltage drop due to demand growth was anticipated and rural electrification was expected.

6.1.6 Power System Analysis and Supply Reliability Assessment

(1) Power Flow Analysis

Power system performances of the preliminary transmission system plans were analyzed at first with the power flow calculation using the PSS/E program of PTI, owned by CEB. Items to which attention shall be paid in carrying out the power flow calculation are mentioned below:

(a) Generator's capability shall be utilized effectively; the rated output at the lagging power factor of 90 to 85% shall be fully utilized and terminal voltage shall be high within the allowable limit to keep transmission voltage high.

(b) A power factor of load substantially affects the voltage profile and judgment of overloading of circuit components in the system. The demand records of grid substations in 1995 indicate that the power factor values can be classified into two groups, in a range of 0.83 to 0.92 in Colombo and surrounding areas and 0.85 to 0.95 in other areas. Assuming this tendency be unchanged, the following power factors were adopted in the Study on a provincial basis.

Power Factor	Provinces
0.90	North Central, Northern, Central, North Western, Eastern, Southern, Uva, Sabaragamuwa
0.85	Colombo, Western North, Western South

(c) The bus voltage of power stations and substations had better be kept high in the peak load time to maintain the consumer supply voltage at normal and to reduce ohmic loss in lines.

(d) Static capacitors shall be arranged properly so as to improve the voltage profile avoiding excessive flow of reactive power in the transmission system at or near the installation point. Adequacy of bus voltage at each station shall also be checked. This measure contributes also to reduction of transmission loss.

(e) To select the least cost alternatives, economic comparison study shall be conducted as required.

(2) Fault Calculations and Dynamic Stability Analysis

After satisfactory results were obtained by the power flow analysis, the fault calculation and dynamic stability analysis were carried out using the PSS/E program.

The fault current data are required to review the breaking capacity of circuit breakers. In order to obtain the maximum short circuit current at all the 220 kV and 132 kV buses, 3-phase short circuit calculation was executed for the proposed system. In this calculation, all the circuit components were assumed to be connected to the system so as to maximize the short circuit current.

The purpose of dynamic stability analysis is to check stability of the power system, whether all generators can be operated without resulting in system separation or islanding, due to abnormal events in the power system, short-circuit and earthing fault or large load variation. Dynamic stability condition is severest for a 3-phase fault followed by autoreclosing and its failure at the power station end of a heavily loaded transmission line (the Kotmale end of the 220 kV Kotmale - Biyagama line for the current system).

(3) Assessment of Power Supply Reliability and Final Evaluation

After confirming that the planned system satisfies various requirements by the power flow analysis, power supply reliability of the planned system was examined quantitatively with the help of the TPLAN program in the PSS/E series. The TPLAN program carries out contingency analysis based on the network data used for the power flow analysis to detect circuit overloads, network separation, voltage limit violations, voltage depression and voltage collapse conditions, and instances of tripping sequences or significant frequency deviations and record in the contingency results file. In this Study, the following results were produced under the single contingency (outage of any one circuit component) cases:

- Automatic evaluation of contingencies
- Overload ranking
- Islanding
- Voltage collapse ranking

In case that the preliminary plan resulted in any of the following conditions, system reinforcement was planned:

- Power flow under the normal or single contingency fault condition exceeded the limits of criteria of any component
- Fault current exceeded the short time current capacity of any facility.
- Voltage variation at the substation bus or at the distribution ends exceeded the allowable ranges mentioned in Clauses 6.1.2 under normal operation or single contingency fault.
- Power loss was estimated to be excessive or system reinforcement was judged to be required.
- Dynamic stability criteria was not satisfied.

In such case, the preliminary plan was revised and power system analysis was repeated till criteria were satisfied. Finally, the transmission system plan was reviewed in view of power supply reliability. Thus, based on planned criteria yearly transmission system extension and reinforcement was prepared step by step after review of technical appropriateness.

(4) Least Cost Evaluation

Among alternative ideas for transmitting power to distant points, say 100 km, the overhead transmission line of normal design is recognized as the least cost means to satisfy technical requirements and applied in the world. Construction of high cost underground cable line can be justified only for city center installation, or in special cases. Selection of the voltage class and conductor size of overhead line must be finalized through economic comparison covering not only construction cost but also the O&M cost and loss evaluation. In calculating annual costs, considerations are given for the following:

- For 132 kV lines, relations between conductor size and maximum sending power shall be clarified.
- For 220 kV lines, relations among number of Zebra conductors, single or bundled, and maximum sending power shall be clarified.
- The annual power and energy values used for loss evaluation are US$ 131/kW and US¢ 2.392/kWh respectively as referred to Clause 9.3. The results are presented in Fig. 6.1.6-1 for 132 kV lines and 6.1.6-2 for 220 kV lines.

6.2 Results of 1995 System Analysis

At first the existing transmission system as of the end of 1995 was analyzed under the 28 November load condition to evaluate the present situation of the system. The system diagram used for the analysis are shown in Fig. 6.2-1 and the results are presented in Fig. 6.2-2. All the system data necessary for system analysis are included in Appendix A6.1.1. Problems of the system noted from the power flow analysis are as follows:

- Reactive power is not sufficient in the Colombo area. Though gas turbine generators in idle are operated for reactive power supply, their capacity is not sufficient to meet the requirement. This causes highly reactive power flow on the Victoria - Kotmale - Biyagama 220 kV line, and makes difficult to keep the target bus voltages of the 220 kV bus at Biyagama and the 132 kV bus at Kolonnawa.
- Large voltage drop is noted on lines to Matugama and Galle to the south, and Anuradhapura and Trincomalee to the north.
- Overload problem is severe for the 132 kV line from Polpitiya to Anuradhapura especially under the single contingency conditions.

Against these problems, improving measures are taken in the system planning for the next step to 2000. They include installation of static capacitors in the Colombo system, reinforcement of the system toward the south and extension of the 220 kV system up to Anuradhapura.

The power supply reliability of the 1995 power system was analyzed using the transmission planning software (TPLAN).

From the results, it is clear that the present transmission system is overloaded in a significant number of areas and is close to its limits, in terms of voltage excursion and consequently there is the strong possibility of system overload and also a risk in some areas of voltage collapse, under certain outage conditions. Any single outage event on the 220 kV network produces, under peak loading conditions, problems with the rest of the network. Consequently any changes to the transmission network need to improve the security of the 220 kV network and where possible reduce the reactive energy transmitted by this network (since poor power factor leads to poor voltage at the receiving end of the network). From the results of the modeling it is clear that the transmission network cannot provide sufficient reactive and active energy transfer from the hydro stations to the Colombo's load center without the aid of load centered generation and static capacitor compensation.

In addition the 1995 system is vulnerable to outages, at peak periods, on the Victoria to Randenigala 220 kV circuit. This can be alleviated by the addition of further generation in the Colombo load area or by provision of a detour transmission line from the Rantembe power station to Laxapana. The 132 kV detour route with two circuits is planned to be secured by 2000 by construction of the Laxapana - Badulla 2-circuit line and addition of the second circuit on the Rantembe - Badulla line.

The circuits between Polpitiya 132 kV to Kolonnawa 132 kV are reported to be vulnerable to power swings and may trip out if they are suddenly called on to carry too much load from their generating stations. They also have to cope with any generation mismatch between the Mahaweli complex, on the 220 kV network, and the Laxapana complex connected to the Polpitiya 132 kV busbars, by connecting the two systems for power interchange.

Analysis of the power system faults for 1993, 1994 and 1995 indicate that the problems of poor transmission security have become even worse over the years. Graphs were reproduced in the Fig. 6.2-3 (1), (2) and (3), which indicated the increasing loss of load in 1993, 1994 and 1995 caused by transmission faults or forced outages compared with those caused by generation faults or forced outages.

One problem area that has become apparent is that parallel running of the 132 kV and the 220 kV networks are creating reliability problems. Hence where new 220 kV circuits are installed it is important that any 132 kV rings that are now in parallel with the 220 kV system are split to prevent circulating currents, unless they have to be run this way for generation security purposes.

The results of the ranking studies are shown in detail in Appendix A6.2.1.

6.3 System Extension and Reinforcement Plans up to 2000

6.3.1 System Reinforcement and New Construction of Substations

(1) Formulation of Extension and Reinforcement Plans

In order to formulate the extension and reinforcement plans of the transmission system up to 2000, the JICA Team prepared the region-wise demand forecasts, examined the CEB's plans indicated in the Medium Voltage Distribution Development Plan, 1995 - 2005, and studied the new plans including the construction of the following five substations required by 2000 in addition to the ongoing projects listed in Table 6.1.5-1.

(a)	Veyangoda substation	(2 x 31.5 MVA)
(b)	Aniyakanda substation	(2 x 31.5 MVA)
(c)	Athurugiriya substation	(2 x 31.5 MVA)
(d)	Sri Jaya'pura substation	(2 x 31.5 MVA)
(e)	Ratnapura substation	(2 x 31.5 MVA)

The Study Team prepared a Power Supply Matrix in cooperation with the CEB's distribution engineers as stated in Clause 4.4.3 with the hypothesis that all the substations listed in Table 6.1.5-1 and the above substations would be commissioned by the year 2000. From the Matrix, the Team examined the sent-out energy from each grid substation and substation loading at the system peaking time. The examination resulted in overloading of the grid substations at Ukuwela, Sapugaskanda, Ratmalana and Pannipitiya.

The first step to solve the overload conditions of the substations is to add transformers and to rearrange load sharing of distribution feeders. The overload conditions in the Western-North and Western-South provinces could not be solved only by this step, and therefore new substations were planned in these areas. Table 6.3.1-1 shows load conditions of the substations before and after implementation of the extension and reinforcement plans.

(2) Extension Plan of Transmission Facilities Related to Development of Power Sources

Scope of a generation project is influenced by amount of the development fund. A generation development project usually includes transmission facilities for connection to the network, but sometimes delivery to a load center is taken into account or nothing is considered. It is, therefore, hard to define the scope of an individual transmission plan for future projects. In this Study transmission facilities involved in a generation plan are assumed to include up to step-up transformers from generator voltage to transmission voltage and associated HV switchgear for transmission circuits. Transmission lines to load centers, tie transformers and distribution transformers are assumed to be included in the scope of the transmission system plan.

Two power plants in the generation expansion plan up to 2000, i.e. the 51 MW KHD diesel plant at Sapugaskanda and 150 MW combined-cycle plant at Muthuragawella, are planned at new sites. Therefore, associated transmission lines and reinforcement of the connecting substations were planned for these two new plants.

(3) Extension and Reinforcement Plans Recommended in the Study

Table 6.3.1-2 and Figure 6.3.1-1 summarize details of the transmission system plans recommended by the Team in this Study, in addition to the on-going plans which are scheduled to be completed by 2000 (Clause 6.1.5). The following are supplemental explanations of the planned major schemes.

(a) Matugama-Galle 132 kV Line

Construction of this transmission line is required by 2000 for reliable operation of the southern power system. CEB planned this line as a 220 kV line and to operate initially at 132 kV. A 220 kV line essential to transmit the generated power of a large thermal plant at Boossa, which is scheduled after 2005. In this region, even though a 220 kV line is constructed a 132 kV line is still required to supply to the growing demand along the west coast. Under such situation, it was proposed to construct a 132 kV line by 2000 and to postpone construction of a 220 kV line till the time of construction of the Boossa plant.

The selected conductor size is Zebra (400 mm^2). Though the Bear conductor (250 mm^2) has enough transmission capacity for use during the plan period, the Zebra conductor was selected according to CEB's intention.

(b) New Galle Substation (2 x 31.5 MVA)

In the existing Galle substation there is available land space for installation of one additional transformer, but the site topography is not suitable for further extension of land and connection of additional transmission lines. Therefore, another substation is required in near future to meet growing demand in the Galle area and to connect additional number of transmission lines. Under such situation, the construction of a new substation was proposed together with construction of the Matugama - Galle 132 kV line.

(c) Kelaniya 132 kV Substation (2 x 63 MVA)

CEB had a plan to construct a new substation to connect the KHD diesel plant to the network at a point between the junction point of the Kolonnawa - Kotugoda line and Sapugaskanda GSS, and to construct a double circuit 132 kV line between the new substation and the Sapugaskanda GSS and dissolve the current T-branch connection. On the other hand, power demand of the existing Biyagama substation and Sapugaskanda GSS is rapidly increasing and a new substation is required in this area.

Under such circumstances, the original plan was canceled and it is proposed to construct a new substation with 2 x 63 MVA capacity at the junction point in the Kelaniya district where the demand density is forecast to be very high. The existing conductors of the Kolonnawa - Kotugoda line are planned to be upgraded to increase transmission capacity. The transmission system plan for connection of the KHD plant with the network is proposed in the next item (d).

(d) Connection of KHD Power Station to the Network

In stead of CEB's original plan to connect the KHD diesel plant (IPP, 51 MW) with a new substation which was canceled as above (c), it was planned after site reconnaissance to connect the power station directly with the Sapugaskanda GSS through a 132 kV line.

A 132 kV single circuit transmission line with Lynx conductors is existing between the Sapugaskanda PS and GSS. This line was planned to be upgraded to a double circuit line with Zebra conductors.

(e) Dehiwala 132 kV Substation (2 x 63 MVA)

Power to Dehiwala district just south of Colombo city is currently supplied from the Ratmalana substation. The rapidly growth of demand in the Ratmalana area is anticipated to reach about 130% of the substation capacity in 2000. The Pannipitiya substation sharing the overloaded portion of Ratmalana will also be overloaded to 110% of its capacity in the same year. Under such circumstance, a new substation is planned in the Dehiwala area for the following purposes:

- Removal of overloading of the Ratmalana and Pannipitiya substations,
- Stable power supply to the Dehiwala areas over the years, and
- Supporting function to power supply to Colombo city.

The new Dehiwala substation was initially planned to be constructed as a 220 kV substation for future extension to Colombo city. However, the substation-wise demand study up to 2015 revealed that the power supply from this substation to Colombo city is necessary after 2010. Hence the substation is planned to be operated at the voltage of 132 kV initially, and be upgraded to the 220 kV operation after 2010 when support to Colombo city becomes necessary. There is an undeveloped and swampy belt zone between the Pannipitiya and Dehiwala substations. It was planned to construct the new transmission line of 220 kV design and operate initially at 132 kV taking difficulties in land acquisition for construction of an additional 220 kV line when required into account. A special attention is required for design of the transmission line facilities as the line route runs near the Ratmalana airport.

(f) 220 kV Connection of the Muthuragawella Combined-Cycle Power Station with the Transmission Network

CEB has a plan to construct the second combined-cycle power plant with the initial installation of 150 MW, to which a 300 MW unit will be added in future, in the Muthuragawella district on the reclaimed land. The original idea was to connect with the Kelanitissa substation through a new 220 kV transmission line, however a lot of difficulties are expected to construct a transmission line to Kelanitissa, which includes underground cable section in the town area and crossing over the Kelani river. The connecting substation was shifted to the Kotugoda substation, as the transmission line will pass through the reclaimed area and land problem will not be severe.

Area under reclamation work is a part of a large lagoon widely extending to the outskirts of Negombo and this area is expected to become an industrial and commercial estate. The planned transmission facilities will function to supply power to the estate in future. This plan includes the reconstruction of the 220 kV switchyard at the Kotugoda substation; this will facilitate connection of additional 220 kV circuits and improve operational reliability.

(g) Revision of Construction Plan of Veyangoda 132 kV Substation

The first coal thermal power plant of Sri Lanka is planned in Puttalam district and to be commissioned by 2002. The planned main receiving substation of the Colombo area is the existing Kotugoda substation, but the existing arrangement of this substation and its surrounding situation are not suitable to receive and handle bulk power due to expected difficulty in acquisition of additional land for large scale remodeling and connection of a large number of lines.

Under such situation, it is planned to modify design the Kotugoda - Veyangoda line from the original plan of 132 kV line to a 220 kV double circuit line with 2 x Zebra conductors and to operate initially at 132 kV for power supply to Veyangoda. The Veyangoda substation was planned as the major 220 kV receiving substation for the Colombo system initially operated at 132 kV and to add 220 kV facilities when the coal thermal power plant is completed. In the detailed design of the 132 kV Veyangoda substation, particular attentions are to be taken for the future addition of 220 kV facilities.

(h) Location of Ampara 132 kV Substation

CEB planned to construct a new 132 kV substation in the suburb of Ampara to discontinue main power receiving from the Inginiyagala power station through the 33 kV distribution network to the Eastern Province areas. To improve the degraded voltage profile in the areas toward the east from Ampara to Kalmunai, it was proposed to continue power supply from Inginiyagala power station with renovation of the existing 33 kV switchgear equipment and shift the planned 132 kV substation to Kalmunai district or else where to improve the voltage situation in the Kalmunai area.

Demand forecast of each substation and power system analysis in this Study were conducted under the assumption that a new substation be constructed in the Ampara district as planned by CEB.

6.3.2 Power System Analysis of the 2000 System

(1) Study Cases

The power flow of the 2000 system was calculated for two cases; rainy and dry seasons. Through the power flow calculations and reliability analysis, the system configuration was amended as required and finally the proposed system plan was determined.

For the final proposed system, 3-phase short circuit current was calculated on the 220 kV and 132 kV buses. The dynamic stability was analyzed for the rainy season case of the proposed system, assuming fault at the Kotmale end of the Kotmale - Biyagama 220 kV line. The two cases of reclosing conditions, success and failure, with time sequences as given below were assumed taking into account performances of the existing facilities.

1) Successful Reclosing
Fault --- (160 ms) --- CBs trip --- (500 ms) --- CBs Close and clearing fault

2) Unsuccessful Reclosing
Fault -- (160 ms) -- CBs trip -- (500 ms) -- CBs Close -- (160 ms) -- CBs trip

Behaviors of generators were calculated and recorded at the four power stations of Kotmale, Victoria, Kelanitissa and New Laxapana.

(2) System Data

The finally proposed system for the year 2000 as the result of the system analysis and reliability assessment is illustrated in Fig. 6.3.2-1. All the system data to be modified from the 1995 system for the 2000 system and generator output schedule are shown in Appendix A6.1.2. The forecast peak demand of each grid substation shown in Table 6.3.1-1 was commonly used for the both cases, dry and rainy seasons.

Due to the difficulties in collecting all the detailed parameters of generators, generator excitation systems including AVRs and turbine governors of the existing equipment within the limited time, available representative data of generators and AVRs were used in the dynamic stability analysis. As a response of governors is relatively slow compared with the time range to evaluate the system stability, the parameters of governors were not taken into account. All the input data for the dynamic stability analysis are included in Appendix A6.1.2.

(3) Results of 2000 System Analysis

(a) Power Flow Calculation

The results of power flow calculation on the proposed system in the rainy and dry seasons are shown in Figs 6.3.2-2 and 6.3.2-3 respectively.

In the rainy season case, the bus voltages of hydropower stations were set high, for instance 1.05 pu at Victoria and 1.06 pu at Randenigala. In case of low voltage setting, the computer calculation didn't converge when the automatic transformer tap adjustment function was activated; the reason may be that the system voltage went down too low. The calculated total system losses was 2.03 % with the high voltage setting and was slightly less than that with the low voltage setting (without automatic tap changing) by around 0.1 %. According to such results, it is judged the bus voltage of hydropower stations shall be kept high especially in the rainy season.

Considerable amount of reactive power sources was essential, particularly in the Colombo area. A large capacity of static capacitors was required to maintain the system voltage at normal and to keep the generator output within the rated operational range. The proposed system indicates that the necessity of static capacitors in the Colombo area was 100 MVA at Pannipitiya and 60 MVA at Kelanitissa to be connected to the tertiary windings of 220/132 kV transformers. CEB has acknowledged the necessity of installing static capacitors, and has a plan to install 45 MVA sets with the ADB loan in 1998. This installation will not be enough for the 2000 system and further addition of 100 MVA at Pannipitiya and 15 MVA at Kelanitissa will be required.

Even after the adjustment of system voltage by transformer taps and the above static capacitors, 132 kV bus voltage of the Chunnakam grid substation didn't satisfy the voltage criteria, i.e. not lower than 0.95 pu. Either a reliable power source in Chunnakam or extension of 220 kV transmission line from Anuradhapura is necessary to maintain the Chunnakam voltage. Keeping in view of the considerable length of the said transmission line, about 200 km, the installation of 30 MW diesel generators at Chunnakam was taken into account in the Study.

(b) Fault Calculation

As the result of fault calculation, the 3-phase short circuit currents at the 132 kV and 220 kV buses of each substation and power station are shown in Table 6.3.2-1 together with the rated breaking current of the existing circuit breakers. This table indicates the results of fault calculation in the stages of 2005 and 2010 as well.

According to the result, the following circuit breakers need to be replaced with the higher rating ones by 2000.

Station Name	Rated Voltage (kV)	Rated Breaking Current (kA)	Fault Current (kA)
Kolonnawa	132	20.0	24.4
Sapugaskanda GSS	132	15.3	20.1
Sapugaskanda GSS	132	11.0	20.1

(c) Dynamic Stability Analysis

The result of the dynamic stability analysis shows that the system will be kept stable after the successful as well as unsuccessful 3-phase reclosing of one circuit following a 3-phase shortcircuit fault at the Kotmale end of the Kotmale - Biyagama 220 kV line.

Fig 6.3.2-4 shows the behaviors of the generator rotor angle, terminal voltage and output power of the above four power stations under the successful reclosing. Fig 6.3.2-5 shows the behavior of the same parameters under the unsuccessful reclosing.

The difference of rotor angle between Kotmale and New Laxapana at the first peak of the swing is 28 degrees. The first peak of the swing appears at about 300 ms after the fault on the Kotmale - Biyagama line, and the swings are well damped thereafter.

6.3.3 Supply Reliability Analysis of the 2000 System

The power system for 2000 as modeled on PSS/E and TPLAN has a total load of 1,400 MW and with technical losses of 29 MW (2.03%) requires some 1,429 MW of generation at the forecast rainy season evening peak. This compares well with the lower load during 1995 of 917 MW and higher technical losses of 37 MW (due to equipment overloads).

Because of the construction of new 220 kV substations and additional 132 kV circuits by the year 2000 the risk of voltage collapse is considerably reduced under single contingency outages. Also the overloads experienced on the present system are eliminated by changes in transformer capacity, additional circuit capacity and by the careful choice of network splitting points (normal open points).

By the year 2000 it is proposed that the 220 kV network is extended to Anuradhapura to act as the main bulk supply point for the northern area. This off-loads the 132 kV lines from Kotmale and Polpitiya and eliminates the risk of voltage collapse from these circuits.

The risk of power system islanding is reduced by the completion of the 132 kV connection between Laxapana and Badulla and the second circuit addition of the Rantembe to Badulla section. This means that for the tripping of the Victoria to Randenigala 220 kV circuit the generation running at Randenigala will still be available to the power system through the 132 kV system. This does of course assume that all the 132 kV circuits are in service. In general it is good utility practice to arrange for higher levels of transmission security for generation to prevent the loss of a circuit causing the loss of a complete power station or group of stations.

At the southern end of the system the one circuit loss of the Balangoda to Deniyaya line results in low voltage at Deniyaya and Galle of 0.879 pu and 0.899 pu respectively, during peak loading conditions. Provided the 132/33 kV tap-changers are in good order and these transformers are not overloaded, then they should keep the voltage on the 33 kV side in limits. Fortunately there are no 132 kV customers in this area. The use of the static var compensators helps to keep Galle's voltage from falling further helps prevent voltage collapse, but again consumers should be given the incentive to correct their own poor power factor.

The detailed results of the ranking studies are shown in the Appendix A6.2.2.

6.4 System Extension and Reinforcement Plans up to 2005

6.4.1 Reinforcement and Construction of New Substations

(1) Formulation of Plans

The plan for extension and reinforcement of the transmission system up to 2005 was formulated on the bases that the under-mentioned substations proposed by the Distribution Development Branch in the Medium Voltage Distribution Development Plan, 1995 - 2005, and all substations planned to improve the voltage profile discussed in Clause 6.1.5 would have been completed by 2005. The Power Supply Matrix was prepared with cooperation of distribution engineers of the CEB's area offices in the same method as that up to 2000. Table 6.4.1-1 shows the results of the study for dissolution of substation overloading, expressed by capacity factor of each substation, before and after the implementation of extension and reinforcement projects.

Substations recommended in the CEB's MV distribution development plan up to 2005 are given below:

(a)	Palekelle substation	(2 x 31.5 MVA, Central area by 2005)
(b)	Kuliyapitiya substation	(2 x 31.5 MVA, North-Western area by 2001)
(c)	Katana substation	(2 x 31.5 MVA, Western-North area by 2005)
(d)	Horana substation	(2 x 31.5 MVA, Western-South area by 2003)
(e)	Ambalangoda substation	(2 x 31.5 MVA, Southern area by 2001)

The following are substations which are required by 2005 to improve voltage profile and to promote rural electrification as discussed in Clause 6.1.5. It is noted that the transformers for the following substations are those removed from the existing substations to replace with larger transformers.

(a)	Vavunia substation	(1 x 10 MVA, Northern area)
(b)	Polonnaruwa substation	(2 x 16 MVA, North-Central area)
(c)	Hambantota substation	(2 x 10 MVA, Southern area)
(d)	Medagama substation	(1 x 10 MVA, Uva area)

Implementation schedule of each substation has been examined on the block diagram for grid substation planning shown in Figure 4.4.1-1. Results of the examination are summarized in Table 6.4.1-2 as the capacity factor of each substation before and after implementation of the extension and reinforcement projects. The table includes the results of the Team's review of the construction schedule in the CEB's development plan as well, and necessary countermeasures are shown in Table 6.4.1-1.

From the above studies, in addition to the above eight grid substations the following four new grid substations were proposed by the Team to meet increasing power demand.

(a)	Muthuragawella substation	(2 x 63 MVA, Western-North area by 2002)
(b)	Gonawala substation	(3 x 31.5 MVA, Western-North area by 2004)
(c)	Kegalle substation	(2 x 31.5 MVA, Sabaragamuwa area by 2004)
(d)	Town Hall substation	(2 x 63 MVA, Colombo city by 2005)

Note: The primary voltage of the Muthuragawella transformer is 220 kV, and normal 132 kV for others.

(2) Extension Plan of Transmission Facilities in Power Source Development Plan

New generation projects scheduled by CEB in its development plan for completion during the 5 year period of 2001 to 2005 are the 900 MW Puttalam coal thermal plant and 70 MW Kukule hydro plant. The Study took into account the transmission system extension associated with the development of these plants according to assumptions in Clause 6.3.1, (2).

The development of the Puttalam coal thermal plant is scheduled as below. The transmission facilities of 900 MW capacity are planned for connecting the plant with the network to be completed prior to the commissioning of the first unit.

- No.1 unit	150 MW	by 2002
-.No.2 unit	150 MW	by 2004
- No.3 unit	300 MW	by 2005
- No.4 unit	300 MW	by 2006

(3) Extension and Reinforcement Plans Proposed in the Study

Table 6.4.1-2 and Figure 6.4.1-1 are prepared to present the details of the plan proposed by the Team to be constructed by 2005. The following are supplemental explanation to the major schemes.

(a) Connection of Puttalam Coal Thermal Power Plant with the Power Network

A 220 kV transmission line of double circuits with 3 x Zebra conductors is required from the power plant to the Veyangoda substation in the Colombo area to send substantial portion of the generated power. For power delivery, addition of 220 kV facilities at the 132 kV Veyangoda substation, upgrading of the 132 kV Kotugoda-Veyangoda transmission line to 220 kV, and power supply to the North-western and Northern-central regions through 132 kV transmission lines were also planned.

(b) Construction of New Chilaw 220/132 kV Substation (2 x 150 MVA)

New Chilaw 220/132 kV substation was planned near the existing T-branching point to the Chilaw substation to dissolve the T-branching to Chilaw and Kuliyapitiya and to meet rapidly growing area demands of developing industries, and others.

(c) Connection of Kukule Hydro-Power Station to the Network

In the Feasibility Study of the Kukule hydro-power project, the power station is planned to be connected with the network through a 132 kV transmission line at the Matugama substation. In addition, a 132 kV transmission line between the power station and the Ratnapura substation was planned in this Study to improve supply reliability to Ratnapura district and to function as a backup provision for power supply to the west coast area.

(d) Kegalle 132 kV Substation (2 x 31.5 MVA)

Although there was an idea to construct a 132 kV line to the Kegalle area either from Kiribatkumbura or Kurunegala, expansion of these substations is difficult due to substation design and surrounding topography. Therefore, it was planned to supply power to the Kegalle area through a new 132 kV line from the existing Thulhiriya substation. While, prior to extension of this line, it is proposed to construct a new 132 kV transmission line between the upgraded 220/132 kV Veyangoda substation and the Thulhiriya substation in order to increase transmission capacity and to improve supply reliability.

(e) Palekelle 132 kV Substation (2 x 31.5 MVA)

Although there is an idea to supply power to the Palekelle area through a 132 kV line to be extended either from the Kiribatkumbura substation or Kotmale power station (outdoor switchyard of the Victoria power station is of 220 kV), expansion of both stations is difficult due to constraint of their surrounding topography. Therefore, it is planned to supply power to the area from the existing Ukuwela power station. The existing switchyard of the power station is located on the slope and land leveling is required for the extension, but no difficulty for land acquisition is anticipated.

(f) Ambalangoda 132 kV Substation (2 x 31.5 MVA)

As seen in Figure 6.1.5-3, voltage drop in the 33 kV system in the Ambalangoda area will not be excessive in 2000 on the condition that new subtransmission lines are constructed from the Galle substation, according to the result of analysis by the Distribution Development Branch. As discussed in Clause 6.1.5, the partial reinforcement of 33 kV system is only a tentative measure if the demand growth in the area is taken into account. The Team proposes to construct the Ambalangoda substation by 2001 to meet rapidly growing demand in the area. For further detailed examination of the voltage regulation in the region based on the Team's recommendation should be re-examined and the construction plan of backbone feeders in the Galle-Ambalangoda area should also be reviewed.

(g) Town Hall 132 kV Substation (2 x 63 MVA)

CEB had a plan to supply power to the Town Hall area through an UG cable line from the planned Sri Jaya'pura substation. While, almost half of this line route is aligned in undeveloped city areas, where will be subject to rezoning in future city planning. It was proposed to supply power to the Town Hall substation by UG cables from the Kolonnawa substation, which will be fed by a 220 kV line to reinforce power transfer capability of the Kolonnawa - Pannipitiya line. The new UG cable line is planned to follow the same route as the existing Kolonnawa - Kollupitiya line.

6.4.2 Power System Analysis of the 2005 System

(1) Study Cases

The power flow of the 2005 system was calculated for the two cases; rainy and dry seasons. Through the power flow calculations and reliability analysis, the preliminary plan was modified as required and finally the proposed system plan was determined. For the final proposed system, 3-phase short circuit current was calculated on the 220 kV and 132 kV buses. As for the dynamic stability analysis, the 3-phase fault of the 220 kV Kotmale - Biyagama line was assumed for rainy season case similar to the 2000 case, however the 3-phase fault on the Puttalam end of the Puttalam - New Chilaw 220 kV line was also analyzed. The conditions for reclosing were similar to those for the 2000 system. Generator behaviors were observed at the four power stations of Puttalam, Victoria, Kelanitissa and New Laxapana.

(2) System Data

The finally proposed 2005 system confirmed through the system analysis and reliability assessment is illustrated in Fig. 6.4.2-1. All system data modified from the 2000 system and schedule of generator output are included in Appendix A6.1.3. The forecast peak demand of each grid substation shown in Table 6.4.1-1 was used for the both cases, rainy and dry seasons.

(3) Results of 2005 System Analysis

(a) Power Flow Calculation

The results of power flow calculation on the proposed system in the rainy and dry seasons are shown in Figs 6.4.2-2 and 6.4.2-3 respectively.

There were no remarkable problems observed in the power flow calculation on the preliminary system except for low voltage at Chunnakam. To avoid the excessive voltage drop at Chunnakam, 20 MVA static capacitor needs to be installed.

(b) Fault Calculation

For the 2005 system, 3-phase short circuit current at 132 kV and 220 kV buses of each substation and power station were calculated as shown in Table 6.3.2-1 together with the rated braking current of existing circuit breakers.

According to the calculation result, in the period from 2001 to 2005, no circuit breaker needs to be replaced.

(c) Dynamic Stability Analysis

The results of analysis in rainy season are shown in Fig. 6.4.2-4 for behaviors of generator rotor angle, terminal voltage and output power of Puttalam, Victoria, Kelanitissa and New Laxapana power stations under the successful reclosing of the Kotmale - Biyagama 220 kV line, and in Fig. 6.4.2-5 for behaviors of the same parameters under the unsuccessful reclosing of the same line.

In the same manner, for dry season Fig. 6.4.2-6 shows behaviors of the same parameters as the above under the successful reclosing of the Puttalam - New Chilaw 220 kV line and Fig. 6.4.2-7 shows the same items under the unsuccessful reclosing of the same line.

The largest deviation of the rotor angle appears at the first peak of the swing both for the successful and unsuccessful reclosing. The largest difference of rotor angle between Puttalam and Kelanitissa, and between Puttalam and Victoria are 36 and 48 degrees respectively. The first peak appears at about 300 ms after the occurrence of fault on the line, and after the first peak the swings were well damped.

The result of the dynamic stability analysis shows that the 2005 system is stable under the successful as well as unsuccessful reclosing.

6.4.3 Supply Reliability Analysis of the 2005 System

The power system for 2005 as modeled on PSS/E and TPLAN has a total load of 2,087 MW and with losses of 38 MW (1.79%) requires some 2,125 MW of generation to meet the forecast rainy season evening peak. The system in the Northern Area is still sensitive to the addition of static var compensation at Chunnakam with the low power factor in the base case.

Following problems with voltage collapse due to the proposed use of parallel connection across 220 kV sources via 132 kV lines, the model was run with these long lines open on the Ampara to Valaichchenai circuit and the Anuradhapura to Puttalam circuits.

The outage of the Victoria - Randenigala 220 kV line causes overload of the 220/132 kV transformer at Rantembe up to 114% of the rated capacity. However the fact that the system is not islanding under these contingencies indicates an improvement on the present system.

The detailed results of the ranking studies are shown in Appendix A6.2.3.

6.5 System Extension and Reinforcement Plans up to 2010

6.5.1 Extension and Reinforcement of Transmission System

(1) Formulation of Plans

Necessity for additional installation of transformers with associated switchgear at existing substations and construction of new substations by 2010 were firstly prepared based on the Power Supply Matrix after implementation of the 2005 plan to expedite the power system analysis. Then, timings of implementation of addition of transformers and construction of new substations were reviewed by checking overload conditions of transformers with the help of the Power Supply Matrixes of the period of 2006 to 2010. Results of the review to dissolve overload conditions are summarized in Tables 6.4.1-1 and 6.4.1-2 as capacity factor of each substation before and after implementation of the plans.

It is found in the Study that the following eight substations are necessary by 2010 in addition to other new substations associated with the generation development discussed in (2) below. Transformer capacities mentioned below are for requirement up to 2010.

(a) Pannala substation (2 x 31.5 MVA, North-Western area by 2010)

(b) Imbulgoda substation (4 x 31.5 MVA, West-North area by 2008)

(c)	Kesbewa substation	(3 x 31.5 MVA, Western-South area by 2006)
(d)	Angoda substation	(3 x 31.5 MVA, Western-South area by 2009)
(e)	Boossa substation	(2 x 31.5 MVA, Southern area by 2009)
(f)	Aguruwela substation	(3 x 31.5 MVA, Savaragamuwa area by 2007)
(g)	Ehiliyagoda substation	(3 x 31.5 MVA, Savaragamuwa area by 2010)
(h)	B substation	(2 x 31.5 MVA, Colombo city by 2007)

In addition to the above substations, eight substations were planned up to 2010 to improve voltage profile and to promote rural electrification utilizing transformers replaced from existing substations.

(2) Transmission Network Extension Plans Associated with Generation Development

Major generating facilities scheduled by CEB in its generation expansion plan in the period of 2006 to 2010 are the following two power stations.

(a)	Trincomalee coal-fired	Eastern area, 3 x 300 MW by 2007, 2009 and 2010
(b)	Boossa combined-cycle	Southern area, 1 x 300 MW by 2008

A 220 kV line of double circuit construction is required for each project. Each line shall have transmission capacity corresponding to the final power station capacity of 1,200 MW for the Trincomalee project and 600 MW for the Boossa project, less consumption by station service and by nearby 132 kV systems.

(3) Extension and Reinforcement Plans Proposed in the Study

Table 6.5.1-3 and Fig. 6.5.1-1 are prepared to show the details of plans up to 2010 proposed by the Team. The following are supplemental explanations to the major schemes.

(a) Connection of the Trincomalee Coal Thermal Power Plant with the Power Network

Double circuit 220 kV transmission lines were planned in the two sections of Trincomalee - Colombo and Victoria - Colombo. Their particulars were determined taking into account the anticipated maximum sending power, the existing and planned 220 kV transmission lines, distances to the load center of Colombo, and system stability as well as system reliability to transmit full power even under one circuit outage. At the same time, connection with the 132 kV systems near the power stations was also planned.

The Trincomalee - Colombo line with 4 x Zebra conductors is planned to be terminated at the 220 kV Veyangoda substation, constructed for the Puttalam coal thermal power station. In order to improve stability of the long transmission line over 240 km, two switching stations were planned on the line, at Herbaria and Wariyapola. The Kotmale - Anuradhapura 220 kV line under construction is also to be connected with this line at the Herbaria switching station. This system is planned to be extended to Paddock to form a strong 220 kV tie for the supply to the Colombo area from the north and south.

The Victoria - Colombo line with 2 x Zebra conductors is planned to be connected to the Pannipitiya 220/132 kV substation via the new Paddock switching station. The right-of-way of the abandoned 66 kV transmission line will be available for use to this line. Construction plan of a 220/132 kV substation near the Polpitiya power station is planned to interconnect with the Laxapana 132 kV system and to improve reliability of the entire 220 kV and 132 kV power systems.

(b) Connection of New Boossa Combined Cycle Plant with the Power Network

Taking into account the planned final power station capacity of 600 MW and transmission distance of around 100 km, construction of a 220 kV double circuits transmission line with 2 x Zebra conductors to the Pannipitiya substation was planned to supply power to the Colombo area and a 132 kV transmission line to the New Galle substation to the Southern province. A new 220/132 kV substation was planned adjacent to the existing Matugama substation to support stable power supply to customers on the western coast.

(c) Aguruwella 132 kV Substation (2 x 31.5 MVA)

The existing Thulhiriya substation is T-branched from the 132 kV Polpitiya-Kolonnawa line. It was planned to construct a new substation near the line branching point, and to dissolve the T-branching and to share the increasing power demand of Thulhiriya and Kegalle.

Suspension of the construction plan of a substation planned in the Sithawakapura industrial complex is under review. Though the Sithawakapura substation is not constructed, power to the industrial complex will be able to be supplied from the Avissawella and Aguruwella substations. The latter may be constructed early depending on demand growth of the Kegalle, Thulhiriya and Avissawella substations.

(d) 132 kV Substations Planned in the Colombo Area

The area-wise power demand forecast was prepared based on the average annual growth rate of energy sold in the recent 10 years. Demand of Kelaniya covered by the Western-North branch office and Ratmalana and Sri Jaya'pura covered by the Western-South branch office have grown at high annual average growth rates of 17.4%, 11.4% and 12.0%, respectively. In the demand forecast, demand share of those three districts to the total demand of the country is estimated to become larger year by year from 26% in 1995 to 36% in 2010. Demand records of 11 branch offices in the past 10 years show that the annual growth rate of demand in the Western-North branch office ranks the 4th position and that in the Western-South branch office on the 6th position. Thus, it is understood that these three districts influence very much the total power demand of the metropolitan area.

Such result seems to be caused by the technique of area-wise demand forecast and unavoidable. As explained in Chapter 4, this is one of the reason that the extension and reinforcement plan of the transmission system, i.e. locations, capacities and construction times of substations, must be reviewed periodically or based on changes in country-wise demand forecast and the generation expansion plan.

The area-wise demand forecast and the nation-wise forecast were coordinated each other in this Study. Therefore, even if the area-wise demand distribution will change on the condition that the nation-wise demand will remain as forecast, capacities of the substations planned in this Study will not differ from the reviewed capacities, although times for addition of transformers and for construction of new substations or location of the substations may be revised more or less.

6.5.2 Power System Analysis of the 2010 System

(1) Study Cases

According to the generation expansion plan of CEB, in 2010 the share of hydro generating capacity against the total capacity will go down to about 30 %. Therefore, the base load portion will be covered by thermal power stations and hydro power stations will be operated for peak power supply. Then, the power flow was calculated only for one case without taking into account the seasonal variation of generation pattern in this stage. For the finally proposed system, 3-phase short circuit current was calculated on the 220 kV and 132 kV buses. The dynamic stability analysis was carried out for the conditions of 3-phase fault at the following points.

1) Trincomalee end of Trincomalee - Herbaria 220 kV line
2) Victoria end of Victoria - New Polpitiya 220 kV line
3) Boossa end of Boossa - Matugama 220 kV line

The conditions for reclosing are similar to those for the 2000 and 2005 cases. The power stations at which generator behaviors were observed are Puttalam, Victoria, Kelanitissa, Trincomalee and Boossa.

(2) System Data

The finally proposed system in 2010 according to the results of power system analysis and reliability assessment is illustrated in Fig. 6.5.2-1. All the system data to be modified from the 2005 system to the 2010 system and schedule of generator output are included in Appendix A6.1.4. Typical data of new generators for dynamic stability analysis are also included in the same Appendix. The forecast peak demand of each grid substation shown in Table 6.5.1-1 was used for the calculation.

(3) Results of 2010 Power System Analysis

(a) Power Flow Calculation

The results of power flow calculation on the proposed system in 2010 are shown in Fig. 6.5.2-2.

In order to satisfy the planning criteria for bus voltage and to keep the generator output in the available operation range, the following static capacitors need to be installed:

Substation Name	Capacity (kVA)
Ampara	10
Biyagama	60
Chunnakam (addition)	20(total 40)
Dehiwala	60
Inginiyagala	10
Kegalle	20
Kelaniya	60
Kolonnawa	120
Kotugoda (addition)	40(total 60)
Matugama	80
Thulhiriya	40
Valaichchenai	10

In view of overloading of the tie transformers under single contingency, the following 220/132 kV transformers were augmented.

Station Name	Rated Voltage (kV)	Addition (MVA)	Total (MVA)
Pannipitiya	220/132	1 x 250	3 x 250
Veyangoda	220/132	1 x 150	3 x 150
Kotugoda	220/132	1 x 250	3 x 250
New Chilaw	220/132	1 x 150	3 x 150
Biyagama	220/132	1 x 250	3 x 250

(b) Fault Calculation

As the result of fault calculation in 2010, 3-phase short circuit currents at 132 kV and/or 220 kV buses of each substation and power station are shown in Table 6.3.2-1 together with the rated braking current of the existing circuit breakers.

According to the result, from 2005 by 2010, the following circuit breakers need to be replaced with circuit breakers with larger breaking capacity.

Station Name	Rated Voltage (kV)	Rated Breaking Current (kA)	Fault Current (kA)
Anuradhapura	132	11.0	13.4
Kollupitiya	132	25.0	25.7
Trincomalee	132	12.5	13.3

(c) Dynamic Stability Analysis

As the result of analysis, Fig. 6.5.2-3 indicates the behaviors of the generator rotor angle, terminal voltage and output power of Puttalam, Victoria, Kelanitissa, Trincomalee and Boossa power stations, in the successful reclosing of the Trincomalee PS - New Herbaria 220 kV line. Fig. 6.5.2-4 shows the behaviors of the same parameters in the unsuccessful reclosing of the same line. In the similar manner, Figs. 6.5.2-5 and 6.4.2-6 show the behaviors of the same parameters as the above in the successful and unsuccessful reclosing of the Victoria - New Polpitiya 220 kV line. Figs. 6.5.2-7 and 6.5.2-8 show the same in the successful and unsuccessful reclosing of the Boossa - Matugama 220 kV line.

The largest deviation of the rotor angles appears at the first peak of the swing both for the successful and unsuccessful reclosing. The largest difference of rotor angle between Trincomalee and Victoria in the reclosing of Trincomalee PS - New Herbaria 220 kV line is 96 degrees.

Although the system is kept stable, the swings of the rotor angles are significantly large especially in the reclosing of the Trincomalee PS to New Herbarana line. In order to avoid system separation, it is recommended to study adoption of the high speed excitation system with a power system stabilizer (PSS) to the planned major power stations.

6.5.3 Supply Reliability Analysis of the 2010 System

The proposed power system for 2010 now has a strong backbone 220 kV ring system of double circuit lines. The load is now forecast to increase to 3,214 MW which with system losses calculated at 63 MW (1.92%) requires some 3,277 MW of generation.

Taking a single level of contingency analysis, there are no new major reliability problems with this proposed network provided 132 kV network splitting is correctly carried out. The new Victoria - Pannipitiya 220 kV backbone now can carry the Laxapana, Canyon and Wimalasurendra generation, connected through the New Polpitiya 220/132 kV substation. This gives improved levels of reliability, particularly in feeding Colombo's load.

It should be noted that the comments given under 2005 relating to paralleling of the 132 kV and 220 kV system are now a major problem across the northern part of the network. These have been covered in previous comments, but in modeling the system it is this model of the proposed power system that has the most problems with parallel networks across both voltage levels at peak load periods.

The overloading of the 220/132 kV transformer at Rantembe caused by the outage of the Victoria - Randenigala 220 kV line 103% of its rated capacity compared with the overload value of 114% for the 2005 system mentioned in Clause 6.4.3. It is obvious that there has been some improvement in system performance due to change in power factor.

The results of ranking analysis are shown in Appendix A6.2.4.

6.6 System Extension and Reinforcement Plans up to 2015

6.6.1 Extension and Reinforcement of Transmission System

(1) Formulation of Plans

As explained in Clause 6.5.1 (3), (d), the share of forecast demand of only three areas of Kelaniya, Ratmalana and Sri Jaya'pura is anticipated to grow further and will become as much as 39% of the national demand in 2015. The tendency of faster growth of power demand in certain particular areas becomes remarkable year by year. Therefore, for the period of 5 years from 2011 to 2015 the following studies were carried out through consultation with CEB.

Load estimated for each substation is the basic data of the system analysis. Substation loads in 2015 were computed from the Power Supply Matrix of 2010. Measures to dissolve overloads were examined by rearrangement of distribution feeders and installation of additional transformers at substations in 2010. Plans to add transformers were examined taking into account limitation in number of feeders for the substations. Table 6.6.1-1 shows results of those examinations. Substation loads in the table were hereafter used for the power system analysis and reliability analysis.

Development of large scale coal thermal plants is planned by CEB in the North-Western, Eastern and Southern Provinces located far from the Colombo area. It is supposed that the forecast demand of the Kelaniya, Ratmalana and Sri Jaya'pura areas in the Western-North and Western-South provinces will actually be distributed to other undeveloped vicinities and rural areas. In fact, there are a number of industrialization projects planned in rural areas, although actual execution plans of these projects have not been finalized at the present.

From the viewpoint of system analysis, it is general that far separation of major power sources and concentrated load centers would causes serious stability problems to the system. The power system analysis on the system configuration shown in Table 6.6.1-1 can be said as a severe side review.

For the overloaded substations whose conditions can not be solved even by adding transformers as referred to in Table 6.6.1-1, required total capacity of new substations for each area in the period of 2011 to 2015 was reviewed referring to the transition of substation capacity factor in each area obtained from the examination of regional demand forecasts for the period of 2000 to 2010. The study concluded necessity of the following 16 grid substations.

(a)	Northern area	Substation (2 x 31.5 MVA)	1 site
(b)	North-Western area	Substation (2 x 31.5 MVA)	2 sites
(c)	Western-North area	Substation (3 x 31.5 MVA)	6 sites
(d)	Western-South area	Substation (3 x 31.5 MVA)	4 sites
(e)	Savaragamuwa area	Substation (2 x 31.5 MVA)	2 sites
(f)	Southern area	Substation (2 x 31.5 MVA)	1 site

For each substation, some connecting transmission line is required. Exact location of each substation is not determined and a 2-circuit transmission line of 10 km in route length with the Zebra or Bear conductors was assumed for each substation to estimate project cost.

It is noted that the substations listed above will not always be constructed in the area as listed, but their locations, implementation timing and capacities shall finally be determined according to review of the plans on trend of the regional demand discussed in Clause 6.5.1 (3), (d).

Results of the studies disclose the overall capacity factor of substation transformers as shown below:

Transition of Capacity Factors of Substations

		1995	2000	2005	2010	2015
Maximum power	(MVA)	1,023	1,655	2,486	3,799	5,832
Transformer capacity	(MVA)	1,549	3,333	4,325	5,570	7,892
Capacity factor	(%)	66	50	57	68	74

(2) Extension Plan of Transmission Facilities in the Generation Expansion Plan

Major generation power plants scheduled by CEB in their development plan of power sources in the five years period of 2011 to 2015 are given below:

(a)	Trincomalee (coal-fired, No. 4 unit)	Eastern area, 300 MW by 2012
(b)	Boossa (combined-cycle, No. 2 unit)	Southern area, 300 MW by 2011
(c)	Mawella (coal-fired, No. 1 & No. 2 Units)	Southern area, 2 x 300 MW by 2013, 2014
(d)	Muthuragawella (combined-cycle, No. 2 unit)	Western-North area, 300 MW by 2015

Except for the Mawella power station, transmission facilities constructed up to 2010 are available and new generation additions and new facilities are not required. New transmission facilities were planned only for the Mawella project.

(3) Extension and Reinforcement Plans Proposed in the Study

Table 6.6.1-2 and Fig. 6.6.1-1 are prepared to show the details of the construction plans proposed by the Team up to 2015, except new grid substations commented in (1) above. Particulars of the transmission facilities for the Mawella project are as follows.

Two routes of 220 kV double circuit transmission line with 2 x Zebra conductors were planned to the load center of Colombo for power delivery of up to 1,200 MW (the planned maximum installed capacity of the power station), route distance, and system stability and reliability. One route is from the Mawella power station to the Boossa power station and therefrom to Colombo through the line constructed for the Boossa project. Another route is from the power station to the Padukka switching station passing through Savaragamuwa province. For raising the system stability, a new switching station was planned at the midpoint of the latter route.

6.6.2 Power System Analysis of the 2015 System

(1) Study Cases

The 2015 system for analysis was assumed to be same as the system configuration in 2010 except for the addition of the new 220 kV lines, Mawella PS to Padukka and Mawella PS to Boossa PS. The assumed system would not correctly represent actual configuration of the power network.

It is not possible to obtain reliable outcomes from such kind of study, and the only power flow analysis was carried out to examine the overview of the system problems in 2015. From the result of power flow calculation, only required additional capacities of 220/132 kV transformers and static capacitors for maintenance of system voltage were estimated.

(2) System Data

The system diagram of the 2015 system for power flow calculation is shown in Fig. 6.6.2-1. All the system data to be modified from the 2010 system to the 2015 system and generator output schedule are shown in Appendix A6.1.5. The load of each substation was the forecast peak demand in Table 6.6.1-1.

(3) Results of 2015 System Analysis

The results of power flow calculation in the stage of 2015 are shown in Figs 6.6.2-2. According to the result, static capacitors of 700 MVA in total are required for the system in the period from 2010 to 2015, and necessary augmentation of grid substation transformers in the same period in the system was estimated to be 1500 MVA in total.

6.6.3 Supply Reliability Analysis of the 2015 System

The power system for 2015 now shows a forecast load of 4,944 MW and losses of 104 MW (2.06%) giving a total forecast generation requirement of 5,048 MW.

The system configuration is virtually same as that for the 2010 system except addition of the Mawella power station and associated transmission circuits. The results of contingency analysis shows major potential problems caused by addition of about 1,700 MW load in the system.

The outage of one circuit of the 132 kV line between the Sapugaskanda PS and GSS results in overloading of the other circuit to 127% of the allowable value. Similarly, there is also overload problem in the Pannipitiya - Ratmalana 132 kV line, being 126% under the one circuit outage.

The detailed results of the ranking studies are shown in the Appendix A6.2.5.

Table 6.1.5 - 1 Subprojects Under Construction and Committed

Augmentation and Extension of Transmission System	Re-marks	Fund Source	Project Name	Commiss. Year
(1) Construction of Chilaw Substation				
a) T-connection line for Chilaw (2cct, 6.8km, Lynx)		IDA	PDTP	Completed
b) Chilaw (2x31.5MVA)		IDA	PDTP	Completed
(2) Construction of Badulla - Laxapana 132kV Transmission Line	a			
a) Laxapana - Badulla 132kV line (2cct, 74.2km, Lynx)		OECF	TSADP	Jul. 96
b) Badulla (two T/L bays for Laxapana line)		OECF	TSADP	Jul. 96
c) Badulla (1x31.5MVA addition)		OECF	TSADP	Jul. 96
(3) Construction of Nuwara Eliya Substation				
a) Nuwala Eliya (2x31.5MVA)		OECF	TSADP	Jun. 96
b) T-connection line for Nuwala Eliya (2cct, _km, Lynx)		OECF	TSADP	Jun. 96
(4) Construction of Avissawella Substation				
a) Avissawella (2x31.5MVA)		OECF	TSADP	Dec.96
b) T-connection line for Avissawela (2cct, 0.5km, Lynx)		OECF	TSADP	Dec.96
(5) 2nd Pi-connection for Kiribatkumbura Substation				
a) 2nd pi-connection line for Kiribatkumbra (2cct, 3.9km, Lynx)		CEB		Completed
b) Kiribatkumbra (two T/L bays for pi-connection arrangement)		Korean		1999
(6) Construction of Matara Substation				
a) Matara (2x31.5MVA)		OECF	TGDP	Nov.97
b) Embilipitiya - Matara 132kV line (2cct, 52km, Lynx)		OECF	TGDP	Nov.97
c) Embilipitiya (two T/L bays for Matara line)		OECF	TGDP	Nov.97
(7) 2nd Pi-connection for Ukuwela Substation				
a) 2nd pi-connection for Ukuwela (2cct, 11km, Lynx)		OECF	TGDP	Nov.97
b) Ukuwela (two T/L bays for pi-connection arrangement)		OECF	TGDP	Nov.97
(8) Constuction of 132kV Puttalam - Anuradhapura Line				
a) Puttalam - Anuradhapura (2cct, 75km, Lynx)		OECF	TGDP	Nov.97
b) Puttalam (two T/L bays for Anuradhapura line))		OECF	TGDP	Nov.97
c) Anuradhapura (two T/L bays for Puttalam line)	b	OECF	TGDP	Nov.97
(9) Reconductoring of 132kV Kotugoda - Bolawatta Line and Double Pi-Connection Arrangement for Bolawatta				
a) Kotugoda - Bolawatta 132kV line (2cct, 22km, Coyote to Zebra)		OECF	TGDP	Nov.97
b) Bolawatta (two T/L bays for pi-connection arrangement)	c	OECF	TGDP	Nov.97
(10) 2nd Pi-connection of Kotmale Power station				
a) T-off of Kotamale (2cct, 6.8km, Lynx)		IDA	SPDTP	Completed
b) Kotmale (two T/L bays for pi-connection arrangement)		IDA	SPDTP	Dec.96

Table 6.1.5 - 1 Subprojects Under Construction and Committed

Augmentation and Extension of Transmission System	Re-marks	Fund Source	Project Name	Commiss. Year
(11) 2nd Circuit of Rantembe - Badulla Line				
a) Rantembe - Badulla 132kV 2nd cct line (1cct(2cct const.), 33km, Lynx)		IDA	SPDTP	Jan.98
b) Rantembe (a T/L bay for Badulla line)		IDA	SPDTP	Dec.96
c) Badulla (a T/L bay for Rantembe line)		IDA	SPDTP	Dec.96
(12) Construction of Veyangoda Substation				
a) Veyangoda (2x31.5MVA)		ADB	SPSEP	Dec.98
b) Kotugoda - Veyangoda 132kV line (220kV design, 2cct, 20km, 2xZebra)	d	ADB	SPSEP	Dec.98
c) Kotugoda (two T/L bays for Veyangoda line)		ADB	SPSEP	Dec.98
(13) Reconductoring of 132kV Sapgaskanda - Biyagama Line				
a) Sapgaskanda - Biyagama 132kV line (2cct, 2.1km, Lynx to Zebra)		ADB	SPSEP	Dec.96
(14) Construction of 220kV New Anuradhapura Substation				
a) Kotmale - New Anuradhapura 220kV line (2cct,163km, Zebra)		IDA	SPDTP	Jan.99
b) New Anuradhapura (2x150MVA transformers)		NORAD	SPDTP	Jan.99
c) Kotmale (two T/L bays for New Anuradhapura line)		NORAD	SPDTP	Jan.99
d) Double pi-connection of Anuradhapura - Trinkomalee line	e	CEB	SPDTP	Jan.99
(15) Upgrading of 132kV Switchgear to 220kV of Kelanitissa Power Station				
a) Biyagama - Kelanitissa 220kV line (2cct, 2xGoat, 12.5km)	f	IDA	K-B220	Jun.98
b) Kelanitissa (GIS with 2x150MVA trans.)	g	IDA	K-B220	Jun.98
c) Biyagama (two 220kV T/L bays for Kelanitissa line)		IDA	K-B220	Jun.98
(16) Construction of Ampara Substation				
a) Inginiyagala - Ampara 132kV line (1cct, 25km, Lynx)	i	NORAD	SPDTP	Jan.98
b) Ampara (2x31.5MVA)		NORAD	SPDTP	Jan.98
c) Inginiyagala (a T/L bay for Ampara line)		NORAD	SPDTP	Jan.98
(17) Upgrading of 132kV Kolonnawa - Sapgaskanda - Kotugoda Line				
a) Kolonnawa - Kotugoda 132kV line (2cct, 28km, Coyote to Zebra)		ADB	SPSEP	Dec.98
b) Junction - Sapgaskanda line (2cct, 4.6km, Lynx to Zebra,)		ADB	SPSEP	Dec.98
(18) Construction of Sithawaka Substation				
a) Sithawaka (2x31.5MVA)		OECF		Mar.98
b) Single pi-connection for Sithawaka (deadend towers)		OECF		Mar.98
(19) Addition of Transformers				
19-1) Panipitiya (1x31.5MVA,Total 91.5MVA)		IDA	PDTP	Completed
19-2) Ratmalana (1x31.5MVA, Total 91.5MVA)		IDA	PDTP	Completed
19-3) ODSS Kolonnawa (2x31.5MVA, Total 123MVA)		OECF	TSADP	Sep.96
19-4) Sapgaskanda (1x31.5MVA, Total 121.5MVA)		ADB	SPSEP	Dec.98
19-5) Kiribatkumbura (1x31.5MVA, Total 3x31.5MVA)		ADB	SPSEP	Dec.98
19-6) Matugama (1x31.5MVA, Total 3x31.5MVA)		ADB	SPSEP	Dec.98
19-7) Bolawatta (1x31.5MVA, Total 3x31.5MVA)		ADB	SPSEP	Dec.98

Table 6.1.5 - 1 Subprojects Under Construction and Committed

Augmentation and Extension of Transmission System	Re-marks	Fund Source	Project Name	Commiss. Year
19-8) Fort (1x30MVA, Total 3x30MVA)		CEB		
19-9) Kollipitiya (1x30MVA, Total 3x30MVA)		KfW		Dec.97
19-10) Thulhiliya (1x31.5MVA, Total 3x31.5MVA)		KfW		Dec.97
(20) Replacement of Transformers				
20-1) Puttalam (2x10MVA to 2x31.5MVA)		OECF	TSADP	Completed
20-2) Anuradhapura (2x10MVA to 2x31.5MVA)		CEB		Dec.96
20-3) Habarana (2x10MVA to 2x31.5MVA)		Korean	PSDP	Dec.98
20-4) Balangoda (2x10MVA to 2x31.5MVA)		Korean	PSDP	1999
20-5) Trincomalee (2x10MVA to 2x31.5MVA)		Korean	PSDP	1999
20-6) Embilipitiya (2x10MVA to 2x31.5MVA)		ADB	SPSEP	Dec.98
20-7) Kurunegara (2x16MVA to 2x31.5MVA)		ADB	SPSEP	Dec.98
20-8) Valaichchenai (2x10MVA to 2x31.5MVA)		ADB	SPSEP	Dec.98
(21) Var Compensator				
21-1) Kotugoda (20MVA)		NORAD	Norad	Dec.98
(22) Static Capacitor				
22-1) Kiribatkumbura (10MVA)		ADB	SPSEP	Dec.98
22-2) Kurunegala (10MVA)		ADB	SPSEP	Dec.98
22-3) Habarana (10MVA)		ADB	SPSEP	Dec.98
22-4) Kelanitissa(45MVA)	h	ADB	SPSEP	Dec.98

Remarks:

1) Project Name
   TSADP : Transmission System Augmentation and Development Project (OECF)
   TGDP : Transmission and Grid Substation Development Project (OECF)
   PDTP : Power Distribution and Transmission Project (IDA)
   SPDTP : Second Power Distribution and Transmission Project (IDA)
   SPSEP : (ADB)
   K-B220 : (IDA)

2) (a) Two T/L bays of Laxapana power station for Badulla line had been constructed under other project prior to the TSADP.
   (b) For Puttalam-Anuradhapura line, the existing Chunnakam line bays were scheduled to be used. However,two new T/L bays for the line are decided to be additionally constructed under the TGSDP.
   (c) A new line is planned to be constructed along the existing 132 kV line and the existing one is moved after the completion.
   (d) Kotugoda-Veyangoda line is proposed to be 220kV design, 2-cct with 2xZebra for future reinforcement and extension of the system, instead of original 132kV line with Lynx.
   (e) New Anuradhapura-Anuradhapura line is proposed to be newly constructed instead of originally planned double pi-connection of the existing Anuradhapura-Trincomalee line for transmitting bulk power to the 132kV system.
   (f) The existing towers are designed as 220kV ones, but number of discs of suspension insulators only will be increased.
   (g) Two T/L bays for extension 220kV system to Kolonnawa shall be provided for future easy arrangement.
   (h) Static capacitor of 60MVA is needed instead of presently planned 45MVA under ADB finance.
   (i) Site of Ampara GSS should be slightly shifed towards Kalmunai.

Table 6.3.1 - 1 Over Load Factor of Transformers of Grid Substations In The Year 2000

Provinces	Grid Substations	Voltage Ratio (kV)	Before Reinforcement Trans. Cap. (MVA)	Before Reinforcement Peak Load (MW)	Before Reinforcement Peak Cap. (MVA)	Before Reinforcement Load (%)	After Reinforcement Trans. Cap. (MVA)	After Reinforcement Peak Load (MW)	After Reinforcement Peak Cap. (MVA)	After Reinforcement Load (%)	Countermeasures
North Centraal	(1) Anuradhapura	132/33	63	25.8	28.7	46	63	25.8	28.7	46	
	(2) Habarana	132/33	63	21.6	24.0	38	63	21.6	24.0	38	
Northern	(3) Chunnakam	132/33	70	25.8	28.7	41	70	25.9	28.8	41	
	(4) Kilinochchi	132/33	10	6.2	6.9	69	10	6.2	6.9	69	
Central	(5) Kiribathkumbura	132/33	94.5	39.3	43.7	46	94.5	42.0	46.7	49	
	(6) Ukuwela	132/33	30	32.1	35.7	119	63	32.1	35.7	57	Replace of transformers
	(7) Rantembe	-/132/3	20	7.6	8.4	42	20	7.6	8.4	42	
	(8) Nuwara Eliya	132/33	63	23.5	26.1	41	63	23.5	26.1	41	Under construction
	(9) Wimalasurendra	132/33	63	14.9	16.6	26	63	14.9	16.6	26	
Nortth Western	(10) Kurunegala	132/33	63	29.6	32.9	52	63	29.6	32.9	52	
	(11) Puttalam	132/33	63	17.4	19.3	31	63	17.4	19.3	31	
	(12) Bolawatta	132/33	91.5	53.5	59.4	65	91.5	53.5	59.4	65	
	(13) Chilaw	132/33	63	22.3	24.8	39	63	32.9	36.6	58	Completed
Western-North	(14) Kotugoda	220/132/33	120	49.5	55.0	46	120	49.5	58.2	49	
	(15) Sapugaskanda	132/33	121.5	123.2	136.9	113	121.5	80.3	94.5	78	
	(16) Biyagama	220/132/33	120	79.7	88.6	74	120	50.3	59.2	49	
	(17) Veyangoda	132/33	63	15.9	17.7	28	63	17.5	20.6	33	Committed
	(18) Aniyakanda	132/33	63	23.1	25.7	41	63	23.1	27.2	43	New construction
	(19) Kelaniya	132/33					126	71.5	84.1	67	New construction
Easterrn	(20) Trincomalee	132/33	63	17.8	19.8	31	63	17.8	19.8	31	
	(21) Inginiyagara	132/33	30	1.5	1.7	6	30	1.5	1.7	6	
	(22) Valaichchenai	132/33	63	12.3	13.7	22	63	12.3	13.7	22	
	(23) Ampara	132/33	63	11.0	12.2	19	63	11.0	12.2	19	Committed
Western-South	(24) Ratmalana	132/33	91.5	100.9	112.1	123	91.5	60.6	71.3	78	
	(25) Pannipitiya	132/33	91.5	88.6	98.4	108	91.5	65.9	77.5	85	
	(26) O.D.S.S(Kolonnawa)	132/33	123	55.6	61.8	50	94.5	55.7	65.5	69	Planned(Renovation)
	(27) Matugama	132/33	94.5	16.8	18.7	20	94.5	16.8	19.8	21	
	(28) Avissawella	132/33	63	15.8	17.6	28	63	15.8	18.6	30	Under construction
	(29) Panadura	132/33	63	28.4	31.6	50	63	28.4	33.4	53	
	(30) Sithawaka	132/33	63	13.3	14.8	23	63	16.2	19.1	30	Under construction
	(31) Athurugiriya	132/33	63	21.5	23.9	38	63	24.6	28.9	46	New construction
	(32) Sri Jaya'pura	132/33	63	36.6	40.7	65	63	39.1	46.0	73	New construction
	(33) Dehiwala	-/132/33					126	55.5	65.3	52	New construction
Southern	(34) Galle	132/33	60	44.3	49.2	82	63	44.3	49.2	78	
	(35) Deniyaya	132/33	30	15.1	16.8	56	30	15.2	16.9	56	
	(36) Matara	132/33	63	33.1	36.8	58	63	33.1	36.8	58	Under construction
	(37) New Galle	132/33	63	44.3	49.2	78	63	44.3	49.2	78	New construction
Uva	(38) Badulla	132/33	94.5	23.1	25.7	27	94.5	23.1	25.7	27	
Sabaragamuwa	(39) Balangoda	132/33	63	10.9	12.1	19	63	10.9	12.1	19	
	(40) Thulhiriya	132/33	94.5	70.1	77.9	82	94.5	51.8	57.6	61	
	(41) Embilipitiya	132/33	63	10.3	11.4	18	63	10.3	11.4	18	
	(42) Ratnapura	132/33	63	21.4	23.8	38	63	21.4	23.8	38	New construction
Colombo	(43) Kelanitissa(KTS)	132/33	120	41.1	45.7	38	120	41.1	48.4	40	
	(44) Sub-E(Kollipitiya)	132/11	90	34.4	58.8	65	90	34.4	62.3	69	
	(45) Sub-F(Fort)	132/11	90	23.3	51.8	58	90	23.3	54.8	61	
	TOTAL		3,073.0	1,402.5	1,604.8	52	3332.5	1,399.6	1,654.6	50	

Remarks: a) Load factor for calculation of peak load in MVA is assumned as 85% for Western-North, Western-South and Colombo and 90% for other areas.

b) Peak load in MVA of Kollipitiya and Fort grid substations is calculated in the basis of day-time peak, i.e 0.65 for Kollipitiya and 0.5 for Fort.

Table 6.3.1 - 2 Proposed New Subprojects for Transmission System up to The Year 2000

Subprojects for Augmentation and Extension	Remarks	Proposed Commiss. Year
(1) Upgrading of 132kV Biyagama - Pannipitiya Line to 220kV		
a) Upgrading of Biyagama - Panipitiya 132kV line to 220kV (2cct, 15.5km, 2xZebra)	a	2000
b) Biyagama (two 220kV T/L bays for Pannipitiya line)		
c) Pannipitiya (2x250MVA, two 220kV T/L bays for Biyagama line)		
(2) Reconductoring of Kolonnawa - Pannipitiya 132kV Line		2000
a) Kolonnawa - Panipitiya 132kV line (2cct, 13km, Lynx to Zebra)		
(3) Construction of Sapugaskanda GSS - KHD 132kV Line		1998
a) Sapugaskanda GSS - KHD 132kV line (2cct, 1.0km, Lynx)		
b) Sapugaskanda GSS (two 132kV T/L bays for KHD line)		
(4) Upgrading of Sapugaskanda P/S - Sapugaskanda GSS 132kV Line		1998
a) Removal of the existing 132kV line (1cct, 1.5km, Lynx)		
b) Construction of 132kV line (2cct, 1.5km, Zebra)		
c) Sapugaskanda P/S (one 132kV T/L bay for Sapugaskanda GSS line)		
d) Sapugaskanda GSS (one 132kV T/L bay for Sapugaskanda P/S line)		
(5) Construction of Ratnapura 132 kV Substation	g	1998
a) Ratnapura (2x31.5MVA)		
b) Balangoda - Ratnapura 132kV line (2cct, 40km, Zebra)		
c) Balangoda (two 132kV T/L bays for Ratnapura line)		
(6) Construction of Aniyakanda 132 kV Substation		1998
a) Aniyakanda (2x31.5MVA)		
b) Double pi-connection for Aniyakanda (2x2cct, 0.2km, Zebra)		
(7) Construction of Athurugiriya 132 kV Substation		1998
a) Athurugiriya (2x31.5MVA)		
b) Triple pi-connection for Athurugiriya (3x2cct, 0.1km, Lynx)		
(8) Construction of Sri Jaya'pura 132 kV Substation		1998
a) Sri Jaya'pura (2x31.5MVA)		
b) Double pi-connection for Sri Jaya'pura (2x2cct, 0.1km, Zebra)		
(9) Construction of New Galle 132 kV Substation	b	2000
a) New Galle (2x31.5MVA)	c	
b) Double pi-connection of New Galle (2x2cct, 0.1km, Lynx)		
(10) Construction of Matugama - New Galle 132kV Line	b	2000
a) Matugama - New Galle 132kV line (2cct, 64km, Zebra)		
b) Matugama (two 132kV T/L bays for New Galle line)		
c) New Galle (two 132kV T/L bays for Matugama line)		
(11) Construction of Kelaniya 132kV GIS	d	2000
a) Kelaniya (2x63MVA)		
b) Triple pi-connection for Kelaniya (3x2cct, 0.1km, Zebra)		
(12) Construction of 132kV Dehiwala Substation		2000
a) Pannipitiya - Dehiwala 132kV line (220kV construction,2cct, 8km, 2xZebra)		
b) Dehiwala (132/33kV:2x63MVA)	c	
c) Pannipitiya (two 132kV T/L bays for Dehiwala line)		

Table 6.3.1 - 2 Proposed New Subprojects for Transmission System up to The Year 2000

Subprojects for Augmentation and Extension	Re-marks	Proposed Commiss. Year
(13) Power Transmission Facilities Related to Muthuragawella Combined Cycle Power Plants		
13-1) Construction of Muthuragawella - Kotugoda 220kV Line		2000
a) Muthuragawella - Kotugoda 220kV line (2cct, 18.0km, 2xZebra)		
b) Kotugoda (two 220kV T/L bays for Muthuragawella line)		
13-2) Rearrangement of Kotugoda 220kV Switchgear	f	2000
(14) Rehabilitation of Kolonnawa Substation		1998
a) Replacement of transformers (3x30MVA to 1x31.5MVA)		
b) Renovation of 132kV switchgears (except for CB)		
c) Renovation of 33kV switchgears		
d) Renovation of control and relay panels for 132kV and 33kV systems		
e) Removal of 66kV and 11kV equipment		
(15) Construction of Valaichchenai - Ampara 132kV Line		1998
a) Valaichchenai - Ampara 132kV line (1cct, 75km, Lynx)		
b) Valaichchenai (one 132kV T/L bay for Ampara line)		
c) Ampara (one 132kV T/L bay for Valaichchenai line)		
(16) Replacement of Transformers		
16-1) Ukuwela (2x15MVA to 2x31.5MVA)		1998
New Subprojects Proposed by Power System Analysis		
(17) Static Capacitor		
17-1) Pannipitiya (100MVA)		2000
17-2) Kelanitissa (total 60MVA)		1998
(18) Replacement of 132kV Circuit Breakers		
18-1) Kolonnawa (20kA to 40kA, 2 sets)		1998
18-2) Sapgaskanda GSS (15.3kA and 11kA to 40kA, 6 sets)		1998

Remarks:

(a) The existing 132kV line has been designed for 220kV.
(b) The existing Galle GSS has no space for the further extension of the 132kV switchyard (but addition of transformers is possible).
(c) Two units of gas turbine of 35MW is planned to be constructed in future for supplying peak power in Southern Area.
(d) The site is proposed to be near the junction point of Kolonnawa - Kotugoda - Sapgaskanda lines in order to dissolve the existing T-connection.
(e) In future 132kV system extension from this substation is needed to supply bulk power to Colombo city area. Therefore, convensional type of substation is preferable for easy arrangement in future.
(f) Kotugoda - Veyangoda 132kV line is planned to be upgraded to 220kV in future.
(g) Bus arrangement is proposed to be reconsidered after detail tophographic survey.

Table 6.3.2-1
Rated Breaking Current of Existing Circuit Breakers and Calculated Three Phase Short Circuit Current (1/4)

Grid Substations and Power Stations		Rated Voltage (kV)	Rated Breaking Current of Existing Circuit Breaker as of Dec. 1995 (kA)		Calculated Three Phase Short Circuit Current, Year of Calculation Stage 2000 (kA)	2005 (kA)	2010 (kA)
1 Aguruwella		132			-	-	16.7
2 Ambalangoda		132			-	7.9	12.2
3 Ampara		132			2.0	2.0	2.1
4 Angoda		132			-	-	21.0
5 Aniyakanda		132			16.2	17.6	20.4
6 Anuradhapura	(1)	132	existing	20.0	7.2	8.8	13.4
	(2)	132	existing	15.5	7.2	8.8	13.4
	(3)	132	existing	11.0	7.2	8.8	13.4 *
7 Athurugiriya		132			14.9	15.4	17.1
8 Avissawella		132			12.0	12.2	8.3
9 Badulla	(1)	132	existing	31.5	6.4	6.7	6.9
	(2)	132	existing	25.0	6.4	6.7	6.9
10 Balangoda		132	existing	31.5	8.4	11.2	14.4
11 Biyagama		220	existing	40.0	14.9	17.7	22.7
12 Biyagama		132	existing	31.5	19.5	19.1	23.8
13 Bolawatta	(1)	132	existing	27.5	8.9	13.1	14.8
	(2)	132	existing	25.0	8.9	13.1	14.8
14 Boossa P/S		220			-	-	11.7
15 Boossa P/S		132			-	-	14.7
16 Bowatenna P/S		132	existing	12.5	3.6	3.7	4.4
17 Canyon P/S	(1)	132	existing	40.0	9.4	9.9	11.0
	(2)	132	existing	25.0	9.4	9.9	11.0
18 Chilaw		132			5.9	12.1	13.8
19 Chunnakam		132	existing	n.a.	1.1	1.4	1.7
20 Dehiwala		220			11.0	12.3	18.0
21 Deniyaya	(1)	132	existing	27.5	3.6	4.4	5.2
	(2)	132	existing	25.0	3.6	4.4	5.2
	(3)	132	existing	11.0	3.6	4.4	5.2
22 Eheliyagoda		132			-	-	10.8
23 Embilipitiya	(1)	132	existing	31.5	4.0	6.1	7.3
	(2)	132	existing	25.0	4.0	6.1	7.3
24 Fort		132	existing	25.0	20.8	14.8	16.2
25 Galle	(1)	132	existing	40.0	3.5	6.3	10.2
	(2)	132	existing	11.0	3.5	6.3	10.2
	(3)	132	existing	10.9	3.5	6.3	10.2

Note :
1) "n.a." means that data is not available.
2) " * " means that the calculated short circuit current is beyond the rated breaking current of the circuit breakers.

Table 6.3.2-1
Rated Breaking Current of Existing Circuit Breakers and Calculated Three Phase Short Circuit Current (2/4)

Grid Substations and Power Stations		Rated Voltage (kV)	Rated Breaking Current of Existing Circuit Breaker as of Dec. 1995 (kA)		Calculated Three Phase Short Circuit Current, Year of Calculation Stage 2000 (kA)	2005 (kA)	2010 (kA)
26 Habarana	(1)	132	existing	25.0	4.0	4.3	5.5
	(2)	132	existing	20.0	4.0	4.3	5.5
	(3)	132	existing	11.0	4.0	4.3	5.5
27 Hambantota		132			-	4.4	5.0
28 Horana		132				7.8	8.6
29 Imbulgoda		132			-	-	16.0
30 Inginiyagara		132	existing	12.5	2.1	2.2	2.3
31 Katana		132			-	14.2	16.4
32 Kegalla		132			-	7.5	8.2
33 Kelanitissa P/S		220			13.9	16.4	19.9
34 Kelanitissa P/S	(1)	132	existing	31.5	24.0	16.4	17.6
	(2)	132	existing	25.0	24.0	16.4	17.6
35 Kelaniya		132			21.7	22.1	26.4
36 Kesbewa		132			-	-	18.1
37 KHD P/S		132			20.5	20.7	24.6
38 Kilinochchi	(1)	132	existing	15.3	1.2	2.4	4.4
	(2)	132	existing	11.0	1.2	2.4	4.4
39 Kiribathkumbura		132	existing	25.0	7.1	7.3	9.5
40 Kollupitiya		132	existing	25.0	20.9	21.9	25.7 *
41 Kolonnawa		220			-	16.0	19.3
42 Kolonnawa	(1)	132	existing	31.5	24.4	24.1	28.9
	(2)	132	existing	20.0	24.4 *	24.1 *	28.9 *
43 Kotmale P/S		220	existing	40.0	12.2	13.3	18.0
44 Kotmale P/S		132	existing	n.a.	8.8	9.2	11.2
45 Kotugoda		220	CB not installed		12.0	16.0	20.3
46 Kotugoda	(1)	132	existing	40.0	14.7	17.5	21.6
	(2)	132	existing	31.5	14.7	17.5	21.6
47 Kukule P/S		132			-	8.7	13.0
48 Kuliyapitiya		132			-	9.5	10.5
49 Kurunegala		132	existing	25.0	4.1	4.2	4.8
50 Laxapana P/S		132	existing	31.5	17.1	18.9	24.6
51 Matale		220			-	-	12.6
52 Matale		132			-	-	14.5
53 Matara		132			2.5	5.9	8.1
54 Matugama		220			-	-	14.9
55 Matugama		132	existing	40.0	4.0	9.8	18.5

Note :
1) "n.a." means that data is not available.
2) " * " means that the calculated short circuit current is beyond the rated breaking current of the circuit breakers.

Table 6.3.2-1
Rated Breaking Current of Existing Circuit Breakers and Calculated Three Phase Short Circuit Current (3/4)

Grid Substations and Power Stations		Rated Voltage (kV)	Rated Breaking Current of Existing Circuit Breaker as of Dec. 1995 (kA)		Calculated Three Phase Short Circuit Current, Year of Calculation Stage: 2000 (kA)	2005 (kA)	2010 (kA)
56 Medegama		132			-	3.6	3.7
57 Muthuragawella P/S		220			10.6	13.2	16.2
58 New Anuradhapura		220			4.5	5.2	8.7
59 New Anuradhapura		132			7.2	8.8	13.3
60 New Chilaw		220			-	14.1	15.9
61 New Chilaw		132			-	15.7	18.8
62 New Galle P/S		132			4.0	7.8	14.7
63 New Habarana		220			-	-	14.6
64 New Laxapana P/S	(1)	132	existing	40.0	17.2	19.0	24.7
	(2)	132	existing	31.5	17.2	19.0	24.7
65 New Polpitiya		220			-	-	16.9
66 New Polpitiya		132			-	-	26.9
67 Nuwara Eliya		132			7.8	8.1	8.6
68 Oruwala		132	existing	n.a.	13.0	13.4	14.6
69 Padukka		220			-	-	20.2
70 Palekelle		132			-	5.2	7.3
71 Panadura		132			5.4	12.9	13.6
72 Pannala		132			-	-	10.8
73 Pannipitiya		220			12.2	13.8	21.4
74 Pannipitiya		132	existing	31.5	18.8	20.6	27.3
75 Polonnaruwa		132			-	2.5	2.8
76 Polpitiya P/S		132	existing	n.a.	17.5	19.3	27.3
77 Puttalam		132	existing	25.0	5.0	12.6	13.2
78 Puttalam P/S		220			-	15.7	14.8
79 Puttalam P/S		132			-	14.8	14.8
80 Randenigala P/S		236	existing	31.5	8.6	8.9	11.4
81 Rantembe P/S		220	existing	25.0	8.1	8.5	10.6
82 Rantembe P/S		138	existing	25.0	6.1	6.4	6.6
83 Ratmalana	(1)	132	existing	31.5	13.8	14.8	17.9
	(2)	132	existing	25.0	13.8	14.8	17.9
84 Ratnapura		132			4.4	8.1	12.9
85 Samanalawewa P/S		132	existing	31.5	7.3	9.4	11.3
86 Sapugaskanda	(1)	132	existing	25.0	20.1	20.2	24.6
	(2)	132	existing	15.3	20.1 *	20.2 *	24.6 *
	(3)	132	existing	11.0	20.1 *	20.2 *	24.6 *
87 Sapugaskanda P/S		142	existing	n.a.	18.1	4.3	24.2

Note :
1) "n.a." means that data is not available.
2) " * " means that the calculated short circuit current is beyond the rated breaking current of the circuit breakers.

Table 6.3.2-1
Rated Breaking Current of Existing Circuit Breakers and Calculated Three Phase Short Circuit Current (4/4)

Grid Substations and Power Stations		Rated Voltage (kV)	Rated Breaking Current of Existing Circuit Breaker as of Dec. 1995 (kA)		Calculated Three Phase Short Circuit Current, Year of Calculation Stage 2000 (kA)	2005 (kA)	2010 (kA)
88 Sithawaka		132			9.7	9.9	11.7
89 Sri Jaya'pura		132			20.3	21.0	25.7
90 Sub-B		132			-	-	17.2
91 Thulhiriya		132	existing	11.0	6.5	11.7	13.5
92 Town Hall		132			-	22.6	26.8
93 Trincomalee	(1)	132	existing	25.0	2.3	2.4	13.3
	(2)	132	existing	15.3	2.3	2.4	13.3
	(3)	132	existing	12.5	2.3	2.4	13.3 *
94 Trincomalee P/S		220			-	-	15.3
95 Trincomalee P/S		132			-	-	13.7
96 Ukuwela		132	existing	25.0	6.5	6.7	10.7
97 Valaichchenai		132	existing	n.a.	1.9	2.0	2.1
98 Vavunia		132			-	4.0	5.5
99 Veyangoda		220			-	14.7	21.1
100 Veyangoda		132			9.3	14.2	19.4
101 Victoria P/S		236	existing	25.0	10.7	11.3	17.0
102 Wariyapola		220			-	-	13.2
103 Wimalasurendra	(1)	132	existing	31.5	14.1	15.2	18.6
	(2)	132	existing	25.0	14.1	15.2	18.6

Note :
1) "n.a." means that data is not available.
2) " * " means that the calculated short circuit current is beyond the rated breaking current of the circuit breakers.

Table 6.4.1 - 1 Over Load Factor of Transformers of Each Grid Substation in The Year 2005

Provinces	Grid Substations	Voltage Ratio (kV)	Before Reinforcement Trans. Cap. (MVA)	Peak Load (MW)	Peak Cap. (MVA)	Load ?	After Reinforcement Trans. Cap. (MVA)	Peak Load (MW)	Peak Cap. (MVA)	Load ?	Countermeasures
North Centraal	(1) Anuradhapura	132/33	63	32.0	35.6	56	63	32.3	35.9	57	
	(2) Habarana	132/33	63	24.0	26.7	42	63	24.2	26.9	43	
	(3) Polonnaruwa	132/33	32	14.3	15.9	50	32	14.4	16.0	50	
Northern	(4) Chunnakam	132/33	70	49.3	54.8	78	70	49.7	55.2	79	
	(5) Kilinochchi	132/33	10	9.8	10.9	109	20	9.9	11.0	55	Addition of transformer
	(6) Vavunia	132/33	10	6.7	7.4	74	10	6.8	7.6	76	New construction
Central	(7) Kiribathkumbura	132/33	94.5	47.4	52.7	56	94.5	36.5	40.6	43	
	(8) Ukuwela	132/33	63	38.8	43.1	68	63	32.0	35.6	56	
	(9) Rantembe	-/132/3	20	7.4	8.2	41	20	7.5	8.3	42	
	(10) Nuwara Eliya	132/33	63	30.3	33.7	53	63	30.6	34.0	54	
	(11) Wimalasurendra	132/33	63	18.0	20.0	32	63	18.2	20.2	32	
	(12) Palekelle	132/33	63	14.9	16.6	26	63	21.9	24.3	39	New construction
North Western	(13) Kurunegala	132/33	63	30.6	34.0	54	63	30.8	34.2	54	
	(14) Puttalam	132/33	63	26.7	29.7	47	63	33.3	37.0	59	
	(15) Bolawatta	132/33	91.5	46.1	51.2	56	91.5	46.5	51.7	56	
	(16) Chilaw	132/33	63	49.8	55.3	88	63	45.5	50.6	80	
	(17) Kuliyapitiya	132/33	63	43.5	48.3	77	63	43.9	48.8	77	New construction
Western-North	(18) Kotugoda	-/132/33	120	63.9	75.2	63	120	60.6	71.3	59	
	(19) Sapugaskanda	132/33	121.5	144.7	170.2	140	121.5	87.7	103.2	85	
	(20) Biyagama	-/132/33	120	86.6	101.9	85	120	72.4	85.2	71	
	(21) Veyangoda	132/33	63	21.3	25.1	40	63	21.5	25.3	40	
	(22) Aniyakanda	132/33	63	34.5	40.6	64	63	34.8	40.9	65	
	(23) Kelaniya	132/33	126	126.1	148.4	118	126	82.7	97.3	77	Addition of transformer
	(24) Muthuragawella	220/33					126	40.9	48.1	38	New construction
	(25) Gonawala	132/33					94.5	50.5	59.4	63	New construction
	(26) Katana	132/33	63	29.6	32.9	52	63	29.9	33.2	53	New construction
Easterrn	(27) Trincomalee	132/33	63	23.2	25.8	41	63	23.4	26.0	41	
	(28) Inginiyagara	132/33	30	0.6	0.7	2	30	0.6	0.7	2	
	(29) Valaichchenai	132/33	63	8.8	9.8	16	63	8.9	9.9	16	
	(30) Ampara	132/33	63	14.6	16.2	26	63	14.8	16.4	26	
Western-South	(31) Ratmalana	132/33	91.5	81.8	96.2	105	123	76.0	89.4	73	Addition of transformer
	(32) Pannipitiya	132/33	91.5	70.7	83.2	91	123	66.6	78.4	64	Addition of transformer
	(33) O.D.S.S(Kolonnawa)	132/33	94.5	109.2	128.5	136	157.5	96.4	113.4	72	Addition of transformer
	(34) Matugama	132/33	94.5	16.9	19.9	21	94.5	17.1	20.1	21	
	(35) Avissawella	132/33	63	26.8	31.5	50	63	27.0	31.8	50	
	(36) Panadura	132/33	63	40.4	47.5	75	63	40.8	48.0	76	
	(37) Sithawaka	132/33	63	22.6	26.6	42	63	19.8	23.3	37	
	(38) Athurugiriya	132/33	63	29.9	35.2	56	63	30.9	36.4	58	
	(39) Sri Jaya'pura	132/33	63	86.8	102.1	162	126	72.0	84.7	67	Addition of transformer
	(40) Dehiwala	-/132/33	126	77.7	91.4	73	126	88.9	104.6	83	
	(41) Horana	132/33	63	19.9	22.1	35	63	20.0	23.5	37	New construction
Southern	(42) Galle	132/33	91.5	52.0	57.8	63	91.5	52.5	58.3	64	
	(43) Deniyaya	132/33	30	20.9	23.2	77	30	21.1	23.4	78	
	(44) Matara	132/33	63	40.4	44.9	71	63	40.8	45.3	72	
	(45) New Galle	132/33	63	51.9	57.7	92	94.5	52.4	58.2	62	Addition of transformer
	(46) Ambalangoda	132/33	63	23.5	26.1	41	63	23.7	26.3	42	New construction
	(47) Hambantota	132/33	20	9.9	11.0	55	20	10.0	11.1	56	New construction
Uva	(48) Badulla	132/33	94.5	27.7	30.8	33	94.5	28.0	31.1	33	
	(49) Medagama	132/33	10	3.4	3.8	38	10	3.4	3.8	38	New construction
Sabaraga-muwa	(50) Balangoda	132/33	63	12.4	13.8	22	63	12.5	13.9	22	
	(51) Thulhiriya	132/33	94.5	81.3	90.3	96	94.5	48.4	53.8	57	
	(52) Embilipitiya	132/33	63	6.9	7.7	12	63	7.0	7.8	12	
	(53) Ratnapura	132/33	63	40.4	44.9	71	63	40.4	44.9	71	
	(54) Kegalle	132/33					63	44.5	49.4	78	New construction
Colombo	(55) Kelanitissa(KTS)	132/33	120	32.6	38.4	32	120	43.9	51.6	43	
	(56) Sub-E(Kollipitiya)	132/11	90	27.6	50.0	56	90	27.9	50.5	56	
	(57) Sub-F(Fort)	132/11	90	31.2	73.4	82	90	31.5	74.1	82	
	(58) Town Hall	132/11					126	31.5	74.1	59	New construction
TOTAL			3748	2088	2448	65	4388	2088	2486	57	

Remarks:
a) Load factor for calculation of peak load in MVA is assummed as 85% for Western-North, Western-South and Colombo and 90% for other areas.
b) Peak load in MVA of Kollipitiya and Fort grid substations is calculated in the basis of day-time peak, i.e 0.65 for Kollipitiya and 0.5 for Fort.

Table 6.4.1 - 2 Over Load Factor of Transformers of Grid Substation by Year between 2000 and 2005

Provinces	Grid Substations	2000 After Reinforcement Trans. Cap. (MVA)	2000 After Peak Load (MW)	2000 After Peak Cap. (MVA)	2000 After Over Load (%)	2001 Before Reinforcement Trans. Cap. (MVA)	2001 Before Peak Load (MW)	2001 Before Peak Cap. (MVA)	2001 Before Over Load (%)	2001 After Reinforcement Trans. Cap. (MVA)	2001 After Peak Load (MW)	2001 After Peak Cap. (MVA)	2001 After Over Load (%)	2002 Before Reinforcement Trans. Cap. (MVA)	2002 Before Peak Load (MW)	2002 Before Peak Cap. (MVA)	2002 Before Over Load (%)	2002 After Reinforcement Trans. Cap. (MVA)	2002 After Peak Load (MW)	2002 After Peak Cap. (MVA)	2002 After Over Load (%)	2003 Before Reinforcement Trans. Cap. (MVA)	2003 Before Peak Load (MW)	2003 Before Peak Cap. (MVA)	2003 Before Over Load (%)	2003 After Reinforcement Trans. Cap. (MVA)	2003 After Peak Load (MW)	2003 After Peak Cap. (MVA)	2003 After Over Load (%)	2004 Before Reinforcement Trans. Cap. (MVA)	2004 Before Peak Load (MW)	2004 Before Peak Cap. (MVA)	2004 Before Over Load (%)	2004 After Reinforcement Trans. Cap. (MVA)	2004 After Peak Load (MW)	2004 After Peak Cap. (MVA)	2004 After Over Load (%)	2005 After Reinforcement Trans. Cap. (MVA)	2005 After Peak Load (MW)	2005 After Peak Cap. (MVA)	2005 After Over Load (%)
North Central	(1) Anuradhapura	63	25.8	28.7	46	63	27.8	30.9	49	63	23.6	26.2	42	63	25.4	28.2	45	63	25.4	28.2	45	63	27.3	30.3	48	63	27.3	30.3	48	63	29.6	32.9	52	63	29.5	32.8	52	63	32.3	35.9	57
	(2) Habarana	63	21.6	24.0	38	63	23.3	25.9	41	63	20.0	22.2	35	63	21.4	23.8	38	63	21.4	23.8	38	63	22.8	25.3	40	63	22.8	25.3	40	63	24.5	27.2	43	63	24.4	27.1	43	63	24.2	26.9	43
	(3) Polonnaruwa									32	10.6	11.8	37	32	11.4	12.7	40	32	11.4	12.7	40	32	12.2	13.6	42	32	12.2	13.6	42	32	13.2	14.7	46	32	13.2	14.7	46	32	14.4	16.0	50
Northern	(4) Chunnakam	70	25.9	28.8	41	70	31.3	34.8	50	70	31.3	34.8	50	70	36.3	40.3	58	70	36.3	40.3	58	70	40.9	45.4	65	70	40.9	45.4	65	70	45.2	50.2	72	70	45.1	50.1	72	70	49.7	55.2	79
	(5) Kilinochchi	10	6.2	6.9	69	10	7.3	8.1	81	10	6.5	7.2	72	10	7.4	8.2	82	10	7.4	8.2	82	10	8.2	9.1	91	20	8.2	9.1	46	20	9.0	10.0	50	20	9.0	10.0	50	20	9.9	11.0	55
	(6) Vavunia									10	4.9	5.4	54	10	5.3	5.9	59	10	5.3	5.9	59	10	5.7	6.3	63	10	5.7	6.3	63	10	6.2	6.9	69	10	6.2	6.9	69	10	6.8	7.6	76
Central	(7) Kiribathkumbura	94.5	42.0	46.7	49	94.5	44.7	49.7	53	94.5	44.7	49.7	53	94.5	47.5	52.8	56	94.5	47.5	52.8	56	94.5	50.7	56.3	60	94.5	50.7	56.3	60	94.5	54.3	60.3	64	94.5	39.9	44.3	47	94.5	36.5	40.6	43
	(8) Ukuwela	63	32.1	35.7	57	63	34.2	38.0	60	63	34.2	38.0	60	63	36.5	40.6	64	63	36.5	40.6	64	63	39.2	43.6	69	63	39.2	43.6	69	63	42.2	46.9	74	63	42.1	46.8	74	63	32.0	35.6	56
	(9) Rantembe	20	7.6	8.4	42	20	8.0	8.9	44	20	8.0	8.9	44	20	8.4	9.3	47	20	6.3	7.0	35	20	6.6	7.3	37	20	6.6	7.3	37	20	7.0	7.8	39	20	7.0	7.8	39	20	7.5	8.3	42
	(10) Nuwara Eliya	63	23.5	26.1	41	63	24.4	27.1	43	63	24.4	27.1	43	63	25.4	28.2	45	63	26.4	29.3	47	63	27.5	30.6	49	63	27.5	30.6	49	63	28.8	32.0	51	63	28.7	31.9	51	63	30.6	34.0	54
	(11) Wimalasurendra	63	14.9	16.6	26	63	15.5	17.2	27	63	15.5	17.2	27	63	16.0	17.8	28	63	16.1	17.9	28	63	16.7	18.6	29	63	16.7	18.6	29	63	17.4	19.3	31	63	17.4	19.3	31	63	18.2	20.2	32
	(12) Palekelle																																					63	21.9	24.3	39
North Western	(13) Kurunegala	63	29.6	32.9	52	63	31.8	35.3	56	63	23.1	25.7	41	63	24.7	27.4	44	63	24.7	27.4	44	63	26.4	29.3	47	63	26.4	29.3	47	63	28.4	31.6	50	63	28.3	31.4	50	63	30.8	34.2	54
	(14) Puttalam	63	17.4	19.3	31	63	19.0	21.1	34	63	23.1	25.7	41	63	25.1	27.9	44	63	25.2	28.0	44	63	27.5	30.6	49	63	27.5	30.6	49	63	30.1	33.4	53	63	30.0	33.3	53	63	33.3	37.0	59
	(15) Bolawatta	91.5	53.5	59.4	65	91.5	56.8	63.1	69	91.5	53.0	58.9	64	91.5	56.4	62.7	68	91.5	56.5	62.8	69	91.5	60.2	66.9	73	91.5	60.2	66.9	73	91.5	64.5	71.7	78	91.5	64.3	71.4	78	91.5	46.5	51.7	56
	(16) Chilaw	63	32.9	36.6	58	63	36.1	40.1	64	63	31.6	35.1	56	63	34.4	38.2	61	63	34.4	38.2	61	63	37.5	41.7	66	63	37.5	41.7	66	63	41.2	45.8	73	63	41.0	45.6	72	63	45.5	50.6	80
	(17) Kuliyapitiya									63	26.6	29.6	47	63	30.0	33.3	53	63	30.0	33.3	53	63	33.9	37.7	60	63	33.9	37.7	60	63	38.4	42.7	68	63	38.3	42.6	68	63	43.9	48.8	77
	(18) Pannala																																								
Western-North	(19) Kotugoda	120	49.5	58.2	49	120	52.9	62.2	52	120	52.9	62.2	52	120	56.4	66.4	55	120	55.3	65.1	54	120	59.1	69.5	58	120	59.1	69.5	58	120	63.5	74.7	62	120	63.3	74.5	62	120	60.6	71.3	59
	(20) Sapugaskanda	122	80.3	94.5	78	122	89.1	104.8	86	122	91.3	107.4	88	122	101.0	118.8	98	122	92.0	108.2	89	122	102.0	120.0	99	122	91.7	107.9	89	122	102.0	120.0	99	122	78.2	92.0	76	122	87.7	103.2	85
	(21) Biyagama	120	50.3	59.2	49	120	56.4	66.4	55	120	56.3	66.2	55	120	62.9	74.0	62	120	56.8	66.8	56	120	63.6	74.8	62	120	75.4	88.7	74	120	84.9	99.9	83	120	63.5	74.7	62	120	72.4	85.2	71
	(22) Veyangoda	63	17.5	20.6	33	63	18.6	21.9	35	63	18.6	21.9	35	63	19.6	23.1	37	63	19.6	23.1	37	63	20.9	24.6	39	63	21.0	24.7	39	63	22.4	26.4	42	63	19.9	23.4	37	63	21.5	25.3	40
	(23) Aniyakanda	63	23.1	27.2	43	63	24.8	29.2	46	63	24.8	29.2	46	63	26.6	31.3	50	63	27.4	32.2	51	63	29.5	34.7	55	63	29.5	34.7	55	63	31.9	37.5	60	63	31.8	37.4	59	63	34.8	40.9	65
	(24) Kelaniya	126	71.5	84.1	67	126	80.0	94.1	75	126	80.0	94.1	75	126	89.3	105.1	83	126	79.0	92.9	74	126	88.3	103.9	82	126	88.3	103.9	82	126	99.2	116.7	93	126	72.8	85.6	68	126	82.7	97.3	77
	(25) Muthurajawella																	126	29.4	34.6	27	126	32.6	38.4	30	126	32.6	38.4	30	126	36.4	42.8	34	126	36.2	42.6	34	126	40.9	48.1	38
	(26) Gonawala																																								
	(27) Katuna																																	63	44.3	52.1	83	94.5	50.5	59.4	63
	(28) Imbulgoda																																					63	29.9	33.2	53
Eastern	(29) Trincomalee	63	17.8	19.8	31	63	18.8	20.9	33	63	18.4	20.4	32	63	19.4	21.6	34	63	19.5	21.7	34	63	20.6	22.9	36	63	20.6	22.9	36	63	21.9	24.3	39	63	21.8	24.2	38	63	23.4	26.0	41
	(30) Inginiyagala	30	1.5	1.7	6	30	1.5	1.7	6	30	0.8	0.9	3	30	0.8	0.9	3	30	0.5	0.6	2	30	0.5	0.6	2	30	0.5	0.6	2	30	0.5	0.6	2	30	0.5	0.6	2	30	0.6	0.7	2
	(31) Valachchenai	63	12.3	13.7	22	63	13.1	14.6	23	63	6.9	7.7	12	63	7.3	8.1	13	63	7.3	8.1	13	63	7.8	8.7	14	63	7.8	8.7	14	63	8.3	9.2	15	63	8.2	9.1	14	63	8.9	9.9	16
	(32) Ampara	63	11.0	12.2	19	63	11.3	12.6	20	63	12.6	14.0	22	63	13.0	14.4	23	63	13.0	14.4	23	63	13.4	14.9	24	63	13.5	15.0	24	63	14.0	15.6	25	63	14.0	15.6	25	63	14.8	16.4	26
Western-South	(33) Ratmalana	91.5	60.6	71.3	78	91.5	66.5	78.2	86	91.5	51.3	60.4	66	91.5	56.4	66.4	73	91.5	56.5	66.5	73	91.5	62.0	72.9	80	91.5	62.0	72.9	80	91.5	68.3	80.4	88	91.5	68.1	80.1	88	123	76.0	89.4	73
	(34) Pannipitiya	91.5	65.9	77.5	85	91.5	71.0	83.5	91	91.5	61.4	72.2	79	91.5	65.9	77.5	85	91.5	58.6	68.9	75	91.5	63.0	74.1	81	91.5	56.6	66.6	73	91.5	61.2	72.0	79	91.5	61.0	71.8	78	123	66.6	78.4	64
	(35) O.D.S.S(Kolonnawa)	94.5	55.7	65.5	69	94.5	59.1	69.5	74	94.5	60.9	71.6	76	94.5	64.6	76.0	80	94.5	65.7	77.3	82	94.5	69.9	82.2	87	94.5	71.0	83.5	88	94.5	76.0	89.4	95	126	75.7	89.1	71	158	96.4	113.4	72
	(36) Matugama	94.5	16.8	19.8	21	94.5	17.9	21.1	22	94.5	15.3	18.0	19	94.5	16.3	19.2	20	94.5	16.3	19.2	20	94.5	17.4	20.5	22	94.5	14.7	17.3	18	94.5	15.7	18.5	20	94.5	47.1	55.4	59	94.5	17.1	20.1	21
	(37) Avissawella	63	15.8	18.6	30	63	16.8	19.8	31	63	16.8	19.8	31	63	17.8	20.9	33	63	17.0	20.0	32	63	18.1	21.3	34	63	20.1	23.6	38	63	21.6	25.4	40	63	24.7	29.1	46	63	27.0	31.8	50
	(38) Panadura	63	28.4	33.4	53	63	30.7	36.1	57	63	42.1	49.5	79	63	45.5	53.5	85	63	45.6	53.6	85	63	49.4	58.1	92	63	33.8	39.8	63	63	36.9	43.4	69	63	36.8	43.3	69	63	40.8	48.0	76
	(39) Sithawaka	63	16.2	19.1	30	63	18.0	21.2	34	63	18.0	21.2	34	63	19.9	23.4	37	63	19.9	23.4	37	63	22.1	26.0	41	63	22.1	26.0	41	63	24.7	29.1	46	63	17.6	20.7	33	63	19.8	23.3	37
	(40) Athurugiriya	63	24.6	28.9	46	63	26.3	30.9	49	63	24.3	28.6	45	63	26.0	30.6	49	63	24.5	28.8	46	63	26.2	30.8	49	63	26.3	30.9	49	63	28.3	33.3	53	63	28.2	33.2	53	63	30.9	36.4	58
	(41) Sri Jaya'pura	63	39.1	46.0	73	63	42.5	50.0	79	63	44.8	52.7	84	63	48.6	57.2	91	94.5	52.5	61.8	65	94.5	57.1	67.2	71	94.5	59.9	70.5	75	94.5	65.4	76.9	81	94.5	65.1	76.6	81	126	72.0	84.7	67
	(42) Dehiwala	126	55.5	65.3	52	126	59.6	70.1	56	126	67.0	78.8	63	126	72.0	84.7	67	126	72.1	84.8	67	126	77.7	91.4	73	126	77.7	91.4	73	126	84.2	99.1	79	126	83.9	98.7	78	126	88.9	104.6	83
	(43) Horana																									63	16.9	19.9	32	63	18.4	20.4	32	63	18.3	21.5	34	63	20.0	23.5	37
	(44) Keshewa																																								
	(45) Angoda																																								
Southern	(46) Galle	60	44.3	49.2	82	60	47.4	52.7	88	60	38.8	43.1	72	60	41.5	46.1	77	60	41.5	46.1	77	60	44.5	49.4	82	60	44.5	49.4	82	60	47.9	53.2	89	60	47.7	53.0	88	94.5	52.5	58.3	62
	(47) Deniyaya	30	15.2	16.9	56	30	16.1	17.9	60	30	15.0	16.7	56	30	16.0	17.8	59	30	17.0	18.9	63	30	18.1	20.1	67	30	18.1	20.1	67	30	19.4	21.6	72	30	19.4	21.6	72	30	21.1	23.4	78
	(48) Matara	63	33.1	36.8	58	63	34.4	38.2	61	63	34.6	38.4	61	63	36.0	40.0	63	63	35.0	38.9	62	63	36.5	40.6	64	63	36.5	40.6	64	63	38.2	42.4	67	63	38.1	42.3	67	63	40.8	45.3	72
	(49) New Galle	63	44.3	49.2	78	63	47.4	52.7	84	63	38.8	43.1	68	63	41.5	46.1	73	63	41.5	46.1	73	63	44.5	49.4	78	63	44.5	49.4	78	63	47.9	53.2	84	63	47.7	53.0	84	94.5	52.4	58.2	62
	(50) Ambalangoda									63	17.9	19.9	32	63	19.3	21.4	34	63	19.3	21.4	34	63	20.7	23.0	37	63	20.7	23.0	37	63	22.4	24.9	40	63	22.4	24.9	40	63	23.7	26.3	42
	(51) Hambantota									20	9.0	10.0	50	20	9.1	10.1	51	20	9.1	10.1	51	20	9.3	10.3	52	20	9.3	10.3	52	20	9.5	10.6	53	20	9.5	10.6	53	20	10.0	11.1	56
	(52) Boossa																																								
Uva	(53) Badulla	94.5	23.1	25.7	27	94.5	24.3	27.0	29	94.5	24.3	27.0	29	94.5	25.5	28.3	30	94.5	23.7	26.3	28	94.5	24.9	27.7	29	94.5	24.9	27.7	29	94.5	26.3	29.2	31	94.5	26.2	29.1	31	94.5	28.0	31.1	33
	(54) Medagama																	10	2.9	3.2	32	10	3.0	3.3	33	10	3.0	3.3	33	10	3.2	3.6	36	10	3.2	3.6	36	10	3.4	3.8	38
Sabaragamuwa	(55) Balangoda	63	10.9	12.1	19	63	11.5	12.8	20	63	11.5	12.8	20	63	12.2	13.6	22	63	12.5	13.9	22	63	13.3	14.8	23	63	13.3	14.8	23	63	14.2	15.8	25	63	11.8	13.1	21	63	12.5	13.9	22
	(56) Thulhiriya	94.5	51.8	57.6	61	94.5	57.7	64.1	68	94.5	43.0	47.8	51	94.5	47.6	52.9	56	94.5	47.6	52.9	56	94.5	52.7	58.6	62	94.5	52.7	58.6	62	94.5	58.6	65.1	69	94.5	43.5	48.3	51	94.5	48.4	53.8	57
	(57) Embilipitiya	63	10.3	11.4	18	63	10.7	11.9	19	63	5.8	6.4	10	63	6.1	6.8	11	63	6.1	6.8	11	63	6.3	7.0	11	63	6.3	7.0	11	63	6.6	7.3	12	63	6.6	7.3	12	63	7.0	7.8	12
	(58) Ratnapura	63	21.4	23.8	38	63	24.3	27.0	43	63	24.2	26.9	43	63	27.4	30.4	48	63	27.5	30.6	49	63	31.1	34.6	55	63	31.1	34.6	55	63	35.5	39.4	63	63	35.3	39.2	62	63	40.4	44.9	71
	(59) Kegalle																																	63	39.6	44.0	70	63	44.5	49.4	78
	(60) Aguruwella																																								
	(61) Ehaliyagoda																																								
Colombo	(62) Kelanissa(KTS)	120	41.1	48.4	40	120	43.4	51.1	43	120	43.4	51.1	43	120	45.7	53.8	45	120	45.7	53.8	45	120	48.3	56.8	47	120	48.3	56.8	47	120	51.2	60.2	50	120	51.1	60.1	50	120	43.9	51.6	43
	(63) Sub-E(Kollupitiya)	90	34.4	62.3	69	90	36.4	65.9	73	90	36.3	65.7	73	90	38.4	69.5	77	90	38.4	69.5	77	90	40.7	73.7	82	90	40.7	73.7	82	90	43.3	78.4	87	90	43.1	78.0	87	90	27.9	50.5	56
	(64) Sub-F(Fort)	90	23.3	54.8	61	90	24.7	58.1	65	90	24.6	57.9	64	90	26.0	61.2	68	90	26.1	61.4	68	90	27.6	64.9	72	90	27.6	64.9	72	90	29.3	68.9	77	90	29.2	68.7	76	90	31.5	74.1	82
	(65) Town Hall																																					126	31.5	57.0	45
	(66) Sub-B																																								
TOTAL		3330	1400	1655	50	3330	1513	1788	54	3518	1513	1787	51	3518	1633	1928	55	3685	1633	1928	52	3685	1766	2084	57	3758	1766	2084	2770	3758	1919	2263	60	3916	1920	2264	58	4391	2088	2469	56

Table 6.4.1-3 Proposed New Subprojects for Transmission System up to The Year 2005

Augmentation and Extension of T/L and GSS	Re-marks	Proposed Commiss. Year
(1) Power Transmission Facilities Related to Puttalam Coal-Fired Thermal Plant		
(1-1) Upgrading Kotugoda - Veyangoda Line & Veyangoda Substation to 220 kV	a	2002
a) Upgrading of Veyangoda substation to 220kV (2 x 150MVA (220/132kV))		
b) Kotugoda (two 220kV T/L bays for Veyangoda line)		
(1-2) Construction of Puttalam P/S - Veyangoda 220 kV Line		2002
a) Puttalam P/S - New Chilaw 220kV line (2cct, 43km, 3 x Zebra)		
b) New Chilaw - Veyangoda 220kV line (2cct, 42km, 3 x Zebra)		
c) Veyangoda (two T/L bays for Puttalam line)		
(1-3) Construction of Puttalam P/S 220/132 kV Substation		2002
a) Puttalam P/S (2 x 150MVA (220/132kV))		
(1-4) Construction of Puttalam P/S - Puttalam 132 kV Line		
a) Puttalam P/S - Puttalam 132kV line (2cct, 22km, 2 x Zebra)		2002
b) Puttalam (two T/L bays for Puttalam P/S line)		
(2) Construction of New Chilaw 220/132 kV Substation		2002
a) New Chilaw (2 x 150MVA (220/132))		
b) Connection of Puttalam - Veyangoda 220kV line (2x2cct, 0.1km, 3xZebra)		
c) Double pi-connection of Bolawatta - Puttalam 132kV line (2x2cct, 0.5km, Lynx)		
d) Connection of Chilaw 132kV line (2cct,0.5km, Lynx)		
e) Connection of Kuliyapitiya 132kV line (2cct, 0.5km, Zebra)		
(3) Construction of Kuliyapitiya 132 kV Substation		2001
a) Double T-connection for Kuliyapitiya (2cct, 18km, Zebra)		
b) Kuliyapitiya (2 x 31.5MVA)		
(4) Construction of Katana 132 kV Substation		2005
a) Katana (2 x 31.5MVA)		
b) Double pi-connection for Katana (2 x 2cct, 0.5km, Lynx)		
(5) Construction of Gonawala Substation		2004
a) Gonawala (2 x 31.5MVA)		
b) Double pi-connection for Gonawala (2 x 2cct, 0.2km, Zebra)		
(6) Construction of Veyangoda - Thulhiliya 132 kV Line		2003
a) Veyangoda - Thulhiliya 132kV line (2cct, 25km, Zebra)		
b) Veyangoda (two 132kV T/L bays for Thulhiliya line)		
c) Thulhiliya (two 132kV T/L bays for Veyangoda line)		
(7) Construction of Kegalle 132 kV Substation		2004
a) Thulhiliya - Kegalle 132kV line (2cct, 19km, Zebra)		
b) Kegalle (2 x 31.5MVA)		
c) Thulhiliya (two T/L bays for Kegalle Line)		
(8) Construction of Palekelle 132 kV Substation		2005
a) Ukuwela - Palekelle 132kV line (2cct, 17km, Zebra)		
b) Ukuwela (two T/L bays for Palekelle line)		
c) Palekelle (2 x 31.5MVA)		

Table 6.4.1-3 Proposed New Subprojects for Transmission System up to The Year 2005

Augmentation and Extension of T/L and GSS	Re-marks	Proposed Commiss. Year
(9) Construction of Polonnaruwa 132 kV Substation		2001
a) Polonnaruwa (2 x 16MVA)	b	
b) Single pi-connection for Polonnaruwa (2cct, 0.5km, Lynx)		
(10) Construction of Vavunia 132 kV Substation		2001
a) Vavunia (1 x 10MVA)	c	
b) Double pi-connection for Vavunia (2cct, 0.5km, Lynx)	d	
(11) Construction of Horana 132 kV Substation	e	2003
a) Horana (2 x 31.5MVA)		
b) Single pi-connection for Horana (2cct, 11.0km, Bear)		
(12) Power Transmission Facilities Related to Kukule Hydropower Plant	f	
(12-1) Construction of Kukule - Matugama 132 kV Line		2002
a) Kukule - Matugama 132kV line (2cct, 27km, Zebra)		
b) Matugama (two 132kV T/L bays for Kukule line)		
(12-1) Construction of Kukule - Ratnapura 132 kV Line		2002
a) Kukule - Ratnapura 132kV line (2cct, 25km, Zebra)		
b) Ratnapura (two 132kV T/L bays for Kukule line)		
(13) Double pi-connection for Panadura 132 kV Substation		2003
a) Panadura - Junction Point line (2cct, 5km, Lynx)		
b) Panadura (two 132kV bays for pi-connection)		
(14) Construction of Ambalangoda 132 kV Substation		2001
a) Ambalangoda (2 x 31.5MVA)		
b) Single pi-connection for Ambalangoda (2cct, 0.1km, Zebra)		
(15) Construction of Hambantota 132 kV Substation		2001
a) Embilipitiya - Hambantota 132kV line (1st cct of 2cct construction, 24km, Bear)	g	
b) Hambantota (2 x 10MVA)		
c) Embilipitiya (one 132kV T/L bays for Hambantota line)		
(16) Construction of New Galle - Matara 132 kV Line		2003
a) New Galle - Matara 132kV line (2cct, 34.0km, Bear)		
b) New Galle (two 132kV T/L bays for Matara line)		
c) Matara (two 132kV T/L bays for New Galle line)		
(17) Construction of Medagama 132 kV Substation		2002
a) Medagama (1 x 10MVA)	c,h	
b) Single pi-connection for Medagama (2cct, 0.5km, Oriole)		
(18) Construction of Paddiruppu 132 kV Substation		2003
a) Paddiruppu (1 x 10MVA)	c,h	
b) Single pi-connection for Paddiruppu (2cct, 5.0km, Lynx)		

Table 6.4.1-3 Proposed New Subprojects for Transmission System up to The Year 2005

Augmentation and Extension of T/L and GSS	Re-marks	Proposed Commiss. Year
(19) Construction of Town Hall 132 kV Substation (GIS)		
a) Kolonnawa - Town Hall 132kV underground cable line (1cct, 4.2km, Cu 800sq.mm, CV cable)		2005
b) Single pi-connection of Kolonnawa - Kollupitiya UGC (2x1cct, 0.2km, Cu 500sq.mm, OF cable)		
c) Kolonnawa (one 132kV T/L bay for Town Hall line)		
d) Town Hall (2 x 63MVA (Final : 3 x 63MVA))		
(20) Upgrading 132kV Kelanittissa - Kolonnawa Line to 220 kV		2003
a) Kelanittissa - Kolonnawa 220kV line (2cct, 2.2km, 2 x Goat)	i	
b) Construction of 220kV GIS at Kolonnawa (2 x 250MVA Transformers)		
c) Kelanittissa (two 220kV T/L bays for Kolonnawa line)	j	
(21) Addition of Transformers		
(21-1) Kilinochchi (132/33kV, 1 x 10MVA, total 2 x 10MVA)		2003
(21-2) Galle (132/33kV, 1 x 31.5MVA, total 91.5MVA)		2005
(21-3) New Galle (132/33kV, 1 x 31.5MVA, total 3 x 31.5MVA)		2005
(21-4) Sri Jaya'pura		
a) 132/33kV, 1x31.5MVA, total 3x31.5MVA)		2002
b) 132/33kV, 1x31.5MVA, total 4x31.5MVA)		2005
(21-5) Kolonnawa		
a) 132/33kV, 1x31.5MVA, total 4x31.5MVA)		2004
b) 132/33kV, 1x31.5MVA, total 5x31.5MVA)		2005
(21-6) Gonawala (132/33kV, 1x31.5MVA, total 3x31.5MVA)		2005
(21-7) Ratmalana (132/33kV, 1x31.5MVA, total 123MVA)		2005
(21-8) Pannipitiya (132/33kV, 1x31.5MVA, total 123MVA)		2005
(21-9) Muthurgawella (220/33kV, 2x63MVA, total 2x63MVA)	k	2002
(21-10) Bowatenna (132/33kV, 1x15MVA, total 1x15MVA)	k,l	2002
New Subprojects Proposed by Power System Analysis		
(22) Static Capacitor		
(22-1) Chunnakam (20MVA)		2004

Remarks :

(a) Kotugoda - Veyangoda line is planned to be designed as 220 kV construction.
(b) Transformers of 16MVA presently used in Kurunegara substation are available for Polonnaruwa.
(c) Transformers of 10MVA presently used are available.
(d) Double pi-connection is needed for reliable and stable operation of the 132kV system in northern area.
(e) In order to meet energy requirement such as planned water supply project, additional reinforcement like double pi-connection may be needed.
(f) Necessary 132kV switching equipment is proposed to be provided under the Kukule project.
(g) One circuit line is proposed to be initially constructed from the economical point of view.
(h) One unit only will be initially provided for cost saving, since no high demand is expected.
(i) Right of way and tower sites of the existing 132kV line is usable.
(j) Two 220kV T/L bays for upgrading Kolonnawa substation to 220 kV are proposed to be provided under the project for upgrading of Kelanittissa substation to 220kV.
(k) Transformers are newly installed for area supply.
(l) Transformers of 15MVA presently used in Ukuwela substation are available for Bowatenna.