No.

National Power Authority
The Republic of Sierra Leone

FINAL REPORT
ON
THE MASTER PLAN STUDY ON POWER SUPPLY IN WESTERN AREA IN THE REPUBLIC OF SIERRA LEONE

SUPPLEMENTAL VOLUME

DISTRIBUTION SYSTEM PLANNING MANUAL

SEPTEMBER 2009

JAPAN INTERNATIONAL COOPERATION AGENCY
（JICA）

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CHAPTER-1

Distribution System Planning Manual

PART-1 Outline and Composition of This Manual

Contents

1. General

1.1 Purpose

This manual describes basic concepts, process and methodology of distribution system planning in order for the NPA's distribution engineers to revise or update the distribution system rehabilitation, enhancement and expansion plans formulated by JICA's Master Plan Study as well as to formulate future distribution plans by themselves.

1.2 Application

This manual shall be applied to distribution system planning in order to cope with the following cases:

(1) Change of the system configuration such as addition of new power sources and/or new consumers including expansion of network,
(2) Degradation of power supply reliability and quality,
(3) Excess of rated capacity of facilities such as short circuit current, line capacity, transformer capacity, etc. and
(4) Increase of maintenance cost due to aging and deterioration.

Optimal distribution system shall not only solve the above cases technically but also mitigate environmental and social impacts and seek economic efficiency.

1.3 Composition of This Manual

This manual consists of two chapters as follows. Chapter-1 describes detailed methodology of distribution system planning, and Chapter-2 includes the information of existing distribution facilities necessary for analyzing current distribution system.

Chapter-1 Distribution System Planning Manual
- Part-1 Outline of This Manual
- Part-2 Short Circuit Current and Voltage Drop Calculation
- Part-3 Power System Analysis
- Part-4 Environmental and Social Considerations
- Part-5 Drawings

Chapter-2 Distribution Facilities Database for Western Area Power System
- Part-1 Facility Register for Distribution Transformers
- Part-2 Facility Register for Ring Main Units
- Part-3 Facility Register for 11kV and 33kV Lines

2. Items to be Considered in Planning

Major items to be considered in various stages of planning are shown in the table below.

Major Items	Rehabilitation	Reinforcement	Expansion
Safety	○	○	○
Standards and codes	○	○	○
Reliability	○	○	○
Quality	Δ *1	○	○
Environmental and social Impacts	Δ *2	Δ *2	○

[Remarks] *1: Rehabilitation stage is deemed as a transitional period from emergency to normal situation and power supply quality is compromised to some extent because urgent recovery of power supply is emphasized.

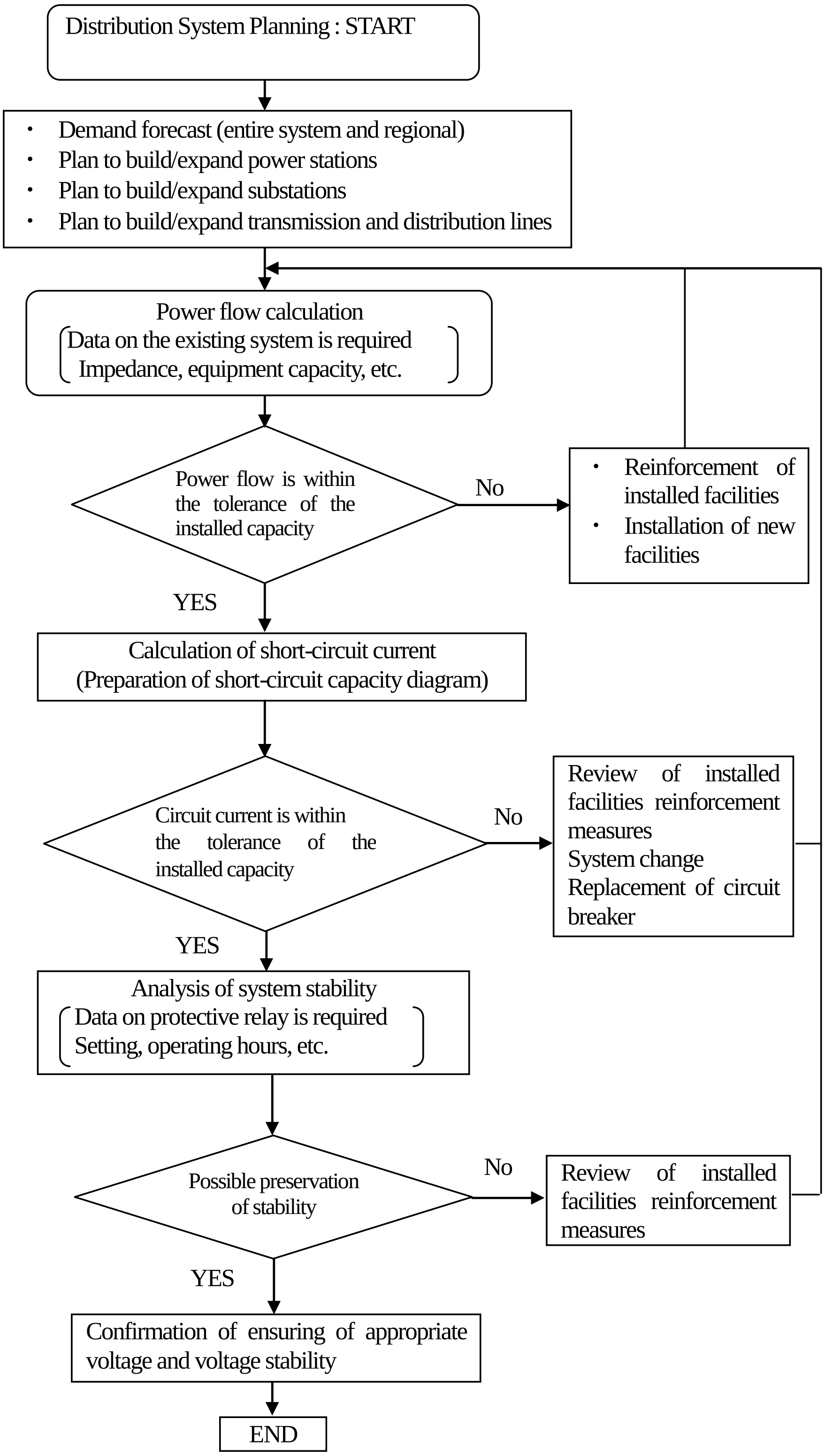
*2: Rehabilitation and reinforcement of distribution system mainly takes place at the same location of the existing system. Therefore, less environmental and social impacts are concerned.

Distribution system rehabilitation, enhancement and expansion planning are aimed at achieving the following targets.

(1) Secure power supply reliability,
(2) Improve power supply quality,
(3) Reduce energy losses,
(4) Improve accessibility to electricity,
(5) Enhance economic efficiency, and
(6) Improve ease of operation and maintenance

3. Process of Distribution System Planning

The following flowchart shows a simplified process of distribution system planning.



4. Pre-conditions to Distribution System Planning

4.1 Design Basis

The following are major items of design basis that are to be applied to distribution system planning. Each item should be clearly defined in order to achieve power supply reliability and quality intended. Attachment to Part-3 Power System Analysis, Chapter-1 of this manual shows design basis and technical standards of 33/11kV and low voltage electrical systems.

1) Voltage and distribution method with permissible voltage fluctuations (see attached Table-1, Part-3, Chapter-1),
2) Standard capacity and line specifications (see section 4.3),
3) Protection method including application of auto reclosing system (see attached Table-1, Part-3, Chapter-1),
4) Short circuit current in each system with duration (see attached Table-1, Part-3, Chapter-1),
5) Installation standards for distribution lines (see attached Table-3, Part-3, Chapter-1), and
6) Ambient conditions including environmental aspect (see attached Table-4, Part-3, Chapter-1).

4.2 Reliability and Quality Standards

(1) Requirements in Normal Power Supply Situation

1) The maximum load current should not exceed the rated capacity of facilities such as transformers, circuit breakers, load isolators, cables and wires, etc.
2) Voltage fluctuation shall be within the standard range.

(2) Requirements in Case of Fault

In case of distribution circuit fault, power distribution should be recovered through non-faulty lines within a short period of time.

(3) Permissible Range of Terminal Voltage

Terminal voltage at the consumers shall be within the following range;

Class of the customers	Range of Terminal Voltage [V]
1. LV: 230 V, single phase	Min.: 200 V Max.: 240 V (220 +/- 20V)
2. LV: 400 V, three phase	Min.: 360 V Max.: 440 V (400 +/- 40V)
3. MV: 11 kV three phase	Min.: 10,450 V Max.: 11,550 V (11,000 +/- 550V)

4.3 Distribution Line Capacity

(1) Standard Capacity

Standard capacity of 11kV and LV lines is as follows.

Description	Unit	Large	Medium	Small	Remarks
1. LV line					AAAC
1) Size	[mm^2]	120	95	70	
2) Current	[A]	380	300	220	
2. 11 kV line					ACSR
1) Size	[mm^2]	240	150	95	
2) Current	[A]	550	400	330	

(2) Normal load limit

The limitation of normal load current shall be decided taking the laying method into consideration.

(3) Continuous current of cables

Continuous current of cables shall comply with IEC.

5. Methodology

5.1 Power Demand Forecast

Power demand forecast is a basis of distribution system planning and shall be reviewed and revised every year to meet the latest socio-economic conditions. In general, econometric method that seeks correlation between socio-economic indicators and power demand is applied to power demand forecast in the entire system. On the other hand, historical trends of load at each substation and population growth at each supply area are mainly used to forecast regional power demand. For the purpose of distribution system planning, regional power demand at each primary substation should be emphasized. The following are to be remarked in revising power demand forecast.

(1) Socioeconomic Indicators

The latest socioeconomic indicators such as GDP, population, etc. and their growth trends are to be acquired from the Ministry of Finance and Economic Development (Economic Policy and Research Unit) and Statistical Office (Statistics Sierra Leone) as they are crucial for the revision of power demand forecast.

(2) Load Current

The maximum load current at each substation and junction station to be used for regional power demand forecast is the average of peak current recorded on three highest days in a year.

5.2 Short Circuit Current and Voltage Drop Calculation

See Part-2 "Short Circuit Current and Voltage Drop Calculation", Chapter-1 for details.

5.3 Power System Analysis

See Part-3 "Power System Analysis", Chapter-1 for details.

5.4 Implementation schedule of distribution reinforcement

Distribution reinforcement works should be completed before the capacity of existing distribution system will reach the limitation of continuous current. Therefore, the following process required before the commencement of work should be taken into consideration in scheduling a reinforcement work.

(1) Duration of land acquisition,
(2) Period of environmental permit,
(3) Season and date when the negative effect of power outage is minimized,
(4) Period of administrative procedure,
(5) Period of equipment and material procurement,
(6) Period necessary to coordinate concerned parties such as city water supply, road authority, telecommunications and transportation agencies, etc.

5.5 Configuration of Facilities

(1) System configuration

Standard configuration of distribution line is a radial pattern and trunk line forms a loop circuit. Standard voltage and electric mode are as follows.

<table>
<tr><th>Nominal Voltage [V]</th><th>Electric mode</th><th>Protection</th><th>Shot circuit current [kA]</th></tr>
<tr><td>LV: 400/230</td><td>Solidly earthed</td><td rowspan="3">Short circuit, over current, grounding fault and auto-reclosing for MV</td><td>30</td></tr>
<tr><td>MV: 11,000</td><td>Earthing transformer</td><td>20</td></tr>
<tr><td>MV: 33,000</td><td>Earthing transformer</td><td>25</td></tr>
</table>

(2) Selection of Type of Facilities

1) Application of Overhead and ground cables

The installation method shall be selected considering circumstances, economic factors and maintenance.

2) Selection of line route

Line route shall be selected considering ease of maintenance and economic efficiency.

3) Selection of equipment

Technical requirements on the facility such as circuit breaker, lightning arresters, etc. shall be coordinated with the system requirements.

PART-2 Short Circuit Current and Voltage Drop Calculation

Contents

Reference Drawings and Documents

1) GE-2025 : Freetown Power System 2025
2) GE-2009-1 : 11/ 33 kV Network, Western Part 2009
3) GE-2009-1 : 11/ 33 kV Network, Eastern Part 2009
4) FR-TRF : Facility Resister for Transformers
5) FR-LINE : Facility Resister for 11 kV and 33 kV Lines

1. Short Circuit Current

1.1 Short Circuit Current on LV System

Short circuit current at secondary terminal of distribution transformer can be calculated by following formula assuming the given condition:

Condition: Neglect system impedance.

Is= P/SQRT(3)/V/%Zx100

Where;

Is:	Short circuit current [kA]
P:	Capacity of transformer [kVA]
V:	Line voltage [V]
%Z:	Percent impedance of Trf. [%]

Example:

P=	1,000	[kVA]
V=	400	[V]
%Z=	6.0	[%]

Calculation:

Is= **24.1** [kA]

Remarks:

1) Above current is also applied as grounding fault current in the preliminary study.
2) To consider asymmetric current, normally 1.25 times is applied. However, in special case it will be more than 1.5 times.

1.2 Short Circuit Current on 11 kV SWGR at Kingtom P/S

(1) Calculation conditions

1) Generators
a) No. 6, 7 & 8 units are connected.
b) No. 1 & 2 DEG units of Blackhall Road P/S are not connected.
2) Bumbuna side:
a) 2 units of Bumbuna are connected with rated output, and
b) Bus-tie CB on 11 kV SWGR at Freetown S/S is [Open]
3) All line impedance is neglected.
4) Bus-tie breaker is closed on 11 kV SWGR at Kingtom P/S

(2) Calculation

Kingtom P/S ↔ Freetown S/S ↔ Bumbuna HPP

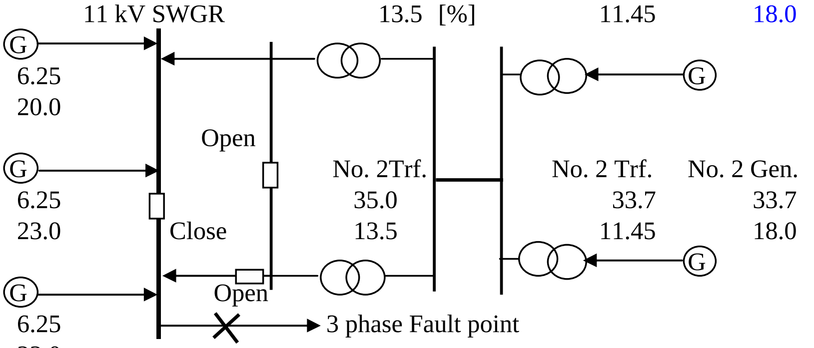
1) System

a) Two units of Bumbuna HPP

b) No. 6 DEG
Capacity [MVA]= 6.25
X"d= 20.0

c) No. 8 DEG
Capacity [MVA]= 6.25
X"d= 23.0

d) No. 7 DEG
Capacity [MVA]= 6.25
X"d= 23.0



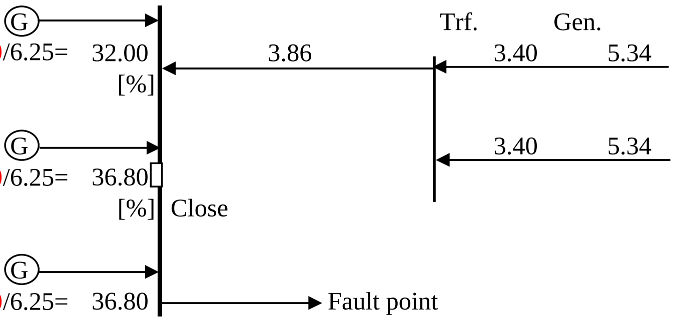
2) Impedance Map-1: 10 **MVA Base**

a) From Bumbuna side
i) 18x10/33.7= 5.34 [%] (% Impedance of Gen.)
ii) 11.45x10/33.7= 3.40 [%] (% Impedance of Trf.)
b) Freetown S/S
13.5x10/35= 3.86 [%] (% Impedance of Trf.)

c) No. 6 DEG
20.0x10/6.25= 32.00 [%]

d) No. 8 DEG
23.0x10/6.25= 36.80 [%]

e) No. 7 DEG
23.0x10/6.25= 36.80 [%]



3) Impedance Map-2: 10 MVA Base

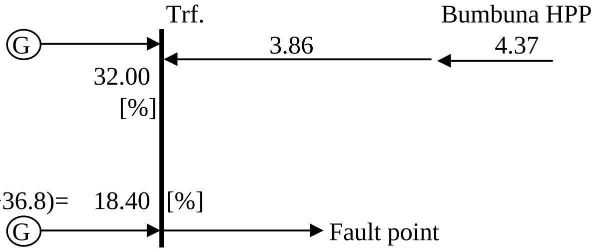
a) From Bumbuna side

8.74x8.74/(8.74+8.74)= 4.37 [%]

b) No. 6 DEG

c) No. 7 & 8 DEG

36.8x36.8/(36.8+36.8)= 18.40 [%]



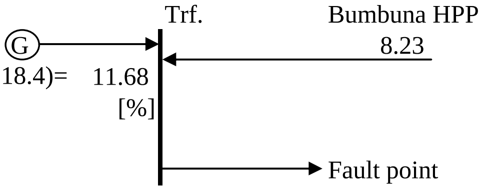
4) Impedance Map-3: 10 MVA Base

a) From Bumbuna side

3.86+4.37= 8.23 [%]

b) From DEG

32x18.4/(32+18.4)= 11.68 [%]



5) Impedance Map-4: 10 MVA base

Zt: Total impedance = 8.23x11.68/(8.23+11.68)= 4.83 [%]

5) Short Circuit Current: Is

Is = Base MVA/(Voltage*Zt*0.01*SQRT(3)) [kA]

Is= **10.9** [kA]

Remarks:

1) Check short circuit current on 11 kV feeder at Freetown S/S
2) Check Blackhall Road P/S are connected to system
3) Confirm considering impedances of 161 kV transmission line & 11 kV line
4) 33 kV system shall be checked
5) Check the system configuration in 2025

2. Calculation Data

No	Deacription	Unit	Data	Remarks
A:	Short Circuit Current of;			
	(1) 161 kV System	[kA]	31.5	
	(2) 33 kV System	[kA]	25.0	
	(3) 11 kV System	[kA]	20.0	
	(4) 0.4 kV System	[kA]	30.0	Assumed at secondary terminal of distribution Trf.
B:	Transformer			
	(1) Bumbuna S/S			
	1) No. 1 Trf.			No. 1 Gen. (13.8 kV)
	a) Capacity	[MVA]	33.7	33.7 [MVA]
	b) Impedance	[%]	11.45	18.0 [%]
	2) No. 2 Trf.			No. 2 Gen. (13.8 kV)
	a) Capacity	[MVA]	33.7	33.7 [MVA]
	b) Impedance	[%]	11.45	18.0 [%]
	(1) Freetown S/S			
	1) Between 161 and 33 kV			
	a) Capacity	[MVA]	15.0	
	b) Impedance	[%]	9.95	
	2) Between 161 and 11 kV			
	a) Capacity	[MVA]	35.0	
	b) Impedance	[%]	13.50	
	(2) Regent S/S			
	1) Capacity	[MVA]	5.0	
	2) Impedance	[%]	8.04	
C:	Generator			
	(1) Bumbuna P/S			
	1) No. 1			
	a) Capacity	[MVA]	33.7	
	b) X"d	[%]	18.0	
	2) No. 2			
	a) Capacity	[MVA]	33.7	
	b) X"d	[%]	18.0	
	(2) Kingtom P/S			
	1) No. 6			
	a) Capacity	[MVA]	6.3	
	b) X"d	[%]	20.0	Assumed
	2) No. 7			
	a) Capacity	[MVA]	6.25	
	b) X"d	[%]	23.0	
	3) No. 8			
	a) Capacity	[MVA]	6.25	
	b) X"d	[%]	23.0	
	(3) Brackhall Road			
	1) No. 1			Assumed
	a) Capacity	[MVA]	10.35	
	b) X"d	[%]	20.0	
	2) No. 2			Assumed
	a) Capacity	[MVA]	10.35	
	b) X"d	[%]	20.0	

3. Calculation of Voltage Drop

3.1 General

This simplified calculation form shall be used as preliminary study applying the following formula:

$$dV=\sqrt{3} \times I \times R$$

Where; dV: Voltage Drop, I: Current, R: Resistance

Calculation formula is simplified using commonly applied data and also using only resistance of the lines that is, without consideration of power factor nor reactance.

Therefore, If the calculation result is "NO GOOD". In such case, detail study shall be conducted considering following items;

1) Actual load current [A] (Peak current during one week)

2) Actual power factor and receiving voltage.

3) Actual line specification is as follows:
a) Use an actual data such as permissible current, resistance and impedance provided by
b) Actual power factor with using following formula;

$$dV=\sqrt{3} \times I \times (R\cos\theta + X\sin\theta)$$

Remarks: Resistance shall be assumed to be 90 deg centigrade if possible.

4) Permissible current for short duration such as One (1) hour rating.

5) In case of LV system, it is necessary to consider Reactance "X" which will affect the voltage drop.

6) Action to be taken when judgment is "NO GOOD":

No.	Action to be taken	Voltage Drop	Cont. current
1)	Check load balance	O	O
2)	Change transformer tap	O	---
3)	Make a separation of connected load to the other feeder	O	O
4)	Check line length which shall be within permissible length	O	---
5)	Change the specification of line	O	O

Sample calculation is attached on next pages. Calculation data to be input shall be Yellow columns only.

A: In case where the sending voltage is 11,000 V at Wilberforce S/S
B: In case where the sending voltage is 10,500 V at Wilberforce S/S

Voltage Drop Calculation from Wilberforce to Lumley

A: Sending Voltage = 11 kV

No.	Description	Unit	Line: A	Line: B	Line: C	Line: D	Line: E	Line: F	Line: G	Remarks
										Voltage
1	**Line data**		A	B	C	D	E	F	G	Nominal: 11,000 [V]
	1) Name of check point		Wilberforce S/S	Jamil	Military Spur	Spur Road	Lumley (Final load)			Maximum: 12,000 [V]
										Minimum: 10,450 [V]
2	**Specification of line**									
	1) Type of line	---	PILC	PILC	PILC	PILC	PILC			
	2) Conductor	---	Cu	Cu	Cu	Cu	Cu			
	3) Core	---	3	3	3	3	3			
	4) Size	[mm^2]	120	120	120	120	120			
	5) Length	[m]	474	520	556	553				
3	**Load Condition**									
	1) Outgoing line current	[A]	200	193	182	143	0			
	2) Transformer load	[A]	-----	7	11	39	143			
	3) Capacity of transformer	[kVA]	-----	300	500	1,630	7,235			
	4) Power factor	---	0.85	0.85	0.85	0.85	0.85			
4	**Voltage Calculation**									
	1) Incoming voltage	[V]	11,000	10,967	10,933	10,901				
	2) Voltage drop	[V]	-----	33	34	32				
	3) % of dV	[%]	-----	0.30	0.31	0.29				
5	**Line data**									
	1) Rated current	[A]	280	280	280	280				
	2) Resistance	[Ohm/km]	0.184	0.184	0.184	0.184				
6	**Others**									
	1) Safety factor of line	---	0.8	0.8	0.8	0.8				
	2) Permissible voltage drop	[%]	5	5	5	5				Total
	3) Energy losses	[W]	6,043	6,173	5,869	3,604				**21,689** [W]
7	**Judgment**									
	1) For voltage drop		**OK**	**OK**	**OK**	**OK**				
	2) For continuous current		**OK**	**OK**	**OK**	**OK**				

Voltage Drop Calculation from Wilberforce to Lumley

B: Sending Voltage = 10.5 kV

No.	Description	Unit	Line: A	Line: B	Line: C	Line: D	Line: E	Line: F	Line: G	Remarks
										Voltage
1	**Line data**		A	B	C	D	E	F	G	Nominal: 11,000 [V]
	1) Name of check point		Wilberforce S/S	Jamil	Military Spur	Spur Road	Lumley (Final load)			Maximum: 12,000 [V]
										Minimum: 10,450 [V]
2	**Specification of line**									
	1) Type of line	---	PILC	PILC	PILC	PILC	PILC			
	2) Conductor	---	Cu	Cu	Cu	Cu	Cu			
	3) Core	---	3	3	3	3	3			
	4) Size	[mm^2]	120	120	120	120	120			
	5) Length	[m]	474	520	556	553				
3	**Load Condition**									
	1) Outgoing line current	[A]	210	203	192	153	0			
	2) Transformer load	[A]	-----	7	11	39	153			
	3) Capacity of transformer	[kVA]	-----	300	500	1,630	7,235			
	4) Power factor	---	0.85	0.85	0.85	0.85	0.85			
4	**Voltage Calculation**									
	1) Incoming voltage	[V]	10,500	10,465	10,429	10,396				
	2) Voltage drop	[V]	-----	35	36	34				
	3) % of dV	[%]	-----	0.33	0.34	0.32				
5	**Line data**									
	1) Rated current	[A]	280	280	280	280				
	2) Resistance	[Ohm/km]	0.184	0.184	0.184	0.184				
6	**Others**									
	1) Safety factor of line	---	0.8	0.8	0.8	0.8				
	2) Permissible voltage drop	[%]	5	5	5	5				Total
	3) Energy losses	[W]	6,632	6,797	6,500	4,100				**24,029** [W]
7	**Judgment**									
	1) For voltage drop		**OK**	**NO GOOD**	**NO GOOD**	**NO GOOD**				
	2) For continuous current		**OK**	**OK**	**OK**	**OK**				

Line Data

1. 6,350/ 11,000 V Cables

1-1). Conductor: Cu [Unit: Ohm/km]

Size [mm^2]	XLPE (IEC502): 90 Deg. Centigrade						PILC (IEC502): 70 Deg. Centigrade					
	1-core			3-cores			1-core			3-cores		
	[A]	R	X	[A]	R	X	[A]	R	X	[A]	R	X
95	320	0.248	0.102	300	0.248	0.101	280	0.227	0.103	245	0.232	0.087
120	360	0.196	0.099	340	0.196	0.098	320	0.181	0.099	280	0.184	0.085
150	410	0.159	0.096	380	0.159	0.095	360	0.147	0.096	315	0.150	0.083
185	460	0.128	0.093	430	0.128	0.092	405	0.118	0.093	355	0.120	0.081
240	530	0.098	0.090	490	0.098	0.098	470	0.091	0.090	410	0.092	0.079
300	600	0.080	0.087	540	0.080	0.087	530	0.073	0.088	460	0.074	0.077
400	680	0.064	0.085	590	0.064	0.084	600	0.058	0.086	520	0.059	0.076
500	750						650	0.048	0.085			

Remarks: Above data are based on steel armor cables and direct buried-in-ground condition

1-2). Conductor: Al [Unit: Ohm/km]

Size [mm^2]	XLPE (IEC502): 90 Deg. Centigrade						Remarks
	1-core			3-cores			
	[A]	R	X	[A]	R	X	
95	250	0.410	0.114	230	0.410	0.101	
120	280	0.325	0.110	265	0.325	0.098	
150	320	0.265	0.107	300	0.265	0.096	
185	360	0.211	0.104	335	211.000	0.092	
240	425	0.161	0.100	380	0.161	0.089	
300	475	0.130	0.097	435	0.130	0.087	
400	540	0.102	0.094	480	0.102	0.084	
500	610	0.081	0.091				

Remarks: Above data are based on steel armor cables and direct buried-in-ground condition

2. Overhead wire [Unit: Ohm/km]

Size [mm^2]	Rated current [A]		Remarks
	AAAC	ACSR (90 Deg.)	
95	305	333	
120	351	392	
150	407	445	
185	464	508	
240	557	607	
300	636	700	
400	894	787	
500	980	926	

PART-3 Power System Analysis

Contents

1. General

This manual shall be used to establish stable and secure power supply system and also to have efficient transmission and distribution of the generated power to the consumers. Major analyzing items and their purposes are as follows;

<table>
<tr><th>Description</th><th>Check Items</th><th>Action to be required (If necessary)</th></tr>
<tr><td>1. Power Flow Calculation</td><td>1) Voltage conditions
2) Energy losses
3) Overloaded facility</td><td rowspan="2">1) Keep voltage within design limit
2) Reduce energy losses
3) Reinforcement of system
4) Increasing capacity
5) Install reactive power supplier
6) Change the system to change load flow
7) Improve T&D, substation, etc.</td></tr>
<tr><td>2. Voltage System Analysis</td><td>1) Margins of voltage stability limits
2) Locate the problematic load points</td></tr>
<tr><td>3. Short Circuit Capacity Calculation</td><td>1) Three-phase short circuit
2) Grounding fault</td><td>1) Change system configuration
2) Install shunt reactance</td></tr>
<tr><td>4. Stability Analysis</td><td>Stable operation of generators</td><td>1) Reducing system impedance
2) Apply AVR of ultra high-speed excitation
3) Adopt power system stabilizers</td></tr>
<tr><td>5. Frequency Calculation</td><td>Fluctuation to be within permissible range</td><td>1) Adopt two-circuit configuration
2) Load shedding</td></tr>
</table>

The system analysis shall be conducted in timely fashion when system conditions and/or configurations are changing with major conditions as follows;

(1) Demand (load conditions),
(2) Development of power station,
(3) New transmission lines,
(4) New 11 and 33 kV lines, and
(5) Others.

Explanation of above items is as follows;

(1) Demand

Peak demand in each area and/or trunk line feeder shall be considered with direction of power flow and also consider waiting consumers and new development plans such as new city planning where demand may be more than 1 MW. Small demand increases shall be considered in item (4) below.

(2) Development of power station

Following items shall be considered for increasing generating output:

1) 10 MW DEG sets in the Kingtom power station in 2010, and
2) 17 MW DEG sets in the Blackhall road power station in 2012.

Remarks: Above new development plans already include our Master Plan Study.

(3) New transmission lines

New lines to be connected to present 11/ 33 kV lines shall be considered including new grid and international transmission lines.

(4) New trunk line of distribution network

This item shall be considered according to the increasing of load in each power supply area and major items to be considered are as follows:

1) When peak demand is close to the rated capacity of the lines
2) Improvement of 11 kV trunk line between;
    a) Blackhall Road P/S and Wellington S/S,
    b) Wellington S/S and Jui S/S,
    c) Jui S/S and Lumpa S/S
    d) Lumpa S/S and Tombo S/S
3) 11 kV network around Tombo area

(5) Others

Following items shall be considered as changes in system configuration:

1) New substations including step up and/or down transformers
2) Reactive power suppliers

2. Preparation of Analysis

Following data shall be provided for reference (see attachments):

(1) Generator with governor characteristics,
(2) Substation (transformer, circuit breaker, protection system, etc.),
(3) Transmission line with protection system,
(4) Distribution network with protection system,
(5) Normal and emergency power flow, and
(6) Demand forecast

3. Power System Analysis

(1) Purpose of Power System Analysis

The power system needs to stably and efficiently deliver the electric power generated by power plants to consumers. In the power facilities construction program for a power system, economic efficiency must be pursued from a long-term perspective since the power facilities constituting the power system require a great deal of money and time for their construction and are to be used over a long period after being completed.

In the planning phase, an analysis of electric power is conducted in ordered to construct optimal facilities with consideration given to future demand trends and to development plans of power sources. In the operational phase, electric power analysis is conducted according to the changes in the system conditions, and as appropriate measures should be considered and taken as required.

(2) To Secure the Supply Reliability

A power system consists of many power facilities including generators, transmission lines, transformers, and distribution lines. The respective power facilities are limited to the electric power which the facilities can carry, and must be operated within their respective capacities.

In addition, facilities need to be formed so as to assure supply reliability against any accidents that can be expected if it is required to maintain safe operation and to avoid possible electric outages caused by the stoppages resulting from operating faults of generators, or due to stoppages caused by lightning striking transmission and distribution facilities (including transmission lines, transformers, and distribution lines), or the stoppages caused by airborne objects.

(3) Data Required for Power System Analysis

The following data need to be prepared in advance for conducting power system analysis:

- Estimation of power demand (profile for which the power system analysis is to be conducted)
- Line constants for the impedances of transmission lines, distribution lines, and transformers

  (Transmission line and distribution line: Number of circuits, positive-phase resistance, positive-phase reactance, and positive-phase capacitance
  Transformer: Positive-phase reactance and tap ratio)
- Constants regarding generators

  (Generator rated capacity, rated output, inertia constant,
  Synchronous reactance (Xd･Xq), transient reactance (Xd'), sub-transient reactance (Xd''･Xq''), armature leakage reactance (Xl), armature time constant (Ta), zero-phase-sequence reactance (X0), negative-phase reactance (X2), AVR (Automatic Voltage Regulator: Device that provides automatic control to maintain generator terminal voltages at constant values) data, governor data)
- Concepts on operation precedence and output distribution for generators
- Presence/absence of reactive power suppliers (types and capacities (actual operational conditions))

In addition to the above items, estimation of future electricity demand and power source development plans is required to conduct analysis in the planning phase.

(4) Types of Power System Analysis

- **Power flow calculation**

There are two methods available for power-flow calculation: The simple power flow calculation (direct current method) which only determines the power flow distribution of active power, and the exact power flow calculation (alternative current method) which determines solutions for the items including voltage, active power, reactive power, and power loss. The simple power flow calculation is often used for an outline study in facility reinforcement plans and for understanding the power flow conditions of loop systems. On the other hand, the exact power flow calculation is often used to grasp voltage conditions and power loss.

A simple power flow calculation, which requires less data for power flow calculation than the exact power flow calculation, can facilitate the calculation. Therefore, this method allows simple checking of the presence/absence of the location where installed capacities are exceeded, and is effective to study the measures for restraining power flows at or below certain installed capacities by reinforcing facilities and/or by increasing the capacities of facilities as a countermeasure against insufficient installed capacities.

[Simple power flow calculation]
First, formulate a simple model of a transmission line in a power system, as shown in Fig. 4-1. (In this model, the capacitance of the transmission line is ignored for simplification.)

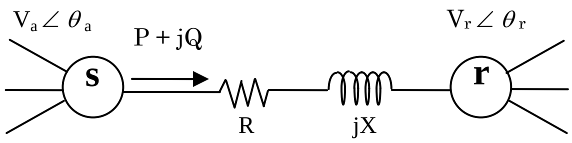


Fig. 4-1 Power flow

When the voltages of the buses (nodes) s and r on both ends of the line having an impedance R + jX are set as $V_s \angle \theta_s$ and $V_r \angle \theta_r$ respectively, as shown in Fig. 4-1, active power P on the transmission side bus s in this line can be expressed by the following equation:

$$P = \frac{X}{R^2 + X^2} V_s V_r \sin(\theta_s - \theta_r) + \frac{R}{R^2 + X^2} \{V_s^2 - V_s V_r \cos(\theta_s - \theta_r)\}$$

Here, the simple power flow calculation can be adopted if the following conditions are met:
① The resistances of the respective lines are much smaller than the reactances.
② Operation is conducted with the voltages of the respective buses close to their rated values.
③ The phase angle differences are small between both ends of the respective lines.
If the resistance of the line is ignored, based on condition ①, active power flow P running through the line can be determined by the following equation:

$$P = \frac{V_s V_r \sin(\theta_s - \theta_r)}{X}$$

$V_s \approx V_r \approx 1.0$(p.u.) from condition ② and $\sin(\theta_s - \theta_r) \approx \theta_s - \theta_r$ from condition ③. Then P can be calculated by the following relational expression:

$$P = \frac{(\theta_s - \theta_r)}{X}$$

On the other hand, the exact power flow calculation is used to grasp the detailed conditions of power systems. The Newton-Raphson method is widely used currently to solve such calculations. This method obtains converged solutions by repeated calculations, which require the use of computers. Though requiring a large amount of data for calculations and troublesome data entry, the method is effective for the study of measures against power losses, voltage drops and for reactive power supplier installation plans.

[Reactive power supplier installation plan]
First, the relationship between reactive power Q and voltage is described simply. There are a few characteristics in the relationship as listed below.

- Voltage tends to drop in the orientation where reactive power flows.
- The greater the loads P and Q on the receiving end, the lower the voltage on the receiving end.
- The greater the impedance Z of the transmission line, the lower the voltage on the receiving end.

To improve this voltage drop on the receiving end, the reactive power needs to be compensated (Q compensation). Q compensation is typified by a Static Condenser (SC), which can inject Q into the system. Conversely, if there is much Q in the system and the voltage is increased, Q compensation is typified by a shunt reactor (ShR), which can take Q from the system.

A plan for installing reactive power suppliers appropriately in this manner in order to adequately maintain the voltage in the power system is referred to as a reactive power supplier installation plan.

- **Voltage stability analysis**

Voltage stability analysis is used to analyze whether the voltage can be maintained stably in the case there is a surge in demand or a failure in the system, and generally uses the system voltage static analytical method as an analytical method. This method is used to evaluate the margins of voltage stability limits or to locate the load points which can be problematic in terms of voltage stability, by a characteristic referred to as the P-V curve which represents how the receiving end voltage V varies against changes in the active power demand P.

If there is a problem in voltage stability, appropriate measures need to be taken including the installation of voltage regulators including reactive power suppliers, and changes in load division by changing configuration.

[P - V curve]
First, formulate a simple model of a power system, as shown in Fig. 4-2. (In this model, the line resistance R is ignored, and the capacitance of the transmission line is ignored for simplification as in the case with the power flow calculation, and the reactive power supplier(s) on the receiving end are simulated as admittance Y.)

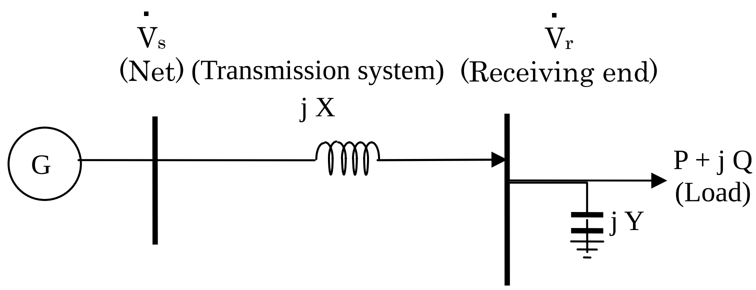


Fig. 4.2 One turbine generator one load model system

The active and reactive powers (P + j Q) supplied to the load as shown in Fig. 4･2 can be expressed by the following equation using line reactance X, reactive power supplier admittance Y, net voltage V_s, receiving end voltage V_r, and the phase angle difference between on net and receiving end θ:

$$P = \frac{V_s V_r \sin\theta}{X}$$

$$Q = \frac{V_s V_r \cos\theta}{X} - \left\{\frac{1}{X} - Y\right\} V_r^{\,2}$$

Here, eliminate θ from the relationship $\sin^2\theta + \cos^2\theta = 1$.

$$P^2 + \left\{Q + \left(\frac{1}{X} - Y\right) V_r^{\,2}\right\}^2 = \left(\frac{V_s V_r}{X}\right)^2$$

Assuming that the load power factor is constant, specify $\alpha = \frac{Q}{P}, Z = \frac{1}{X} - Y$ and adjust the equation for V_r. A quartic equation for V_r is obtained as shown below.

$$Z^2 V_r^{\,4} + \left(2PZ\alpha - \frac{V_s^{\,2}}{X^2}\right) V_r^{\,2} + \left(1 + \alpha^2\right) P^2 = 0$$

Solve the equation for V_r to obtain the following equation.

$$V_r = \sqrt{\frac{\frac{V_s^{\,2}}{X^2} - 2PZ\alpha \pm \sqrt{\frac{V_s^{\,4}}{X^4} - 4PZ\alpha\frac{V_s^{\,2}}{X^2} - 4P^2Z^2}}{2Z^2}}$$

In the above equation, if demand P is changed, receiving end voltage V_r is varied accordingly. This characteristic, or the characteristic expressing how the receiving end voltage is varied according to the changes in the demand is referred to as the P-V curve, as generally shown in Fig. 4･3.

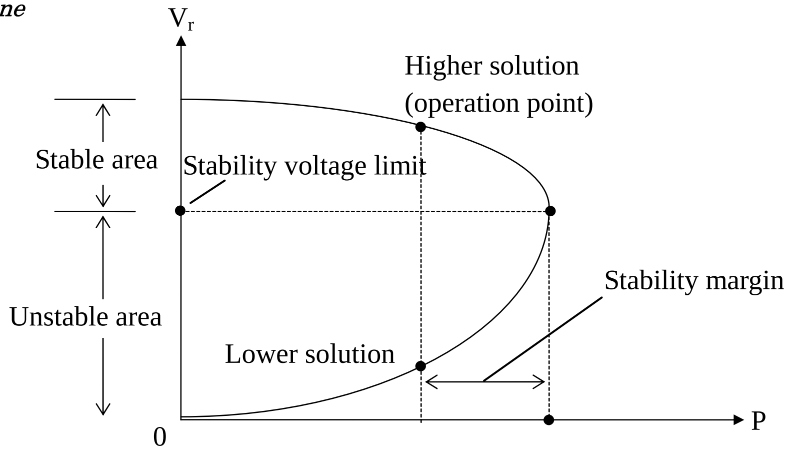


Fig. 4･3　P-V curve

As shown in Fig. 4･3, there are two solutions for the same demand P: A solution (higher solution) corresponding to an ordinary operation point, and another solution (lower solution). In addition, it is found that corresponding voltage cannot be obtained to greater demand than a certain level even if it is attempted to increase demand. The P and V at this point are referred to as "stability power limit" and "stability voltage limit" respectively in terms of voltage characteristics.

- **Short circuit capacity calculation**

  The short circuit capacity calculation determines the system voltage and current in cases where system failures, including grounding faults and short circuit faults, occur in transmission and distribution facilities, and is used to check whether the fault current exceeds the rated interrupting capacities of circuit breakers and/or the rated short-time capacities of transmission lines, or to grasp how much voltage drops due to such failures.

  If the short circuit capacity exceeds a facility capacity, the corresponding facility might be damaged in case of failure. To avoid such problems, appropriate measures need to be taken, such as changing the system configuration (from a loop to a radial system), installation of series reactors or upgrading the facilities.

[Short circuit capacity calculation]
Short circuit capacity S can be expressed by the following equation using three-phase short circuit current I_s and line voltage V:

$$S = \sqrt{3}V\ [\mathrm{kV}]\ I_s\ [\mathrm{A}]\ \ [\mathrm{kVA}] = \sqrt{3}V\ [\mathrm{kV}]\ I_s\ [\mathrm{kA}]\ \ [\mathrm{MVA}]$$

Three-phase short circuit current I_s can be determined by the following equation if the impedance viewed from the fault location to the system side is specified as Z:

$$Is = \frac{V[\mathrm{kV}]}{\sqrt{3}Z[\Omega]}\ [\mathrm{kA}]$$

Fig. 4･4 Three-phase short circuit fault

- **Stability analysis**

  The generators connected to a system need to be operated stably. The degree to which the generators can be operated stably is referred to as stability. Stability analysis is to analyze whether the oscillations of generators will be converged stably or not when disturbances (including load changes in power systems and power facility failures including lightning strikes) occur in the system. If a generator cannot be operated stably, step-out synchronization will result, which may cause unstable conditions as a chain reaction, possibly leading to system blackout. Stability analysis needs to cover steady state stability and transient stability. An appropriate analytical method should be selected according to the purpose of the analysis.

  The countermeasures against stability problems includes the adoption of multiple conductors and superior voltage for reducing impedance on the system side and the adoption of an automatic voltage regulator (AVR) in the ultra high-speed excitation system and a power system stabilizer (PSS: Device that feeds supplementary signals to the AVR to control possible disturbances in the power system and thereby stabilize the generator) on the generator side.

[Steady state stability]
Steady state analysis refers to stability in relation to comparatively small disturbances including ordinary load fluctuations and system switching.
[Transient stability]
Transient stability refers to stability in relation to comparatively large disturbances including lightning striking transmission lines.

- **Frequency calculation**

  Frequency calculation is to calculate the frequency fluctuations in an emergency in the event of the occurrence of imbalance of demand and supply including power source fallout or load drop, or frequency fluctuations due to load fluctuations, and is used to check whether the frequency fluctuations fall within a certain tolerance.

  If the frequency fluctuations are likely to exceed the tolerance, appropriate measures need to be considered, including changing lines to a two-circuit configuration for preventing power source fallout or load drop, and load shedding and/or power shedding using automatic system controller(s).

  There is a method available as a measure for calculating frequency fluctuation widths which uses the system frequency constant characteristic. The system frequency fluctuation characteristic refers to a constant representing the relationship between the amount of imbalance of demand and supply, and the amount of frequency changes.

  $$\Delta P = K\Delta F$$

  (ΔP: Amount of imbalance of demand and supply [MW]; ΔF: Amount of frequency changes [0.1Hz]; K: System frequency characteristic constant [MW/0.1Hz])

  K is a constant expressing the amount of imbalance of demand and supply required to change the frequency of 0.1 Hz. This constant, which varies for respective systems, should be determined from actual frequency fluctuations.

[Tolerance of frequency fluctuations]

Production (generation) must always match consumption (load) since it is difficult to store a large amount of power. Frequency is increased (or decreased) if the generation is larger (or smaller) than the load. Since frequency is determined by the speeds of the generators connected the power system, frequency fluctuations means that there are generator speed fluctuations.

As shown in Tab. 4‧1, frequency ranges allowing safe operation are set for generators, which are subjected to mechanical restrictions including the resonance of turbine blades of turbine generators caused by frequency deviations and the degraded capability of feed water pumps.

Tab. 4‧1 Requirements for frequencies of rotating electrical machines (JISC4034-1)

Frequency range	Requirements at voltage values from 0.95 to 1.03 [p.u.]
0.98 - 1.02 [p.u.]	No practical problems should be caused by continuous operation.
0.95 - 1.03 [p.u.]	No practical problems should occur.

(5) Flow of power system analysis

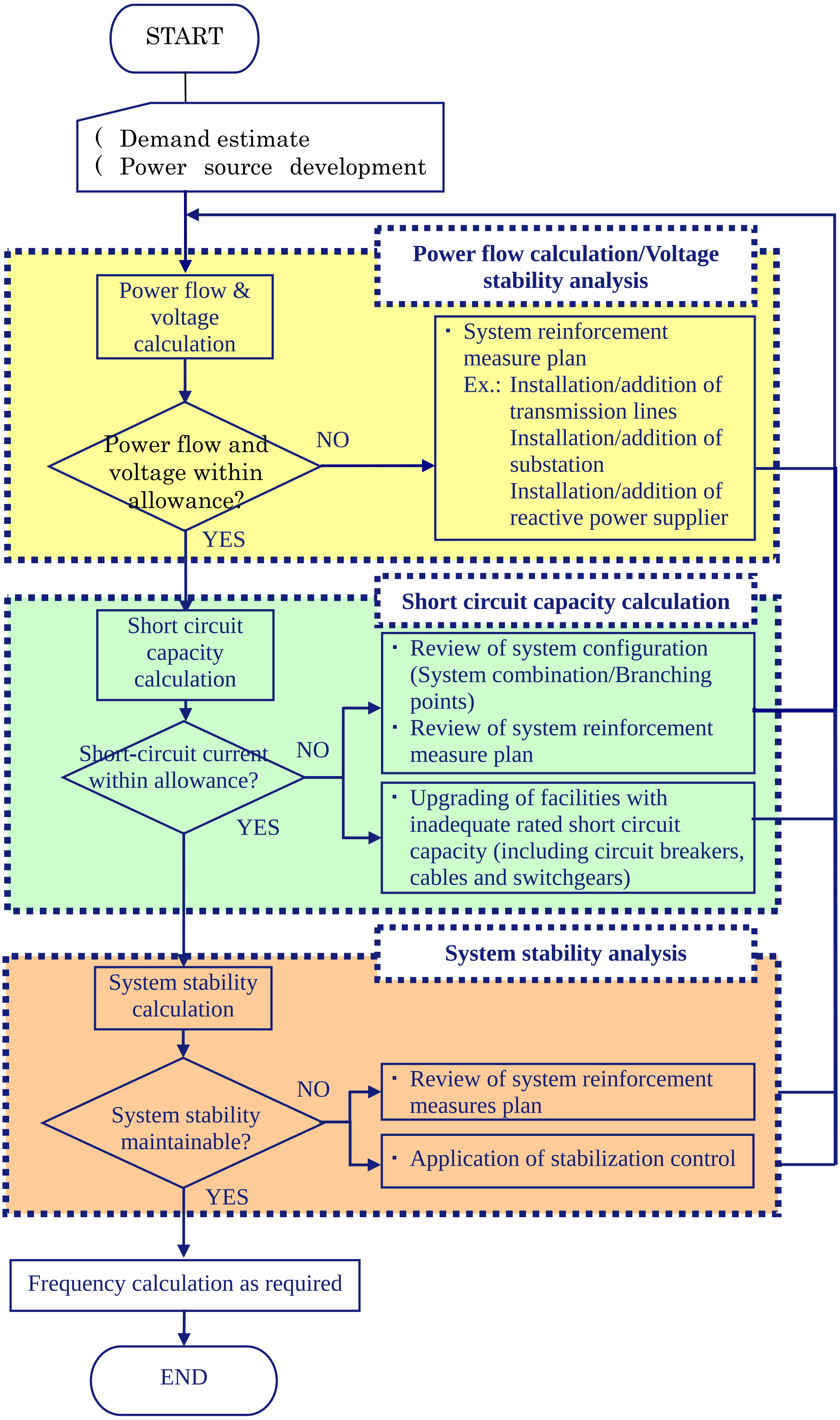


Table-1: (1) Electrical System

No.	Item	Unit	33 kV	11 kV	Low Voltage AC	Low Voltage DC
1.	Voltage					
	1) Nominal	[V]	33,000	11,000	400/230	110
	2) Maximum	[V]	36,000	12,000	432/240	125
2.	Short circuit current (Sym.1-sec.)	[kA]	25	20	30	2
3.	Lightning impulse withstand voltage	[kV]	170	95	-	-
4.	Power frequency	[kV]	70	38	3	-
5.	Wiring method		3 phase 3 wires		3 phase 4 wires	2 wires
6.	Neutral earthing method		Earthed through earthing transformer		Solidly earthed	(-)
7.	Frequency	[Hz]	50			-
	Permissible voltage fluctuation	[%]	+5 ～ -5		+8 ～ -8	+/-10
8.	Creepage distance	[mm/kV]	25			-
9.	Voltage drop allowance for feeder	[%]	7		5	10
10.	Requirement of sectionalization:				-	-
	1) Auto recloser	[set]	Every 10 km with LA		-	-
	2) Load isolator	[set]	Every 5 km with LA		-	-
11.	Earthing of steel materials				Every tenth For Terminal, Section and T-off	-
	1) Equipment mount poles	---	All poles, Every two			
	2) At sectionalizing points	---	Next poles (Both sides)			
12.	Type and size of earthing wire	[mm^2]	＞Cu-35 mm^2, PVC		＞Cu-16 mm^2, PVC	-
13.	Overhead grounding wire	---	Required	Not required		

Source: The Study Team

Table-1: (2) Special Requirement

No.	Item	33 kV		11 kV
1.	Overhsad grounding wire	OPGW (Min. 12 cores & 50 mm^2)		Not required
2.	Transformer			
	1) LV Secondary voltage	415		
	2) Tap changer	7 x +/- 1.25% with AVR		2 x +/- 2.5%
	3) Losses	Low loss and/or high efficiency type		
	4) HV/LV terminals	Voltage/ Place:	Foundation	Pole
		a) HV	Elephant	Open air
		b) LV	Elephant	Elephant
3.	Provision of interface panel for SCADA	Yes		Not required
4.	Circuit Breaker	For incoming & outgoing feeder (except transformer feeder)		
	1) Overhead line feeder	With Auto-reclosing (79)		
	2) Under ground cable feeder	With under frequency (81)		Not necessary
5.	Accuracy class for;			
	1) CT/VT & Wh meter	1) Less than 0.5		
	2) Others	2) More than 1.0		
6.	Discharge current of LA	More than 10,000 Amps		

Source: The Study Team

Table-2: Electrical Design Base

No.	Item	Unit	33 kV	11 kV	Low Voltage AC	Low Voltage DC
1.	Minimum ground clearance					
	1) Over open ground	[m]	6.0		5.0	-
	2) Over roads, railways, canals	[m]	7.0 (*1,*2)		6.0	-
	3) Over telecommunication lines	[m]	2.5		1.0	
	4) Under 161 kV lines	[m]	3.0		3.0	
	5) Under 33 kV lines	[m]	3.0		2.5	
	6) Under 11 kV lines	[m]	2.5		2.0	
	7) Near building					
	a) Vertical	[m]	Not allowed (*1)		1.5	-
	b) Horizontal	[m]	2.0		2.0	-
2.	Minimum distance of OHW between:					
	1) Phase to Phase	[mm]	370	315	300	-
	2) Phase to Ground	[mm]	320	220	200	-
3.	Minimum distance between 11/33kV and low voltage conductors for combination pole:	[mm]	1,500		---	-
4.	Poles					
	1) Type of pole	---	Steel	Concrete/ Steel/Wood	Steel/Wood	-
	2) Length	[m]	Min. 12	12	8/9	
5.	Location of poles from center of road					
	1) Arterial	[m]	15			-
	2) Secondary and Local	[m]	10			-
6.	Maximum pole span					
	1) Inside of town/village	[m]	90		45	-
	2) Outside of town/village	[m]	100		50	
7.	Span of tension pole					
	1) Inside of town/village	[m]	900		450	
	2) Outside of town/village	[m]	1,000		500	
8.	A. Overhead conductor					
	1) Specification	---	ACSR		AAAC	Cu
	2) Size	[mm^2]	120/240	95/150	50/70/120	As required
	3) Allowable current (MVA)	[A]	351/557	305/407	160/220/351	
	B. Underground cable					
	1) Specification	---	XLPE, Cu, with steel armor			
	2) Size (Feeder/Trunk)	[mm^2]	120/240	185/300		As required
	3) Distribution capacity	[MVA]	19/27	8/10		
9.	Maximum sag of the line	[%]	3			-
10.	Insulator					
	1) Specification	---	Porcelain/Glass			-
	2) Type					
	3) a) Tension insulator	---	10' Disc type		Bobbin	
	b) Suspension insulator	---	Pin/Post type			-
	4) Color	---	Brown/Green		White/Brown	-
	5) Creepage distance	[mm/kV]	25		---	

Remarks: *1: Safety factor shall be twice.
*2: Special provision to keep safety, such as net under lines, shall be considered.

Source: The Study Team

Teble-3: Climatic Conditions for Design

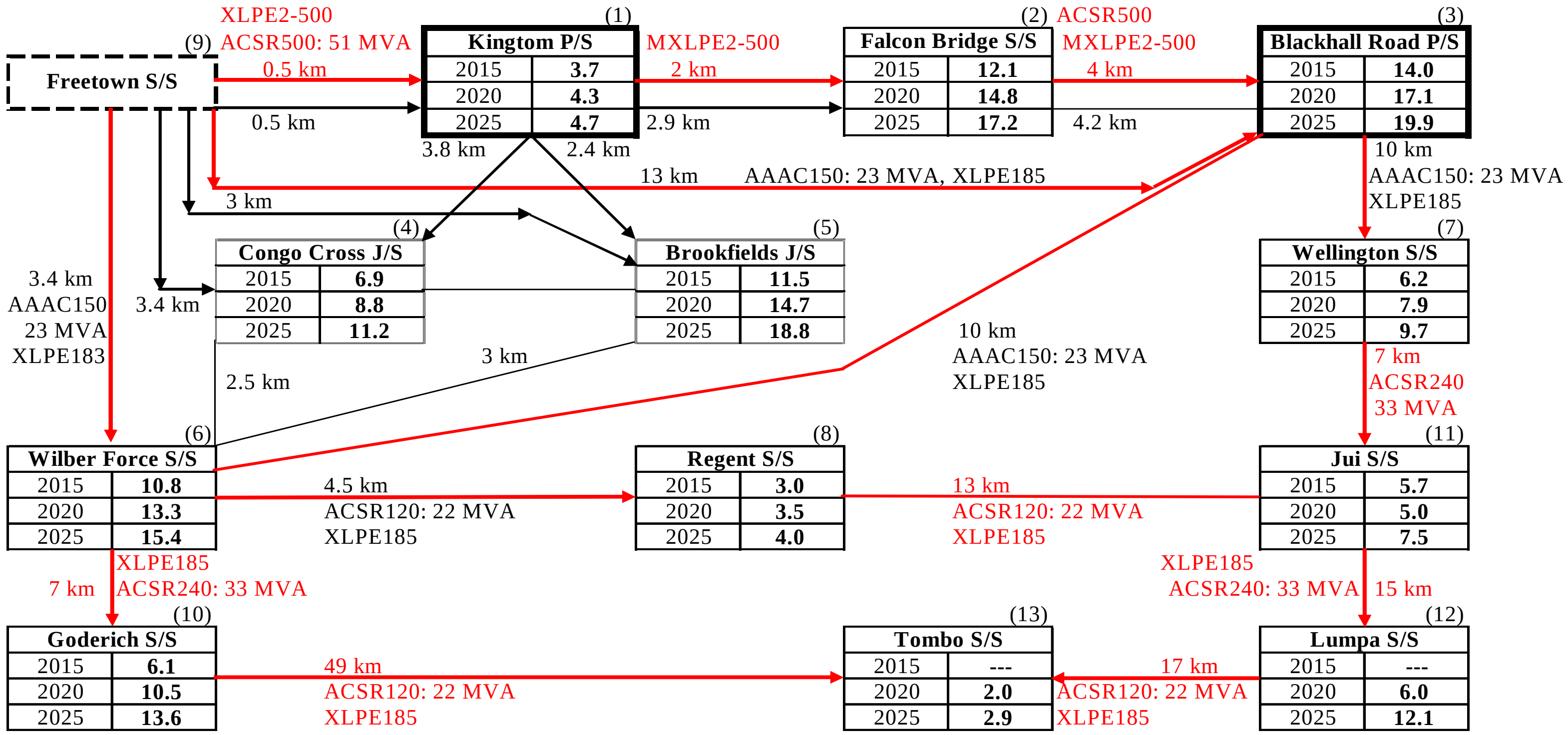
No. Description	Unit	Conditions	Remarks
1. Mean Sea Level	m	0 to 1,100	
2. Temperature;	℃		
1) Max.		45	
2) Mean		30	
3) Min.		10	
3. Rainfall;	mm		
1) Annual precipitation		320	
2) 1 Hour max.		10	
4. Humidity;	%		
1) Max.		95	
2) Mean (Dry/ Rainy)		35/75	
5. Wind velocity;	m/sec		
1) Max.		40	
2) Normal		15	
6. Wind direction;	---		
1) Dry season		North	
2) Rainy season		North-West	
7. Snow accumulation	cm	Nil	
8. Frozen soil	cm	Nil	
9. Periods;	---		
1) Dry season		December to April	
2) Rainy season		May to November	
10. Seismic force	g	0.2	
11. Max. Solar Radiation	$W/m^2/Day$	800 - 1,200	
12. Special conditions;			
1) Isokeraunic level	Times	150	
2) Dusty	---	No	
3) Sandstorm	---	Yes	
4) Fog or mist	---	Yes	
5) Hamatarn	---	Yes	

Remarks: Above data shall be applied Western Area District only.

Source: The Study Team

Peak Demand Forecast in Each Area (2015/2020/2025)

(Unit: MW)



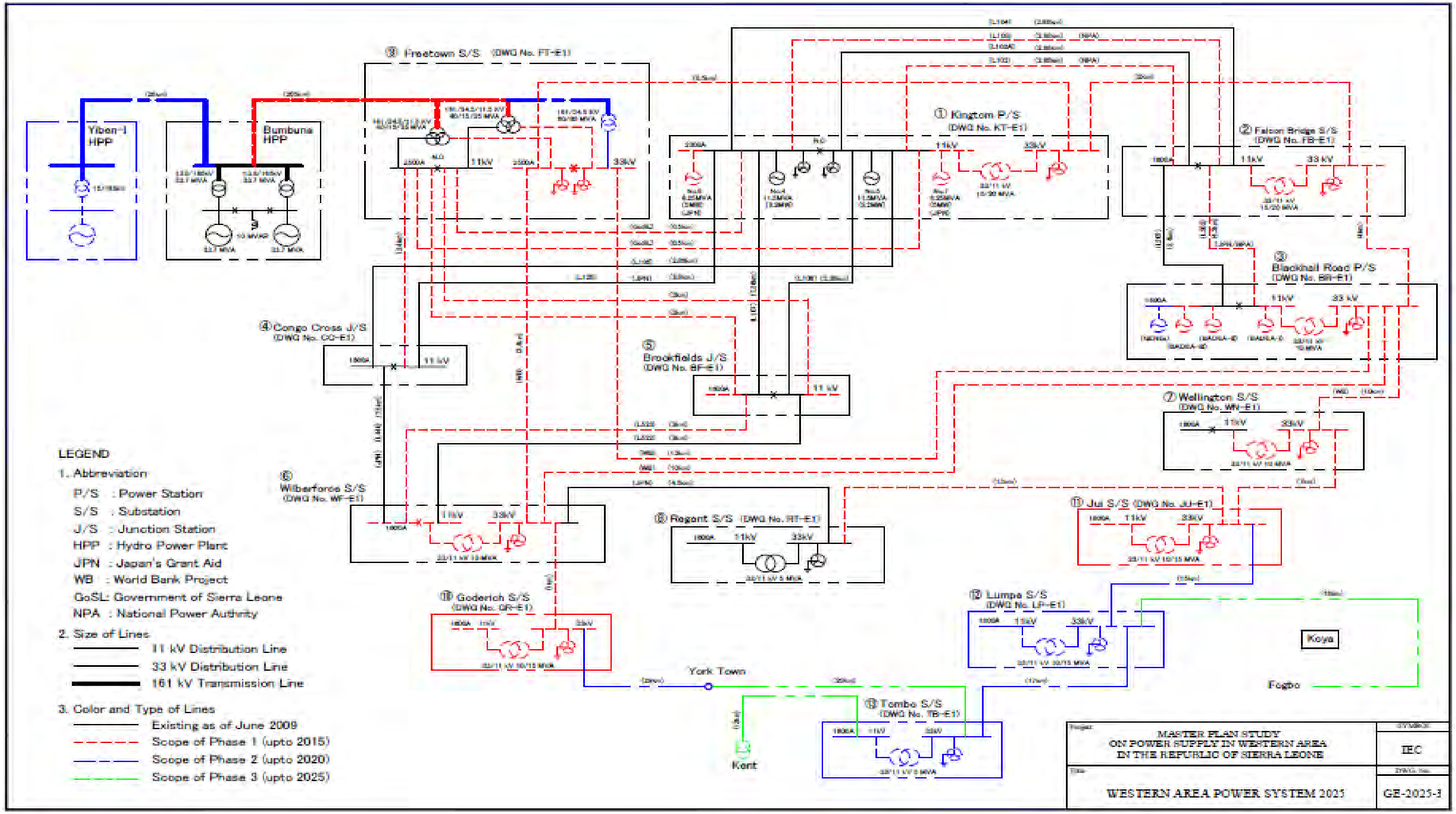
Legend:
: 33 kV Trunk Line (red line)
: 11 kV Trunk Line (black line)

Abbreviation
J/S: Junction Station
P/S: Power Station
S/S: Substation

Total	[MW]
2015	80.0
2020	107.9
2025	137.0

Source: JICA Study Team

Freetown Power System 2025



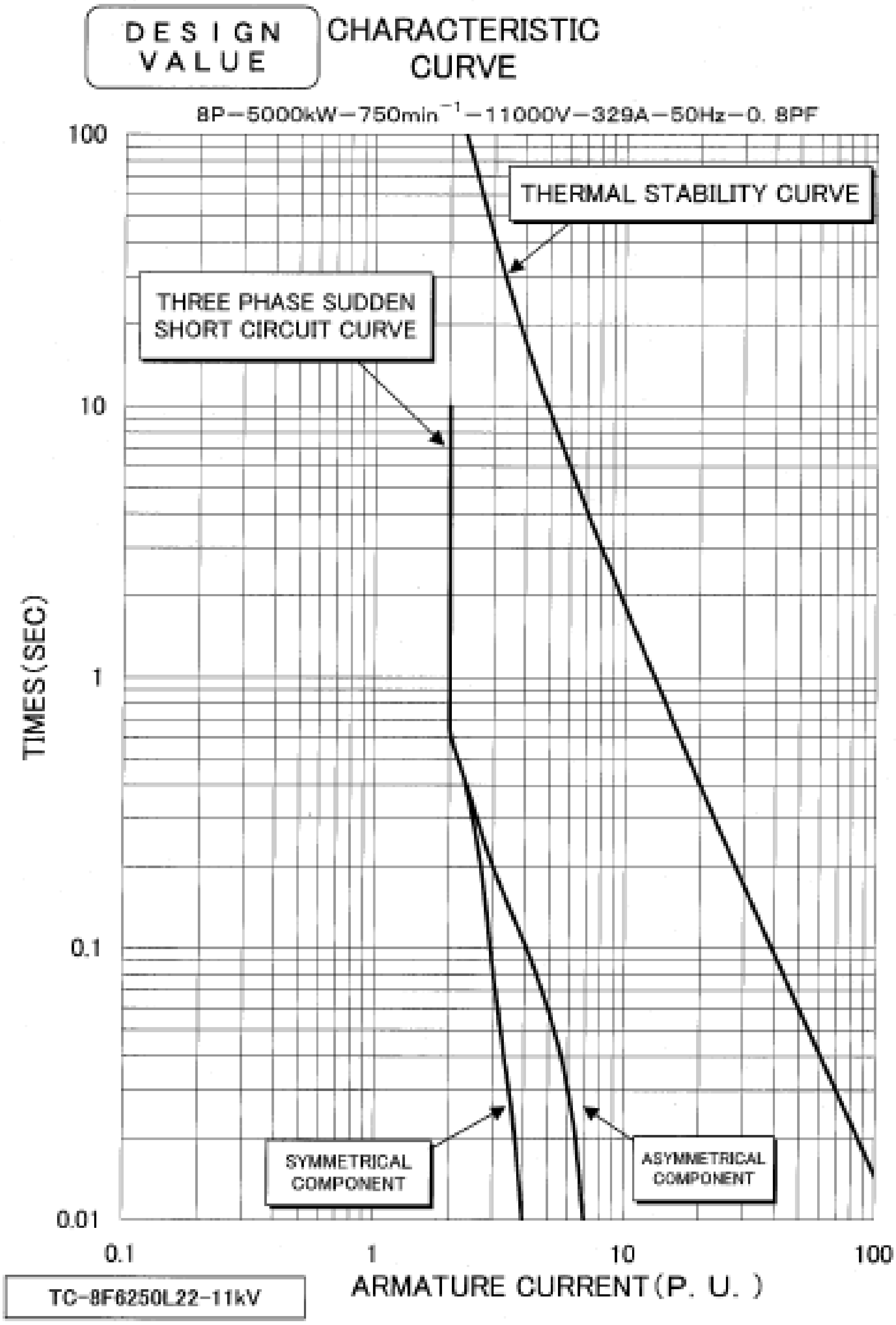
Source: JICA Study Team

Data Sheet for Generator

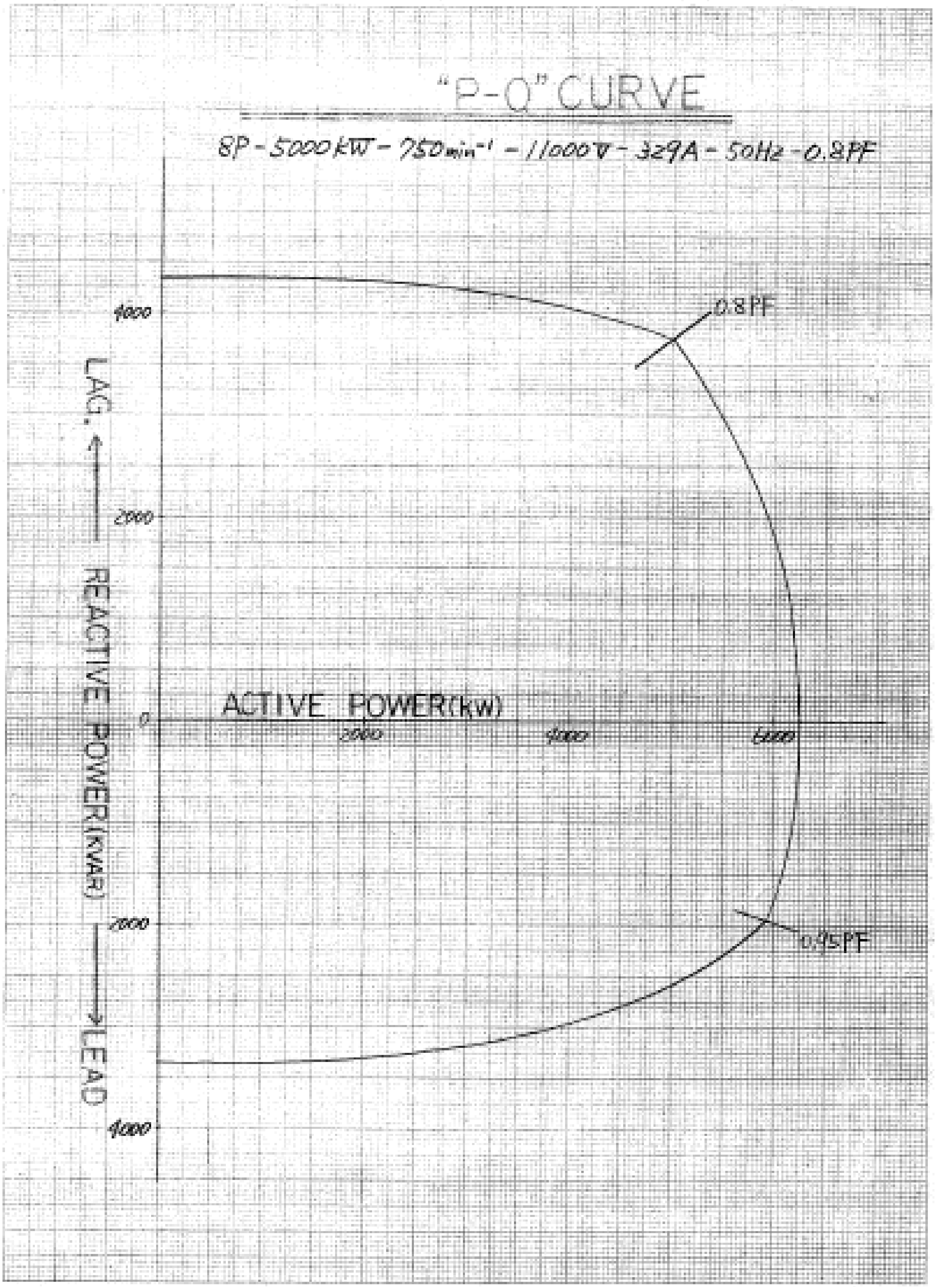
No.	Description	Unit	Data
1	NUMBER OF GENERATOR	[Set]	2
2	TYPE	---	NTAKL-SCP
3	RATED POWER	[kW]	5000
4	RATED VOLTAGE	[V]	11,000
5	RATED CURRENT	[A]	329
6	RATED POWER FACTER		0.8 (Lagging)
7	NUMBER OF POLES	[Poles]	8
8	RATED SPEED	[rpm]	750
9	FREQUENCY	[Hz]	50
10	RUNAWAY SPEED	[rpm]	N.A.
11	GD^2	[kg^2]	6,544
12	ROTATING DIRECTION	---	CLOCKWISE (VIEWED FROM P.M.G. SIDE)
13	PHASES CONNECTION	---	STAR
14	REACTANCE		
	1) D-AXIS REACTANCE (Xd)	---	1.4
	2) D-AXIS TRANSIENT REACTANCE (Xd')	---	0.32
	3) D-AXIS SUBTRANSIENT REACTANCE (Xd")	---	0.23
	4) Q-AXIS REACTANCE (Xq)	---	0.81
	5) Q-AXIS SUBTRANSIENT REACTANCE (Xq")	---	0.27
	6) ZERO SEQUENCE REACTANCE (X0)	---	0.13
	7) NEGATIVE SEQUENCE REACTANCE (X2)	---	0.25
	8) POITIER REACTANCE (Xp)	---	0.20
	9) D-AXIS REACTANCE, UNSATURATED (Xdu)	---	1.6
	10) D-AXIS TRANSIENT REACTANCE (Xdu')	---	0.36
	11) D-AXIS SUBTRANSIENT REACTANCE (Xdu")	---	0.23
	12) Q-AXIS REACTANCE (Xqu)	---	0.89
	13) Q-AXIS SUBTRANSIENT REACTANCE (Xqu")	---	0.27
	14) SHORT CIRCUIT RATIO (K)	---	0.73
15	TIME CONSTANT		
	1) OPEN CIRCUIT TIME CONSTANT (Tdo')	---	4.5
	2) SHORT CIRCUIT TRANSIENT TIME CONSTANT (Td')	---	0.98
	3) SHORT CIRCUIT SUBTRANSIENT TIME CONSTANT (Td")	---	0.029
	4) SHORT CIRCUIT DC OFFSET TIME CONSTANT (Ta)	---	0.13
16	VOLTAGE DISTORTION FACTOR	---	Less than 10%
17	INSULATION CLASS	---	F
18	EFFICIENCY		
	1) 50%-0.8 pf	[%]	95.6
	2) 60%-0.8 pf	[%]	96.0
	3) 70%-0.8 pf	[%]	96.3
	4) 80%-0.8 pf	[%]	96.4
	5) 90%-0.8 pf	[%]	96.5
	6) 100%-0.8 pf	[%]	96.5
19	CONTINUOUS REACTIVE POWER WITH 0 pf OVER EXCITED		
20	CONTINUOUS REACTIVE POWER WITH 0 pf UNDER EXCITED		SHOWN IN P-Q CURVE
21	CONTINUOUS ACTIVE POWER		

Source: JICA Study Team

Ref. No. KT-DEG: Data Sheet with P-Q curve



Source: JICA Study Team



Source: JICA Study Team

Ref. No. FR-TRF-1: HV-MV Transformer Data

No.	Description	Unit	Kingtom	Blackhall Road	Wellington	Wilberforce	Regent	Freetown		Bumbuna			
								No.1 MTr	No. 2 MTr	No. 1 MTr	No. 2 MTr	Step-up Tr.	Reactor
1	Capacity	[MVA]											
	1) ONAN		15	10	10	10	5	32/28/12	32/28/12	33.7	33.7	5	10 [Mvar]
	2) ONAF		20	---	---	---	---	40/35/15	40/35/15	---	---	---	---
2	Voltage	[V]	33/11	33/11	33/11	33/11	33/11	161/11.5/34.5	161/11.5/34.5	13.8/165	13.8/165	13.8/34.5	13.8
3	Tap	---	+/- 4x2.5%	+/- 8x1.25%	+/- 8x1.25%	+/- 8x1.25%	+4x1.25% -12x1.25	+/- 10x1.25%	+/- 10x1.25%	+/- 2x3.75%	+/- 2x3.75%	+/- 2x2.5%	---
4	%Z at rated capacity												
	1) HV/LV	[%]	No information	9.49	No information	9.32	8.04	---	---	11.45	11.44	(6>)	18.23 [Ω]
	2) H1/H2	[%]	---	---	---	---	---	13.5	13.5	---	---	---	---
	3) H1/H3	[%]	---	---	---	---	---	10.02	9.95	---	---	---	---
	4) H2/H3	[%]	---	---	---	---	---	5	5	---	---	---	---
5	Winding	---	Ynd11	Dyn11	Dyn11	Dyn11	Dyn11	YNynd11	YNynd11	YNd11	YNd11	Dyn5	Yn
6	LIWV	[kV]	170/75	170/70	170/75	170/70	170/70	650/95/170	650/95/170	125/650-N325	125/650-N325		125
7	AC	[kV]	75/35	95/38	75/35	95/38	95/38	275/38/70	275/38/70	70/150	70/150		50
8	Manufacturer												
	1) Name	---	Alstohm Savoisienne	Construzione Tranformator i Electrici		Construzione Tranformator i Electrici	France Transfo	ABB	ABB	Coemsa Ansaldo			AEG ETI
	2) Year	---	1980	1997	1980	1997	2008	1994	1994				1997
9	Earthing Tr.												
	1) Current/time	[A/Sec.]	Not Installed		300/10	300/10	300/10						
	2) Impedance	[Ohm]			207.55	204.26	190.5						
	3) LIWV/AC	[kV]			170/70	170/70	170/70						
	4) Manufacturer												
	a) Name	---				Construzione	France Tr.						
	b) Year	---				1997	2008						
	c) Winding	---				ZN	Zn						
Operation Conditions			Future	Future	Future	Future	(2M/2009)	(5M/2009)	(5M/2009)	(5M/2009)	(5M/2009)	(5M/2009)	Future

Remarks: LIWV: Lightning Impulse Withstand Voltage AC: AC Power Frequency

Source: JICA Study Team

Future 11 kV and 33 kV Lines

No.	From	To	ID No.	Laying Method	Length [m]	Specification of Line				Remarks
						Conductor	Core	Size (mm2)	Type	
33 kV Line										
1	Freetown S/S	Wilberforce S/S (1)	L3901	U/G	1,000	Cu	3	185	XLPE	2010
	Freetown S/S	Wilberforce S/S(2)	L3901	O/H	2,400	Al	1x3	150	AAAC	2010
2	Freetown S/S	Blackhall Road P/S (1)	L3902	U/G	1,000	Cu	3	185	XLPE	2010
	Freetown S/S	Blackhall Road P/S (2)	L3902	O/H	12,000	Al	1x3	150	AAAC	2010
3	Freetown S/S	Kingtom P/S (1)	L3903	U/G	100	Cu	3x2	500	XLPE	2011
	Freetown S/S	Kingtom P/S (2)	L3903	O/H	400	Al	1x3	500	ACSR	2011
3		**Sub-Total**		**Total**	**16,900**	**O/H**	**14,800**			
1	Wilberforce S/S	Regent S/S (1)	L3601	U/G	3,200	Cu	3	185	XLPE	
	Wilberforce S/S	Regent S/S (2)	L3601	O/H	1,300	Al	1x3	120	ACSR	
2	Wilberforce S/S	Goderich S/S (1)	L3602	U/G	1,000	Cu	3x2	185	XLPE	2013
	Wilberforce S/S	Goderich S/S (2)	L3602	O/H	6,000	Al	1x3	240	ACSR	2013
1		**Sub-Total**		**Total**	**11,500**	**O/H**	**7,300**			
1	Kingtom P/S	Falcon Bridge S/S	L3101	U/G	2,000	Cu	3x2	500	M-XLPE	2012
1		**Sub-Total**		**Total**	**2,000**	**O/H**	**0**			
1	Falcon Bridge S/S	Blackhall Road P/S (1)	L3201	U/G	3,000	Cu	3x2	500	M-XLPE	2013
	Falcon Bridge S/S	Blackhall Road P/S (2)	L3201	O/H	1,000	Al	1x3	500	ACSR	2013
1		**Sub-Total**		**Total**	**4,000**	**O/H**	**1,000**			
1	Blackhall Road P/S	Wilberforce S/S (1)	L3301	U/G	1,000	Cu	3	185	XLPE	2010
	Blackhall Road P/S	Wilberforce S/S (1)	L3301	O/H	9,000	Al	1x3	150	AAAC	2010
1	Blackhall Road P/S	Wellington S/S (1)	L3302	U/G	1,000	Cu	3	185	XLPE	2010
	Blackhall Road P/S	Wellington S/S (2)	L3302	O/H	9,000	Al	1x3	150	AAAC	2010
1		**Sub-Total**		**Total**	**20,000**	**O/H**	**18,000**			
1	Regent S/S	Jui S/S (1)	L3804	U/G	1,000	Cu	3	185	XLPE	2013
	Regent S/S	Jui S/S (2)	L3604	O/H	12,000	Al	1x3	120	ACSR	2013
1		**Sub-Total**		**Total**	**13,000**	**O/H**	**12,000**			
1	Wellington S/S	Jui S/S (1)	L3701							
	Wellington S/S	Jui S/S (2)	L3701	O/H	7,000	Al	3x2	185	ACSR	2013
1		**Sub-Total**		**Total**	**7,000**	**O/H**	**7,000**			
1	Jui S/S	Lumpa S/S (1)	L31101	U/G	1,000	Cu	3x2	185	XLPE	2017
	Jui S/S	Lumpa S/S (2)	L31101	O/H	14,000	Al	1x3	240	ACSR	2017
1		**Sub-Total**		**Total**	**15,000**	**O/H**	**14,000**			
1	Goderich S/S	York	L31001	O/H	29,000	Al	1x3	120	ACSR	2016
	York	Tombo S/S	L31001	O/H	20,000	Al	1x3	120	ACSR	2022
1		**Sub-Total**		**Total**	**49,000**	**O/H**	**49,000**			
1	Lumpa S/S	Tombo S/S (1)	L31201	U/G	1,000	Cu	3	185	XLPE	2017
	Lumpa S/S	Tombo S/S (2)	L31201	O/H	16,000	Al	1x3	120	ACSR	2017
1		**Sub-Total**		**Total**	**17,000**	**O/H**	**16,000**			
		Summary of 33 kV								
			Under Ground Cable		**16,300**					
			Over Head Wire		**139,100**					
		Total		**U/G**	**155,400**					
11 kV Line										
1	Kingtom P/S	Freetown S/S	L105A	U/G	500	Cu	3x2	500	XLPE	2010
2	Kingtom P/S	Freetown S/S	L118	U/G	500	Cu	3x2	500	XLPE	2010
3	Congo Cross J/S	Freetown S/S	L450	O/H	3,400	Al	1x3	240	ACSR	2020
4	Brookfields J/S (1)	Freetown S/S (1)	L550	U/G	500	Cu	3	185	XLPE	2020
	Brookfields J/S (1)	Freetown S/S (2)	L550	O/H	2,500	Al	1x3	240	ACSR	2020
5	Brookfields J/S (2)	Freetown S/S (1)	L551	U/G	500	Cu	3	185	XLPE	2020
	Brookfields J/S (2)	Freetown S/S (2)	L551	O/H	2,500	Al	1x3	240	ACSR	2020
5		**Sub-Total**		**Total**	**10,400**	**O/H**	**8,400**			

Source: JICA Study Team

Clearing Time Limit of Bumbuna System

(Reference Only)

With reference to the 161kV system stability studies carried out for the Bumbuna Project, in the worst conditions, the analysis checked for this purpose takes into account the following:

1 unit in service (30 MW)

- 1-phase-to-ground fault: 0.1s + 1s single pole reclosure
- 1-phase-to-ground fault: 0.5s + 1s to 1.5s single pole reclosure
- 3-phase fault: 0.1s + 0.5s 3-phase pole reclosure with P<5MW
- 3-phase fault at HV step-down transformer: 0.1s
- 3-phase fault at 11 kV switchgear breaker in Freetown: 0.2s

2 units in service (60 MW) and 26 MW in Kingtom TPP

- 3-phase fault at 11 kV switchgear breaker in Freetown: 0.2s
- 3-phase fault at HV step-down transformer: 0.1s
- 1-phase-to-ground fault: 0.5s

No PSS is provided with the AVR static excitation system.

Source: Bumbuna

Technical Information of 11/33/161 kV CB

No.	Name of Station	Feeder for Trunk Line				Bus-tie		Other Feeders				Remarks
		Incoming		Outgoing				Step-down Transformer		Other		
		In [A]	SCC [kA]	In [A]	SCC [kA]	In [A]	SCC [kA]	In [A]	SCC [kA]	In [A]	SCC [kA]	
A.	**Bumbuna HPP: 161 kV**	---	---	3,150	40	---	---	---	---	---	---	
B.	**Freetown S/S**											
	1) 161 kV	3,150	40	---	---	---	---	---	---	---	---	3-sec.
	2) 33 kV	1,250	25	1,250	25	1,250	25	630	25	630	25	Plan
	3) 11 kV	2,500	25	1,250	16	1,250	16	1,250	16	1,250	16	
100	**Kingtom P/S**											
	1) 33 kV	1,250	25	1,250	25	---	---	630	25	630	25	Plan
	2) 11 kV	1,250	25	1,250	25	2,300	25	630	25	630	25	
200	**Falcon Bridge S/S**											
	1) 33 kV	1,250	25	1,250	25	---	---	630	25	630	25	Plan
	2) 11 kV	1,250	20	1,250	20	1,250	20	630	20	630	20	3-sec.
300	**Blackhall Road P/S**											
	1) 33 kV	1,250	25	1,250	25	---	---	630	25	630	25	Plan
	2) 11 kV	1,250	20	1,250	20	1,250	20	630	20	630	20	3-sec.
400	**Congo Cross J/S**											
	1) 11 kV	1,250	20	1,250	20	1,250	20	630	20	630	20	3-sec.
500	**Brookfields J/S**											
	1) 11 kV	1,250	20	1,250	20	1,250	20	630	20	630	20	3-sec.
600	**Wilberforce S/S**											
	1) 33 kV	1,250	25	1,250	25	---	---	630	25	630	25	Plan
	2) 11 kV	1,250	20	1,250	20	1,250	20	630	20	630	20	3-sec
700	**Wellington S/S**											
	1) 33 kV	1,250	25	1,250	25	---	---	630	25	630	25	Plan
	2) 11 kV	1,250	20	1,250	20	1,250	20	630	20	630	20	3-sec
800	**Regent S/S**											
	1) 33 kV	630	25	630	25	---	---	630	25	630	25	
	2) 11 kV	1,250	20	1,250	20	1,250	20	630	20	630	20	3-sec
FP	**Goderich, Jui, Lumpa & Tombo S/S**											
	1) 33 kV	630	25	630	25	---	---	630	25	630	25	Plan
	2) 11 kV	1,250	20	1,250	20	1,250	20	630	20	630	20	Plan

Remarks: In: Rated current SCC: Short Circuit Current

Source: JICA Study Team

PART-4 Environmental and Social Considerations

Environmental and Social Considerations

It is important during the planning stage to examine what kinds of environmental and social impacts will be anticipated and what kinds of necessary measures can be taken to avoid or mitigate the identified adverse impacts. The table below is an environmental checklist for power distribution lines. This is a modified version based on the original version developed by Japan Bank for International Cooperation. It is recommended to use this checklist to recognize the expected adverse impact caused by renewal, reinforcement and extension of distribution systems, and then to change the route to a new one which has less impacts or devise mitigation measures. Regarding examples of mitigation measures, please refer to Chapter 7 in the Main Report.

Category	Environmental Item	Main Check Items	How to collect relevant information in Sierra Leone
Natural Environment	Protected Areas	① Is the project site located in protected areas designated by the country's laws or international treaties and conventions? Is there a possibility that the project will affect the protected areas?	① Check the map of protected areas in Sierra Leone produced by DACO/SLIS, which is available at http://www.daco-sl.org/encyclopedia/8_lib/8_2b5_pa.htm. ② Collect additional information from the Ministry of Agriculture, Forestry and Food Security
	Ecosystem	① Does the project site encompass primeval forests, tropical rain forests, ecologically valuable habitats (e.g., coral reefs, mangroves, or tidal flats)? ② Does the project site encompass the protected habitats of endangered species designated by the country's laws or international treaties and conventions? ③ If significant ecological impacts are anticipated, are adequate protection measures taken to reduce the impacts on the ecosystem? ④ Are adequate measures taken to prevent disruption of migration routes and habitat fragmentation of wildlife, and livestock? ⑤ Is there a possibility that improved access by the project will cause impacts, such as destruction of forest, poaching, desertification, reduction in wetland areas, and disturbance of ecosystem due to introduction of exotic (non-native invasive) species and pests? Are adequate measures for preventing such impacts considered? ⑥ In cases where the project site is located in undeveloped areas, is there a possibility that the new development will result in extensive loss of natural environments?	① Collect information from the Ministry of Agriculture, Forestry and Food Security, NGOs and research institutions. ② Check the Red List of International Union for Conservation of Nature and Natural Resources (IUCN) for threatened species.
	Topography and Geology	① Is there soft ground on the route of power lines that may cause slope failures or landslides? Are adequate measures considered to prevent slope failures or landslides, where needed? ② Is there a possibility that civil works, such as cutting and filling will cause slope failures or landslides? Are adequate measures considered to	

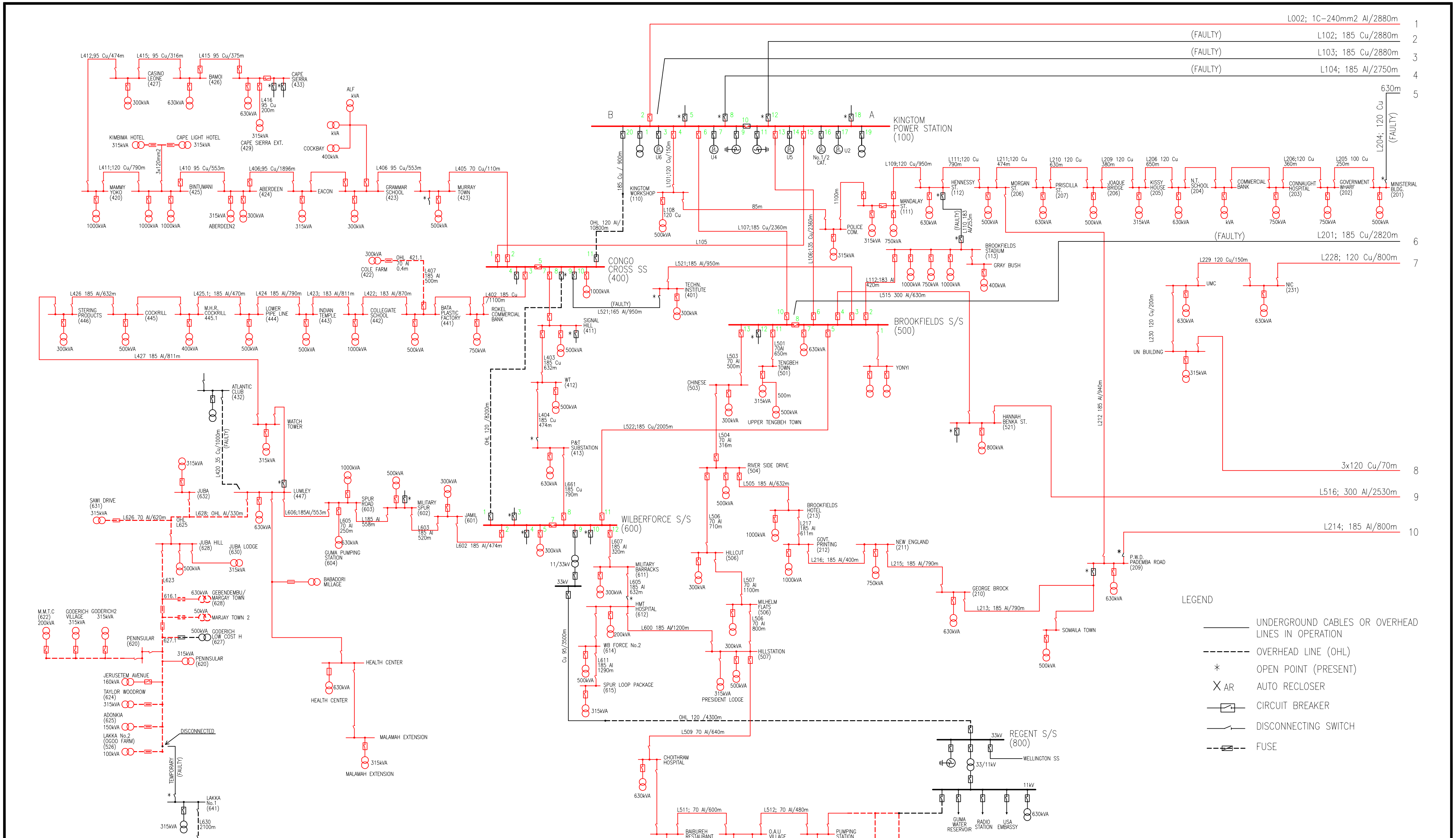
		prevent slope failures or landslides? ③ Is there a possibility that soil runoff will result from cut and fill areas, waste soil disposal sites, and borrow sites? Are adequate measures taken to prevent soil runoff?	
Social Environment	Resettlement	① Is involuntary resettlement caused by project implementation? If involuntary resettlement is caused, are efforts made to minimize the impacts caused by the resettlement? ② Is adequate explanation on relocation and compensation given to affected persons prior to resettlement? ③ Is the resettlement plan, including proper compensation, restoration of livelihoods and living standards developed based on socioeconomic studies on resettlement? ④ Does the resettlement plan pay particular attention to vulnerable groups or persons, including women, children, the elderly, people below the poverty line, ethnic minorities, and indigenous peoples? ⑤ Are agreements with the affected persons obtained prior to resettlement? ⑥ Is the organizational framework established to properly implement resettlement? Are the capacity and budget secured to implement the plan? ⑦ Is a plan developed to monitor the impacts of resettlement?	① Collect information on settlements from Ministry of Lands, Country Planning and the Environment and Local Councils. However, settlements are expanding rapidly. It is necessary to see the planed route firsthand. ② Work with Ministry of Social Welfare and Gender Affairs to obtain information on vulnerable groups. ③ Ministry of Lands, Country Planning and the Environment has the standards for valuation of land and assets. ④ Learn past experiences from other ministries and agencies.
	Living and Livelihood	① Is there a possibility that the project will adversely affect the living conditions of inhabitants? Are adequate measures considered to reduce the impacts, if necessary? ② Is there a possibility that diseases, including communicable diseases, such as HIV will be introduced due to immigration of workers associated with the project? Are adequate considerations given to public health, if necessary? ③ Is there a possibility that installation of structures, such as power line towers will cause radio interference? If significant radio interference is anticipated, are adequate measures considered?	
	Heritage	① Is there a possibility that the project will damage the local archeological,	① Collect information from the Ministry of Tourism and

		historical, cultural, and religious heritage sites? Are adequate measures considered to protect these sites in accordance with the country's laws?	Cultural Affairs
	Landscape	① Is there a possibility that the project will adversely affect the local landscape? Are necessary measures taken?	
	Ethnic Minorities and Indigenous Peoples	① Where ethnic minorities and indigenous peoples are living in the rights-of-way, are considerations given to reduce impacts on the culture and lifestyle of ethnic minorities and indigenous peoples? ② Does the project comply with the country's laws for rights of ethnic minorities and indigenous peoples?	
Others	Waste	① Is dangerous (such as PCB contained transformer, waste oil) or recyclable waste (such as copper wires) discharged? ② Is a proper waste management system established?	
	Soil Contamination	① Is the operation and maintenance system of transformers established to avoid oil leaks?	
	Accidents	① Are there any structure under power lines and within certain clearance limit?	
	Impacts during Construction	① Are adequate measures considered to reduce impacts during construction (e.g., noise, vibrations, turbid water, dust, exhaust gases, and wastes)? ② If construction activities adversely affect the natural environment (ecosystem), are adequate measures considered to reduce impacts? ③ If construction activities adversely affect the social environment, are adequate measures considered to reduce impacts? ④ If necessary, is health and safety education (e.g., traffic safety, public health) provided for project personnel, including workers?	
	Monitoring	① Does the proponent develop and implement monitoring program for the environmental items that are considered to have potential impacts? ② Are the items, methods and frequencies included in the monitoring program judged to be appropriate? ③ Does the proponent establish an adequate monitoring framework	

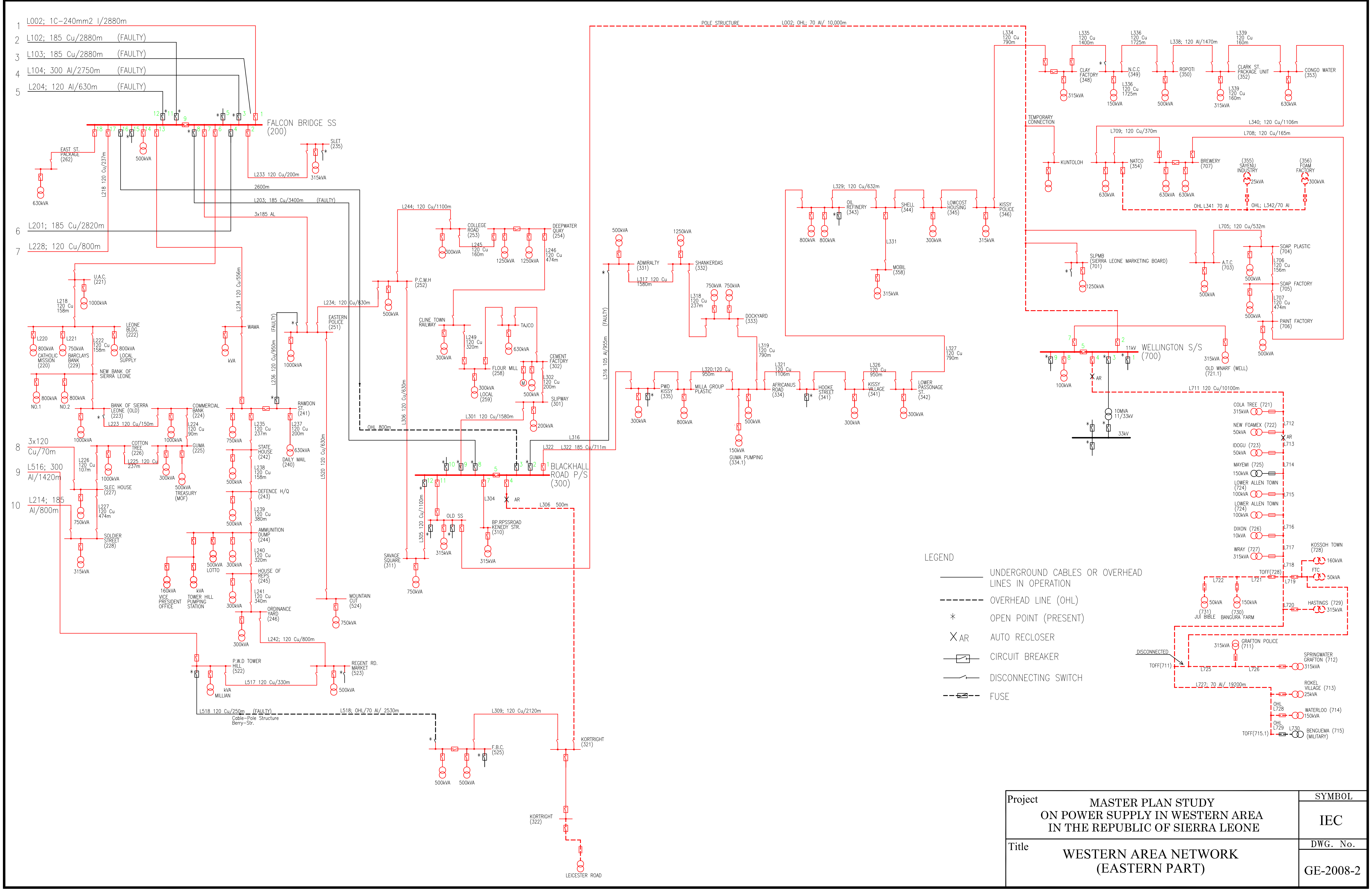
		(organization, personnel, equipment, and adequate budget to sustain the monitoring framework)? ④ Are any regulatory requirements pertaining to the monitoring report system identified, such as the format and frequency of reports from the proponent to the regulatory authorities?	
Permits and Explanation	EIA and Environmental Permits	① Have EIA reports been officially completed? ② Have EIA reports been approved by authorities of the host country's government? ③ Have EIA reports been unconditionally approved? If conditions are imposed on the approval of EIA reports, are the conditions satisfied? ④ In addition to the above approvals, have other required environmental permits been obtained from the appropriate regulatory authorities of the host country's government?	① Check the Environmental Protection Agency Act for the EIA procedures. ② Collect additional information from the Environmental Protection Agency if necessary.
	Explanation to the Public	① Are contents of the project and the potential impacts adequately explained to the public based on appropriate procedures, including information disclosure? Is understanding obtained from the public? ② Are proper responses made to comments from the public and regulatory authorities?	

PART-5 Drawings

CONTENTS



Project	MASTER PLAN STUDY ON POWER SUPPLY IN WESTERN AREA IN THE REPUBLIC OF SIERRA LEONE	SYMBOL IEC
Title	WESTERN AREA NETWORK (WESTERN PART)	DWG. No. GE-2008-1



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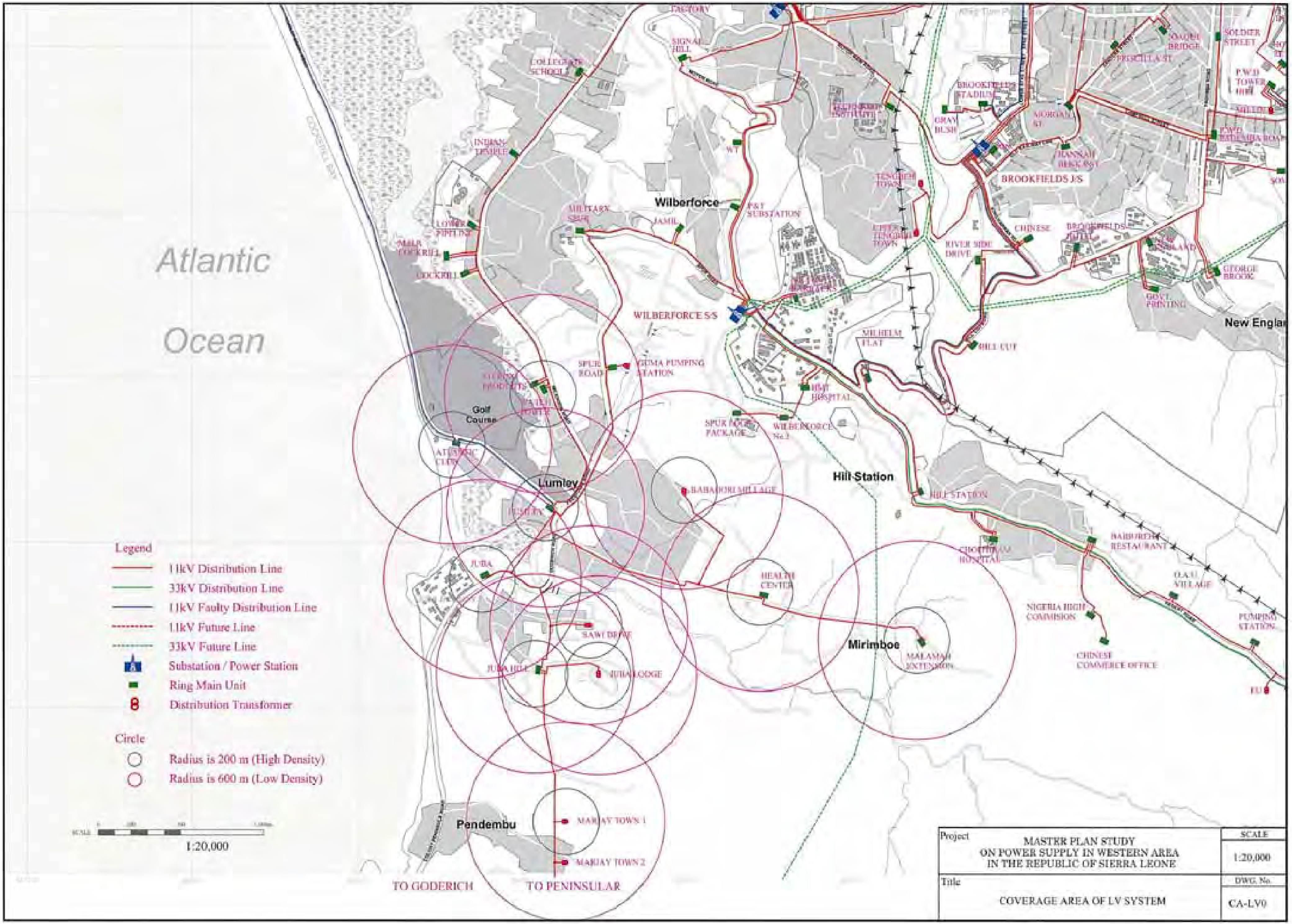
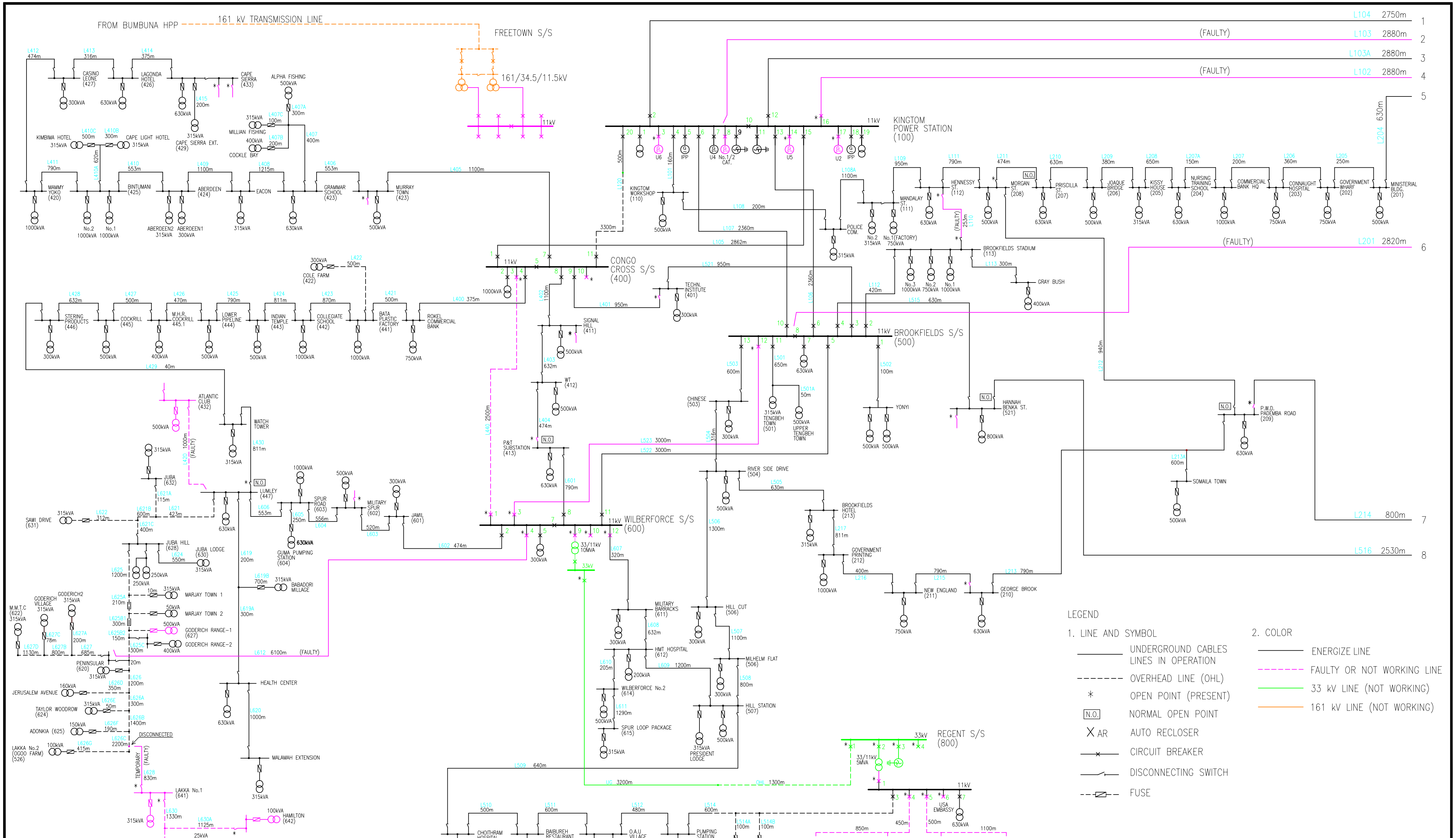


Atlantic
Ocean
Wilberforce
WILBERFORCE S/S
BROOKFIELDS J/S
Hill Station
Lumley
Golf
Course
Mirimboe
Pendembu
New Englar
COLLEGIATE SCHOOL
SIGNAL HILL
INDIAN TEMPLE
LOWER PIPELINE
COCKRILL
MILITARY SPUR
JAMIL
P&T SUBSTATION
GRAY BUSH
MORGAN ST
HANNAH BENKA ST
TENGBEH TOWN
UPPER TENGBEH TOWN
RIVER SIDE DRIVE
CHINESE
GEORGE BROOK
GOVT. PRINTING
SOLDIER STREET
P.W.D TOWER HILL
HILL CUT
SPUR ROAD
GUMA PUMPING STATION
WILHELM FLAT
SPUR ROAD PACKAGE
WILBERFORCE No.1
BABADORI VILLAGE
HILL STATION
CHOITHRAM HOSPITAL
BAIBUREH RESTAURANT
O.A.U. VILLAGE
NIGERIA HIGH COMMISION
CHINESE COMMERCE OFFICE
PUMPING STATION
EU
HEALTH CENTER
MALAMAH EXTENSION
LUMLEY
JUBA
SAWI DRIVE
JUBA HILL
JUBA LODGE
MAMAY TOWN 1
MAMAY TOWN 2
TO GODERICH
TO PENINSULAR
Legend
11kV Distribution Line
33kV Distribution Line
11kV Faulty Distribution Line
11kV Future Line
33kV Future Line
Substation / Power Station
Ring Main Unit
Distribution Transformer
Circle
Radius is 200 m (High Density)
Radius is 600 m (Low Density)
1:20,000
Project
MASTER PLAN STUDY
ON POWER SUPPLY IN WESTERN AREA
IN THE REPUBLIC OF SIERRA LEONE
SCALE
1:20,000
Title
COVERAGE AREA OF LV SYSTEM
DWG. No.
CA-LV0



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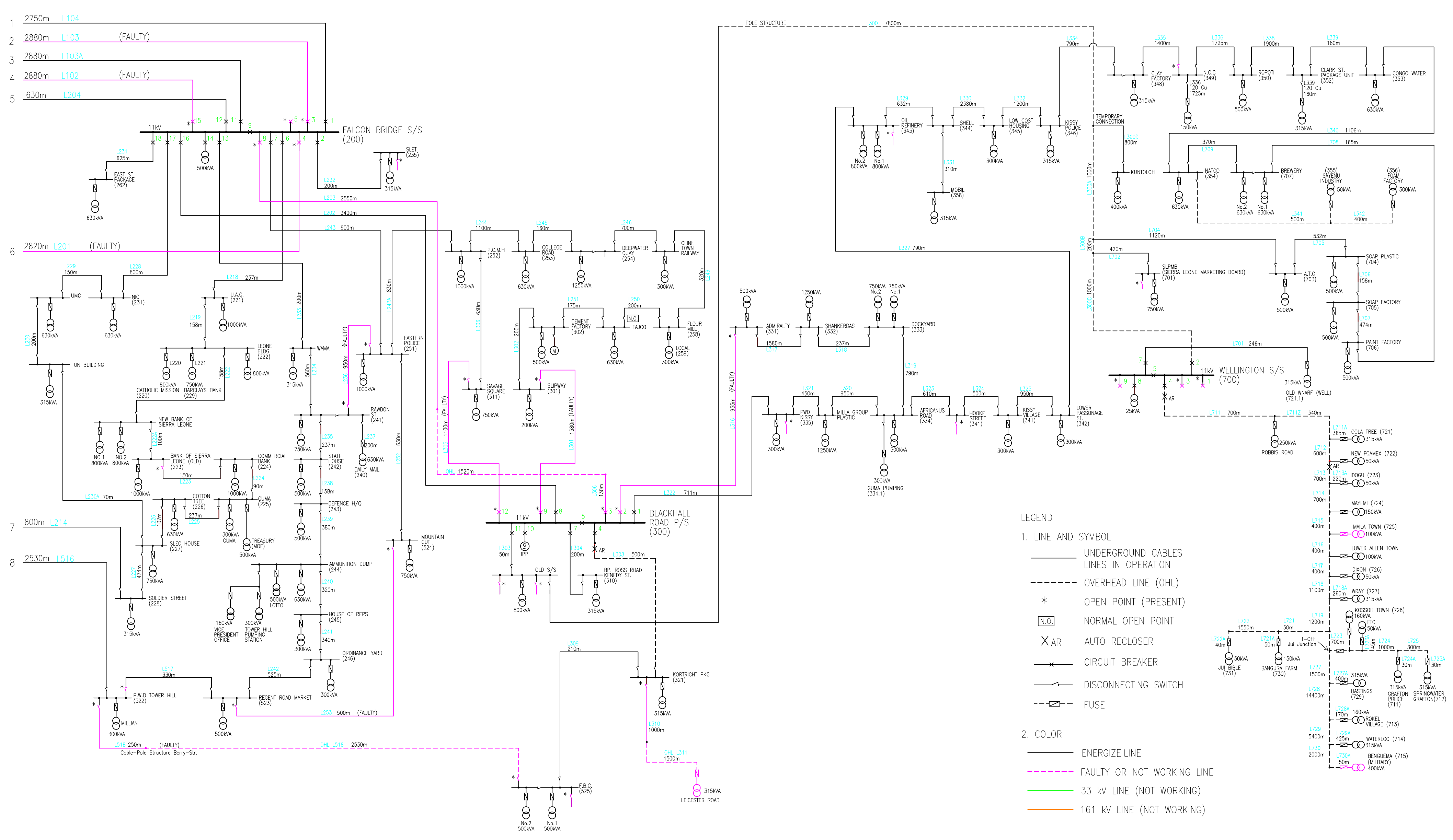

Project	MASTER PLAN STUDY ON POWER SUPPLY IN WESTERN AREA IN THE REPUBLIC OF SIERRA LEONE	SYMBOL: IEC
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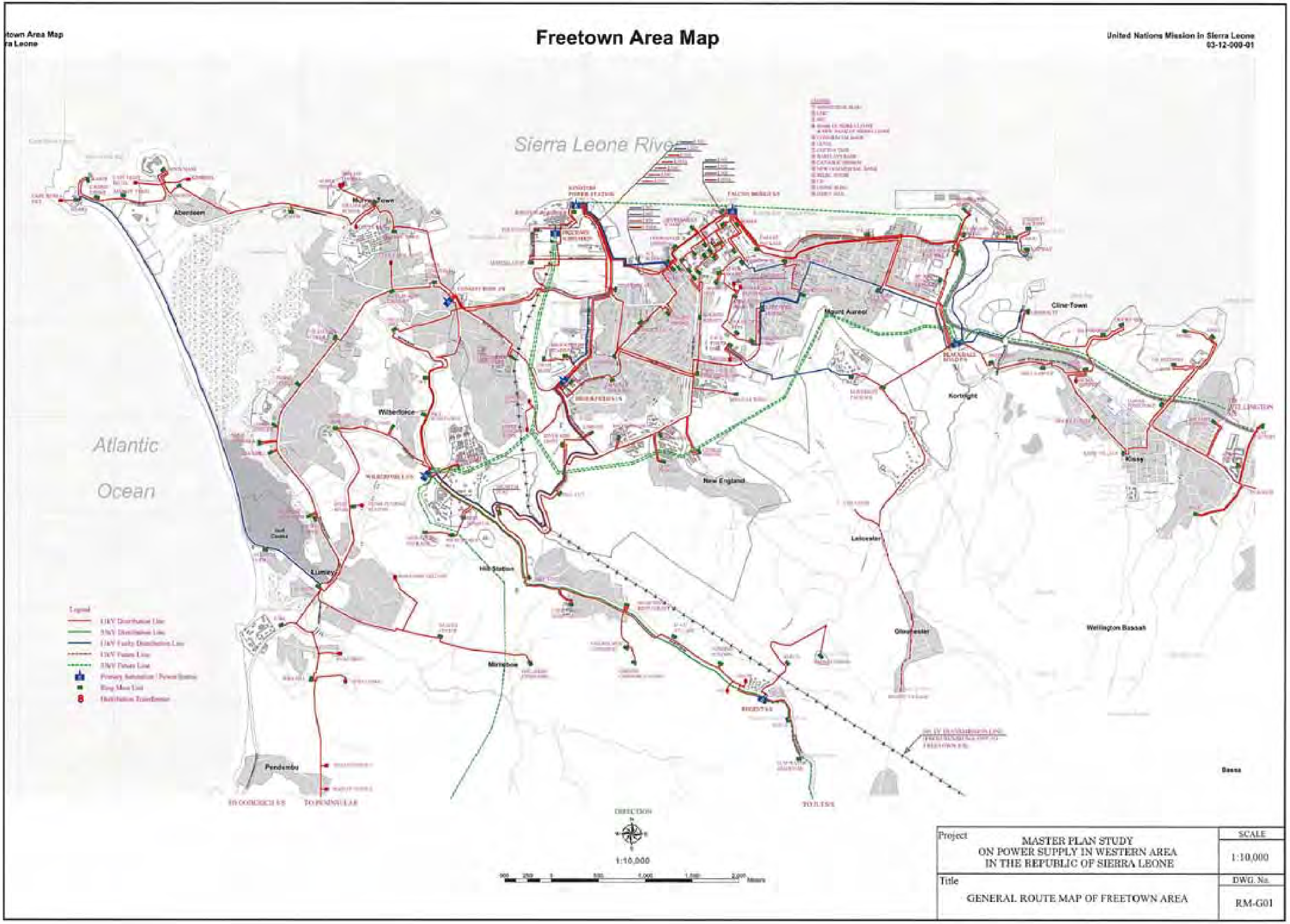
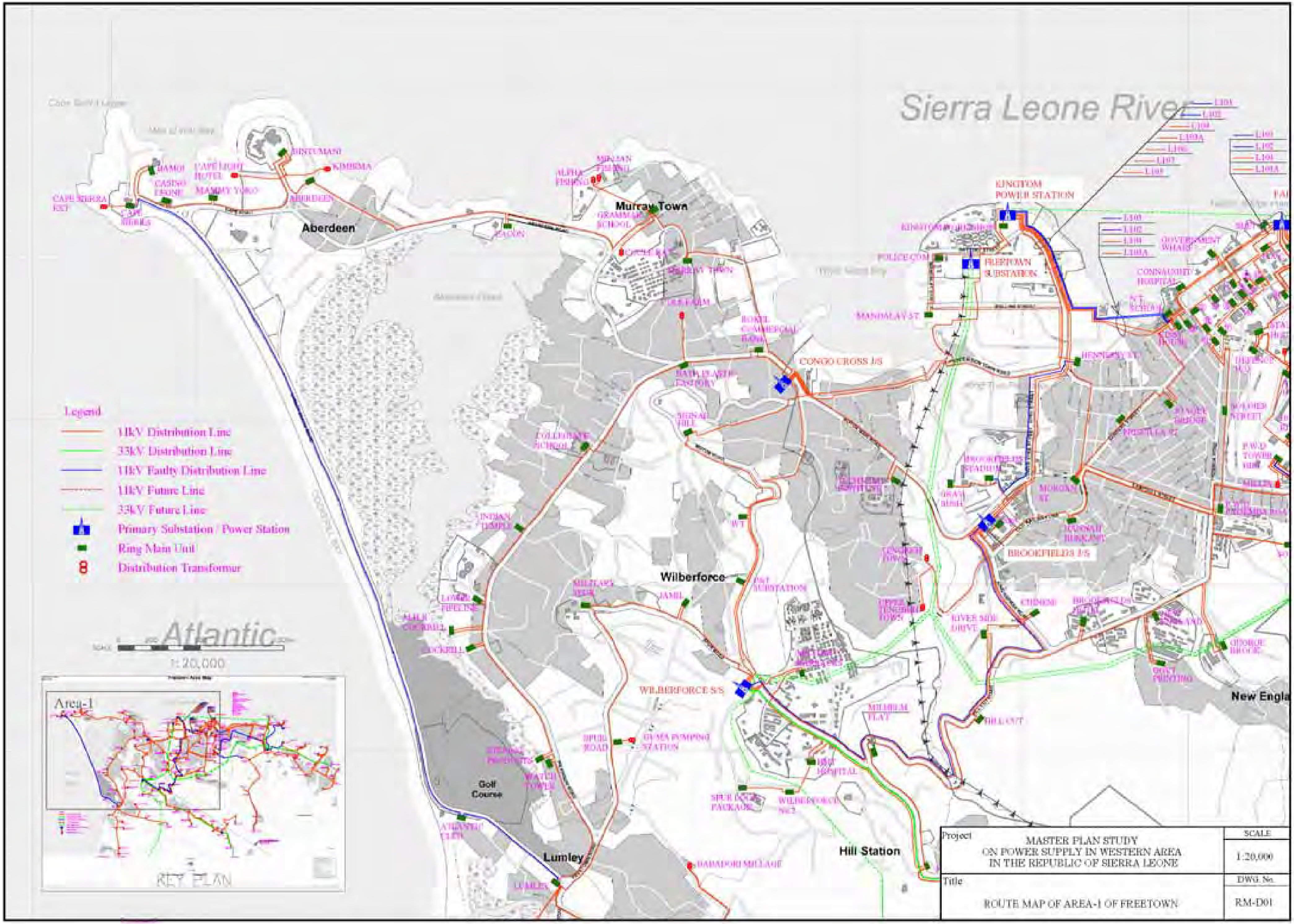
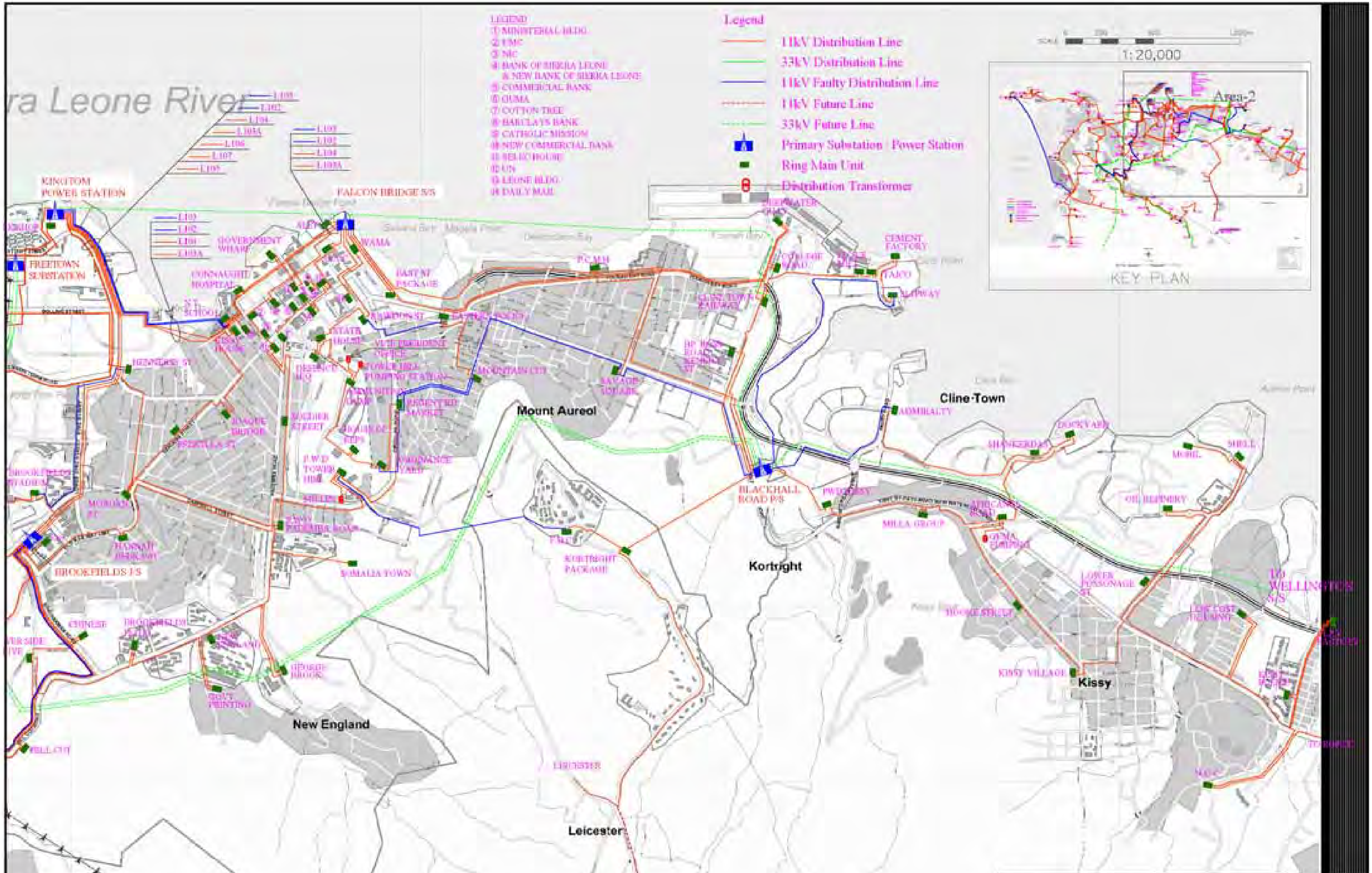


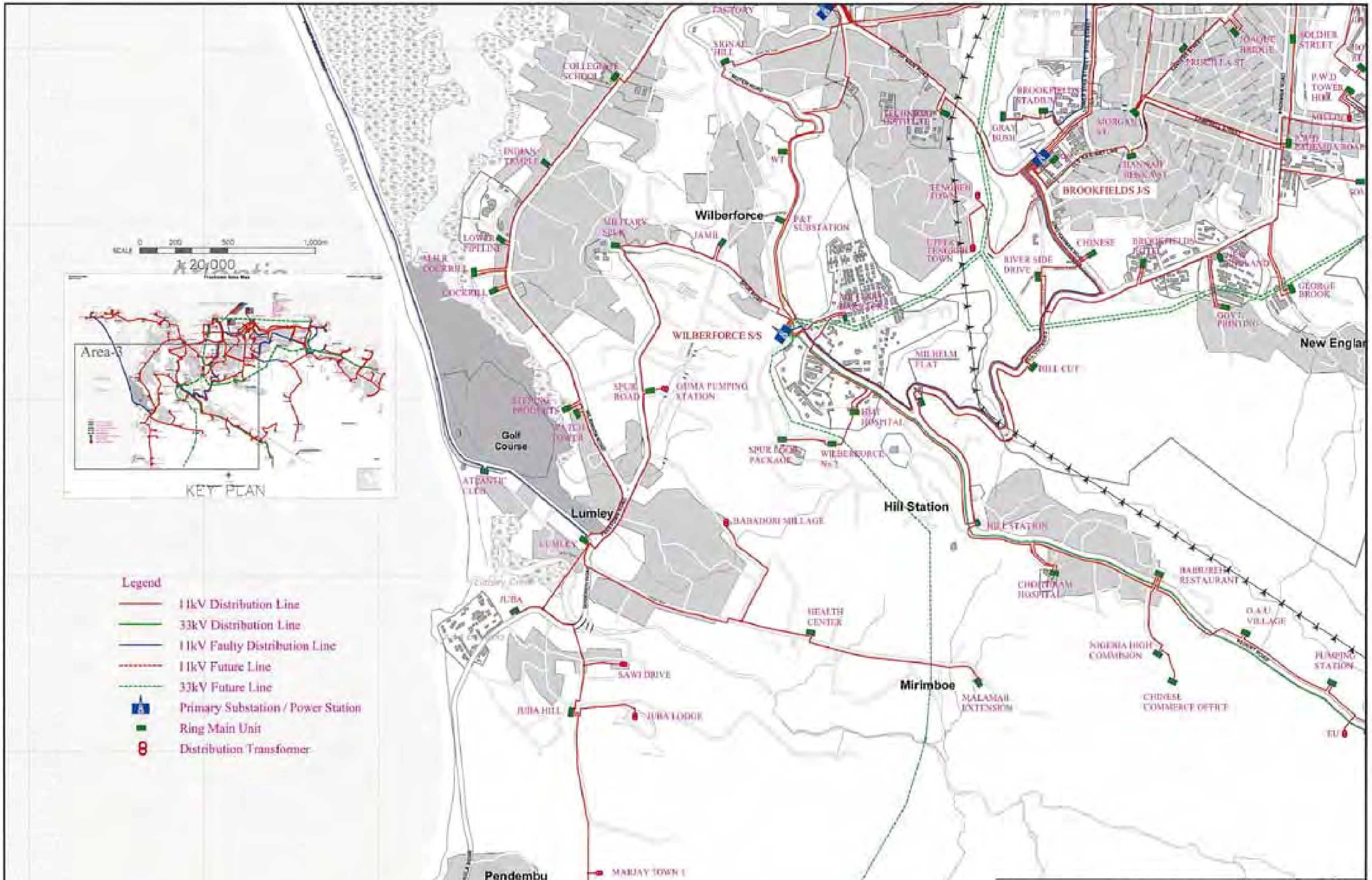
Freetown Area Map
United Nations Mission in Sierra Leone
03-12-000-01
Sierra Leone River
Atlantic
Ocean
Aberdeen
Murray Town
Wilberforce
Lumley
Hill Station
Mount Aureol
Cline Town
Kortright
Kissy
New England
Leicester
Gloucester
Wellington Bassah
Pendembu
Regent
TO GODERICH S/S
TO PENINSULAR
1:10,000
Meters
Project
MASTER PLAN STUDY
ON POWER SUPPLY IN WESTERN AREA
IN THE REPUBLIC OF SIERRA LEONE
SCALE
1:10,000
Title
GENERAL ROUTE MAP OF FREETOWN AREA
DWG. No.
RM-G01



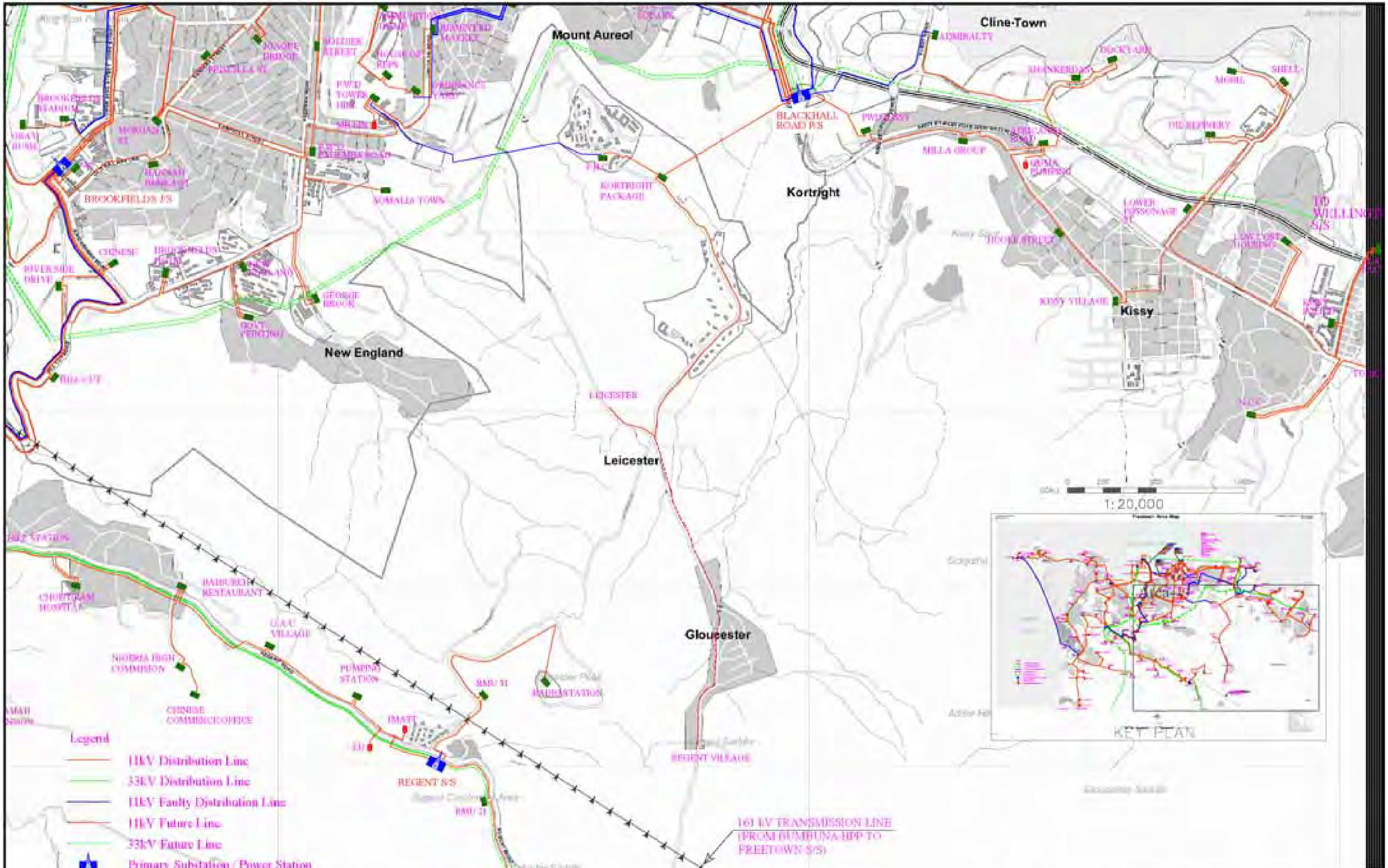
Sierra Leone River
Aberdeen
Murray Town
Wilberforce
Lumley
Hill Station
Golf Course
Atlantic
KINGTOM POWER STATION
FREETOWN SUBSTATION
CONGO CROSS S/S
BROOKFIELDS S/S
WILBERFORCE S/S
Legend
11kV Distribution Line
33kV Distribution Line
11kV Faulty Distribution Line
11kV Future Line
33kV Future Line
Primary Substation / Power Station
Ring Main Unit
Distribution Transformer
1:20,000
Area-1
KEY PLAN
Project
MASTER PLAN STUDY
ON POWER SUPPLY IN WESTERN AREA
IN THE REPUBLIC OF SIERRA LEONE
SCALE
1:20,000
Title
ROUTE MAP OF AREA-1 OF FREETOWN
DWG. No.
RM-D01



Project	MASTER PLAN STUDY ON POWER SUPPLY IN WESTERN AREA IN THE REPUBLIC OF SIERRA LEONE	SCALE 1:20,000
Title	ROUTE MAP OF AREA-2 OF FREETOWN	DWG. No. RM-D02



Project		SCALE
	MASTER PLAN STUDY ON POWER SUPPLY IN WESTERN AREA IN THE REPUBLIC OF SIERRA LEONE	1:20,000
Title		DWG. No.
	ROUTE MAP OF AREA-3 OF FREETOWN	RM-D03



Project	MASTER PLAN STUDY ON POWER SUPPLY IN WESTERN AREA IN THE REPUBLIC OF SIERRA LEONE	SCALE 1:20,000
Title	ROUTE MAP OF AREA-4 OF FREETOWN	DWG. No. RM-D04