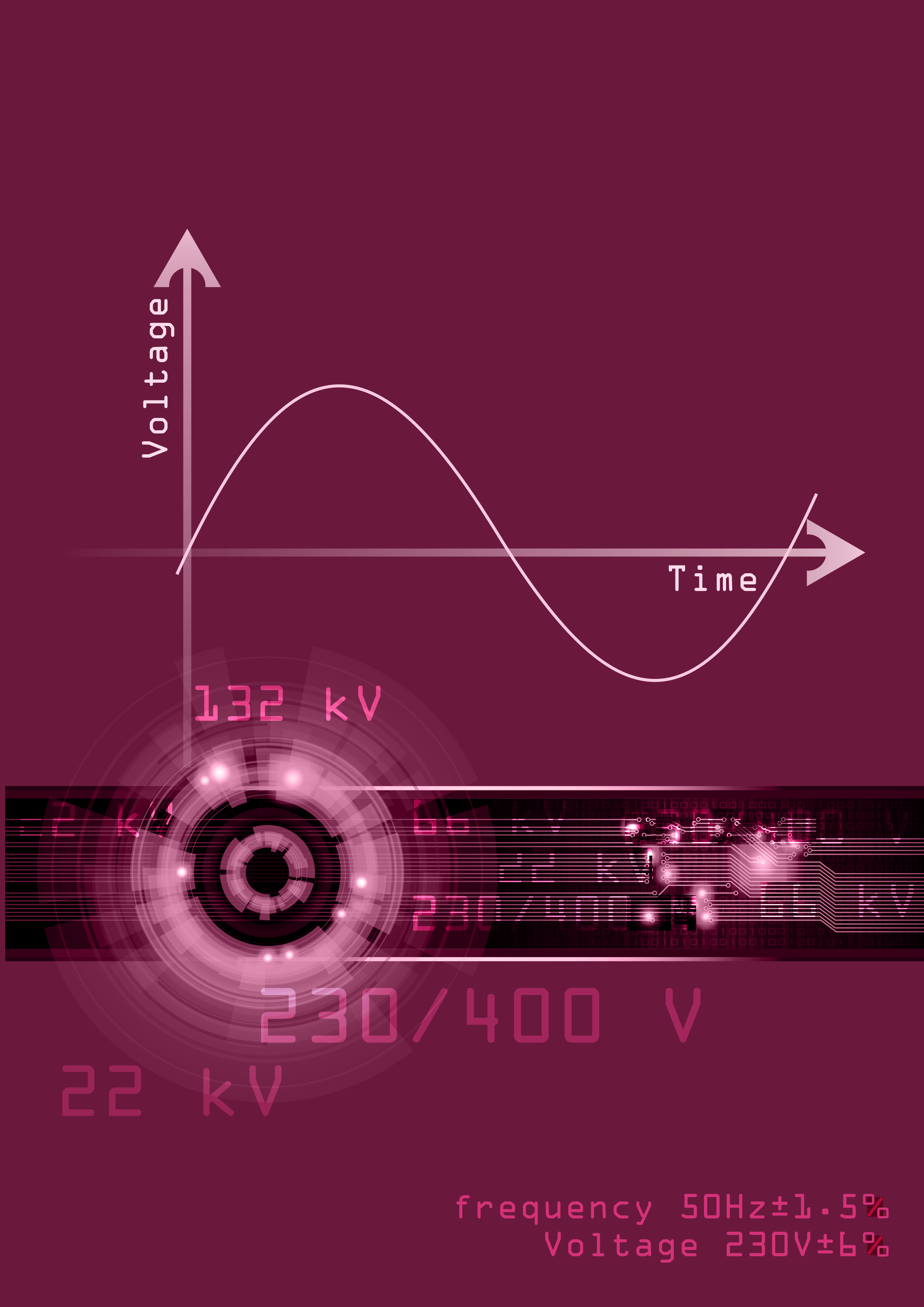

Voltage
Time
132 kV
230/400 V
22 kV
frequency 50Hz±1.5%
Voltage 230V±6%

Does Quality of Electricity Supply Matter?

Besides reliability, electricity supply is judged by its quality. Quality of supply is intrinsically dependent on strict adherence to international standards for system design and operation with the strong involvement of all business partners.

CEB, in its commitment, shall continue to invest so as to perfect the quality of electricity supply!

TRANSMISSION AND DISTRIBUTION PLAN 2013–2022

Chapter 6

The Mauritius electricity network is made up of the Transmission and Distribution (T&D) systems, which are wholly owned and operated by the CEB. The transmission network, operating at the highest voltage of 66 kV, transports power in bulk from the main sources of generation to various 66 kV-to-22 kV *substations** scattered over the island.

The CEB's distribution system supplies electricity at lower voltages from its substations to various customers' premises through 22 kV-to-415 V and 6.6 kVto- 415 V distribution transformers. As at the end of 2011, the CEB's T&D assets were worth around Rs 6.9 billion, reflecting the massive investment made in the electric network over the years.

Given the size and importance of the network, it is imperative to ensure its proper management. Above all, the planning of the network is critical so that the CEB can support continuously the long-term social and economic developments of Mauritius and Rodrigues. The key objective of the electricity network planning is to determine the upgrading and expansion requirements of the electric network in order to guarantee the quality and reliability of electricity supply for the nation and the economic players.

6.1 THE PRESENT TRANSMISSION AND DISTRIBUTION NETWORK

In a power system, the T&D network is the lifeblood of the system. In this section, a short conspicuous exposé on the evolution of the CEB's T&D network is presented.

6.1.1 The CEB Transmission Network

Figure 4.3 in Chapter 4 illustrates the Mauritian transmission network, which consists of sixteen major substations and 300 kilometres of single-circuit transmission lines. The transmission network is made up of a mix of underground cables and overhead lines. Overhead lines, which form around 94% of the network, greatly predominate because of their practicality and lower costs. Although they are more costly, underground cables are generally installed in places where there are environmental, or other, concerns.

The supporting structures of overhead lines, transmission-line towers and concrete poles are designed, among other standard design criteria, to withstand tropical cyclones having wind speeds within the range of 150 to 280 kilometres per hour. Part of the CEB's transmission network has also been built for operation at 132 kV, when the need arises.

In fact, in 1996, the final report for the project on **'Assistance in Generation and Transmission Planning'** recommended introducing the 132 kV system voltage while retaining the 66 kV network as a sub-transmission network. The recommendation was based on the assumption that all new generation units would be centralised in the region of Port Louis. It was thus anticipated that the existing 66 kV transmission capability would reach its limit during peak demand periods and, consequently, would require transmission voltage upgrade to 132 kV by 2007. In the light of that recommendation, the 132 kV double-circuit transmission lines were built.

However, moving towards the higher transmission voltage level would require additional investment in 132 kV-to-66 kV power transformers, protective relays, 132 kV gas-insulated *switchgears** and training of the CEB's technical staff. Space requirement for the installation of the 132 kV equipment was already catered for at the Saint-Louis, Ebène, Amaury, Wooton, Dumas and the future L'Avenir substations, which would form part of the 132 kV transmission network backbone.

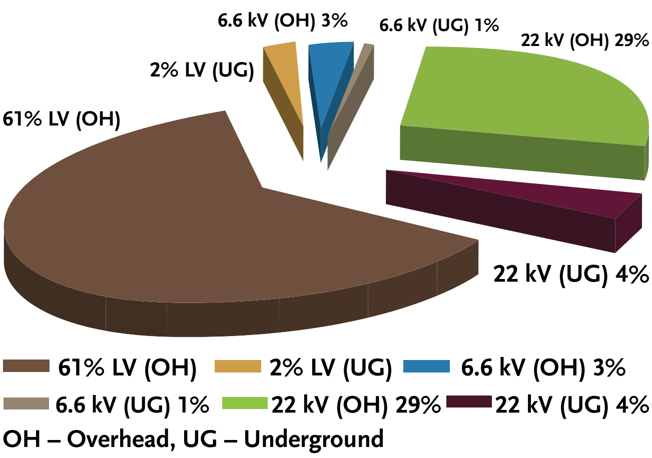
** See glossary*

Subsequently, by adopting the decentralised generation expansion approach, CEB took the strategic decision to defer the upgrading of the transmission network to 132 kV. Under this new approach, new power stations - the CTDS and the CTSav Power Plants in the South, FSPG and CEL Power Stations in the East and the CTBV Power Plant in the North - were constructed to meet the increasing *power demand**.

6.1.2 Distribution Network

Today, CEB delivers electricity to approximately 422,000 customers across the island through its distribution system, which operates at medium voltages of 22 kV and 6.6 kV and low voltages of 230 V single-phase and 400 V three-phase. As at 2011, CEB had approximately 8,450 kilometres of electric distribution lines. The break-down of the line length, in terms of different voltages and types of cable, is shown in Figure 6.1.

FIGURE 6.1: Voltage Distribution at Distribution Level



OH – Overhead, UG – Underground

The distribution network consists of overhead lines and underground cables. In town centres, such as Port Louis, Curepipe, Vacoas, Quatre Bornes and Rose Hill, and where access to the construction of an overhead network is not practical, underground cables are used.

Traditionally, the flow of electricity in the distribution network was uni-directional from the CEB's substations to its customers. Since 2011, the distribution system has undergone a major change as customers are henceforth able to generate their own electricity and export the excess to the distribution network.

This change in the distribution network structure presents new challenges for the CEB, in terms of the planning, design and operation of the network. To meet some of these challenges, CEB, after having elaborated the SSDG's Grid Code, is now in the process of developing a grid code for its 22 kV network. These changes are considered as stepping-stones towards the setting up of a future *Smart Grid**. A brief on the proposed Grid Code and the conceptual *Mauritius Smart Grid* is given in Section 6.6.2 and Section 6.6.3 respectively.

6.2 POWER SYSTEM MODELING AND PLANNING

As an electric network grows in dimension, its complexities and vulnerabilities also increase, albeit more than proportionately. Assessing the impact of challenges on the CEB's power system requires the use of appropriate analysis tools.

6.2.1 Power System Analysis Tools

CEB carries out detailed system studies (power system modelling and analysis) using a licenced state-of-the-art simulation software. The software is used to its full capability to plan the national electric network so as to ensure quality and reliable electricity supply for the present and the future. The main functionalities of the software used for system planning exercises are shown in Figure 6.2.

FIGURE 6.2: Functionalities of Simulation Software

*Load Flow Analysis**	• Power Flow and Loading Conditions • Voltage Profiles • *Reactive Power Compensation**
*Fault level Analysis**	• *Short Circuit Level* • Choice and upgrading of Equipment
*Stability Analysis**	• Integration of conventional generation units • Integration of variable renewable sources of generation • Determine the critical fault clearing time

6.2.2 Power System Modelling

Power system analysis and studies generally start with the formulation of appropriate mathematical models of the existing generation, transmission and distribution systems. These models, which form the foundation of simulation processes, are made up of mathematical equations representing the technical characteristics of each component of the power system. In fact, the said characteristics are usually obtained from, either manufacturer's datasheets, and/or through test and field measurements.

CEB, on its own, developed the generation and transmission (power system) models of Mauritius and

** See glossary*

Rodrigues, which were initially used to perform only power flow and short circuit analyses. In order to enhance the power system model, in 2009, CEB sought consultancy services to develop comprehensive models of control systems (voltage and frequency) of all power plants in Mauritius.

Similarly, comprehensive control systems models of Rodrigues' power plants were developed by in-house experts. The enhanced power system models now also enable transient stability analysis.

Today, CEB has mathematical models of its power systems which are more realistic. With these enhanced models, the level of confidence is substantially boosted when performing analysis and planning studies. Using these models, CEB is now able to assess better the potential impact of disturbances and integration of variable renewable power sources on the frequency and voltages of the power systems. The present developed power system models had enabled the following advanced system studies:

- Re-development of the Fort Victoria Power Station to accommodate six new generation units;
- System Impact Studies for the wind power integration of 29.4 MW at Plaine Sophie and 9 MW at Plaine des Roches;
- System Impact Studies for the wind power integration of 1.28 MW in Rodrigues;
- Re-development of the Saint-Louis Power Station for addition of 4 to 6 generating units;
- Interconnection of a 100 MW Power Plant at Pointe aux Caves;
- Interconnection of major loads, for example Bagatelle Mall, Cargo Freeport Zone at Plaisance, Highlands City, Jin Fei, Neotown, amongst others;
- Reactive Power Compensation; and
- Transmission Voltage Upgrade.

With the increasing number of connected distributed generation projects (SSDGs & MSDGs), CEB is extending the above system modelling approach to improve its distribution network planning. However, extending this approach will require, upstream, the implementation of a *Geographical Information System (GIS)** of the whole electricity network. The GIS will be a support to the nascent Spatial Load Forecast*. The value added of a GIS is discussed further in Section 6.6.1.

** See glossary*

6.2.3 Network Planning Process

The flowchart in Figure 6.3 on the next page illustrates the network planning process.

Basically, network planning is the process of ensuring reliable flow of electricity at *high voltage** from generation sources to various substations and, ultimately, to end-users, after stepping down to low voltage level. The process of network planning is mainly dependent on inputs from the Load Forecast and Generation Planning.

Using data from the *SCADA** of the *System Control Centre**, the process starts by validating the transmission model so that it reflects the actual network operating conditions.

To assess the impact of load growth and/or new generation units on the transmission network, inputs from the *Spatial Load Forecast** and Generation Expansion Plan are used. Using these inputs, simulations of the transmission network for each planning year are performed so as to identify abnormal conditions, such as overloading, low and high voltage conditions.

System reinforcements are then developed to overcome these abnormalities and simulations are performed again in order to validate the proposed reinforcements. In case more than one solution is technically feasible, the least-cost one is proposed for implementation.

6.2.4 Planning Criteria

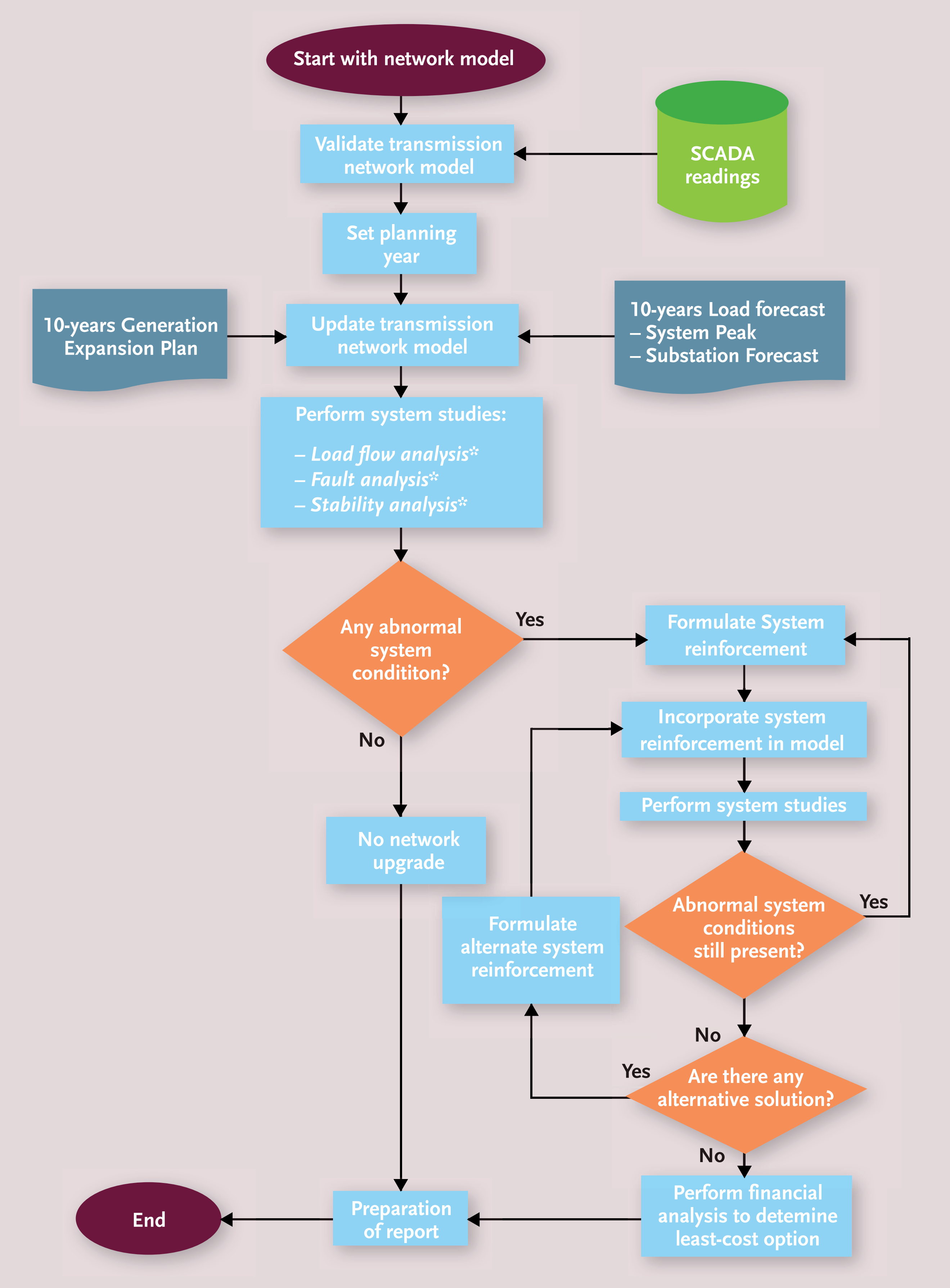
In general, planning criteria are technical boundaries, defined in a Grid Code, within which an electrical system should operate so as to ensure the reliability and quality of electricity supply.

Transmission Planning Criteria

The reinforcements of the transmission system are guided by several factors, amongst others:

- Power transfer requirements;
- Location and size of new major loads;
- Location and size of new generation units;
- Location and size of renewable generation sources;
- Expected retirement of existing generation units;
- Least-cost expansion of network, while minimising transmission losses; and
- Environmental constraints.

FIGURE 6.3: Network Planning Process



* *See glossary*

'N minus 1' Minimum Standard Security Criterion

As best practice, the transmission system is designed with built-in redundancy. To ensure security of supply, CEB has adopted the *'N minus 1'* criterion, which ensures continuity in supply in the event of failure of any **one** transmission line and/or main power transformer.

Distribution Planning Criteria

CEB has adopted the following criteria to perform distribution planning:

- The distribution network is designed in such a manner that all *spur lines** with load above 100 Amperes and 22 kV feeders have a back-up supply.
- Keep the number of *switching operations** to a minimum so as to enable fast restoration of supply.
- Ensure feeder's loading under normal conditions is limited to 50% of conductor nominal current rating.
- The voltage limit should be within statutorily prescribed limits under normal conditions. Voltage regulation at the nominal value of 230 V for single-phase supply and 400 V for three-phase supply should be within ± 6%.
- Adopt the closed *busbar** configuration at 22 kV in CEB's substation so as to satisfy the *'N minus 1'* security criterion. This requires operating the *tap changers** on parallel transformers in the *Master-Slave configuration** in order to ensure that all tapping is carried out in unison.

6.3 TRANSMISSION NETWORK EXPANSION PLAN

Transmission planning assesses network expansion alternatives; it deals with uncertainty and determines large investments for the long term. New power plants, large-scale integration of renewable energy sources and upgrade of transmission voltage level also drive the transmission planning.

6.3.1 CEB Transmission Network as at 2012

As described in Chapter 3 on the review of IEP 2003-2012, a number of network expansion projects were undertaken so as to further improve the CEB's transmission network reliability.

The current status of the transmission network, including the proposals made in the IEP 2003-2012, is schematically shown in Figure 6.4 on the next page.

* *See glossary*

6.3.2 Location of Favourable Injection Point

For both economic and technical reasons, it is more than desirable to have generation power plants distributed over the island, instead of having them centralised in a particular area. In general, the following problems arise with centralisation:

a) Lack of flexibility in operating a network;
b) Increase in transmission losses; and
c) Huge investment required when the need for upgrading to higher voltages arises.

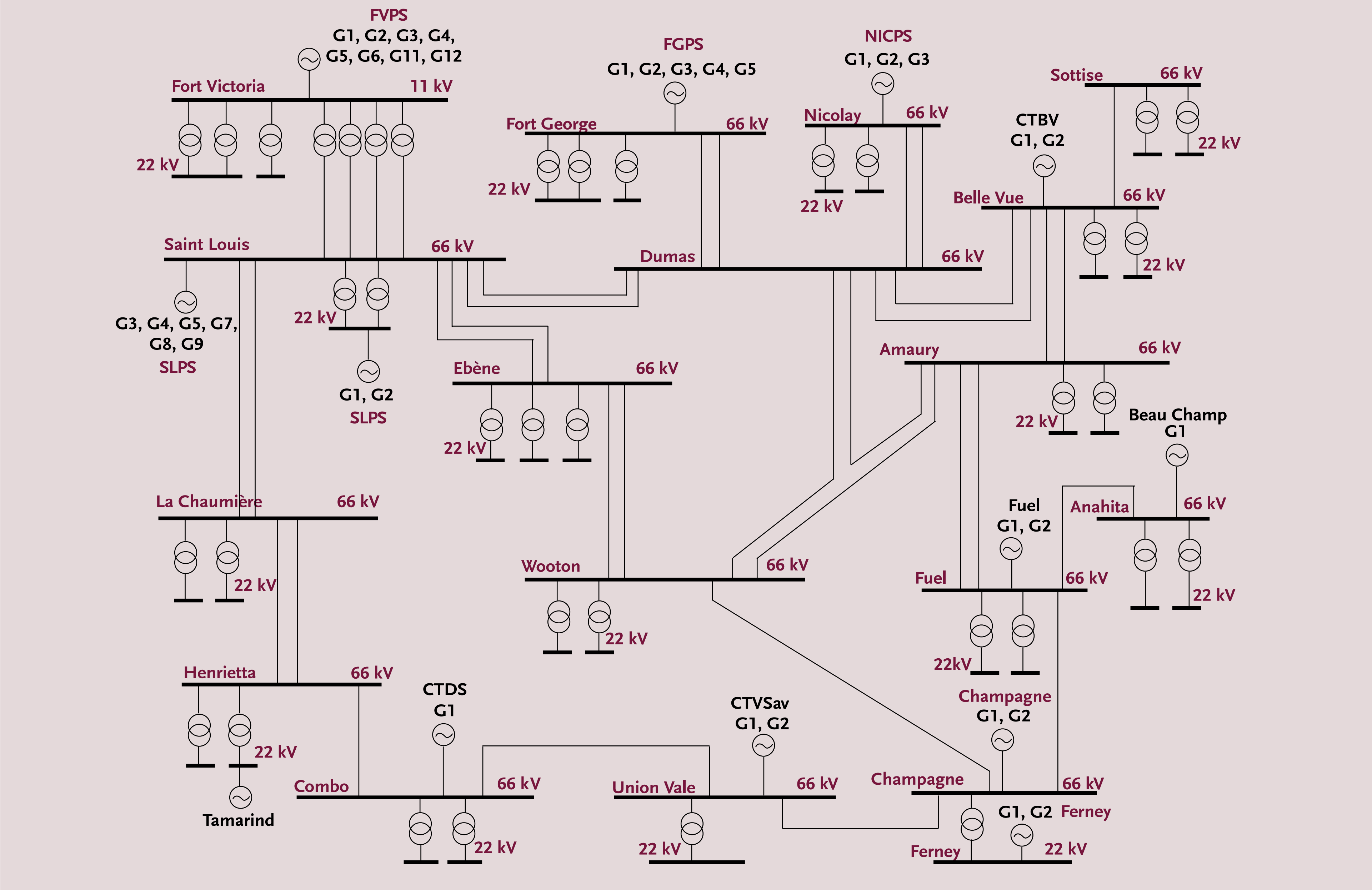
Today, as illustrated in Figure 4.3 in Chapter 4, the western part of Mauritius is the only region that has minimal generation facilities. The present generation expansion plan makes mention of capacity requirements of 50 MW in 2015 and another 50 MW in 2016. To meet these capacity requirements, the company (Mauritius) CT Power Ltd will construct a 100 MW pulverised-coal power plant at Pointe aux Caves in the West.

For this new 100 MW generation capacity, power injection will be made at La Chaumière substation. This will require the CEB to upgrade La Chaumière substation and to lay two 132 kV underground cables which will connect La Chaumière substation with the Ebène substation. This network expansion project is essential so as to relieve the Saint-Louis–Ebène transmission lines, which may otherwise reach their limits at 66 kV in the medium term given the current and expected major developments taking place in the centre of the island.

Based on the generation expansion plan, 50 MW new generation capacity has been proposed for the year 2017 and another 50 MW for the year 2021. Based on the assumption that the total 100 MW generation capacity will be sited in the same location, transmission studies were carried out to determine the most favourable injection point(s).

Five scenarios, based on geographical location, were analysed for the possible injection points and the results were ranked in the order of lowest capital investment required for the *interconnection facilities**. The analysis showed that the western region is the most favourable injection point, followed by the East, North, Port Louis Area and the South regions successively.

FIGURE 6.4: Schematic Diagram of the Transmission Network for Year 2012



6.3.3 The 2013-2015 Transmission Expansion Plan

To overcome present network constraints, following system studies, a transmission expansion plan for the period 2013-2015 has been developed.

Figure 6.5 on the next page shows the proposed changes in the transmission network for the short term. This short-term network expansion plan, as detailed in the following sub-sections, is already at its implementation stage, except for the upgrading of the Wooton and Belle Vue substations.

Case Noyale Substation

The substation, which was earmarked in the previous IEP for construction at Le Morne in 2005, will now be constructed at Case Noyale, due to non-availability of land at Le Morne. This new substation will be interconnected to the transmission network by two new transmission lines from the Combo and Henrietta substations.

Numerous problems were, and are still being, encountered in the acquisition of the right-of-way for the erection of the transmission line from the Combo substation. The delay in the construction of the substation has exacerbated the low voltage and reliability problems in the southwest region of Mauritius.

As a short-term solution, CEB is using the 66 kV transmission line from Henrietta as a 22 kV distribution line. Given the current situation, the construction of the Case Noyale substation is thus a **top priority** for the CEB.

Belle Vue to Sottise 66 kV Line

The Sottise substation, commissioned in 2005, is fed by a single 66 kV transmission line. In case of outage of this 66 kV line, the Sottise substation can only, and partially, be supplied by the present 22 kV feeders from the Belle Vue substation. This state-of-affairs does not satisfy the CEB's *'N minus 1'* security criterion.

In the previous IEP, it was planned that a second transmission line from the Amaury substation passing through Goodlands to the Sottise substation be constructed so as to improve the reliability of the network. Due to right-of-way problems and high costs associated with an alternative underground cable, that proposal was revised.

Accordingly, it was decided instead to construct the second transmission line from the Belle Vue substation. The project is in progress and shall be completed in 2014.

Saint-Louis–Fort Victoria Lines

Fort Victoria Power Station is connected to the Saint-Louis substation through four oil-filled cables, which were commissioned in the 1970s. Following the recent re-development of the Fort Victoria Power Station, whereby the generating capacity has been increased up to 107 MW, CEB has taken the decision to lay two additional copper *XLPE (Cross-Linked Polyethylene)** cables of higher capacity so as to improve reliability and maximise power evacuation towards the Saint-Louis Power Station.

Riche Terre Substation

The construction of the Riche Terre substation was initiated to supply the Jin-Fei project as well as to relieve the Nicolay substation, which has already reached its secured capacity level. Due to delays in the Jin-Fei project, the commissioning of the substation has been rescheduled for 2014.

Ebène Substation

The 66 kV Ebène substation is being upgraded to increase its transmission and short-circuit rating so as to remain within safe operational limits. This upgrade shall be completed by the end of 2014.

Wooton Substation

Similar to the Ebène substation, the Wooton substation will also need upgrading in order to increase its transmission and short-circuit rating. This upgrade is proposed for completion before the end of 2015.

Belle Vue Substation

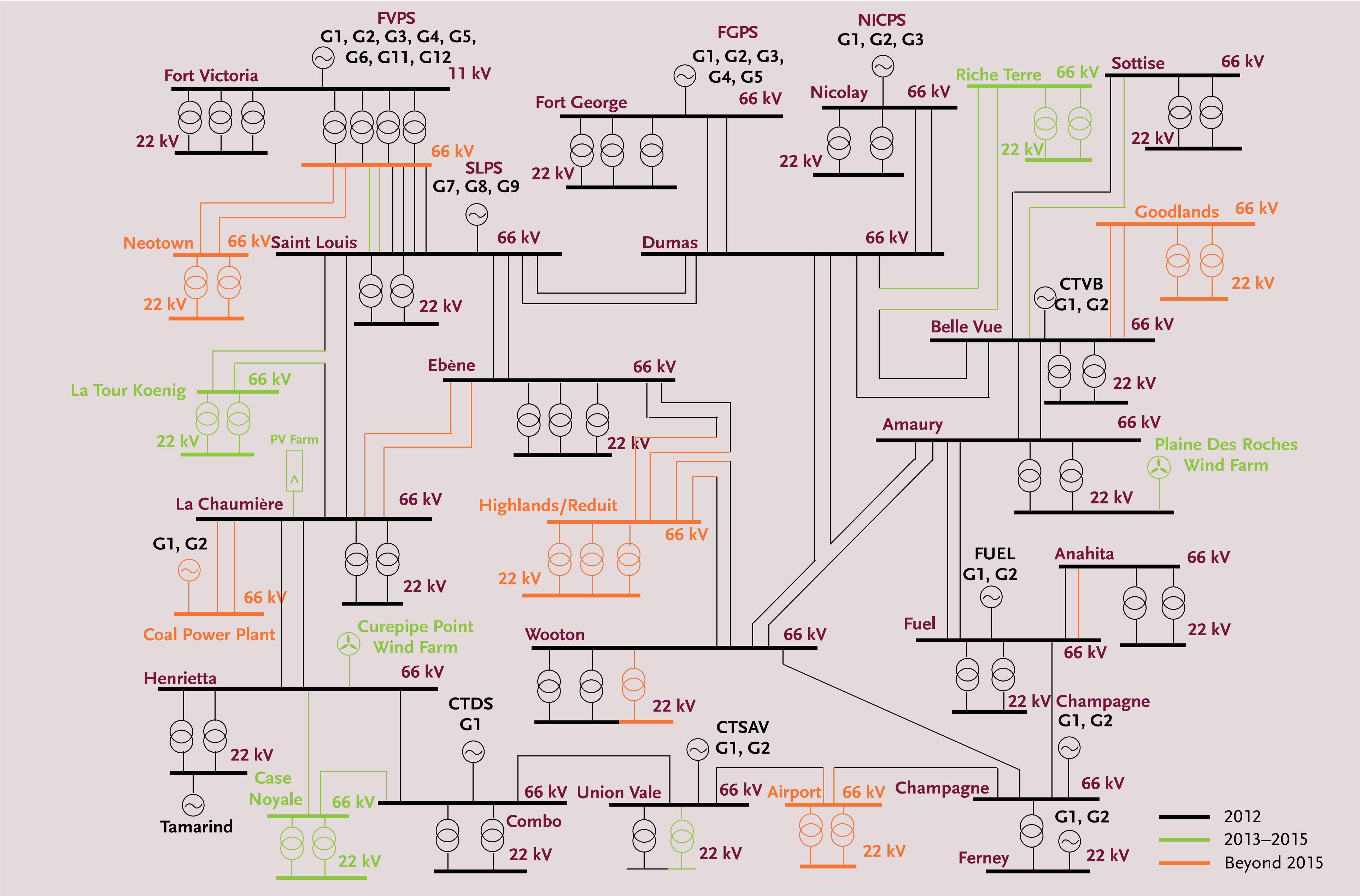
The 66 kV busbar at Belle Vue substation has already reached its limits in terms of short-circuit capacity and, therefore, an immediate attention is most warranted.

La Tour Koenig Substation

This substation was earmarked in the previous IEP to meet the anticipated load growth in the La Tour Koenig region and Coromandel Industrial Zone. As the load growth was not significant enough to trigger its construction as planned, the commissioning of the substation has been rescheduled for 2014.

** See glossary*

FIGURE 6.5: Schematic Diagram of the Transmission Network for the Period 2013-2022



Note: *Schematic diagram does not include the next 2 x 50 MW Power Plants, which have been planned for 2017 and 2021, as the siting(s) of the power plants are yet to be determined.*

6.3.4 Proposed Transmission Expansion Plan 2016 and Beyond

From 2016 and beyond, CEB will have to implement the following projects so as to maintain reliable electricity supply. The proposed upgrade/expansion of the transmission network, as depicted in Figure 6.5 on the previous page, is detailed hereunder.

New Substation in the Region of Trianon

A new substation will be required to serve the growing loads in the regions of Reduit, Highlands and Trianon. It will not only ensure electricity supply to new developments but will also help to alleviate the Wooton substation and the Ebène substation, which will be reaching their loading limits by 2017. In this regard, two possible locations – Reduit and Highlands – have been identified for this new substation. Land acquisition procedures have accordingly been initiated.

Airport Substation

A new substation will be required by 2019 in the region of the SSR Airport. This new substation will supply the New Cargo Freeport Zone at Plaisance and, by extension, will relieve nearby substations and cater for the load growth in the region of Le Chaland and Plaisance. Consequently, the existing transmission line between Champagne and Union Vale Substations will be rerouted, passing through the new Airport substation.

Goodlands Substation

In the previous IEP, a substation was proposed in the region of Goodlands so as to cater for major industrial development, which in fact did not materialise. As such, there was no need for the construction of the Goodlands substation during the period 2003-2012. Recent market surveys, however, indicate that there is now the prospect of major commercial and land development in the northeast region. In this context, a new substation may be required in the region of Goodlands by the end of the planning period.

Anahita Substation

Presently, Anahita substation is fed by one 66 kV transmission line from FUEL substation. A second transmission line, as a back-up supply from Champagne substation, would have been ideal to improve the reliability of supply. Facing major topographical constraints, this option, however, does not appear to be cost-effective. It is more appropriate that the second transmission line be constructed from the FUEL substation.

La Chaumière Substation

According to the Load Forecast, La Chaumière substation will be nearing its limits in terms of secured transformer capacity by 2022. In this respect, the substation will be upgraded to accommodate an additional 66 kV-to-22 kV transformer in anticipation of load growth in the western region.

Neotown Substation

The Neotown project at Les Salines in Port Louis is a new mixed-use land development having a declared load of around 70 MVA. To meet this load (demand), CEB is planning to construct a 66 kV-to-22 kV substation at Les Salines, which will be supplied by two 66 kV underground cables from the Fort Victoria Power Station. This development will necessitate the construction of a 66 kV substation at the Fort Victoria Power Station. However, the construction of the substation will depend on major milestones in the implementation of the Neotown Project.

6.3.5 Upgrading of Transmission Network

In general, fault level is largely affected by the addition of generation units. The location of the two 50 MW generation capacities, which will be required in 2017 and 2021, will dictate the need for upgrading CEB's related substations.

As regard to the 66 kV transmission infrastructures, CEB will consolidate/replace its old 66 kV Steel-Lattice Towers in order to further improve the physical integrity of the transmission infrastructure. This action will contribute towards the objective of ensuring more security of electricity supply during cyclonic season.

6.3.6 Reactive Power Compensation

As in the case of the above-mentioned new substations (La Tour Koenig, Riche Terre, Case Noyale and others), system studies show that 22 kV reactive power compensation will also be required at the Nicolay substation and additional capacitor banks will be required at the Amaury, La Chaumière, Sottise and Wooton substations.

The proposed reactive power compensation will contribute towards minimising the *reactive power** flow along the transmission network and reducing *power loss** and voltage drop. The proposed additions will be progressively required depending on the individual substation's load growth.

* *See glossary*

6.3.7 Transmission Voltage Upgrade

A network simulation exercise has revealed that maintaining operation of the grid at the current 66 kV voltage level will not be problematic for the transmission of the upcoming 200 MW power generation over the period 2013-2022. This finding, however, holds only if the 200 MW generated power originate from at least two different power plants, each having a capacity not exceeding 100 MW.

Under such a scenario, by the end of the planning period, some of the CEB's transmission lines will be reaching 50% loading under normal conditions and 100% loading under emergency conditions. To prevent overloading, planning to upgrade the transmission lines to 132 kV voltage level will start when loading condition has reached 40% under normal conditions. As per current load forecast, the planning exercise will, most likely, begin a few years before 2022.

In case the upcoming 200 MW power generation is centralised, the requirement to upgrade the interconnection facility (transmission lines, switchgears, power transformers, etc.) at 132 kV voltage level will be required by 2017.

Notwithstanding the above, it is recommended that all new and existing transmission lines, which would be required for the interconnection of future planned power plant(s) with either the Saint-Louis, Dumas, Amaury, Wooton or Ebène substations, be designed at voltage level of 132 kV. The transmission lines so designed will enable power transmission of the *ultimate*[1] capacity of the future planned power plant(s).

6.3.8 Summary of the Impact on Existing, New and Future Substations

With respect to the above proposed transmission expansion projects, the loadings on existing, new and future substations are expected to evolve over the planning period. Table 6.1 below summarises the impact on these substations.

6.4 DISTRIBUTION NETWORK EXPANSION PLAN

Presently, the distribution network is supplied from sixteen substations purposely sited in specific locations over the island, as illustrated in Figure 6.6 on the next page. From each substation, *feeders**, operating in *radial configuration**, are extended outwards to supply customers within a delimited service area. The back-up security for each feeder is provided by a second feeder, either from the same or another substation.

The distribution network expansion plan is mainly guided by inputs from the spatial load forecast and construction of new substations as proposed in the transmission plan in Section 6.3.

For the purpose of this IEP, CEB has adopted a standard planning technique so as to delimit the region to be supplied by each substation. The approach to determine a service area boundary (delimitation of regions) is based on costs of feeders, electric network losses' costs and service interruption exposure. The result of this exercise is shown in Figure 6.6 on the next page.

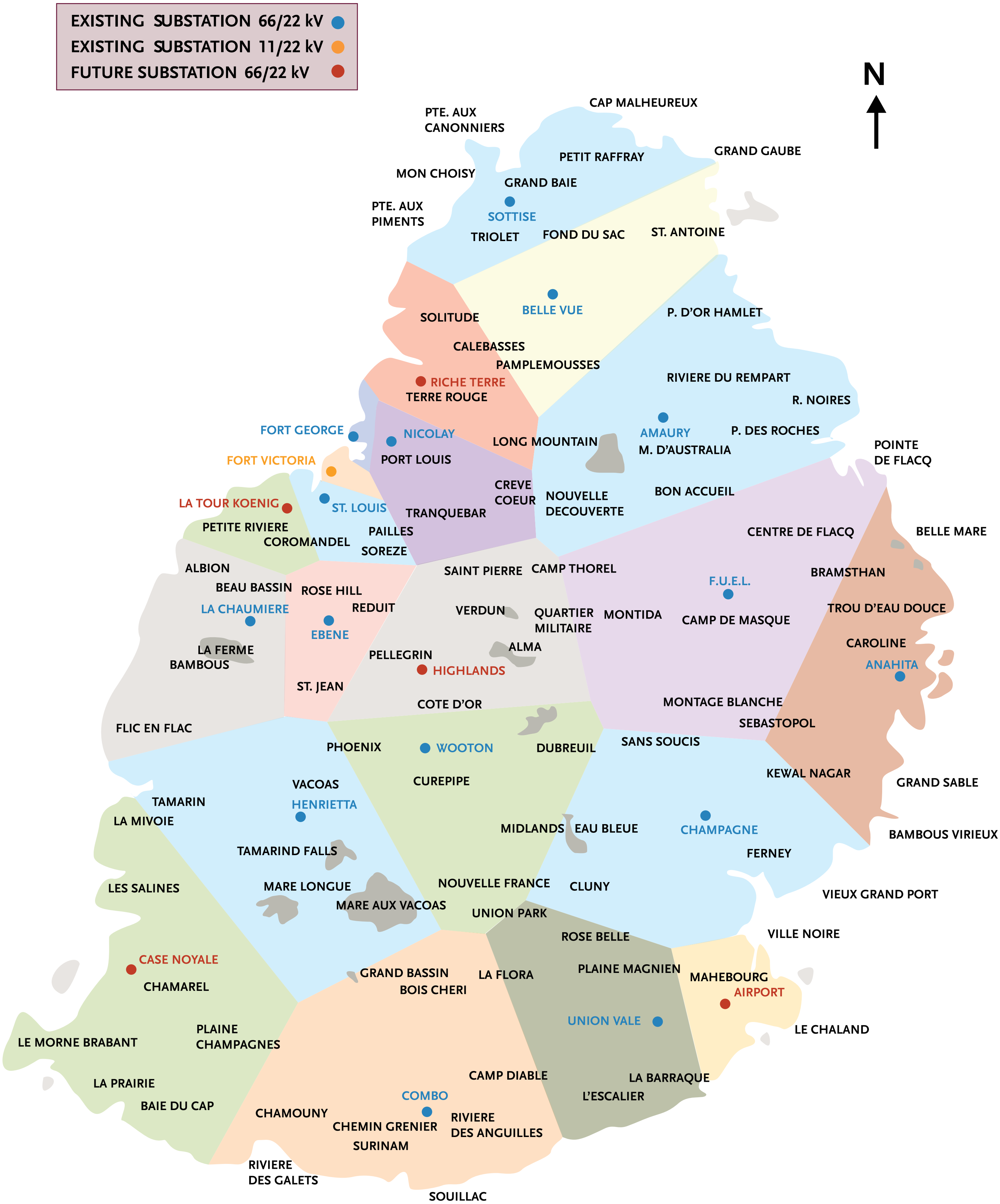
TABLE 6.1: Impact of the Transmission Plan on Existing, New and Future Substations' Loadings (MW)

Year	Ebène	Highland Trianon†	Wooton	Henrietta	Case Noyale†	Combo	Belle Vue	Riche Terre†	Nicolay	Fort George	Fort Victoria†	Saint Louis	La Tour Koenig†
2012	44	–	37	39	–	9	36	–	29	28	40	49	–
2013	45	–	39	41	–	13	36	–	30	35	40	46	–
2014	46	–	40	33	13	8	28	21	21	34	41	28	19
2015	48	–	41	34	13	9	30	21	22	35	42	29	20
2016	32	33	34	29	14	9	31	22	23	37	44	30	20
2017	33	34	35	30	14	9	32	23	23	38	45	31	21
2018	35	35	36	30	15	10	33	23	24	38	46	32	22
2019	36	36	36	31	15	10	34	24	24	39	47	32	22
2020	37	38	37	31	16	11	35	25	24	40	49	33	23
2021	38	39	38	32	16	11	36	26	25	40	50	33	24
2022	39	40	39	33	16	11	37	27	25	41	52	34	24

†New and Future Substations

[1]*Ultimate refers to the maximum designed generation capacity of a particular power plant.*
**See glossary.*

FIGURE 6.6: Delimited Service Areas of each Substation



6.4.1 Distribution Network Expansion Plan 2013-2015

In response to the demand forecast, described in Chapter 4, and to ensure long-term reliable electricity supply in Mauritius, the following proposals were/are made, as part of the short-term distribution plan, in the context of this IEP.

Port Louis Area

The distribution network in the Port Louis area, with around sixty distribution feeders, is one of the densest networks in Mauritius. The new 11 kV-to- 22 kV Fort Victoria substation in the Port Louis area will be fully operational in 2013.

With this new network set-up, loads will be redistributed among the substations (Fort George, Nicolay, Fort Victoria and Saint-Louis substations) supplying the Port Louis area. The redistribution of power flow will help to further reduce distribution losses and ensure the reliability and *quality of supply**.

In accordance with the previous IEP, to improve the network covering the Plaine Verte region, the conversion of the 6.6 kV feeders from Nicolay substation, which is currently under implementation, is expected to be completed by the end of 2014.

The North

For the northern area, the following will be required:

(1) One additional feeder from Belle Vue substation to supply major projects, which are under development, along the northern motorway.

(2) With the commissioning of the second 66 kV transmission line from Belle Vue substation to Sottise substation, the present 22 kV interconnector between Sottise and Belle Vue substations will no longer be required. The 22 kV interconnector will thus be split into two 22 kV feeders from Belle Vue and Sottise substations respectively. These two proposed feeders will be used to match the expected increase in load in the region of Pointe aux Cannoniers and Goodlands.

According to load forecast, the loading on Amaury substation will continue to increase and, consequently, the present transformer capacity at that substation will need to be upgraded to 2 x 36/45 MVA.

The South

It is expected that the areas in the vicinity of Plaisance and Le Chaland will undergo major development in the coming years. Therefore, a new 22 kV feeder from the Union Vale substation will be required to supply these regions in the short term.

The Southwest

As mentioned earlier, with the construction of a new 66 kV-to-22 kV substation at Case Noyale, a completely new set-up of distribution feeders, will be available to serve the regions of La Mivoie, Case Noyale, Le Morne and La Prairie.

The East

The eastern regions, mainly Bel Air, Trou d'Eau Douce, and Beau Champ, are presently supplied from the FUEL and Ferney substations. Following the commissioning of the Anahita 66 kV-to-22 kV substation, new 22 kV feeders from the substation are being erected to share the load in these regions. A redistribution of load will thus relieve the FUEL and Ferney substations. This configuration will enhance the network reliability and help in reducing distribution network losses.

The Centre

In line with the objective to reduce distribution line losses, the on-going conversion of 6.6 kV networks to 22 kV in the regions of Quatre Bornes, Rose Hill, Vacoas and Curepipe should continue.

To serve upcoming mixed-use land developments in the regions of Côte d'Or and Highlands, two new feeders from Wooton substation will need to be erected.

The West

With the rapid development in the West, one new feeder from La Chaumière substation will be required to serve upcoming loads at Médine and Flic en Flac. The new feeder will improve the power quality during abnormal network configuration.

6.4.2 Long-Term Distribution Network Expansion Plan (Year 2015 Onwards)

Below is a description of the long-term distribution network expansion plan for the period 2015-2022.

Port Louis Area

The previous IEP had earmarked the region of La Tour Koenig for the construction of a new substation. The

** See glossary*

substation, which is currently under construction, will not only supply the targeted industrial zone of La Tour Koenig, but will also supply via new outgoing feeders the regions of Pointe aux Sables, Petite Rivière and Coromandel, among others. With this new set-up, the importance of the Coromandel switching station will be studied.

Upon full operationalization of the Fort Victoria substation, the importance of Line Barracks and La Poudrière *switching stations** in the electricity distribution network will need to be redefined.

In the long term, with load growth in the centre of Port Louis, either a third power transformer with new 22 kV outgoing feeders at Nicolay substation or a new substation at Chateau d'Eau will be required so as to ensure the *'N minus 1'* security criterion.

The North

With the expected commissioning of the Riche Terre substation, part of the growing load in the northern areas will be catered for. The Riche Terre substation will supply some localities (Balaclava, Terre Rouge, Bois Marchand, Baie du Tombeau and Riche Terre) presently supplied by the Belle Vue, Nicolay, Fort George and Sottise substations. Consequently, these substations will be relieved.

The South

The feeders from the new proposed Airport substation will be configured to provide back-up for the Union Vale substation and to meet load growth in the region.

The Centre

Towards the end of the planning period, the Wooton substation, which serves the regions from Curepipe to Rose Belle, Phoenix and Providence, will no longer satisfy the *'N minus 1'* criterion, in terms of power transformer capacity. Consequently, by the year 2020, a third 36/45 MVA power transformer will be required so as to cater for the normal load growth in the aforementioned regions.

6.4.3 Upgrading of Distribution Network

As part of its operational plan, CEB will continue to progressively replace its old wooden and circular concrete poles, especially those which have been in service for more than half a century. This on-going project is in line with the CEB's goal to ensure reliability of supply.

In addition, to reduce hazards associated with the network, CEB will gradually replace bare 22 kV wires by insulated cables, wherever and whenever mandated, and continue the exercise of insulating LV lines so as to enhance safety and reliability.

6.5 GRID INTEGRATION OF RENEWABLE ENERGY (RE) SYSTEMS

In its Long Term Energy Strategy (LTES), Government has set the targets to promote renewable energy in the energy mix of Mauritius. Integration of renewable energy into the utility grid can either be at the transmission level or at the distribution level, depending on the capacity of the generation plant.

Large-scale variable renewable energy generation, such as Wind and Solar Farms, is connected to the transmission system. Medium- and Small-scale distributed generation are normally connected to the medium-voltage or low-voltage distribution systems respectively.

While the integration of *firm*[1] renewable energy sources', such as 'bagasse', hydro and biomass, does not pose technical challenges or constraints, the *time-varying*[2] nature of wind and solar power presents challenges with respect to system stability, security, operation and power quality. These challenges are of particular concern for a small-sized and insular power system, such as for the CEB, which is characterised by a small number of generating units, low spinning reserve and low *system inertia**.

6.5.1 System Constraints for Variable Renewable Energy (RE) Integration

Two main aspects, namely frequency and voltage, are considered for the integration of variable renewable energy, as discussed below.

Frequency Aspects

As per regulatory requirements, CEB has to maintain the supply frequency within ±0.75 Hz of the nominal value 50 Hz so as to ensure the safe and reliable operation of electrical equipment and appliances.

For planning purposes, CEB uses the limit of ±0.5 Hz for system frequency deviation to ensure system sta

[1] '*Firm* renewable energy source' in this context means constant power output from a renewable energy generation plant.
[2] '*Time-varying*' in this context means varying power output from a renewable energy generation plant over time.
* *See glossary*

bility, security and the reliability of supply. The limit of ±0.5 Hz caters for the condition, whereby a *generator trip** coincides with the minimum system frequency, caused by a sudden drop in *time-varying* renewable energy generation, to help in minimising the extent of load shedding and the risk of total system breakdown.

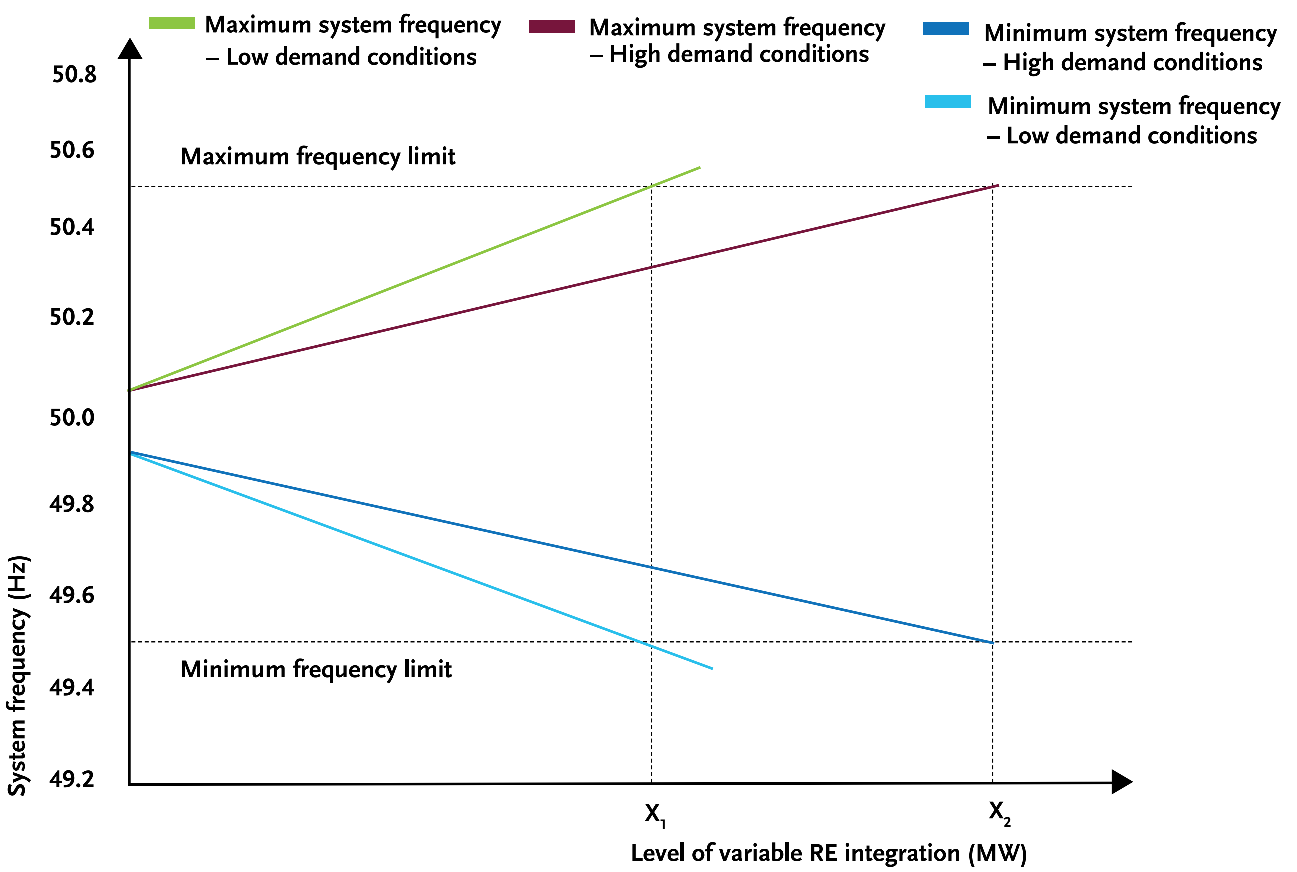
Under normal operating condition, by ensuring system frequency within the stated limits, power generation safely matches system demand. The frequency band of ±0.5 Hz about the nominal value of 50 Hz enables safe system control during the mismatch between instantaneous demand and supply. The mismatch is due to the inherent delays of the generating units to follow the varying load demand.

During system operation with no *time-varying* renewable energy source, the frequency deviation is around ±0.1 Hz about the nominal value. With the integration of *time-varying* renewable energy, this frequency deviation inevitably increases. It is even more pronounced during the low demand conditions, when the system inertia is low and the amount of spinning reserve is less. The frequency deviation limits of ±0.5 Hz is thus used to determine the maximum capacity of *time-varying* renewable energy which can be safely integrated in the CEB's system, as shown in Figure 6.7 below.

In Figure 6.7 below, X_1 and X_2 represent the maximum level of variable renewable energy (MW) that can be safely integrated in the Mauritius Power System during minimum and maximum load (demand) conditions respectively, while maintaining the system frequency within ±0.5 Hz of the nominal value of 50 Hz. X_1 and X_2 are determined by the level of demand and the amount and quality (response time of the generation system) of spinning reserve.

Generally, in our context, the minimum demand conditions occur between midnight and six o'clock in the morning, when solar energy source is not available. On the other hand, the maximum demand conditions occur during the daytime. Usually, during the daytime period both solar and wind power can be tapped off. Given these specific conditions, it is therefore possible to optimise the integration of *time-varying* renewable energy through a mix of wind and solar power technologies.

FIGURE 6.7: Impact of RE Integration on the System Frequency



* *See glossary*

However, due to the intermittent nature of these RE sources, the full capacity of the RE technologies can seldom be optimised. One possible solution to the inherent disturbances of the variable RE is the use of energy storage system, as far as it is economical.

In addition to the above, it is possible to further integrate *time-varying* renewable energy while maintaining the system frequency within the required limits, if the amount of spinning reserve is increased. Although it is technically possible to do so, such an option is not usually financially viable. Increasing the spinning reserve beyond 10% to 15% will result into operating the generating units at lower efficiencies, hence, increasing their cost of operations.

Voltage Aspects

As per regulatory requirements, CEB needs to maintain a voltage of 230 V ± 6% at customers' terminals. Renewable energy-based generators are operated in the *power factor** control mode and their interconnections to Low-Voltage (LV) network or Medium-Voltage (MV) network inevitably lead to rise in voltage, as shown in Figure 6.8 below.

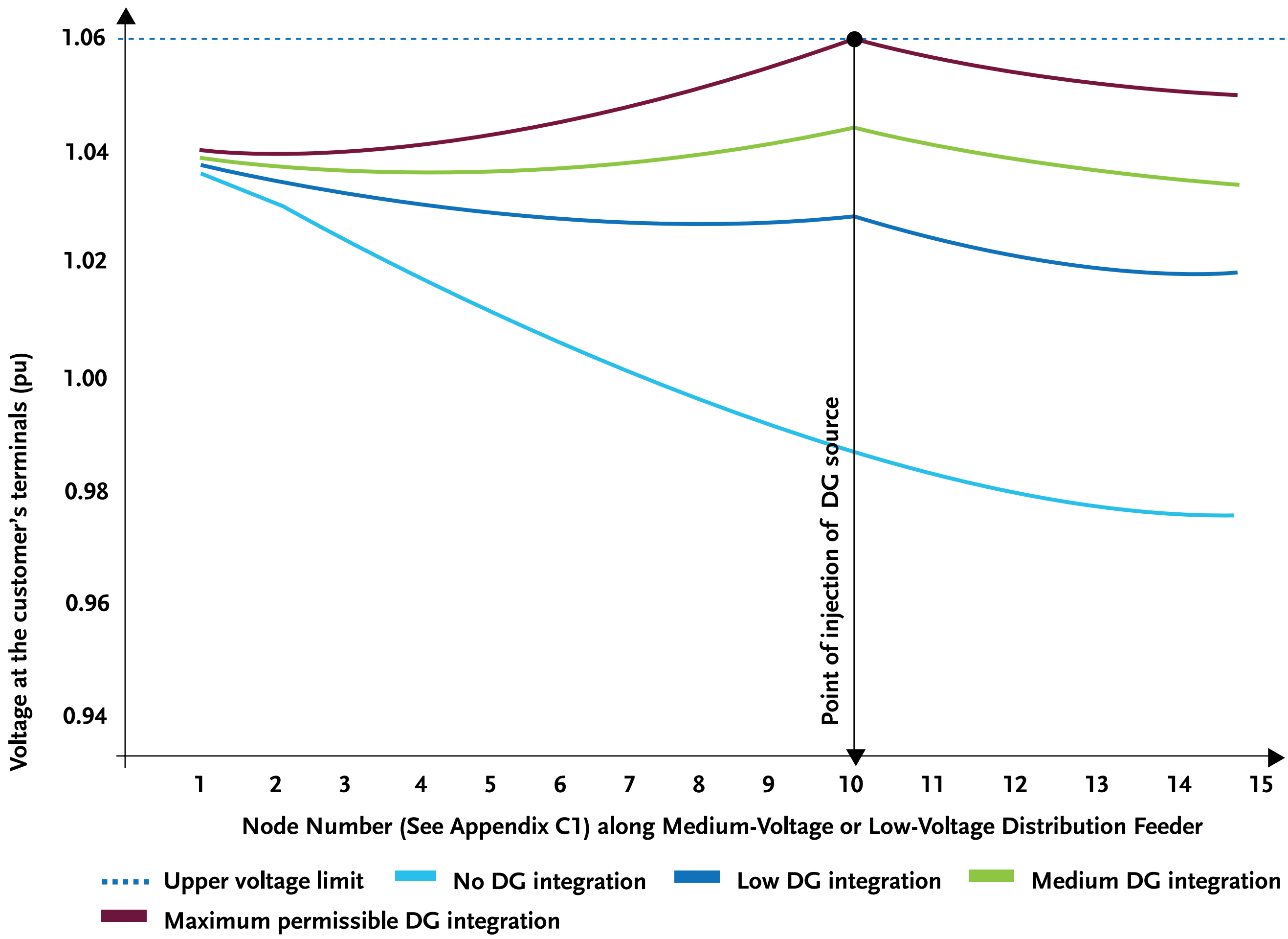
For operating voltage requirements:

- Maximum RE Farm capacity that can be interconnected to a low-voltage feeder is 50 kW. This type of RE installation falls under the Small-Scale Distributed Generation (SSDG) Scheme.

- Depending on the location and specific feeder's absorption capacity, maximum RE Farm capacity that can be interconnected to existing medium-voltage (22 kV) feeders is 2 to 4 MW. Connection of such RE installation requires a prior detailed system study under the Medium-Scale Distributed Generation (MSDG) Scheme.

- Depending on the technology and the substation's absorption capacity, RE Farms of capacity above 4 MW up to 10 MW can be connected through dedicated 22 kV line to the CEB's 22 kV busbar.

FIGURE 6.8: Voltage Profile for different level of Distributed Generation Integration



* See glossary

- RE Farms of capacity more than 10 MW have to be connected to the CEB's 66 kV substation busbar system.

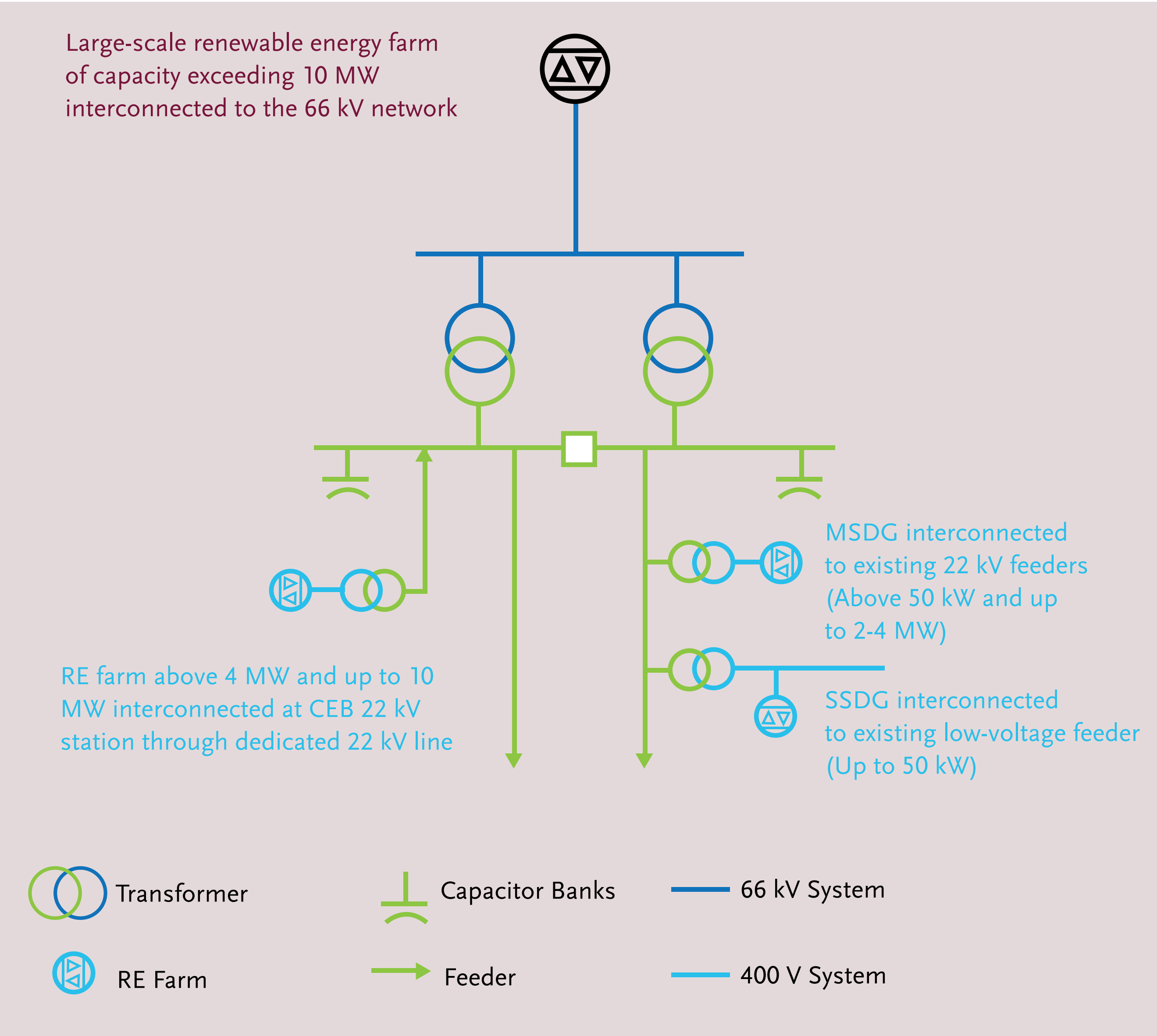
In addition to the voltage rise, the variable power output from the RE farms leads to fluctuation in voltage along the low-voltage and medium-voltage feeders. As a mitigation measure, advanced automatic voltage control will be required for power transformers and *capacitor** banks in substations.

The interconnections of the variable renewable energy installations of different capacity are illustrated in Figure 6.9 hereunder.

6.5.2 International General Guidelines on Optimal Variable RE Integration

According to some **experts**[1] in the field of RE, the maximum amount of variable renewable energy that can be safely integrated in an insular power system is about 15% to 20% of the prevailing load demand. This level of RE integration, however, is intrinsically dependent on the availability of fast-responding conventional generating engines, which is critical so as to regulate the system frequency. Regulating the power system frequency is the most fundamental requirement to ensure reliable and quality electricity supply. To increase level of RE integration above the threshold, as per the experts, installation of battery energy storage system (BESS) becomes inevitable.

FIGURE 6.9: SSDG, MSDG AND LSDG Interconnections



[1]*Parsons Brinckerhoff Africa (PB Power) in the Wind Integration Study for Mauritius and International Renewable Energy Agency (IRENA).*
** See Glossary.*

Given the above and in the absence of reliable and sufficient information, while taking into account upcoming RE projects in Mauritius, it is difficult at this stage to determine the optimal level of RE technology that can be integrated in the local power system. Therefore, to facilitate the integration of future RE projects, CEB upstream will perform technical system studies so as to assess their feasibilities and to determine their interconnections' requirements.

6.5.3 System Enhancement to Allow Higher Integration of Renewable Energy (RE)

Given the current state-of-affairs, CEB's actual power system will not be able to accommodate the targeted amount of RE capacity as set in the Government's LTES 2009-2025. However, to enable higher penetration of renewable energy sources, CEB, as part of its research work, shall investigate on the possibility to:

- Enhance the system frequency regulation *via* modernisation of the *governing system**;
- Implement *Automatic Voltage Control** at substation levels;
- Reduce power output variability by encouraging geographical dispersion of renewable power plants;
- Curtail power output from renewable energy sources during periods of low system demand;
- Use weather simulation software to determine the day-ahead generation from RE Farms to assist in dispatching, hence ensuring a better quality of supply; and
- Use large-scale battery energy storage system to help in ensuring stable power supply.

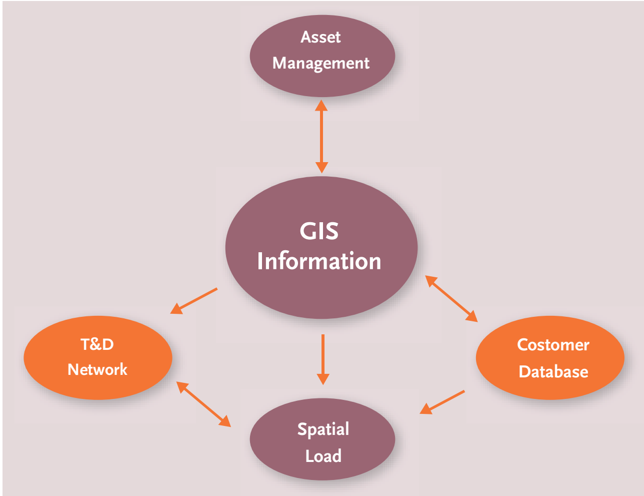
6.6 MODERNIZING THE NATIONAL ELECTRICITY NETWORK

In its strategic quest to modernise the national electricity network, CEB has already kick-started discussions on a few key elements of today's high-tech power system. These include: the building of a Geographical Information System (GIS) of the electric network; developing a transmission and medium-voltage grid code; and laying the foundation (roadmap) for a future smart-grid.

6.6.1 Geographical Information System

The Geographical Information System (GIS) – a computer-based system – will store virtual information relating to the physical aspects of the CEB's network. It will permit the viewing, understanding, questioning, interpreting and visualizing of data in many ways that reveal relationships, patterns and trends in the form of maps, reports and charts. These capabilities of the GIS will assist in load forecasting and transmission and distribution planning activities, as illustrated in Figure 6.10 below.

FIGURE 6.10: Geographical Information System Interaction



Recognising the improvement that the GIS can bring to its planning and forecasting activities, CEB has already initiated the process of studying the implementation of the GIS. Upon successful implementation of the GIS, System Planning simulation software will be interfaced with the proposed GIS system so as to enable the conduct of detailed technical studies of the distribution system. In the same vein, CEB will also use the GIS for asset management. The result would be a geographical database of each component of its electric system, IT system and power plants, among others.

6.6.2 Grid Codes

The Grid Code is a technical document that sets out the rules governing the development and operation of the electrical network. It provides the technical guidelines and operational specifications, which generators connected to the network need to comply with.

Until very recently, CEB did not require Grid Codes since there were not many requests for connection of small and medium generators, and requests were mainly for traditional large generators, of which the electrical behaviour on the transmission network are very well understood. However, now, faced with increasing requests to integrate safely, economically and reliably the maximum amount of renewable gene-

* *See glossary*

ration projects, CEB is finding it necessary to develop appropriate Grid Codes. Likewise, a Grid Code for the low-voltage network was developed in 2010 for the SSDG project.

A transmission Grid Code will be specifically relevant for large-scale Wind and Solar Farms that will be connected to the transmission network. For example, based on the network operating characteristics, it will establish the responsibilities of large-scale Wind and Solar Farms to support the grid during, and after, disturbances. The MV distribution network Grid Code on the other hand will cater for issues that arise in the areas of protection and operation with the connection of distributed generation. CEB will start the development of a Transmission and MV Distribution Grid Code in 2013.

6.6.3 Smart Grid Technology

First introduced in the late 1990s, the term 'Smart Grid' in the power system sector describes a new concept of interactions between the stakeholders of an electric utility. In fact, 'Smart Grid' means adding IT intelligence in the network so as to allow more efficient and accurate grid management.

The known benefits of Smart Grid are numerous: peak load curtailment; demand response; automatic call centre; remote metering; automatic response upon fault detection and higher capability to integrate diverse renewable energy sources, amongst others.

With its on-going projects, such as the deployment of *smart meters** (elaborated in Section 10.3) which is one of the main components to build a smart grid, CEB is already attempting to advance on this smart journey, but shall do so cautiously.

In fact, in accordance with the Government's Energy Strategy Action Plan 2011-2025, supports of experts to conduct research and studies are being envisaged so as to enable the CEB, in the coming years, to confirm the feasibility of building the 'Mauritius Smart Grid'.

However, it is to be recognized that development of most Smart Grids around the world is still at their embryonic stages.

Generally, the implementation of such a grid is planned on an incremental basis spanning over several years. For instance, the *South Korean's roadmap*[1] for the implementation of a national smart grid has been phased over 20 years. Therefore, it goes without saying that the building of the 'Mauritius Smart Grid' will not be for tomorrow, given our limited resources.

[1]More information on the South Korean roadmap can be obtained at www.smartgrid.or.kr/10eng4-1.php
* *See glossary.*