REPORT OF THE COMMITTEE OF INQUIRY INTO THE

NATIONWIDE BLACKOUTS OF 19TH, 21ST AND 22ND JANUARY 2008
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EXECUTIVE SUMMARY

Between 6th February and 9th April 2008, a Committee appointed by the Energy Regulation Board conducted an Inquiry into the countrywide blackouts of 19th, 21st and 22nd January 2008. The Committee inspected the three main power stations, the switchyards, the transmission substations, and the site of a 330 kV transmission tower that had collapsed on December 30th 2007. Further the Committee visited the National Control Centre, the CEC Control Centre and the points of interconnection with the Zimbabwean and Congolese systems. The Committee interviewed top and senior management of Zesco, CEC and LHPC, the Control Room staff at the National Control Centre, the CEC Control Centre, and the Regional Control Centre in Lusaka. The Committee further received written and oral submissions from consumers. The oral submissions were from the Chamber of Mines and its affiliates, the Millers’ Association, and the Ndola Lime Company, all of whom provided written statements as well.

The following is a summary of the outcomes of the Inquiry:

FINDINGS

Finding 1:
The blackout was initiated by a disturbance in the Zimbabwean grid which resulted in the loss of a major load. This was consistent with the behavior of generators at Kariba South and Kariba North power stations and the sequence in which the protective devices operated.

Finding 2:
The blackout was initiated by a spurious tripping on the 330 kV transmission line No.2 from Kariba North to Leopards Hill. The failure of this line completely isolated Kariba North from the national grid because on December 30th a tower on the only other line, Line No.1, had collapsed in heavy rains. This also meant that there could be no imports or exports with Zimbabwe.

Finding 3:
The blackout of 22nd January 2008 was caused by a collapse of the system voltage due to insufficient generation capacity. The Zambian system had been isolated from Zimbabwe and Kariba North Bank Power Station was not available on this day because both lines that evacuate power from the station were out of service. Kafue Gorge Power Station was operating at maximum generation without any reserve margin at all.
On the causes of the blackout on 19th January 2008

Finding 4:
After all the machines at both power stations on the Kariba complex tripped, the national grid experienced a total loss of generation amounting to 644 MW. This caused the overloading and subsequent tripping of the machines at Kafue Gorge and Victoria Falls power stations, which resulted in the blackout.

Finding 5:
The generators at Kafue Gorge and Victoria Falls power stations tripped because the system did not have adequate means to adjust the load in order to balance it with the diminished available generation after the tripping of Kariba North Bank Power Station. In respect of this, the Committee noted the following:

(i) The system had no spinning reserve;
(ii) Load management under dynamic conditions was inadequate;

Finding 6:
The transmission tower that had collapsed three weeks earlier was out service at the time of the disturbance. If the line had been in service, the extent of the overload condition would have been reduced. Together with an effective under-frequency load management scheme and adequate spinning reserve, the loss of Kafue Gorge could have been prevented.

Finding 7:
The extent of the blackout in the southern and western regions could have been mitigated by grading the protection such that the Victoria Falls is isolated at Muzuma towards Kafue West and not by tripping the Victoria Falls – Muzuma line.

On the Causes of the blackout on 21st January 2008

Finding 8:
The blackout was initiated by a spurious tripping on the 330 kV transmission line No.2 from Kariba North to Leopards Hill. The failure of this line completely isolated Kariba North from the national grid because on December 30th a tower on the only other line, Line No.1, had collapsed in heavy rains. This also meant that there could be no imports or exports with Zimbabwe.
Finding 9:
The system conditions following the disturbance were similar to those of 19th of January. The sudden loss of about 583 MW on the national grid as a result of the tripping of the Kariba North-Leopards Hill line resulted in overloading and subsequent tripping of Kafue Gorge and Victoria Falls power stations.

Finding 10:
Only three machines were available producing a total of 444 MW, practically at maximum. Therefore there was no spinning reserve and, combined with inadequate dynamic load management, the tripping of the machines at Kafue Gorge was inevitable.

Finding 11:
The extent of the blackout in the southern and western regions could have been mitigated by grading the protection such that the Victoria Falls is isolated at Muzuma towards Kafue West and not by tripping the Victoria Falls – Muzuma line.

Finding 12:
It is likely that the blackout would have been avoided had the Kariba North-Leopards Hill Line 1 been in service at the time of the fault because the power that was being transferred at the time was below the maximum capacity of one line.

On the Causes of the Blackout on 22nd January 2008

Finding 13:
The system capacity was limited to the generation at Kafue Gorge and Victoria Falls Power Station amounting to 693 MW. Both stations were generating at their maximum and there was no spinning reserve. The blackout could have been avoided by better, more judicious load management.

Finding 14:
The extent of the blackout in the southern and western regions could have been mitigated by grading the protection such that the Victoria Falls is isolated at Muzuma towards Kafue West and not by tripping the Victoria Falls – Muzuma line.

Finding 15:
Had the line with a collapsed tower been restored before the disturbance, there is a possibility that the power system could have been saved by the availability of extra power from Kariba North power station.
On the Restoration of the System after the Blackouts

Finding 16:
The black starting of the power stations was inordinately long particularly on 19th January when it took more than 8 hours to put the first machines on line at Kafue Gorge and Kariba North Bank.

Finding 17:
The following factors contributed to the delay in black starting the power stations and restoring the system as a whole:

i. Inadequate skills and knowledge concerning procedures, voltage control and loading during black start;
ii. Delayed start of standby Diesel Generators at Kariba North and Kafue Gorge power stations on 19th January 2008;
iii. Equipment failure due to delayed or suspended maintenance schedules;
iv. Equipment failure due to high system voltages;
v. General disorder at the National Control Centre due to interference from non-NCC staff;
vi. Absence of senior staff at Kariba North power station on 19th January 2008;
vii. High system voltages caused by low load conditions compounded by absence of line compensation equipment on the Copperbelt;
viii. Failure of monitoring equipment such as Remote Terminal Units;
ix. Failure of PAX phones and other telecommunication facilities;
x. Limited knowledge in synchronizing on a dead bus;
xi. Vehicle breakdown for operational staff in Kabwe;

The Power Rehabilitation Project and its Delayed Implementation

Finding 18:
The Power Rehabilitation project had for many years substantially reduced the system available capacity. The following are some of the reasons that contributed to delays in completing the project:

(i) Changes in the scope of the project in order to up-rate the generators and to undertake unforeseen repairs after machines were opened;
(ii) Zesco’s failure to pay on time the costs that were additional to the borrowed funds;
(iii) Misunderstandings or disagreements between Zesco and its lenders on procedures for release of payments to contractors;
At the time of its visit to Kariba North Bank Power Station the Committee noted that the contractor had stopped work and demobilized. The delays gave the impression that the project did not receive adequate attention.

**Finding 19:**
As a result of the delayed completion of the PRP:

(i) The system was operated with inadequate spinning reserves, even considering the support available from the Southern African Power Pool;
(ii) Scheduled maintenance on equipment was delayed thereby increasing the likelihood of failure.

**The recommendations of the Report on the blackout of June 4th 2006**

**Finding 20:**
At the time of the disturbances in January 2008 and during the Committee’s investigation, Zesco had not submitted to the Energy Regulation Board a formal report on the implementation of the recommendations of the Technical Team that had investigated the blackout of June 4, 2006.

**Finding 21:**
A number of important recommendations of the report on the blackout of 4th June 2006 had not been implemented or could not be verified including:

(i) Automatic under-frequency load shedding;
(ii) System stability studies;
(iii) Reliability standards.

**Finding 22:**
The ERB had not instituted a mechanism for continuously monitoring the implementation of the recommendations of the Technical Team Report on the June 4, 2006 blackout. This had weakened the force of the recommendations.

**On the ZESA Interconnector and the Southern African Power Pool**

**Finding 23:**
The focus on the regional grid as the source of the disturbances and the decision to disconnect the tie-line deflected attention from the inherent weaknesses of the Zambian grid.

**Finding 24:**
On 22nd January, the operation of the system did not take account of the disconnection of the tie-line and therefore that the normal emergency support from the SAPP grid was
no longer available. This can be the only explanation for running the generators at Kafue Gorge at maximum output.

Finding 25:
The disconnection of the ZESA tie-line and the concurrent segregation of the SAPP into sub-grids points to serious weaknesses of the regional network brought to the fore by the generation capacity deficit

Finding 26:
A level of mistrust developed between ZESA and Zesco and prevented the utilities from sharing important technical information that would have aided the understanding of system behavior when the disturbances occurred. The structure of SAPP was not helpful as there were no enforceable instruments to compel utilities either to operate to mandatory standards or to provide technical information when necessary.

Finding 27:
At the time of preparing this report the ZESA – Zesco tie-line was still disconnected. This had deprived Zesco of critical dynamic and short-term support.

On the regulatory framework

Finding 28:
The Energy Regulation Board had not developed a sufficiently detailed framework for the requirements of operating the national grid. In particular this refers to specific requirements for power generation and transmission management standards.

Finding 29:
The Energy Regulation Board has not been forceful in the enforcement of licence conditions. The reasons are unclear, but may have to do with weakness in institutional arrangements.
RECOMMENDATIONS

The recommendations proceed from the Committee’s stance that while establishing the source of disturbances is necessary for reconstructing the events, it is far more important to prepare for abnormal conditions so that the impacts are minimized.

(i) **Automatic Under-frequency Load Shedding**

On all three days the Committee is persuaded that the absence of an effective automatic under-frequency load-shedding scheme played a major role in the failure to contain the scope of the disturbances. This matter was subject of a recommendation after the blackout of June 4, 2006. This Committee repeats the recommendation that Zesco immediately reviews the control of loads under emergency conditions. Zesco should immediately engage its partners, especially the CEC, and the major industrial and mining consumers on this matter.

(ii) **System Capacity and Spinning Reserve**

The second most important factor for the cascading of faults into total blackouts had to do with the failure to maintain a generation spinning reserve. While the Committee understands the pressure that Zesco is currently under to minimize load-shedding, the absence of a spinning reserve contributed to the inability of the system to contain the abnormal conditions that arose during the three days. The Committee recommends that Zesco reviews system operation and ensures that a reasonable reserve capacity is maintained in the interest of system stability.

(iii) **Power Rehabilitation Project**

This recommendation is related to Recommendation (ii) in so far as it concerns the available generation capacity. For the duration of the PRP the system has been operating with substantially reduced capacity. This is often compounded by faults on the available machines, some of them due to the changes implemented during the PRP, thus further reducing generation capacity. The Committee recommends that Zesco places the highest priority on the completion of the Power Rehabilitation Project. In particular, the payments to contractors should have first call on available resources.

(iv) **System Reinforcement**

The dynamic stability limit of the system is severely compromised by inadequate sources of reactive power. The Committee recommends that Zesco immediately undertakes an analysis of the system to determine the reinforcement that is required to improve stability. Zesco should work with its partners, mainly CEC, to determine the investment needed and how it should be shared. Both Zesco and CEC should also
accelerate the enforcement of minimum power factor operation by the large industrial users.

(v) Line Maintenance
The transmission grid is critical to the security of supplies from the power stations. The immediate challenge concerns the susceptibility of glass porcelain insulators to catastrophic failure, and even to vandalism. While recognizing the limitations under the current conditions of high demand and reduced capacity due to rehabilitation, the Committee nevertheless recommends that every opportunity should be taken to continue the programme of replacing the glass insulators with the newer rubber type. In this vein, the Committee further urges ZESCO to review the temporary arrangements on the Kariba North – Leopards Hill line to ensure that the line is appropriately secured before the 2008/09 rain season.

(vi) Protection System
An important objective of the protection system should be that, in the event of a severe fault, the protection should be such as to maintain supplies to those areas that can be isolated from the affected areas. Apart from maintaining supplies to some parts of the country, such measures reduce the time of restoration of the rest of the system. The Committee recommends that ZESCO takes immediate steps to explore and determine such possibilities. In particular, the Committee recommends that the protection grading between Victoria Falls and Kafue West substation be reviewed so that in the event of a shutdown of the main power stations essential loads in Choma and surrounding areas can be maintained.

(vii) System Monitoring
The Committee had difficulty reconstructing some of the events that occurred during the disturbances because the recorders and protective relays on the system were not time-synchronized. The Committee further noted that ZESCO faced the same difficulty. The Committee therefore recommends that ZESCO takes immediate steps to acquire any equipment that is needed to synchronize the so-called ‘time stamping’ on all event recorders. This also applies to synchronization with the recorders on the CEC network. CEC should take similar steps on the Copperbelt network.

(viii) Black Start Procedures
Following a blackout it is necessary to minimize the period of restoration as this has a significant impact on the risk posed to human life, and on operational losses and inconveniences suffered by the consumers. The Committee recommends that ZESCO and
CEC review their Black Start Procedures and ensure a continuous state of readiness of systems and personnel. In particular the following should be attended to immediately:

(i) Ensure that all standby equipment is available at all times; the operation of all station diesel generators should be automatic, i.e. should not require human intervention.

(ii) Ensure continuous training of all power station and control room staff especially to take account of evolving technology, changes to plant configurations and the recruitment of new staff.

(iii) Ensure that all communications equipment remains in service during emergencies, including the Remote Terminal Units on the SCADA.

(iv) Ensure that staff in remote stations is adequately provided with transport and other logistics to facilitate their prompt availability during emergencies.

(ix) **New Generation Capacity**

The Committee recognizes that until significant new generation capacity is developed there will be difficulties and compromises in running the Zambian system. The Committee therefore recommends that the current efforts to build new power stations be redoubled. To supplement its own efforts, the Government requires the participation of the private sector. In this regard the Committee recommends that the Office for Promoting Private Power Investment and the Framework and Package of Incentives be urgently reviewed in the light of experience to date.

(x) **Regulatory Framework**

The Committee noted the progress made on the implementation of a Grid Code for the Zambian system. The Committee recommends that, in view of the shortcomings evident from the experience of the blackouts, the Grid Code should be enhanced to provide detailed technical requirements for the operation of the system. This may be through the expansion of the current provisions or by rules supplementary to the Code.

(xi) **Enforcing license conditions**

The Committee notes that regulating Zesco poses unique challenges for the ERB because the utility is publicly owned. This is a common phenomenon worldwide. Nevertheless, the Committee views the credibility and effectiveness of ERB as critical to the success of the industry as a whole. The Committee therefore recommends that the Government works with the ERB to identify areas in the institutional and legal frameworks that need to be reviewed in order to enhance the ERB's effectiveness as a regulator.
(xii) **Economic Impact**
Due to the constraints noted in the report, the Committee was unable to fully assess the impact of the blackouts and, more generally, the current load-shedding regime on the economy. The Committee recommends that the Government and the ERB commissions a separate study on this matter in order to provide important planning information.

(xiii) **Implementation of Recommendations**
The Committee recommends that the ERB immediately institutes a mechanism for monitoring the implementation of recommendations made in this report and those from the Technical Team Report on the June 4, 2006 blackout. Time frames should be agreed with the concerned parties as necessary and the ERB should ensure compliance by the licensees.

(xiv) **The Southern African Power Pool**
The Committee recommends that the Government urges its counterparts in SADC to urgently review the virtual dismantling of the SAPP through the continued disconnection of critical interconnectors. Zambia’s position should be one of keeping the sub-regional grid connected while the issues brought to the fore by the generation deficit are urgently addressed by the utilities. Weighing the risk of system disturbances against the benefits of interconnection, the Committee’s view is that such risks are outweighed by the benefits.

(xv) **Regional Operating Standards**
The Committee further recommends that the Zambian government leads efforts to develop enforceable operating standards among the members of SAPP. The Committee’s view is that a body external to SAPP, such as the Regional Electricity Regulators’ Association, should be tasked to work with SAPP in developing and administering an acceptable operating regime which should have the highest endorsement of the Southern African Development Community. The standard should set out the minimum operating requirements for the Operating Members of SAPP
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2. Ms Betty Mulenga
3. Ms Wendy Musonda

Prof. J. M. Mwenechanya

Chairman
LIST OF ABBREVIATIONS AND ACRONYMS

BPC  Botswana Power Company
CEC  Copperbelt Energy Corporation Plc
NAMPOWER  Namibian Power Company
ERB  Energy Regulation Board
kV  Kilovolts
kWh  Kilowatt-hour
MVA  Mega volt-amperes
MW  Megawatt
MWh  Megawatt hour
ESKOM  Eskom Limited (South African National Electric Utility)
RERA  Regional Electricity Regulators Association
SAPP  Southern African Power Pool
SNELL  Societe National d’Electricite (DRC)
TANESCO  Tanesco Limited (Tanzanian National Electric Utility)
ZESA  Zimbabwe Electricity Supply Authority
ZESCO  Zesco Limited (Zambian National Electric Utility)
1. INTRODUCTION

The Zambian power system experienced countrywide blackouts on 19th, 21st and 22nd January 2008. On February 6, 2008, the Chairman of the Energy Regulation Board (ERB) established a Committee of Inquiry to investigate the causes of the blackout and recommend ways to reduce the possibility of future recurrence.

The terms of reference for the inquiry were as follows:

a) Inquire into, investigate and determine the operation of the protection system, tracing the steps in the cascade from the incidence of the fault to the blackout, with the view to establishing whether ZESCO had implemented the recommendations of the Technical Team Report into the 4 June 2006 Nationwide Blackout;

b) Inquire into, investigate and determine the condition and operating status of generating stations, switchgear and the main transmission lines before the events;

c) Inquire into, investigate and establish the load flow conditions before the fault, including imports and exports;

d) Establish what was the load on the Zambia-Zimbabwe inter-connector before the fault at Kariba North Bank Power Station;

e) Inquire into, investigate and determine what was the status of the Zambian System before the Nationwide Power Outage of 19 January, 2008 and that of 21 January, 2008;

f) Inquire into, investigate and establish whether or not the event which caused the Nationwide Power Outage of 19 January, 2008 and 21 January, 2008 originated from within the Zambian System or whether they originated from outside;

g) Inquire into, investigate and establish whether the collapsed pylon on the Kariba-Leopards Hill Line played any role in the events, and to what extent.

h) Establish to the extent possible, the impact on the economy, of the Nationwide Power Outages of 19 January 2008 and 21 January 2008.

i) Make Recommendations to reduce the recurrence of similar events as those of 19 January, 2008 and 21 January, 2008; and
This report presents the outcomes of an Inquiry into the country-wide blackouts that occurred on 19th, 21st and 22nd January 2008. The Inquiry was conducted over an eight-week period between 6th February and 9th April 2008. The Committee used this limited time to gain as good an understanding as possible of the system and of the events that took place in January. It is the Committee’s view that it obtained sufficient information to adequately answer to the Terms of Reference.

The Committee, in carrying out its functions, was faced with two challenges that are worth noting. The first was that information on operation of the Zimbabwean power system was limited and difficult to verify. Zesco and ZESA appeared reluctant to share information with each other, and attempts to obtain a view from the Coordinating Centre of the Southern African Power Pool (SAPP) failed due to communication problems with the Centre. Furthermore, at the time of reporting, SAPP had not yet posted on its website an authoritative account of the events of January 2008. The information would have provided additional confirmation of the events of 19th and 21st January when the Zesco and ZESA systems were still interconnected. Nevertheless, the Committee is confident that there was sufficient basis for arriving at the findings reported herein.

The second challenge was that the time stampings for the event recorders on the Zambian system were oftentimes not synchronized. This caused some delay and doubt because of different interpretations of the sequence of events. However, here too, the Committee was able to analyze the technical information sufficiently to support its findings.

The report is divided into seven chapters, including this introductory chapter.

Chapter 2 provides an overview of the fundamentals of electricity and is intended to assist the reader to understand the report and to provide a context for the blackouts.

Chapter 3 identifies the role of the Southern African Power Pool (SAPP) in the context of the regional power system. The chapter discusses the important role that SAPP provides to its members, which is to provide mutual support during emergencies and to enhance system stability in the face of disturbances. It also gives an overview of the interconnected system.

Chapter 4 describes the events of the 19th, 21st and 22nd January, starting from normal operating conditions, then going into a period of the disturbance. The chapter provides
details on the cascade phase of the blackouts as it spread across the country, and explains why the system performed as it did. It ends with the time it took from the blackouts to full system restoration.

Chapter 5 addresses issues related to the economic impact that the three consecutive blackouts had on the overall economy. The chapter discusses the fact that a comprehensive assessment of the impact of the nation-wide blackouts on the economy was constrained by the available time and resources. Such an assessment would have required the Committee to develop an econometric model and a formal methodology for obtaining the data. In the circumstances, the committee relied on the limited submissions received to assess the economic impact.

Chapter 6 provides the findings of the committee.

Chapter 7 presents the committee’s recommendations for preventing future blackouts and reducing the scope of any that occur.
2. **ELECTRICITY IN ZAMBIA**

This is a background chapter intended to assist the reader to understand the report and to provide a context for the blackouts.

**Electricity supply;**

Electricity lies at the heart of any modern or modernizing society, providing power to industry and commerce, and to households. A great amount of power is needed to supply a country such as Zambia, which has a large and growing mining industry and a fast growing population. It often happens that electricity is required at locations that are distant from where it is produced. This is because generating stations must be near the resource used to produce the electricity. Thus, for example, coal-fired power stations are located near coal mines and hydropower stations are constructed on suitable sites along rivers.

To ensure that electricity is available at the point of use involves a complex arrangement of machinery, switches, wires and other equipment. Figure 1 shows the elements of a supply system.

![Figure 1: Elements of a supply system](image)

There will usually be a generator hall that houses a number of individual generators. A generator produces electricity at a level that is not economical for transmission because it is too low and would require big cables to transport it across long distances. This is because of the high current associated with low voltages. In order to reduce the current, and therefore the size of the cables, the electricity from the generator is...
passed through a step-up transformer which raises the voltage to the required transmission voltage. Thus, at Kafue Gorge and Kariba North Bank power stations, the generators produce eighteen thousand volts (or 18 kV), which is raised to 330 kV for transmission. The combination of a generator and its associated step-up transformer is often referred to as a generating unit.

Specially designed steel towers or pylons support the wires that transport the electricity to the consumers. These high voltage towers often traverse difficult, remote terrain for long distances. The towers and lines are also subject to mechanical and electrical failure caused, for instance, by overgrown vegetation, extreme weather and large birds in flight. In inhabited areas the towers may also be weakened by vandalism, and occasionally collapse even when the forces are within the design limits. Therefore utilities have comprehensive programs of line surveillance and maintenance that may involve the use of aircraft. A transmission system that connects different parts of a country to the supply generators is known as a national grid.

The types of customers served by a utility may be classified according to the level of voltage at which they are supplied. At the high end are the very large customers who take power directly from transmission; at the low end are the household customers who require low voltages suitable for powering domestic appliances. Figure 1 shows three types of consumers: high voltage, medium voltage and low voltage. For each customer category step-down transformers are used to reduce the transmission voltage to the requirements of the different consumers. In the Zambian system the most significant high voltage customer to Zesco is the Copperbelt Energy Corporation, which retransmits and distributes the electricity to its copper mining consumers. The medium voltage consumers are represented by a wide range of industrial users.

**Protection and Reliability**

Because of the complexity of an electricity supply system, many things can go wrong and result in irrecoverable damage to expensive equipment and the loss of supply to consumers. The damage may be due to overheating of equipment leading to fires or due to uncontrolled mechanical forces in generating units. Therefore, over the years, the industry has developed highly sophisticated means of minimizing the occurrence and scope of such events. A utility will adopt a protection philosophy that best suits its objectives and will implement a protection system that is in line with the philosophy. At its most basic level, the protection system will aim to prevent damage to all equipment.

However a protection system is divided into several subsystems, known as protection zones, all of which may sense a disturbance but will wait for the subsystem that is closest to the fault to isolate the fault. Thus, correct time-coordination among the
protection zones ensures that, when a fault occurs, a minimum amount of equipment is taken out of service. This contributes to the reliability of the system. In the electricity supply industry reliability is an important concept: it is a measure of the ability of a utility to maintain a continuous supply of acceptable quality to its customers. Reliability is in two parts: the continuity of supply, and its adequacy. Protection systems aim to assure continuity while adequacy is a matter of balancing the supply to changing demand, a subject that will be discussed later in this report. Well run utilities constantly review measures towards reliability. The utility regulator will usually set and enforce standards of operation that will attract financial and other sanctions when violated.

**Hydro-generation**

Well over ninety per cent of the electricity in Zambia is produced by hydropower stations. Figure 2 shows the parts of a hydropower station.

![Hydroelectric Dam](image)

**Figure 2: Hydroelectric Dam**

Water stored in a dam reservoir is channeled to a turbine which spins the shaft of a generator. Two factors determine the power generated: the difference in height from the top of the dam to the position of the turbine, and the volume of water flowing in the channel, which is known as a penstock. At the top of the penstock - at the dam - there is an intake gate which can be used to shut off the water to the turbine in order
to stop the generator. This may be done to carry out maintenance or the gate may close automatically as a protective measure against mechanical damage to the generator under faulty conditions of operation. At the entrance to the turbine the water is regulated by means of guide vanes in order to control the speed of rotation. The speed of rotation determines the frequency of the generated voltage.

**Voltage and Frequency**

A power station is required to maintain a voltage and frequency that are consistent with a national standard. The standard frequency in Zambia, and throughout the sub-region, is fifty cycles per second or 50 Hertz, shortened to 50 Hz. The law requires that Zesco maintains this frequency within the range 49.5 to 50.5 Hz. The standard voltage depends on the level at which it is used. Low voltage consumers, the households, are supplied at 220 Volts, and this is allowed to vary between 209V and 231 V (or +/- 5%).

The task for the utility is to ensure that, after all the stages of transmission and distribution, the voltage available at the point of consumption is within these limits. This is a significant challenge because as it travels along the wires used for transmission and distribution the voltage drops progressively. It is therefore necessary to compensate for this drop for customers at the end of long lines; on the other hand, customers connected to the same lines, but located close to supply transformers, should not experience high voltages. In contrast, when long lines at high voltage are lightly loaded the voltage at the end of the line rises. This is caused by an electrical phenomenon called line capacitance whose effect is to progressively increase the voltage as the distance from the source increases. This can cause serious operational problems and it requires that the utility installs equipment and devices to counteract this effect.

When consumers switch equipment on and off, they impose varying conditions on the supply system. This causes the voltage and frequency to fluctuate. The voltage and frequency tend to rise when consumers switch off equipment and they tend to decrease when customers require more power. The utility ensures that the resulting fluctuations in the voltage and frequency remain within acceptable limits. However, generators have limited ability to track changes, and when such limits are exceeded the protection system detects this as an abnormal condition and responds by disconnecting the affected generators. After the generator is disconnected it may continue to spin and go into uncontrolled acceleration. Under such conditions the intake gate closes automatically and stops the water flow. The utility then needs to reduce the load, i.e. switch off some customers, so that the remaining load matches the capacity of the healthy generators. If the systems and procedures fail to respond quickly enough to the
changes in load, all the generators may go into a cascade of failure that may lead to a total blackout.

**Black Start Procedures**

Ordinarily the complete shutdown of a system is a rare event. Nevertheless, utilities must prepare for the possibility of a shutdown by ensuring that there are arrangements to enable timely and orderly restoration of normal supplies. In general power stations require electrical supplies for initial start up. When the system is operating normally, the transmission or distribution system provides this supply. When there is a total blackout the stations must obtain the electrical supply from small auxiliary generating plant located on-site. Therefore it is common that all stations that are required to have a Black Start capability have standby diesel generators.

At a minimum the requirement for Black Start capability would involve the following:

- The ability to start one unit at a power station from shutdown in agreed timescales without the use of external supplies;
- The capability to energize part of the system within a specified period of instruction from the National Control Centre
- The capability to accept instantaneous loading of demand blocks in agreed ranges, e.g. 10 to 30 MW; at the same time, the frequency should be maintained in an acceptable range of, typically, 47 to 52 Hz
- The ability to maintain a high service availability on both main and auxiliary generating plant, preferably upwards of 90%;
- Reactive capability to charge the immediate Transmission/Distribution systems;

In some systems the mandatory procedures, anticipate the possible tripping of the Transmission/Distribution systems, and therefore require a power station to have the capability for three sequential Black Starts within two hours.

To support these and other requirements the power station must ensure that the fuel for standby facilities is available, and that power station staff fully understand what needs to be done when there is an emergency.

Similar complementary requirements are established for load management at the National Control Centre and at other control centres. The most important of these are the Regional Control Centre in Lusaka and the CEC Control Centre in Kitwe.
Features of generation and transmission in Zambia

In Zambia, there are three major power stations located in the south of the country at Kafue, Siavonga and Livingstone, and all of are hydro-based. The highest consumption of electricity is for mining and mineral processing on the Copperbelt, several hundred kilometers away from the power stations. Over the last thirty years the Copperbelt mines have maintained a level of consumption that is anywhere between 60 and 75% of the total national consumption. The challenge of operating the Zambian grid system is framed by this important feature.

2.7.1 Kafue Gorge

The Kafue Gorge Power Station, the largest of the three, was fully commissioned in 1976 with an installed capacity of 900 megawatts (MW) from six generating units. In 1989 the cables evacuating the power from the power house to the switchyard at the surface caught fire, and the power station was extensively damaged. For about eighteen months while the station was being rehabilitated Zambia imported electricity from its neighbours. By 1991, the station had been restored and redesigned with enhanced security features. About ten years later, in 2002, Zesco secured loans amounting to about US$250 million to rehabilitate the system, focusing especially on the power stations, the distribution network and parts of the transmission grid. The Power Rehabilitation Project (PRP), as it became known, was still underway at the time of preparing this report.

Some time after the start of the PRP, Zesco secured more funds to carry out additional work on the generators so that, for the same amount of water, they would increase the electricity output by 10%. Therefore at the end of the Power Rehabilitation Project, the capacity of Kafue Gorge Power Station was expected to increase from 900 to 990 MW. Because of the design of the station, the generators at Kafue Gorge had to be taken out in pairs for the rehabilitation works. This meant that two generating units, equivalent to an output of 300 MW, were out of service at any one time.

2.7.2 Kariba North Bank

The Kariba North Bank Power Station was commissioned in 1971, taking advantage of an existing dam built at an earlier time when Zambia and Zimbabwe were members of a colonial federated state of Rhodesia and Nyasaland. Four machines were installed with a total rating of 600 MW, similar in size to the first power station on the south bank of Zambezi River, the Kariba South Bank Power Station in today's Zimbabwe. Two transmission lines link the two power stations, creating an important facility for power
transfer between the two countries and among the other interconnected regional states. These lines are known as tie lines, because they “tie” two systems together.

Similar to Kafue Gorge, the Kariba North Bank Power Station was undergoing rehabilitation at the time of this report. And, similarly again, Zesco decided to up-rate the generating sets during rehabilitation, but here the projected increase was 20%. Thus, the output of the power station would increase from 600 to 720 MW. During the Power Rehabilitation Project one generating set was taken out at any one time, representing a further decrease of 150 MW in available total national capacity.

2.7.3 Victoria Falls

The Victoria Falls Power station consists of three separate parts, labeled A, B, and C. The earliest of these is Station A, built in 1938 and rated at 8 MW. Stations B and C were commissioned, respectively, in 1969 and 1972, giving a total installed capacity of 108 MW. This capacity had never been available from inception due to a design problem that caused vibrations in Station B. To avoid the vibrations the output was restricted to 80 MW.

The Power Rehabilitation Project at Victoria Falls was nearly complete at the time of preparing this report. Due to these works, which also involved a much-needed modernization of the switching equipment, the station was restored to almost full design capacity. The station abstracts water upstream of the Victoria Falls, the most important tourist attraction in Zambia. The diversion of water for electricity generation is a source of constant concern to the tourism industry, particularly during periods of low river flow. Therefore, during such periods Zesco has agreed to reduce the water intake into the power station, which correspondingly reduces the station output of power.

Victoria Falls Power Station also supplies electricity to border settlements in Namibia and Botswana.

2.7.4 Lunsemfwa and Mulungushi

Apart from the three main Zesco power stations there are two others owned by an Independent Power Producer, the Lunsemfwa Hydro-Power Company or LHPC. Its power stations at Lunsemfwa and Mulungushi produce a total of 38 MW, fully contracted to Zesco. At the time of reporting LHPC had started work on a project to increase the output by 10 MW.
Transmission and Copperbelt Energy Corporation

As stated earlier, one special feature of the Zambian grid concerns the way in which electricity reaches the mines on the Copperbelt. After the mines were nationalized, in the late sixties, the national mining company, the Zambia Consolidated Copper Mines, created Power Division (out of the earlier Copperbelt Power Company), which purchased power in bulk and distributed it to the mining divisions. In the early nineties a privatization program transferred the mines back into private ownership and Power Division was packaged and sold as Copperbelt Energy Corporation, CEC. Because of the relatively high electricity consumption of the mining operations, CEC is by far the largest customer to Zesco and an important partner in managing the transmission grid. It owns and operates transmission lines at 220 kV and 66 kV. It also transmits and distributes power on behalf of Zesco to its customers on the Copperbelt.

The Copperbelt Energy Corporation has standby gas turbine alternators (GTA) amounting to 80 MW. This arrangement exists to assure security of supplies to the mines. In the closed underground environment it is essential that ventilation is not interrupted for prolonged periods because of the danger this poses to the lives of the miners. It is equally important that the mines continuously pump water out of the mining areas underground in order to avoid flooding. When the mines are at normal production thousands of people are underground at the various mines.

The Copperbelt Energy Corporation transmission grid is linked to the Congo through a 220 kV interconnector, or tie-line owned by the Corporation. The link, like the one at Kariba North Bank, creates a path for power exchange between the two countries. It also connects the Congolese system to the region, enabling the interconnected regional countries to share electricity resources and to support one another during emergencies. The Congo is a net exporter of electricity and has considerable potential to increase the exports. At the time of the report, various projects were underway to increase power transfer from the Congo on this interconnector. In addition, five countries on the western side of the SADC region had formed a special purpose company, Westcor, to build a transmission line for 3,500 MW from the Inga dam complex in Congo to South Africa and passing through the Democratic Republic of Congo, Angola, Namibia, and Botswana. Figure 3 shows the Zambian Grid.
Figure 3: The Zambian Grid

Supply, Demand and Spinning Reserve

An electricity supply system must have the capacity to supply the maximum power that may be demanded of it. As pointed out before, since electricity cannot be stored there must be an adequate resource and an appropriately sized plant to instantaneously deliver the power at the time and place that it is needed. Thus the installed capacity must match the maximum demand. In addition, it is prudent and standard practice to ensure that the available capacity has a reserve margin over and above the actual demand. A spinning reserve is a synchronized unused capacity that can be activated quickly by the System Operator to offset the differences between the scheduled load/production and the real load/production. It is a means of controlling the frequency of the network. Without such a reserve, the system is prone to failure because the demand could vary, even for short periods, and push the system beyond its ability to recover.

Electricity demand varies according to the time of day, day of the week and season of the year. The daily peaks usually occur during early evening times, reflecting the demand for cooking and entertainment in homes; special national and international events such as World Cup football or popular television shows could also impose special
demands. During the cold months, the evening peak demand could be increased further, compared to the warm months, due to the use of electric heaters.

The demand in Zambia has been increasing steadily as the economy has grown, bringing new industries and expanding old ones; there has also been a contribution from the increased number of households enjoying electricity supply. Between 2002, and 2007 the peak demand increased from about 1100 MW to 1600 MW. Therefore, even as the supply capacity was reduced due to the Power Rehabilitation Project, the demand grew rapidly, putting pressure on Zesco to find other sources of additional power. Mostly the demand was managed using supplementary imported power from South Africa and, to a lesser extent, the Democratic Republic of Congo. The importations reduced Zesco’s profitability since the additional costs were not fully recoverable through the tariff. Thus there was a limit to how much could be imported, and Zesco had to resort to load shedding, thereby suppressing the true demand. The electricity shortfall in the eighteen months leading to 2008 rapidly emerged in the public domain as a regional crisis, and the opportunities for imports diminished.

Zesco had made maximum use of the sub-regional grid in SADC to manage the demand. Critically, though, Zesco was able to rely on the interconnections to provide operational reserves, enabling Zesco to run its own generators at near-full capacity.

**Zesco Limited and Tariffs**

Zesco is a wholly state-owned utility that combines all aspects of delivering electricity to consumers. In the public eye it is seen as a provider of a service for development, and not as an enterprise that pursues the commercial interests of profit and maximizing value to its shareholders. To a large extent, this thinking informed the attitudes of government and successive managements of Zesco Limited. Therefore, policy objectives since 1994, aimed at improving the technical and financial performance of the utility proved difficult to follow through. The tension between commercial viability of a utility and the immediate social objectives, especially in an environment of pervasive poverty is common to essential services such as electricity and water. The most crippling impact was that electricity tariffs remained below cost-reflective levels, sending wrong signals to the consumers and providing insufficient resources for maintenance and service expansion. Viewed in this context, the start of a massive programme of rehabilitation of Zesco plant and equipment through the Power Rehabilitation Programme, signaled, to a large extent, a failure by the utility to raise sufficient revenue and keep pace with the requirements of a prudent maintenance regime for over many years.

This shortcoming had a significant impact on the implementation of the Project. Sometime after the start of the project, its scope was increased to take advantage of
recent technology. In addition, when the machines were opened up, additional works were deemed necessary; in one case at Kariba North, it was discovered that the design drawings for one unit were different from the actual configuration. These changes were not fully anticipated in the Project funding and the additional costs had to be met by Zesco.

**The Energy Regulation Board**

In 1995, the government created the Energy Regulation Board as an independent entity to oversee the whole energy sector. For the electricity sub-sector the thinking was that the planned reforms would result in a utility that would pursue commercial goals that had the potential to harm the public interest. A regulator was therefore needed to moderate such appetites and thereby ensure that a balance could be struck between profitable operation and customer interests including reliability and quality of service. A further justification for a regulator was that other measures had been introduced to attract the participation of the private sector. An independent regulator was expected to enhance Zambia’s attractiveness as an investment destination in the power sector.

However, the reform of Zesco did not go as far as had been envisaged, and the participation of the private sector was limited to the sale of the assets of Zambia Consolidated Copper Mines – CEC and LHPC. In the circumstances, it is fair comment that the utility and the government have tended to give primacy to immediate social objectives as opposed to the long-term commercial viability of the utility. Nevertheless the ERB has endeavoured to support and encourage Zesco’s efforts, such as they are, towards viable management of the utility. In 2005, ERB commissioned a Cost of Service Study in order to provide a sound basis for determining the price of electricity to the various categories of consumers. The study's conclusion that electricity was underpriced came as no surprise, but it was the first attempt to put figures to the extent of the price erosion. It also outlined an approach to the treatment of the cost of generation expansion. In 2007, the ERB approved a three-year price adjustment coupled to performance benchmarks.

**3. The Southern African Power Pool**

The Southern African Power Pool is an electricity market offering trading opportunities for its members. There are two categories of membership: Operating Members whose grids have interconnections with other states; and Non-operating Members that have potential to build interconnectors. Thus of the fourteen members of SADC, the twelve on-shore members of SADC belong to SAPP, and of these, Angola, Malawi and Tanzania are yet to become Operating Members.
Figure 4 shows the SAPP interconnections and their transfer capacities in 2008. The amount of electricity traded daily is small, and mostly the members have long-term bilateral contracts. The SAPP serves another important role: to provide mutual support to members during emergencies and to enhance system stability in the face of disturbances.

The member states are represented by the Chief Executives of the respective national utilities. A centre located in Harare, Zimbabwe, is managed by a Coordinator on behalf of the utilities. With regard to operational issues, the SAPP relies on peer pressure to improve standards. There are no enforceable instruments for reliability such as one may find in other, more regimented regional markets. This reflects the current status of SADC as a voluntary grouping of sovereign members. In such circumstances, there can be a wide disparity of standards and operational practices among members.

The SAPP member utilities are regulated by national regulators, and nearly all of them are independent regulators. Inevitably there are variations in the scope and effectiveness of the regulatory frameworks. Partly to address such differences, the SADC Regional Electricity Regulators’ Association (RERA) was established, grouping independent regulators from member states. RERA’s purpose is to advocate a sound and harmonized regulatory framework. An ideal arrangement, one that RERA aspires to, is one where it is able to enforce common regulatory standards among the members of SAPP in matters of technical standards and methods of tariff determination. This seems some way off, and will require that SADC recognizes and adopts RERA’s set of regulatory principles at the highest level.
Figure 4: SAPP Interconnections and their transfer capacities
4. THE POWER BLACKOUTS

In the normal course of operations, an electricity supply system is subjected to myriad sources of disturbances including adverse weather conditions, failure of equipment, human error, and the handiwork of vandals. In many incidents, there is often a complex combination of such factors. Therefore, it is impossible to eliminate disturbances on an electrical system, especially as some of them are outside the control of the utility. In establishing causes, the Committee distinguished between causes of disturbances and causes of the blackouts. The causes of the disturbances are the abnormal conditions that initiated the event. Because the Zambian grid is part of a sub-regional grid, the Southern African Power Pool, these causes may occur outside the Zambian system. However, more important is to understand why the disturbances caused total blackouts in Zambia.

In this section we describe and analyze the three blackouts that occurred between 19th and 22nd January 2008. Based on an analysis of each incident, the Committee drew conclusions on the source of the disturbance and the cause the total blackout.

For each date, the Committee as much information as was readily available on the status of the power stations and the transmission grid just prior to each disturbance. To a large extent, the conditions in the system at the time of a disturbance determine how the system responds.

BLACKOUT OF 19th JANUARY 2008

4.7.1 Pre-fault Status of Generating Plant

(i) Kafue Gorge Power Station on 19th January
Prior to the system disturbance Kafue Gorge Power Station was generating a total of 597.6 MW from four generator units. Unit 1 was generating 150 MW, Unit 2 was generating 148 MW, Unit 3 was generating 150 MW and Unit 4 was generating 149.6 MW. Generators 5 and 6 were out of service for rehabilitation and up-rating under the Power Rehabilitation Project (PRP). Therefore, out of the total installed capacity of 900MW only 600MW of capacity was available and the station output of 597 MW was very nearly (99.5%) the full capacity of the station at the time.
Table 1: Kafue Gorge Power Station (19th January)

<table>
<thead>
<tr>
<th>Generator</th>
<th>Status</th>
<th>Output (Megawatts)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit No.1</td>
<td>In service</td>
<td>150.0</td>
<td></td>
</tr>
<tr>
<td>Unit No.2</td>
<td>In service</td>
<td>148.0</td>
<td></td>
</tr>
<tr>
<td>Unit No.3</td>
<td>In service</td>
<td>150.0</td>
<td></td>
</tr>
<tr>
<td>Unit No.4</td>
<td>In service</td>
<td>149.6</td>
<td></td>
</tr>
<tr>
<td>Unit No. 5</td>
<td>Out of service</td>
<td>0</td>
<td>Under PRP</td>
</tr>
<tr>
<td>Unit No. 6</td>
<td>Out of service</td>
<td>0</td>
<td>Under PRP</td>
</tr>
</tbody>
</table>

**TOTAL OUTPUT** 597

**AVAILABLE CAPACITY** 600

One 17.5/330KV generator transformer T3 had been out of service since December 2007 awaiting replacement with a bigger unit under the PRP. The spare transformer, TQ, had therefore been in service at the time of the fault.

The switchyard was in normal condition and standby facilities i.e. batteries, two diesel generators and the 33-KV line to Kafue, were available.

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Figure 5: Pre-fault status at Kafue Gorge Power Station (19th January)
(ii) Kariba North Bank Power Station (19th January)
Prior to the system disturbance Kariba North Bank power station was generating a total of 472 MW from three generator units 1, 2 and 4. Unit 1 was generating 162 MW, Unit 2 was generating 160 MW, and Unit 4 was generating 150 MW. Generator 3 was out of service for rehabilitation and up-rating works under the Power Rehabilitation Project. Generators 1 and 2 have been up-rated by 30MW each thereby giving a total installed capacity of 660MW. Generator 4 has not yet been rehabilitated and up-rated. The Committee estimated that the available capacity at the time of the fault is estimated was 490 MW, 170 MW each from the Units 1 and 2, and 150 MW from Unit 4. The reason for the estimate is that although Units 1 and 2 have been up-rated to 180 MW, Zesco submitted that the available capacity was dependent on the level of generation at Kariba South, which meant that at most times the available head was less than the maximum possible.

Imports through the ZESA route were maintained at 172 MW. This provided a total of 644 MW was being transmitted from Kariba to Leopards Hill substation.

Table 2: Kariba North Bank Power Station (19th January)

<table>
<thead>
<tr>
<th>Generator</th>
<th>Status</th>
<th>Output (Megawatts)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit No.1</td>
<td>In service</td>
<td>162.0</td>
<td>Up-rated under PRP</td>
</tr>
<tr>
<td>Unit No.2</td>
<td>In service</td>
<td>160.0</td>
<td>Up-rated under PRP</td>
</tr>
<tr>
<td>Unit No.3</td>
<td>Out of service</td>
<td>0</td>
<td>Under PRP</td>
</tr>
<tr>
<td>Unit No.4</td>
<td>In service</td>
<td>150.0</td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL OUTPUT**  
472

**AVAILABLE CAPACITY**  
490 (est.)

**TIE-LINE IMPORT**  
172

The switchyard was in normal condition and the standby facilities i.e. batteries and the diesel generator were available.

The standby diesel generator was available, but the Committee heard that it could only be operated locally. The generator did not have an automatic transfer facility and it could not be operated from the Control Room because the necessary circuits had not been wired.
(iii) **Victoria Falls Power Station (19th January)**
The power station comprises three stations; A, B and C with installed capacities of 8MW, 60MW and 40MW respectively. The rehabilitation works at the station under the Power Rehabilitation Project had been completed before the blackout.

Prior to the system disturbance Victoria Falls Power Station was generating a total of 78 MW out of the total installed capacity of 108 MW.

Before the fault, all the units in station A were undergoing repairs. In station B Unit B5 was out of service due to burnt stator and field windings since March 2006 and Unit B6 was out of service for repairs. All machines at station C were in service.

The switchyard was in normal condition and standby facilities i.e. batteries unit, uninterruptible power supply (UPS) and the diesel generator were available. The control for the diesel generator was set to AUTO, which meant that the generator automatically switched on as soon as it sensed loss of supply. The new 220-KV Katimamulilo breaker could only be operated locally at the switchyard or from NCC because it had not yet been connected to the Victoria Falls control room.

(iv) **Lunsemfwa and Mulungushi Power Stations (19th January)**
Mulungushi and Lunsemfwa Power Stations owned and operated by Lunsemfwa Hydro Power Company, are situated 65 km and 100 km east and north-east of Kabwe
respectively. Prior to the fault, generation was being maintained at 36.2 MW. All other equipment was in normal working order. The entire plant and standby facilities were in normal condition.

4.7.2 Pre-fault Status of the Transmission Network

(i) The 330-kV Network (19th January)
All the major 330-kV equipment was available and in service except for the Kariba-Leopards Hill No.1 line which had been out of service since 30th December 2007 when tower No. 145 collapsed in heavy rains and flooding. Therefore, only Line 2 was available for the transfer of power from Kariba North Power Station and the power flow on the Zesco-Zesa tie-line.

The two ZESCO-ZESA 330kV tie-lines were in service and the power flow prior to the disturbance was 172MW into the ZESCO system. Kariba South tie-lines KS1 and KS2 were carrying 107MW and 65MW respectively. The Committee was not provided with a satisfactory explanation for the difference of the loading of these two lines. If the lines were connected to a common bus at Kariba South, and similarly at Kariba North, the line loads should have been equal. There was no confirmation of the bus configuration at Kariba South. Zesco also raised the possibility of a metering error, especially as it was not possible to balance the power flows between the sources at Kariba and the transmission line to Leopards Hill.
Collapsed Tower
On December 30th 2007, a 330 kV tower on Line 1 of from Kariba North Bank Power Station to Leopards Hill substation had collapsed, putting the line out of service. Between November and December the Siangwenu River changed course in high tide. The tower collapsed after the strong river currents eroded the foundation of the tower. The line had been switched off the day before when it became clear that the tower was at risk. Other towers in this and nearby areas were at risk because of the sandy loose soils into which the tower foundations are sunk. Zesco had not completed the restoration of the line by the time of the first blackout on 19th January 2008, and this weakened the Zesco system against the severe disturbances that occurred. Difficult access to the site and the mobilization of materials delayed the work. Zesco had sought the assistance of the defence forces and the Committee found them camping at the site. When the Committee visited the site of the tower on 14th February 2008, the line had been restored by erecting a new tower. The position of the new tower disturbed the normal inter-tower spacing, creating very low sag across the river that had damaged the original tower. The Committee was informed that the installation would be reviewed as soon as weather conditions permitted.

Line 1, Kariba North Bank to Leopards Hill
The remains of the collapsed tower in the middle of the Siangwenu River which had changed course between November and December 2000

Line 1, Kariba North Bank to Leopards Hill
The footing of the new tower
The Committee inspected another location along the route of the transmission lines from Kariba North Bank power station to Leopards Hill substation. Here, too, some towers were at risk of being swept away by the floods and Zesco had instituted contingency measures to save a tower that was most at risk.

(ii) The 220-kV Network (19th January)
All the 220-kV lines were in service. These include the ZESCO and CEC transmission lines and the interconnector with SNEL in the Democratic Republic of Congo (DRC).

Prior to the disturbance the power flow on the SNEL-CEC Interconnector was about 190 MW into the Zambian system.

(ii) The 660-kV Network (19th January)
The two power stations belonging to LHPC are linked to the national grid at “14 Miles” step-down substation through two 66-kV transmission lines. These lines were in service. All the 66-kV lines belonging to CEC and ZESCO across the country were in service.

(iii) Imports and Exports (19th January)
Prior to the disturbance the tie-line flows were as follows:

- ZESA to ZESCO 172MW
- SNEL to ZESCO 190MW
4.7.3 The Disturbance of 19th January

(i) The Source of the Disturbance
From a review of the sequence of events and the reports and submissions by Zesco, the Committee concluded that the disturbance was caused by the loss of a major load on the ZESA system. A considerable power swing occurred leading to unstable conditions of frequency on both the ZESA and Zesco networks. The Committee could not establish which lines tripped in the Zimbabwe network or the magnitude of the load that was lost.

(ii) The Fault Cascade (19th January)
As a result of the disturbance, an over-speed condition developed at both Kariba South and Kariba North Bank power stations. All the machines at Kariba South Power Station tripped on governor over-speed and Unit 2 at Kariba North tripped on over frequency. The tie-lines then tripped on under frequency and Unit 1 at Kariba North Power Station tripped on excitation limit followed by the Kariba North-Leopards hill line 2 tripping on over current.

The loss of the generation at Kariba North and the imports from the ZESA caused an overload condition at Kafue Gorge and, consequently, a total shutdown of the station.

The sequence of events as recorded at the National Control Centre (NCC) was as follows:

*Table 3: Sequence of events at Kariba North Bank Power Station (19th January)*

<table>
<thead>
<tr>
<th>Power Station</th>
<th>Circuit</th>
<th>Time</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kariba North</td>
<td>G2</td>
<td>19:38:22.700</td>
<td>Over frequency protection operated</td>
</tr>
<tr>
<td>Kariba North</td>
<td>G2</td>
<td>19:38:22.800</td>
<td>Master trip relay operated</td>
</tr>
<tr>
<td>Kariba North</td>
<td>G2 CB 290</td>
<td>19:38:23.200</td>
<td>Breaker opened</td>
</tr>
<tr>
<td>Kariba North</td>
<td>Kariba South 2</td>
<td>19:38:26.500</td>
<td>Under frequency protection operated, master trip relay operated</td>
</tr>
<tr>
<td>Kariba North</td>
<td>Kariba South 1</td>
<td>19:38:26.500</td>
<td>Under frequency protection operated, master trip relay operated</td>
</tr>
<tr>
<td>Kariba North</td>
<td>Kariba South 2</td>
<td>19:38:26.900</td>
<td>CB 405 opened</td>
</tr>
<tr>
<td>Kariba North</td>
<td>Kariba South 1</td>
<td>19:38:26.900</td>
<td>CB 105 opened</td>
</tr>
<tr>
<td>Kariba North</td>
<td>G1</td>
<td>19:38:32.450</td>
<td>Master trip relay operated</td>
</tr>
<tr>
<td>Kariba North</td>
<td>G1 CB 190</td>
<td>19:38:32.900</td>
<td>Breaker opened</td>
</tr>
<tr>
<td>Kariba North</td>
<td>G1</td>
<td>19:38:33.850</td>
<td>Over frequency protection operated</td>
</tr>
<tr>
<td>Kariba North</td>
<td>G4 CB 490</td>
<td>19:39:30.827</td>
<td>CB opened</td>
</tr>
</tbody>
</table>
Table 4: Sequence of events at Kafue Gorge Power Station (19th January)

<table>
<thead>
<tr>
<th>Power Station</th>
<th>Circuit</th>
<th>Time</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kafue Gorge</td>
<td>G1</td>
<td>19:39:04.722</td>
<td>CB opened</td>
</tr>
<tr>
<td>Kafue Gorge</td>
<td>G2</td>
<td>19:39:22.725</td>
<td>CB opened</td>
</tr>
<tr>
<td>Kafue Gorge</td>
<td>G3</td>
<td>19:39:23.727</td>
<td>CB opened</td>
</tr>
<tr>
<td>Kafue Gorge</td>
<td>G4</td>
<td>19:39:23.729</td>
<td>CB opened</td>
</tr>
</tbody>
</table>

Table 5: Sequence of events at Victoria Falls Power Station (19th January)

<table>
<thead>
<tr>
<th>Power Station</th>
<th>Circuit</th>
<th>Time</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Victoria Falls</td>
<td>T1B CB</td>
<td>19:39:26.942</td>
<td>CB Err Status 00</td>
</tr>
<tr>
<td>Victoria Falls</td>
<td>T1B CB</td>
<td>19:39:26.943</td>
<td>CB opened</td>
</tr>
</tbody>
</table>

4.7.4 Analysis of the Cascade of 19th January

The shutdown of Kariba North power station was inevitable following the loss of major load in the ZESA system which had led to the loss of all generation at Kariba South and the tripping of the Zesco-ZESA tie-line.

Prior to the event, the three Zambian power stations were generating a total of 1172 MW and the imports on the Zesa and SNEL lines totaled 362 MW, giving a total system demand of 1534 MW. The loss of generation from Kariba and the ZESA import amounted to 644 MW or 42% of the demand at the time.

The Committee noted that the protection systems effectively prevented damage to major equipment and that most failures were consequential to transient conditions that arose especially during the attempts to restore the system.

The loss of this magnitude of load was a major shock to the grid and it is clear to the Committee that Zesco did not have the means for limiting the scope of the disturbance, which could have prevented a total blackout. A combination of adverse factors was at play. First, the system was operating without any spinning reserve, as all the power stations were at maximum available generation. A spinning reserve would have reduced the impact of the lost generation and imports. Second, the automatic under-frequency load shedding scheme was either inoperable or completely absent at critical load points. An effective system would enable Zesco to respond to the loss of generation by automatically switching off appropriate loads thereby balancing the demand with the generation available. Third, the network was in urgent need of reinforcement to improve its dynamic stability. To dampen the oscillations that large power swings can give rise to, and especially to control voltages, the network urgently needs reactive power compensation equipment designed and installed after a sound dynamic analysis of the network. Zesco informed the Committee that it had the tools and the capacity to
undertake such analyses. It is the view of the Committee that, while it is not possible even with these measures, to guarantee system stability absolutely, there is no doubt that the inadequacies contributed to the total shutdown of the Zambian grid.

The Committee considered whether the tower that had fallen on Line 1 of the Kariba-Leopards Hill line would have made any difference to the total collapse of the system. The Committee noted that the severity of the power swing arose from the total loss of contribution from the Kariba North Power Station and the ZESA imports amounting to 172 MW. However, the Committee also noted that the protection system on Unit 4, which had not undergone rehabilitation, enabled it to continue running a full minute after Line 2 had tripped. Therefore, if Line 1 had been in service, it would have provided a path for the generation from Unit 4. This would have reduced by about 25% the amount of load that attempted to transfer to the other two power stations causing the overload. Combined with all of some of the measures outlined above, the Committee’s view is that a total blackout could have been prevented.

Furthermore, the Committee concluded that the extent of the blackout in the southern region would have been substantially reduced by correct grading of the protection system. Instead of isolating the southern system by the Victoria Falls-Muzuma line, the protection should instead trip the line Muzuma to Kafue. In that way, much of the load in Choma and surrounding areas would continue to be supplied from Victoria Falls Power Station.

4.7.5 System Restoration (19th January)

For the consumer when a blackout occurs, the challenge is to ensure that emergency supplies available to critical loads to avoid possible loss of life and minimize irreversible damage to equipment. For the utility, the challenge is to restore the system to normalcy as quickly as possible in order to limit the hardship and harm caused to customers; to limit the loss of revenue to the utility; and to maintain customers’ confidence in the integrity of the supply network. The time taken to restore system could have significant long-term effects on the performance of the national economy.

Under conditions of a total failure, Zesco sets in motion a process to start the system from scratch. This is a complex process that essentially requires Zesco to balance a gradual build up of load with correspondingly gradual increase in generation. The main players are the National Control Centre, the Control Room staff at the power stations, Regional Control Centre in Lusaka and the CEC Control Room in Kitwe. Standard routines have been worked out describing what needs to be done at the various centres following a declaration of a blackout by the National Control Centre. These are known as Black Start Procedures.
(i) **Emergency supplies to Mining loads (19th January)**
Underground mining operations have a high priority because of the danger of losing thousands of lives if electrical supplies become unavailable for extended periods. Ventilation and water pumping are the primary requirements. The Copperbelt Energy Corporation supplies electricity to the mines on the Copperbelt and provides emergency power through standby gas turbine alternators (GTAs) that have a total installed rating of 80 MW. The emergency procedures identify which of the mine loads should be supplied when such an emergency occurs. The GTAs are located at Luano substation (40MW), Bancroft (20 MW) Kankoyo (10 MW) and Mufulira (10 MW). During an emergency, the CEC Control Centre, using established procedures, liaises with the electrical staff of the mines to isolate all loads except the emergency loads, known as CAT III loads. The CEC network also has a 220 kV line interconnector with SNEL in the DRC.

On 19th January the SNEL interconnector had tripped following the blackout in Zambia. At 19.50 hrs, the line was reestablished and at 21.12 hrs all mining consumers had sufficient supplies for loads under CAT III. Further, some of the CEC standby GTAs were used to augment the imported power. The Committee noted that SNEL agreed to supply this power even in the absence of a contract either with Zesco or CEC.

(ii) **Kariba North Power Station (19th January)**
During the attempts to restore Kariba North Bank Power Station a number of equipment failures occurred, including the following:

- Generator G1 governor actuator was clogged. The remedy required isolation of the governor system to enable work to proceed, a process that required forty minutes to complete.
- Generator 2 had the combined bearing and turbine cooling water strainer clogged. When the generator tripped, the intake gate on this unit also closed, shutting water off to the turbine. The cleaning works on the strainer took up to 6 hours. Opening of the closed intake gate took one hour.
- Generator 4 current asymmetry second stage operated. This meant that the generator had to undergo maintenance and repair works which would require some days.

The black start was also delayed by difficulties experienced in starting the standby diesel generator that was required for powering essential switching equipment. First, the diesel generator could not be started remotely, and some time was lost in driving to the diesel generator from the Control Room in the power house. Second, the generator had a long-standing malfunction that was circumvented by fiddling with some control cards.

Further delay arose from insufficient orientation of staff to new systems that had been implemented under the Power Rehabilitation Project. In particular, this refers to procedures for closing circuit breakers on a dead bus.
The power station was finally made available at 03:32 hours on 20th January 2008 starting with G2 and G1. This was more than eight hours after the blackout.

(ii) **Kafue Gorge Power Station (19th January)**
At Kafue Gorge Power Station, the following happened:

- Generator G1 had a flash-over on the excitation slip-rings. When the exciter was opened, it was discovered that the insulator had cracked and required repair. This fault meant that G2 would no longer play a part in the restoration process.
- During one attempt, the 11 kV surge arrester on the Leopards hill sub-station 330/88 kV 90 MVA transformer T1A got damaged and was on fire. System restoration was suspended to facilitate isolation of this transformer.

Further restoration delay was experienced when (air-blast) circuit breakers at Leopards Hill substation failed operate due to low air pressure. It was decided to use isolators instead.

Numerous unsuccessful attempts were made to restore the system using Kafue Gorge Power Station. The station succeeded to charge the 330-kV bus bar after the 12th attempt at 04:10 hours the next day using G4. This was about eight and half hours after the onset of the blackout. The last generator (G2) was synchronized to the grid at about 06:29 hrs on Sunday, 20th January 2008.

(iii) **Victoria Falls power station (19th January)**
Victoria Falls Power Station was restored independently from the rest of the grid. The first generator came on at 20:04hrs, less than forty minutes after loss of supply. Loading started with Livingstone at 20:10hrs and restoration was completed at 22:26hrs. The station operated in an islanded condition until Sunday 20th at 13:59hrs when it was synchronized to the rest of the grid.

(iv) **Load centres**
Supplies to various load centres were progressively made available as follows:

*Table 6: system restoration at various load centers in the country*

<table>
<thead>
<tr>
<th>STATION</th>
<th>TIME</th>
<th>DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lusaka</td>
<td>03:32hrs</td>
<td>20 January 2008</td>
</tr>
<tr>
<td>Kabwe</td>
<td>04:50hrs</td>
<td>20 January 2008</td>
</tr>
<tr>
<td>Kafue Town</td>
<td>05:17hrs</td>
<td>20 January 2008</td>
</tr>
<tr>
<td>Copperbelt</td>
<td>06:04hrs</td>
<td>20 January 2008</td>
</tr>
<tr>
<td>Kansanshi</td>
<td>07:11hrs</td>
<td>20 January 2008</td>
</tr>
<tr>
<td>Pensulo</td>
<td>14:00hrs</td>
<td>20 January 2008</td>
</tr>
</tbody>
</table>
(v) **SNEL interconnector (19th January)**
ZESCO supplies were synchronized to SNEL at 06:04 hours on 20th January 2008

(vi) **Lusaka Area (19th January)**
The restoration of Lusaka loads commenced at 03:32 hrs on 20th January 2008 and was completed at about 06:54 hrs the following day. At the same time, the 330kV lines to the Copperbelt were being progressively switched.

(vii) **The Copperbelt (19th January)**
The restoration process in the Copperbelt involved the supply of emergency power to the essential loads via the DRC-Zambia 220kV line and the standby GTA owned by CEC starting at 19:50 hours and by 21:12 hours CEC had availed emergency power to all the mine customers. However, the available power through the DRC-Zambia Interconnector is limited and only Category III loads were supplied until ZESCO supplies were synchronized to SNEL at 06:04 hours on 20th January 2008. At this point onwards, the mines were able to gradually pick up more power and power to the main towns was restored.

(viii) **The Southern System (19th January)**
The Southern System comprising Victoria Falls and the associated transmission lines was restored independently of the rest of the grid. The first generator came on at 20:04hrs. Loading started with Livingstone loads at 20:10hrs. Restoration was completed at 22:26hrs and the station operated as an island until Sunday 20th January 2008 at 13:59hrs when it was synchronized to the grid.
BLACKOUT OF 21ST JANUARY 2008

4.7.6 Pre-fault Status of Generating Plant - 21st January

(i) Kafue Gorge Power Station
Prior to the system disturbance Kafue Gorge power station was generating a total of 444 MW into the national grid from three generator units. Unit 2 was generating 147 MW, Unit 3 was generating 150MW and Unit 4 was generating 147MW. On this particular day generator 1 was out for repairs as a result of the incident of the 19th of January 2008. Generators 5 and 6 were out of service for rehabilitation and up-rating under the Power Rehabilitation Project (PRP). Therefore, out of the total installed capacity of 900 MW only 450 MW of capacity was available. The station was generating at nearly the maximum available capacity.

<table>
<thead>
<tr>
<th>Generator</th>
<th>Status</th>
<th>Output (Megawatts)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit No.1</td>
<td>In service</td>
<td>0</td>
<td>On maintenance</td>
</tr>
<tr>
<td>Unit No.2</td>
<td>In service</td>
<td>147.0</td>
<td></td>
</tr>
<tr>
<td>Unit No.3</td>
<td>In service</td>
<td>150.0</td>
<td></td>
</tr>
<tr>
<td>Unit No.4</td>
<td>In service</td>
<td>147.0</td>
<td></td>
</tr>
<tr>
<td>Unit No.5</td>
<td>Out of service</td>
<td>0</td>
<td>Under PRP</td>
</tr>
<tr>
<td>Unit No.6</td>
<td>Out of service</td>
<td>0</td>
<td>Under PRP</td>
</tr>
</tbody>
</table>

The switchyard was in normal condition and standby facilities i.e. batteries, two diesel generators and the 33-KV line to Kafue, were available.

TOTAL OUTPUT 444
AVAILABLE CAPACITY 450
(ii) Kariba North Bank Power Station (21\textsuperscript{st} January)
Prior to the system disturbance Kariba North Bank power station was generating a total of 473 MW from three generator units 1, 2 and 4. Unit 1 was generating 162MW, unit 2 was generating 161MW and unit 4 was generating 150MW. Generator 3 was out of service for rehabilitation and up-rating works under the Power Rehabilitation Project.

\textit{Table 8: Kariba North Bank Power Station 21\textsuperscript{st} January}

<table>
<thead>
<tr>
<th>Generator</th>
<th>Status</th>
<th>Output (Megawatts)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit No.1</td>
<td>In service</td>
<td>162.0</td>
<td>Up-rated under PRP</td>
</tr>
<tr>
<td>Unit No.2</td>
<td>In service</td>
<td>161.0</td>
<td>Up-rated under PRP</td>
</tr>
<tr>
<td>Unit No.3</td>
<td>Out of service</td>
<td>0</td>
<td>Under PRP</td>
</tr>
<tr>
<td>Unit No.4</td>
<td>In service</td>
<td>150.0</td>
<td></td>
</tr>
</tbody>
</table>

| TOTAL OUTPUT | 473 |
| AVAILABLE CAPACITY | 490 (est.) |
| TIE-LINE IMPORT | 112 |

The switchyard was in normal condition and standby facilities i.e. batteries and the diesel generator ware available. The diesel generator was on local.
(iii) **Victoria Falls Power Station (21st January)**
Prior to the system disturbance Victoria Falls power station was generating a total of 80MW out of the total installed capacity of 108MW.

In station A repairs to Units A1 and A3 were still ongoing, but Units A2 and A4 were in service. In station B Unit B5 was unavailable due to burnt stator and field windings since March 2006. All machines in station C were in service.

The switch yard was in normal condition and standby facilities i.e. batteries/UPS and the diesel generator were available. The diesel generator was set to AUTO which meant that the generator automatically switched on as soon as it sensed loss of supply. The new 220-KV Katimamulilo breaker could only be operated locally at the switchyard or from NCC because it had not yet been connected to the Victoria Falls Power Station control room.

(iv) **Lunsemfwa and Mulungushi Power Stations (21st January)**
Total generation at Lunsemfwa and Mulungushi hydro power stations was 36.1MW. The entire plant and standby facilities were in normal condition.
4.7.7 Pre-fault Status of the Transmission Network – 21st January

(i) The 330-kV Network (21st January)
All the major 330kV equipment was available and in service except for the Kariba-Leopards Hill No.1 line which was out of service for repairs after a tower was washed away by heavy rains on 30th December 2007.

The two ZESCO-ZESA 330kV tie-lines were in service and the power flow prior to the disturbance was 112 MW into the ZESCO system. Kariba South tie-lines KS1 and KS2 were carrying 66 MW and 46 MW respectively.

(ii) The 220-kV Network (21st January)
All the 220-kV lines were in service. These include the ZESCO and CEC transmission lines and the interconnector with the Democratic Republic of Congo (DRC).

Prior to the disturbance the actual power flow on the DRC-Zambia Interconnector was 60 MW flowing into Zambia.

(iii) The 660-kV Network (21st January)
All the 66kV transmission lines for CEC and ZESCO systems were in service.

(iv) Tie-line Flows (21st January)
Prior to the disturbance the actual tie-line flows were as follows:

- ZESA to ZESCO 112MW
- SNEL to ZESCO 60MW
4.7.8 The Disturbance of 21st January

(i) The Source of the Disturbance (21st January)
The Committee attributes the source of the disturbance to the tripping of the Kariba North-Leopards Hill line 2.

As to the cause of the tripping, Zesco submitted that the line had tripped due to an over current and that there was no fault on the line at the time of the tripping. Zesco exhibited the voltage and current waveforms up to the time of the fault intended to prove the over current condition on the line. Zesco informed the Committee that the waveforms had been downloaded from a distance protection relay (Micom P442).

Examining the information and Zesco’s analysis the Committee noted the following:

- That the waveforms did not show an over current just prior to the fault. The current at the time of the tripping was between 980 A and 1100 A, which was below the over current setting of 1250 A.

- That the power transfer just prior to the tripping was not unusually high at 583 MW and that on 19th January the line had been carrying 644 MW without tripping.

Therefore the Committee did not accept the submission by Zesco that there had been an over current on the line before it tripped. But, indeed there appeared to be no fault when it tripped. The Committee thus concludes that the tripping of this line was spurious and that this was the source of the disturbance. It is possible that settings had been changed inadvertently or otherwise, although, according to Zesco this was unlikely. The Committee also noted that this line developed a fault during the recovery process. A line patrol revealed that some insulators had shattered. It is possible that the insulation could have progressively degraded during the recovery process after the 19th January blackout due to high voltages. Further the Committee was unable to confirm any prior events on the ZESA system on this day.

(ii) The Fault Cascade (21st January)
Only Line 2 on the Kariba North-Leopards Hill line circuit had been available prior to the fault because Line 1 was still unavailable due to a collapsed pylon. As consequence, both Kafue Gorge and Victoria Falls power stations tripped out on over load.
The sequence of events as captured at the National Control Centre (NCC) was as follows:

**Table 9: Sequence of events on 21st January**

<table>
<thead>
<tr>
<th>Power Station</th>
<th>Circuit</th>
<th>Time</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>KNB - L/Hill</td>
<td>Line 2</td>
<td>19:27:34.530</td>
<td>Over current</td>
</tr>
<tr>
<td>Kariba North</td>
<td>G2</td>
<td>19:27:38.930</td>
<td>Over frequency</td>
</tr>
<tr>
<td>Kariba North</td>
<td>G1</td>
<td>19:27:43.130</td>
<td>Over frequency</td>
</tr>
<tr>
<td>Kafue Gorge</td>
<td>G4</td>
<td>19:28:35.769</td>
<td>Under frequency</td>
</tr>
<tr>
<td>Kafue Gorge</td>
<td>G3</td>
<td>19:28:35.770</td>
<td>Under frequency</td>
</tr>
<tr>
<td>Kafue Gorge</td>
<td>G2</td>
<td>19:28:36.768</td>
<td>Overload</td>
</tr>
</tbody>
</table>

Consequently, Victoria Falls power station tripped at 19:30 hours completing the nationwide blackout.

4.7.9 Analysis of the Fault Cascade of 21st January

The overcurrent tripping of Kariba North-Leopards hill line 2 caused the loss of 585 MW supply to the Zambian grid. The total generation at the time of the tripping was 1196 MW. Therefore the loss represented nearly fifty per cent of the demand prior to the fault.

The Committee found that the same factors that contributed to the cascading of the fault on 19th January were valid here. These included:

- The system was operating without any spinning reserve, as all the power stations were at maximum available generation.
- The automatic under-frequency load shedding scheme was either inoperable or completely absent at critical load points.
- The network was in urgent need of reinforcement to improve its dynamic stability.

Just as on 19th January, the Committee concluded that inappropriate protection grading meant that the southern and western regions could not be saved.

Regarding the role of the fallen tower on Kariba North-Leopards hill line 1 on this day, the Committee’s view is that had both lines been in service at the time of the incidence, it is likely that the blackout could have been averted as the two lines could have shared the load.
Failure of Insulator on Tower No. 37 on Line 1 Kariba/Leopards Hill on 21st January 2008

The steel structure that supports the wires for electricity transmission stands in soil and can conduct electricity from the wires into the ground. Such an occurrence would cause extremely high current to flow, possibly causing considerable damage to all associated equipment along the transmission line and at the power station. Measures are therefore taken to prevent contact between the towers and the wires during normal and abnormal operating conditions.

In one such design, the tower and the wire are separated by glass disc insulators mounted on a string. The number of discs on the string determines the magnitude of the voltage that the whole string can withstand before it breaks down and conducts electricity to the tower and into the ground. When they fail, the discs may crack but remain in place, or they may shatter altogether. Therefore over time and with repeated high voltage events, the tower insulators degrade and require regular inspection and replacement. For discs that shatter, visual inspection suffices and replacement can be undertaken on this basis. When the discs crack or are otherwise damaged without completely shattering, more sophisticated means of damage detection are required. The replacement work requires that the line be switched off for a time.

On Line 2 from Kariba North Bank Power Station to Leopards Hill Substation, Tower No. 37 was of the type described above. From the sequence of events starting with 19th January and the observations during the investigations, the committee concluded that over the period 19th to 21st January Tower No. 37 became a weak link on the line. The tower insulation was progressively degraded due to transient high voltages caused by the high number of switchings, particularly during the many attempts to restore supplies after the blackout of 19th January. Eventually out of the design no. of 19, only ...(no.) discs were
left on the string, the remainder having completely shattered. The inspection of the string showed evidence of arcing and tracking.

The investigating team further observed that on several other towers three of four glass discs were missing and had not been replaced. Zesco staff explained that this was standard practice, and that discs were replaced only after five or six had shattered. Staff also explained that it had become increasingly difficult to switch the lines off for such maintenance because of the high demand for electricity. The Committee further heard that a programme had begun to replace the insulators with a different, rubber based type that was less prone to failure. However, even though materials were available to replace all the glass insulators, the opportunities for undertaking the work were severely limited because of the pressure to keep the transmission lines in service. Approximately 10% of the work had been done.

4.7.10 System Restoration on 21st January

(i) **Emergency Supplies to Mining loads (21st January)**
The SNEL interconnector had tripped when the blackout occurred in Zambia. The line was reestablished at 19.48 hrs and began supplying essential loads under CAT III. The standby Gas Turbines Alternators (GTAs) belonging to CEC were also brought in to provide further support to the mines. The Zesco and SNEL systems were synchronized at 00:59 hrs, about five and half hours after the onset of the blackout.

(ii) **Kariba North Power Station (21st January)**
The first attempt to restore the system was at Kariba North Bank Power Station. After successfully running up the machines, the operators tried to charge Kariba North-Leopards Hill line No.2, but this failed twice. The protection indicated that there was a sustained fault on the line, about 18 km from Kariba. The line was isolated, earthed and a permit to work was issued to facilitate line repairs. As Line 1 had not been restored, this meant that Kariba North could play no further part in the restoration process.

(ii) **Kafue Gorge Power Station (21st January)**
At this point the efforts to restore the system shifted to Kafue Gorge power station and the first attempt was made at 20:07 when the circuit breaker for Generator 4 was closed. Five seconds later it tripped. At 20:27 the second attempt to restore the system through Generator 2 succeeded when the generator breaker was closed and the lines into Leopards Hill substation were charged. This was one hour after the blackout occurred.

(iii) **Victoria Falls power station (21st January)**
Victoria Falls power station was restored independently of the rest of the grid at 20:26 hours and was later synchronized to the grid on 22 January at 07:44 hours.

(iv) **Lusaka Area (21st January)**
The restoration of most of the loads in Lusaka was completed by 23:30 hrs.
(v) **The Copperbelt (21st January)**
The restoration process in the Copperbelt involved the supply of emergency power to the essential loads via the DRC-Zambia 220kV line and the standby GTA owned by CEC. However, the available power through the DRC-Zambia Interconnector is constrained and only Category III loads were supplied until 00:59 hours when ZESCO and CEC system were synchronized. At this point onwards, the mines were able to gradually pick up more power, and power to the main towns was restored.

(vi) **The Southern System (21st January)**
The Southern System comprising Victoria Falls and the associated transmission lines was restarted independent of the rest of the grid. The Southern System was synchronized to the grid on 22 January at 07:44 hours.
BLACKOUT OF 22\textsuperscript{nd} JANUARY 2008

After the disturbances and blackouts of 19\textsuperscript{th} and 21\textsuperscript{st} January, Government announced a decision to disconnect the tie-line with ZESA. At the time of the disturbance on this date, 22\textsuperscript{nd} January, the tie-line had been disconnected. Furthermore, the second 330-kV Leopards Hill line from Kariba was undergoing repairs after an earth fault had developed upon failure of insulators. Therefore on this day, Kariba North Bank Power Station was completely unavailable and played no part in the incident.

4.7.11 Pre-fault Status of Generating Plant – 22\textsuperscript{nd} January

(i) Kafue Gorge Power Station (22\textsuperscript{nd} January)
Prior to the system disturbance Kafue Gorge power station was generating a total of 596 MW into the national grid from four generator units. Units 1, 2, 3 and 4 were generating 155 MW, 140 MW, 152 MW and 149 MW respectively. Generators 5 and 6 were out of service for rehabilitation and up-rating under the Power Rehabilitation Project. Therefore, out of the total installed capacity of 900MW only 600MW of capacity was available. The total generation of 596 MW was 99.3% of the available capacity.

<table>
<thead>
<tr>
<th>Generator</th>
<th>Status</th>
<th>Output (Megawatts)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unit No.1</td>
<td>In service</td>
<td>155</td>
<td></td>
</tr>
<tr>
<td>Unit No.2</td>
<td>In service</td>
<td>140</td>
<td></td>
</tr>
<tr>
<td>Unit No.3</td>
<td>In service</td>
<td>152</td>
<td></td>
</tr>
<tr>
<td>Unit No.4</td>
<td>In service</td>
<td>149</td>
<td></td>
</tr>
<tr>
<td>Unit No. 5</td>
<td>Out of service</td>
<td>0</td>
<td>Under PRP</td>
</tr>
<tr>
<td>Unit No. 6</td>
<td>Out of service</td>
<td>0</td>
<td>Under PRP</td>
</tr>
</tbody>
</table>

**TOTAL OUTPUT** 596
**AVAILABLE CAPACITY** 600

The switchyard was in normal condition and standby facilities i.e. batteries, two diesel generators and the 33-KV line to Kafue, were available.
(ii) Kariba North Bank Power Station (22nd January)
Kariba North Bank power station was not connected to the national grid because both transmission between Leopards Hill and Kariba North Bank were unavailable. However, at Kariba North Bank, Unit 1 was in operation supplying station auxiliaries, the local Siavonga load and Kariba South Bank Power Station through the 11kV inter-connector.

(iii) Victoria Falls Power Station (22nd January)
Prior to the system disturbance Victoria Falls power station was generating a total of 97 MW out of the total installed capacity of 108 MW.

Before the fault, unit A2 and A4 at station A were in service while A1 and A3 were still undergoing repairs. At station B unit B5 was out due to burnt stator and field windings since 2006/2007. All machines at station C were in service.

The switchyard was in normal condition and standby facilities, i.e. batteries/UPS and the diesel generator, were available. The diesel generator was set to AUTO. The new 220-kV Katimamulilo breaker could only be operated locally at the switchyard or from NCC because it had not yet been connected to the Victoria Falls Power Station control room.

(iv) Lunsemfwa and Mulungushi Power Stations (22nd January)
The total generation at Lunsemfwa and Mulungushi hydro power stations was 35.8MW. The entire plant and standby facilities were in normal condition.
4.7.12 Pre-fault Status of the Transmission Network – 22\textsuperscript{nd} January

(i) **The 330-kV Network (22\textsuperscript{nd} January)**  
Prior to the fault, Kariba-Leopards Hill No.1 line was out of service for repairs after a tower had been washed away due to heavy rains. Kariba-Leopards Hill No.2 was being prepared for energizing after replacing broken insulators on the line and the 330kV Kariba North Bank-Kariba South Bank lines 1 and 2 were out of service. All the other major 330kV equipment was available and in service.

(ii) **The 220-kV Network (22\textsuperscript{nd} January)**  
All the 220KV lines were in service. These include the ZESCO and CEC transmission lines and the interconnector with the Democratic Republic of Congo (DRC).

(iii) **The 66-kV Network (22\textsuperscript{nd} January)**  
All the 66kV transmission lines for CEC and ZESCO systems were in service.

(iv) **Tie-line Flows (22\textsuperscript{nd} January)**  
Prior to the disturbance the actual tie-line flows were as follows:

<table>
<thead>
<tr>
<th>Source</th>
<th>Power (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZESA to ZESCO</td>
<td>0</td>
</tr>
<tr>
<td>SNEL to ZESCO</td>
<td>90</td>
</tr>
</tbody>
</table>

4.7.13 The Disturbance of 22\textsuperscript{nd} January

(i) **The Source of the Disturbance**  
The sequence of events on 22\textsuperscript{nd} January was initiated by the closing of the cylinder gate on Unit 2 at Kafue Gorge Power Station. This meant that the water to this generator was cut off and the, which had been producing 155 MW stopped generating. This caused the cascade of trippings on the other three stations at the stations and consequently the loss of the entire system.

The Committee noted that during the Power Rehabilitation Project the design of the control system for the cylinder gates had been changed. Previously the actuating circuits had been supplied by dc power, and this had been changed to ac. The Committee learnt that after the change in design, the control circuits had exhibited instability. The cylinder gate for Unit 2 had the worst history of mal-operations.

(ii) **The Fault Cascade**  
The closing of the cylinder gate for unit 2 at Kafue Gorge power station led to a cascade of tripping of the other three station units. Victoria Falls Power Station was disconnected from the grid at Victoria Falls.
The sequence of events as captured at the National Control Centre (NCC) was as follows:

<table>
<thead>
<tr>
<th>TIME</th>
<th>STATION</th>
<th>CIRCUIT</th>
<th>REMARKS</th>
</tr>
</thead>
<tbody>
<tr>
<td>17:50:30.536</td>
<td>Victoria Falls</td>
<td>Muzuma</td>
<td>CB 105 Err Status 00</td>
</tr>
<tr>
<td>17:50:30.552</td>
<td>Victoria Falls</td>
<td>T1A</td>
<td>CB 1TOA Err Status 00</td>
</tr>
<tr>
<td>17:50:30.552</td>
<td>Victoria Falls</td>
<td>Muzuma</td>
<td>CB 105 opened</td>
</tr>
<tr>
<td>17:50:30.553</td>
<td>Victoria Falls</td>
<td>T1A</td>
<td>CB 1TOA opened</td>
</tr>
<tr>
<td>17:50:30.565</td>
<td>Victoria Falls</td>
<td>T1A</td>
<td>CB 1TOA Err Status 00</td>
</tr>
<tr>
<td>17:50:30.565</td>
<td>Victoria Falls</td>
<td>T1A</td>
<td>CB 1TOA closed</td>
</tr>
<tr>
<td>17:50:30.587</td>
<td>Victoria Falls</td>
<td>T1A</td>
<td>CB 1TOA Err Status 00</td>
</tr>
<tr>
<td>17:50:30.588</td>
<td>Victoria Falls</td>
<td>T1A</td>
<td>CB 1TOA Opened</td>
</tr>
<tr>
<td>17:50:37.501</td>
<td>Kafue Gorge</td>
<td>G4</td>
<td>CB Err Status 11</td>
</tr>
<tr>
<td>17:50:37.502</td>
<td>Kafue Gorge</td>
<td>G3</td>
<td>CB Err Status 11</td>
</tr>
<tr>
<td>17:50:37.507</td>
<td>Kafue Gorge</td>
<td>G3</td>
<td>CB Opened</td>
</tr>
<tr>
<td>17:50:37.508</td>
<td>Kafue Gorge</td>
<td>G4</td>
<td>CB Opened</td>
</tr>
<tr>
<td>17:50:38.499</td>
<td>Kafue Gorge</td>
<td>G2</td>
<td>CB Err Status 00</td>
</tr>
<tr>
<td>17:50:38.499</td>
<td>Kafue Gorge</td>
<td>G1</td>
<td>CB Err Status 00</td>
</tr>
<tr>
<td>17:50:40.492</td>
<td>Kafue Gorge</td>
<td>G1</td>
<td>CB opened</td>
</tr>
<tr>
<td>17:50:40.492</td>
<td>Kafue Gorge</td>
<td>G2</td>
<td>CB opened</td>
</tr>
</tbody>
</table>
### Table 12: Substation Indications (Alarm annunciations)

<table>
<thead>
<tr>
<th>STATION</th>
<th>CIRCUIT</th>
<th>INDICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Victoria Falls</td>
<td>Muzuma</td>
<td>under frequency</td>
</tr>
<tr>
<td>Victoria Falls</td>
<td>33/220kV T1A</td>
<td>under frequency</td>
</tr>
<tr>
<td>Kafue Gorge</td>
<td>G1</td>
<td>over load</td>
</tr>
<tr>
<td>Kafue Gorge</td>
<td>G2</td>
<td>cylinder gate opening</td>
</tr>
<tr>
<td>Kafue Gorge</td>
<td>G3</td>
<td>over load</td>
</tr>
<tr>
<td>Kafue Gorge</td>
<td>G4</td>
<td>over load</td>
</tr>
</tbody>
</table>

#### 4.7.14 Analysis of the Fault Cascade of 22nd January

On this day, Zesco’s generation capacity was limited to the available generation at the two power stations: Kafue Gorge and Victoria Falls. Kariba North was unavailable because both transmission lines were out of service. The pre-fault conditions show that the available capacity at Kafue Gorge was 600 MW. With 596 MW recorded minutes before the disturbance, it is clear that the power station was operating at its absolute maximum. The total available generation was less than 700 MW, well below the demand at this time of day. Zesco staff further pointed out to the Committee that on the evening of 22nd January the Africa Cup of Nations soccer tournament was being shown on television, and this may have added to the pressure to maintain the highest generation possible thereby keeping the load shedding to the minimum possible. Given the huge shortfall in available capacity these efforts were little short of heroic, but ultimately detrimental to the proper management of the system.

Without a spinning reserve, and given the inherent weaknesses of the system regarding reactive power capacity, the Committee concluded that the system experienced a voltage collapse. This was first seen on the Victoria Falls-to-Muzuma line and then the tripping of generators at Kafue Gorge.
January Blackouts

Voltage Stability
Voltage instability or voltage collapse occurs on a power system when voltages progressively decline until stable operating voltages can no longer be maintained. This is precipitated by an imbalance of reactive power supply and demand. There can be one or more causes of this: increases in real or reactive loads, high power transfers, or the loss of generation or transmission facilities. Unlike the phenomenon of transient instability, where generators lose synchronism with the rest of the power system within a few seconds or less after a critical fault, voltage instability can occur gradually within tens of seconds or minutes.

Other than the contractual requirement to maintain voltage at specific levels, voltage control throughout the power system ensures proper operation of all equipment on the network and avoids the phenomenon of voltage collapse. Voltage is a local parameter influenced mainly by load variations and reactive power flows. To control the voltage it is necessary to distribute reactive power sources throughout the network (generation units, capacitors, reactors, etc.) A system under strain may exceed its capacity to supply the required reactive power. Below a certain low level, known as the critical voltage, one comes up against limits of power than can be transmitted, and this brings about the collapse of the voltage if no measures are taken.

For an interconnected system such as the Zambian grid, it is possible for short periods to draw the necessary reactive power form neighbouring systems. After the blackout of 21st January, the Zambian system was disconnected from the SAPP grid in the south, where the largest systems of South Africa and Zimbabwe are located. The Committee during its investigation also determined that the two power stations available on that evening were producing at maximum capacity. It is clear that the system was at high risk of instability from voltage collapse.

The Committee has concluded that the blackout of 22nd January could have been avoided by more prudent management of the load.

The Committee also observed that had the fallen tower been restored before 22nd January, there was a possibility that the system collapse could have been prevented by the additional generation from Kariba North Power Station.

The extent of the blackout in the southern and western regions could have been mitigated by correct protection grading by tripping at Muzuma towards Kafue and thereby maintaining supply to Choma and surrounding areas.

4.7.15 System Restoration on 22nd January

(i) Supplies to Emergency loads
Emergency supplies from SNEL were not immediately available on this day, and CEC was advised that there would be no support available for about 90 minutes while SNEL attended to faults that had affected its own system. Therefore, essential loads on the Copperbelt were supplied from the standby GTAs which had an available capacity of only 50 MW. Between 17:58 hours and 19:01 hours, all GTAs except Bancroft GTA2 and Luano GTA1 were in service. Imports from DR Congo via the 220kV Karavia line were...
only available from 18:54 hours. The ZESCO and CEC systems were synchronized at 20:39hrs at Luano.

(ii) **Kafue Gorge Power Station**
The Committee noted that the restoration process on this, the third blackout in four days, proceeded much more quickly than the first two. The first generator, Unit 1, was brought into service at 18.31, only forty minutes after the onset of the blackout. By 20.30 hrs all units at Kafue Gorge were back on line.

(i) **Kariba North Bank Power Station (22\textsuperscript{nd} January)**
Zesco had continued with efforts to bring back the Kariba-Leopards Hill line and in the course of the evening of 22\textsuperscript{nd} January Zesco completed the replacement of the broken insulators. Line 2 was thus restored to service. The two available units, 1 and 2, were synchronized at 20.15 hrs. Unit 4 was undergoing repairs to the excitation system and Unit 3 was under rehabilitation.

Kariba North power station was now available following the replacement of damaged insulators on the Kariba-Leopards hill line 2. Supply was restored to the bulk supply stations, starting with Lusaka at 18:32hrs. Essential loads on the Copperbelt were supplied from Congo on the 220 kV Karavia Line starting at 18:25hrs. The loads were progressively restored as follows:

<table>
<thead>
<tr>
<th>STATION</th>
<th>TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lusaka</td>
<td>18:32 hrs</td>
</tr>
<tr>
<td>Kabwe</td>
<td>20:00 hrs</td>
</tr>
<tr>
<td>Kafue Town</td>
<td>19:04 hrs</td>
</tr>
<tr>
<td>Copperbelt</td>
<td>20:45 hrs</td>
</tr>
<tr>
<td>Kansanshi</td>
<td>21:04 hrs</td>
</tr>
<tr>
<td>Pensulo</td>
<td>22:42 hrs</td>
</tr>
</tbody>
</table>

Kariba North Bank Power Station was synchronized to the grid at 20:15hrs. Only generator 1 and 2 were restored at the station.

(iii) **Victoria Falls Power Station (22\textsuperscript{nd} January)**
The station had remained in service following the tripping of the Muzuma line at Victoria Falls switchyard. However, the first attempt to restore the 220 kV supplies to Muzuma
tripped the entire station and a black start procedure had to be used to restore supplies.

Local loads were eventually supplied at 20:01 hrs, Muzuma line at 20:27 hrs and Katimamulilo 220kV line at 20:43 hrs. Victoria Falls Power Station was synchronized to the grid at 20:30hrs.
5. ECONOMIC IMPACT

A comprehensive assessment of the impact of the nationwide blackouts on the economy was constrained by the available time and resources. Such an assessment would have required the Committee to develop and econometric model and a formal methodology for obtaining the data. In the circumstances, the committee relied on the limited submissions received to assess the economic impact.

5.1 Role of electricity in the national economy

Zambia has in recent years experienced steady economic growth mainly driven by sectors such as agriculture, mining, manufacturing and tourism. All the sectors use electricity to varying degrees. This growth has been enhanced by increased investment among others in mining, manufacturing and construction particularly in residential and this have had an impact on electricity consumption( see figure below). This can be evidenced by the increase in demand of electricity from 1,100 MW in 2002 to 1,600MW in 2007.It is for this reason that the FNDP recognizes electricity as a priority area in the strategies for National Vision 2030 in which aspires Zambia to be a prosperous middle income country by 2030. The graph below depicts the consumption of electricity and the contribution to GDP of the various sectors in 2007.

Figure 14: Electricity consumption and contribution to GDP by Sector
5.2 **Economic Impact of Power Outages**

The national wide black outs of January 2008 had adverse effects on the economy. All electricity customers were affected by the blackouts. However, consumers who use electricity in the evening and night *manufacturing, mining and households among others* were most affected as the blackouts occurred during this time.

5.2.1 **Loss of production**

The total duration of the outages due to the blackouts was about 13 hours for Lusaka and 20 hours for the Copperbelt. However, the actual production hours lost by industries were more due to plant start up requirements. On the Copperbelt, the resumption of production in industries was further prolonged by delays in stabilizing voltage levels.

Loss of production was due to interruption of power supply resulting from the power blackouts. Industries experienced complete stoppage of operations, as manufacturing processes were interrupted. Further costs were incurred due to process cleanup, wastages of work in progress materials and restoration efforts.

Mining and quarrying companies experienced disruptions in the water pumping activities resulting in flooding and hence further delaying the resumption of production. The loss in production will have an effect on the contribution of various sectors to the economy hence a slowdown the recent economic performance.

5.2.2 **Damage to plant and equipment**

A number of customers experienced damage to equipment ranging from office equipment to plant machinery. Most customers interviewed submitted that the damage to equipment was due to high voltage during the restoration of power. Damage to equipment resulted in additional costs of repairs and replacements. As regards to some mines and quarries, loss of power resulted in flooding, consequently damaging some equipment. Ndola Lime Company Limited submitted that their kiln developed faults due to frequent power interruptions.

Power utilities also reported damage to some of their plant and equipment. Damage to generation equipment was reported at both Kariba North Bank and Kafue Gorge Power stations resulting from the power disturbances. Some generators at both power stations were damaged. CEC submitted that one of their transformers at Luano substation was damaged due to high voltages during restoration.
5.2.3 Health and Safety implications
Submissions from the mines indicated that a number of miners were underground at the time of the blackouts. On the 19th January 2008 about 2,900 miners were underground and on 21 January 2008 about 300 miners were underground at Mopani Copper Mines. These miners were at risk from possible ventilation failure and flooding. Risks to human life could also have arisen due to power failures in institutions such as hospitals and airports especially where standby generators were not available.

5.2.4 Increased Load shedding
Prior to the blackouts Zesco was undertaking some load shedding due to reduced generation capacity as a result of the Power Rehabilitation Project (PRP). After the blackouts, the load shedding levels increased because the Zesco-ZESA interconnector through which Zesco could import power to mitigate the deficit was disconnected. This prompted Zesco to carry spinning reserves which has further reduced the available power, resulting in increased load shedding.

Therefore increased load shedding has both short and long term effects. For instance, the Millers Association of Zambia (MAZ) submitted that production capacity of mealie meal, flour and stock feed has been severely reduced resulting in shortages of the products which may fuel price increases. This may be a contributory factor to the rise in inflation.

The impact of the January blackouts and load shedding has increased the need for investment in expensive alternative power supply such as diesel generators which will result in increased cost of production leading to a rise in prices of products and services, thus further fuelling inflation. For instance, the Millers Association submitted that they are investing in diesel generators a more costly option which cost has to be passed on to the consumers.

5.2.5 Other impacts of January 2008 blackouts
Lessons learnt from the January 2008 blackouts include;

- Increased public awareness of the status of the electricity industry and its reduced capacity to meet demand.
- Increased awareness in the usage of energy saving appliances as a way of managing the demand by the public.
- Increased awareness to the policy makers as to the urgent need to invest in new generation capacity.
• From the customers interviewed, there were some indications of willingness to pay more for as long as there is guaranteed and reliable supply of power.

5.3 Conclusion

In summary, the blackouts which occurred in January 2008 posed various challenges to both the consumer and the utility company. For the consumer when a blackout occurs, the challenge is to ensure that emergency supplies available to critical loads to avoid possible loss of life and minimize irreversible damage to equipment. For the utility, the challenge is to restore the system to normalcy as quickly as possible in order to limit the hardship and harm caused to customers; to limit the loss of revenue to the utility; and to maintain customers’ confidence in the integrity of the supply network. The time taken to restore system could have significant long-term effects on the performance of the national economy.

Due to resource constraints and the absence of a formal econometric model the committee was unable to carry out a comprehensive assessment of the impact of the January 2008 electricity blackouts on the economy.

Nevertheless based on the submissions received below are some of the immediate economic impact of the power blackouts. Loss of production;

• damage to plant and equipment;
• increased load shedding;
• health and safety implications; and
• Increased awareness by stakeholders of the status of the electricity and the need to urgently address the power deficit.

The long term effects of the blackouts and continued load shedding will have far reaching consequences vis-a-vis macroeconomic instability, overshadowing the good economic performance recorded in the recent years and slowing down the projected economic growth rate of 7 percent during the FNDP period. It is therefore important that appropriate measures are undertaken to forestall future occurrences and that there is need to increase investment in electricity generation plant to satisfy the electricity needs that would propel Zambia into a prosperous middle income country by the year 2030.

The Committee recommends that a comprehensive assessment of the impact of the national wide power black outs and load shedding on the economy is undertaken to facilitate policy formulation and provide valuable information to other stakeholders.
6. FINDINGS
In this section the Committee gives a summary of its findings. Analyses from which the findings are derived will be found in the relevant parts of the report. In its treatment of the incidents, the Committee makes a distinction between, on one hand, the proximate causes of the disturbances and, on the other hand, the circumstances that led to total blackouts.


Finding 1:
The blackout was initiated by a disturbance in the Zimbabwean grid which resulted in the loss of a major load. This was consistent with the behavior of generators at Kariba South and Kariba North power stations and the sequence in which the protective devices operated.

The loss of major load in Zimbabwe caused shutdowns of the Kariba South and Kariba North power stations, and the tripping of the ZESCO-ZESA interconnector and the Kariba North-Leopards hill 330 kV transmission line No.2.


Finding 2:
The blackout was initiated by a spurious tripping on the 330 kV transmission line No.2 from Kariba North to Leopards Hill. The failure of this line completely isolated Kariba North from the national grid because on December 30th a tower on the only other line, Line No.1, had collapsed in heavy rains. This also meant that there could be no imports or exports with Zimbabwe.


Finding 3:
The blackout of 22nd January 2008 was caused by a collapse of the system voltage due to insufficient generation capacity. The Zambian system had been isolated from Zimbabwe and Kariba North Bank Power Station was not available on this day because both lines that evacuate power from the station were out of service. Kafue Gorge Power Station was operating at maximum generation without any reserve margin at all.
The start of the voltage collapse caused abnormal conditions and the cylinder gate on Unit 2 at Kafue Gorge Power Station closed, thereby shutting down the first generator in the sequence.

6.4. **On the causes of the blackout on 19th January 2008**

*Finding 4:*  
After all the machines at both power stations on the Kariba complex tripped, the national grid experienced a total loss of generation amounting to 644 MW. This caused overloading and subsequent tripping of the machines at Kafue Gorge and Victoria Falls power stations, which resulted in the blackout.

*Finding 5:*  
The generators at Kafue Gorge and Victoria Falls power stations tripped because the system did not have adequate means to adjust the load in order to balance it with the diminished available generation after the tripping of Kariba North Bank Power Station. In respect of this, the Committee noted the following:  

(i) The system had no spinning reserve;  
(ii) Load management under dynamic conditions was inadequate.

*Finding 6:*  
The transmission tower that had collapsed three weeks earlier was out service at the time of the disturbance. The effect of this was to increase the impact of the disturbance and to reduce the system’s dynamic stability limit. If the line had been in service, the extent of the overload condition would have been reduced. Together with an effective under-frequency load management scheme and adequate spinning reserve, the loss of Kafue Gorge could have been prevented.

*Finding 7:*  
The extent of the blackout in the southern and western regions could have been mitigated by grading the protection such that the Victoria Falls is isolated at Muzuma towards Kafue West and not by tripping the Victoria Falls – Muzuma line.

6.5. **On the Causes of the blackout on 21st January 2008**

*Finding 8:*  
The blackout was initiated by a spurious tripping on the 330 kV transmission line No.2 from Kariba North to Leopards Hill. The failure of this line completely isolated Kariba North from the national grid because on December 30th a tower on the only other line,
Line No.1, had collapsed in heavy rains. This also meant that there could be no imports or exports with Zimbabwe.

**Finding 9:**
The system conditions following the disturbance were similar to those of 19th of January. The sudden loss of about 583 MW on the national grid as a result of the tripping of the Kariba North Power Station and the loss of imports from Zesco – ZESA tie-line resulted in overloading and subsequent tripping of Kafue Gorge and Victoria Falls power stations.

**Finding 10:**
Only three machines were available producing a total of 444 MW, practically at maximum. Therefore there was no spinning reserve and, combined with inadequate dynamic load management, the tripping of the machines at Kafue Gorge was inevitable.

**Finding 11:**
The extent of the blackout in the southern and western regions could have been mitigated by grading the protection such that the Victoria Falls is isolated at Muzuma towards Kafue West and not by tripping the Victoria Falls – Muzuma line.

**Finding 12:**
Regarding the role of the fallen tower on Kariba North-Leopards hill line 1 on this day, the Committee’s view is that had both lines been in service at the time of the incidence, it is likely that the blackout could have been averted as the two lines could have shared the load.

**6.6. On the Causes of the Blackout on 22nd January 2008**

**Finding 13:**
The system capacity was limited to the generation at Kafue Gorge and Victoria Falls Power Station amounting to 693 MW. Both stations were generating at their maximum and there was no spinning reserve. The blackout could have been avoided by better, more judicious load management.

**Finding 14:**
The extent of the blackout in the southern and western regions could have been mitigated by grading the protection such that the Victoria Falls is isolated at Muzuma towards Kafue West and not by tripping the Victoria Falls – Muzuma line.

**Finding 15:**
Had the line with a collapsed tower been restored before the disturbance, there is a possibility that the power system could have been saved by the availability of extra power from Kariba North power station.
6.7. On the Restoration of the System after the Blackouts

Finding 16:
The black starting of the power stations was inordinately long particularly on 19th January when it took more than 8 hours to put the first machines on line at Kafue Gorge and Kariba North Bank. There was a progressive improvement for the subsequent blackouts of 21st and 22nd January.

Finding 17:
The following factors contributed to the delay in black starting the power stations and restoring the system as a whole:

i. Inadequate skills and knowledge concerning procedures, voltage control and loading during black start;
ii. Delayed start of standby Diesel Generators at Kariba North and Kafue Gorge power stations on 19th January 2008
iii. Equipment failure due to delayed or suspended scheduled maintenance;
iv. Equipment failure due to high system voltages
v. General disorder at the National Control Centre due to interference from non-NCC staff
vi. Absence of senior staff at Kariba North power station on 19th January 2008
vii. High system voltages caused by low load conditions compounded by absence of line compensation equipment on the Copperbelt
viii. Failure of monitoring equipment such as Remote Terminal Units
ix. Failure of PAX phones and other telecommunication facilities
x. Limited knowledge in synchronizing on a dead bus
xi. Vehicle breakdown for operational staff in Kabwe

6.8. The Power Rehabilitation Project and its Delayed Implementation

Finding 18:
The Power Rehabilitation project had for many years substantially reduced the system available capacity. The following are some of the reasons that contributed to delays in completing the project:

- Changes in the scope of the project in order to up-rate the generators and to undertake unforeseen repairs after machines were opened;
- Zesco’s failure to pay on time the costs that were additional to the borrowed funds;
• Misunderstandings or disagreements between Zesco and its lenders on procedures for release of payments to contractors;

At the time of its visit to Kariba North Bank Power Station the Committee noted that the contractor had stopped work and demobilized. The delays gave the impression that the project did not receive adequate attention, especially during the initial period when demand for electricity was relatively low.

Finding 19:
As a result of the delayed completion of the PRP:

• The system was operated with inadequate spinning reserves, even considering the support available from the Southern African Power Pool;
• Scheduled maintenance on equipment was delayed thereby increasing the likelihood of failure.


Finding 20:
At the time of the disturbances in January 2008 and during the Committee’s investigation, Zesco had not submitted to the Energy Regulation Board a formal report on the implementation of the recommendations of the Technical Team that had investigated the blackout of June 4, 2006.

Finding 21:
A number of important recommendations of the report on the blackout of 4th June 2006 had not been implemented or could not be verified including:

• Automatic under-frequency load shedding;
• System stability studies;
• Reliability standards.

Finding 22:
The ERB had not instituted a mechanism for continuously monitoring the implementation of the recommendations of the Technical Team Report on the June 4, 2006 blackout. This had weakened the force of the recommendations.

Finding 23: The focus on the regional grid as the source of the disturbances and the decision to disconnect the tie-line deflected attention from the inherent weaknesses of the Zambian grid.

Finding 24: On 22nd January, the operation of the system did not take account of the disconnection of the tie-line and therefore that the normal emergency support from the SAPP grid was no longer available. This can be the only explanation for running the generators at Kafue Gorge at maximum output.

Finding 25: The disconnection of the ZESA tie-line and the concurrent segregation of the SAPP into sub-grids points to serious weaknesses of the regional network brought to the fore by the generation capacity deficit.

Finding 26: A level of mistrust developed between ZESA and Zesco and prevented the utilities from sharing important technical information that would have aided the understanding of system behavior when the disturbances occurred. The structure of SAPP was not helpful as there were no enforceable instruments to compel utilities either to operate to mandatory standards or to provide technical information when necessary.

Finding 27: At the time of preparing this report the ZESA - Zesco tie-line was still disconnected. This had deprived Zesco of critical dynamic and short-term support.

6.11. On the regulatory framework

Finding 28: The Energy Regulation Board had not developed a sufficiently detailed framework for the requirements of operating the national grid. In particular this refers to specific requirements for power generation and transmission management standards.

Finding 29: The Energy Regulation Board has not been forceful in the enforcement of licence requirements. The reasons are unclear, but may have to do with weakness in institutional arrangements.
7. RECOMMENDATIONS

Times of adversity provide important opportunities for learning lessons and identifying actions that help to build strength for the future. Three country-wide blackouts occurred over a four day period in January 2008. Understandably this was cause for considerable alarm for everyone because electricity occupies such a prominent place in the development plans of the country and in the daily lives of the people. The Committee presents these recommendations as the most urgent matters that need to be addressed for increased security and reliability of supplies. They require actions to be taken by the principal actors in the industry, namely, Zesco, the ERB and the Government. The implementation of the recommendations will also require the cooperation of Zesco’s partners in electricity supply – CEC and LHPC - and the consumers, particularly the mining and heavy industrial consumers.

The Committee recognizes that development is a continuum of many steps, some small, others big. But whether big or small, all the steps are necessary for sustained progress, provided only that they are taken. The converse also holds true: that if measures identified in reports of this kind remain only as ink on paper, stagnation and even regression are guaranteed.

The recommendations proceed from the Committee’s stance that while establishing the source of disturbances is necessary for reconstructing the events, it is far more important to prepare for abnormal conditions so that the impacts are minimized. Clearly it is also important to identify and prevent those sources of disturbances over which the utility has control.

7.1. Automatic Under-frequency Load Shedding

On all three days the Committee is persuaded that the absence of an effective automatic under-frequency load-shedding scheme played a major role in the failure to contain the scope of the disturbances. This matter was subject of a recommendation after the blackout of June 4, 2006. This Committee repeats the recommendation that Zesco immediately reviews the control of loads under emergency conditions. Zesco should immediately engage its partners, especially the CEC, and the major industrial and mining consumers on this matter.

7.2. System Capacity and Spinning Reserve

The second most important factor for the cascading of faults into total blackouts had to do with the failure to maintain a generation spinning reserve. While the Committee
understands the pressure that Zesco is currently under to minimize load-shedding, the absence of a spinning reserve contributed to the inability of the system to contain the abnormal conditions that arose during the three days. The Committee recommends that Zesco reviews system operation and ensures that a reasonable reserve capacity is maintained in the interest of system stability.

### 7.3. Power Rehabilitation Project

This recommendation is related to Recommendation 7.2 in so far it concerns the available generation capacity. For the duration of the PRP the system has been operating with substantially reduced capacity. This is often compounded by faults on the available machines, some of them due to the changes implemented during the PRP, thus further reducing generation capacity. The Committee recommends that Zesco places the highest priority on the completion of the Power Rehabilitation Project. In particular, the payments to contractors should have first call on available resources.

### 7.4. System Reinforcement

The dynamic stability limit of the system is severely compromised by inadequate sources of reactive power. The Committee recommends that Zesco immediately undertakes an analysis of the system to determine the reinforcement that is required to improve stability. Zesco should work with its partners, mainly CEC, to determine the investment needed and how it should be shared. Both Zesco and CEC should also accelerate the enforcement of minimum power factor operation by the large industrial users.

### 7.5. Line Maintenance

The transmission grid is critical to the security of supplies from the power stations. The immediate challenge concerns the susceptibility of glass porcelain insulators to catastrophic failure, and even to vandalism. While recognizing the limitations under the current conditions of high demand and reduced capacity due to rehabilitation, nevertheless every opportunity should be taken to continue the programme of replacing the glass insulators with the newer rubber type. In this vein, the Committee further urges Zesco to review the temporary arrangements on the Kariba North – Leopards Hill line to ensure that the line is appropriately secured before the 2008/09 rain season.
7.6. **Protection System**

An important objective of the protection system should be that, in the event of a severe fault, the protection should be such as to maintain supplies to those areas that can be isolated from the affected areas. Apart from maintaining supplies to some parts of the country, such measures reduce the time of restoration of the rest of the system. The Committee recommends that Zesco takes immediate steps to explore and determine such possibilities. In particular, the Committee recommends that the protection grading between Victoria Falls and Kafue West substation be reviewed so that in the event of a shutdown of the main power stations essential loads in Choma and surrounding areas can be maintained.

7.7. **System Monitoring**

The Committee had difficulty reconstructing some of the events that occurred during the disturbances because the recorders and protective relays on the system were not time-synchronized. The Committee further noted that Zesco faced the same difficulty. The Committee therefore recommends that Zesco takes immediate steps to acquire any equipment that is needed to synchronise the so-called ‘time stamping’ on all event recorders. This also applies to synchronization with the recorders on the CEC network. CEC should take similar steps on the Copperbelt network.

7.8. **Black Start Procedures**

Following a blackout it is necessary to minimize the period of restoration as this has a significant impact on the risk posed to human life, and on operational losses and inconveniences suffered by the consumers. The Committee recommends that Zesco and CEC review their Black Start Procedures and ensure a continuous state of readiness of systems and personnel. In particular the following should be attended to immediately:

i. Ensure that all standby equipment is available at all times; the operation of all station diesel generators should be automatic, i.e. should not require human intervention.

ii. Ensure continuous training of all power station and control room staff especially to take account of evolving technology, changes to plant configurations and the recruitment of new staff.

iii. Ensure that all communications equipment remains in service during emergencies, including the Remote Terminal Units on the SCADA.

iv. Ensure that staff in remote stations is adequately provided with transport and other logistics to facilitate their prompt availability during emergencies.
7.9. **New Generation Capacity**

The Committee recognizes that until significant new generation capacity is developed there will be difficulties and compromises in running the Zambian system. The Committee therefore recommends that the current efforts to build new power stations be redoubled. To supplement its own efforts, the Government requires the participation of the private sector. In this regard the Committee recommends that the Office for Promoting Private Power Investment and the Framework and Package of Incentives be urgently reviewed in the light of experience to date.

7.10. **Regulatory Framework**

The Committee noted the progress made on the implementation of a Grid Code for the Zambian system. The Committee recommends that, in view of the shortcomings evident from the experience of the blackouts, the Grid Code should be enhanced to provide detailed technical requirements for the operation of the system. This may be through the expansion of the current provisions or by rules supplementary to the Code.

7.11. **Enforcing license conditions**

The Committee notes that regulating Zesco poses unique challenges for the ERB because the utility is publicly owned. This is a common phenomenon worldwide. Nevertheless, the Committee views the credibility and effectiveness of ERB as critical to the success of the industry as a whole. The Committee therefore recommends that the Government works with the ERB to identify areas in the institutional and legal frameworks that need to be reviewed in order to enhance the ERB’s effectiveness as a regulator.

7.12. **Economic Impact**

Due to the constraints noted in the report, the Committee was unable to fully assess the impact of the blackouts and, more generally, the current load-shedding regime on the economy. The Committee recommends that the Government and the ERB commissions a separate study on this matter in order to provide important planning information.

7.13. **Implementation of Recommendations**

The Committee recommends that the ERB immediately institutes a mechanism for monitoring the implementation of recommendations made in this report and those from the Technical Team Report on the June 4, 2006 blackout. Time frames should be
agreed with the concerned parties as necessary and the ERB should ensure compliance by the licensees.


The Committee recommends that the Government urges its counterparts in SADC to urgently review the virtual dismantling of the SAPP through the continued disconnection of critical interconnectors. Zambia’s position should be one of keeping the sub-regional grid connected while the issues brought to the fore by the generation deficit are urgently addressed by the utilities. Weighing the risk of system disturbances against the benefits of interconnection, the Committee’s view is that such risks are outweighed by the benefits.

7.15. Regional Operating Standards

The Committee further recommends that the Zambian government leads efforts to develop enforceable operating standards among the members of SAPP. The Committee’s view is that a body external to SAPP, such as the Regional Electricity Regulators’ Association, should be tasked to work with SAPP in developing and administering an acceptable operating regime which should have the highest endorsement of the Southern African Development Community. The standard should set out the minimum operating requirements for the Operating Members of SAPP.
APPENDIX A

PERSONS INTERVIEWED BY THE COMMITTEE

1. Rhodnie Sisala, Managing Director, Zesco
2. Christopher Nthala, Director Generation, ZESCO
3. Musonda Chibulu, Director Power Rehabilitation Project, ZESCO
4. Joe Chiyasa, Director Distribution, ZESCO
5. Poliana Chimwala, Company Secretary, ZESCO
6. Rodger Luka Chiwaya, Transmission Technologist, ZESCO National Control Centre
7. Sefelino Spider Mulenga, Chief System Controller, ZESCO National Control Centre
8. George Muyunda, Graduate Engineer, ZESCO National Control Centre
9. Kafukanya, Shift Charge, ZESCO National Control Centre
10. Stanford Kalonga Yamba, Shift Charge, ZESCO National Control Centre
11. Chanagala Nswana, ZESCO Chief Engineer Protection- Generation,
12. Clement Siame, ZESCO Chief Engineer Protection, Transmission
13. Ernest Banda, ZESCO Principal Transmission Engineer South
14. Kalimanyando Simwanza, Shift Charge, ZESCO National Control Centre Charge
15. Aggrey Koloto Daka, Control Technologist, ZESCO National Control Centre
16. Spend Angasishe, Shift Charge ZESCO Kariba North Bank Power Station
17. Boyd Kancheya, Control Technologist, ZESCO National Control Centre
18. Sidney Kangwa, Shift Charge, Kariba North Bank Power Station
19. Linus Chanda, Chief Engineer Kariba North Bank Power Station
20. **Wesley Lwiindi**, Project Engineer, Kariba North Bank Power Station
21. **Cyprian Chitundu**, Power Station Manager, Kariba North Bank Power Station
22. **Charles Kisala**, Station Superintendent, ZESCO Leopards Hill Substation
23. **Mufalali Kakoma**, Acting Shift Charge, Kafue Gorge Power Station
24. **Charles Musonda**, Acting Shift Charge Kafue Gorge Power Station
25. **Grace Kampamba**, Control Technologist Kafue Gorge Power Station
26. **Akambelwa Muyunda**, Control Technologist Kafue Gorge Power Station
27. **Eric Fulaza**, Graduate Engineer Kafue Gorge Power Station
28. **Samuel Sinkala**, Chief Operations Engineer, Kafue Gorge Power Station
29. **Masiye Mwale**, Power Station Manager Kafue Gorge Power Station
30. **Ntankakuya Evans**, ZESCO Regional System Operator
31. **Godfrey Katongo**, System Controller CEC
32. **Robby Phiri**, System Controller, CEC
33. **William Chokani Chirwa**, Electro Technical Manager, CEC
34. **Willard Milambo**, Maintenance Manager CEC
35. **Neil Croucher**, Managing Director CEC
36. **Humphrey Mulela**, Director Operations CEC
37. **Emmanuel Sampa Katepa**, Manager Asset Managements, CEC
38. **Aaron Botha**, Technical Director CEC
39. **Felix Mubanga**, Electrical Engineer, Konkola Copper Mines Plc
40. **Alaguve Mookkandi**, Konkola Copper Mines Plc
41. **L. Ikafa**, Chibuluma Mines
42. **N.J. W. Bell**, Mopani Copper Mines Plc

43. **Peter Bykrich**, Mopani Copper Mines

44. **Robald Kambalati**, Mopani Copper Mines Limited

45. **Paul Mulenga**, Chambishi NFC plc

46. **Lawrence Chileshe**, Chamber of Mines Zambia

47. **Cosmas Mwenda**, Victoria Falls Power Station Manager

48. **John Musambachime**, Senior Control Technologist Victoria Falls Power Station

49. **Stanley Singoi**, Principle Shift Charge Victoria Falls Power Station

50. **Kayata**, Shift Charge, Victoria Falls Power Station

51. **Mulobela Shakapanga**, Electrical Engineer Victoria Falls Power Station

52. **Silvester Hibajene**, Executive Director Energy Regulation Board

53. **Illlac Chiti**, Director Operations Lunsemfwa Hydro Power Company

54. **Amos Daudi**, Managing Director Ndola Lime Company Limited
APPENDIX B: WRITTEN SUBMISSIONS

WRITTEN SUBMISSIONS WERE RECEIVED FROM THE FOLLOWING:

1. Mopani Copper Mines Plc
2. Ndola Lime Company Limited
3. Konkola Copper Mines Plc
4. Luanshya Copper Mines Plc
5. Worldridge Investments Limited
6. Lunsemfwa Hydro Power Company Limited
7. Copperbelt Energy Corporation Plc
8. Zesco Limited
9. Lusaka District Development Coordinating Committee
10. Millers Association of Zambia
11. Charles Mukupa
12. Ms Sara K. Luwisha
APPENDIX C:

DESCRIPTION OF COMMITTEE’S INVESTIGATION AND PROCESS OF DEVELOPING RECOMMENDATIONS

On 6th February 2008 the Energy Regulation Board constituted a Committee of Inquiry to inquire into and investigate the circumstances and causes of the Nationwide Power outages of 19th, 21st and 22nd January 2008.

In its inquiry and investigation the Committee visited all the major infrastructure involved in the three incidents and interviewed operational staff who were on duty. The Committee reviewed literature on similar occurrences in other jurisdictions. The Committee in trying to assess the impact of the blackouts on the economy interviewed major electricity consumers such as the mines, millers, and manufacturers. The Committee however noted that a full economic impact of the blackout can only be established if a more comprehensive study is undertaken.

On 6th February 2008, the Committee held its first meeting at the Energy Regulation Board, where it set out a schedule of activities. The Committee decided to place adverts in the media inviting members of the general public and interested stakeholders to make written submissions on any matters relating to the power outages. Letters were also sent to business houses, the Chamber of Mines, the Association of manufactures and other large consumers of electricity. On 8th February 2008 the Committee met to discuss among other things, the structure of the report and its contents. On the same day the Committee visited the Zesco national control centre and began sitting to interview control staff that were on duty on the material dates.

The Committee continued to sit and hold interviews at the Zesco national control centre on the 11th and 12th of February 2008. On 14th February 2008 the Committee visited the Kariba North Bank Power Station, the Kariba North Bank Switch Yard, the and held interviews with control staff who were on duty on the days of the incidents. On the morning of 15th February 2008 the Committee continued to have interviews at Kariba North Bank Power Station and in the afternoon visited the two Kariba- Leopards Hill lines to see the point at which the insulators failed and to view the collapsed tower 145, on Line 2 which is about twenty kilometres from the Kafue - Chirundu Road.

On the afternoon of 15th February 2008 the Committee, visited Leopards Hill Sub station and interviewed the station superintendent and his control staff who were on duty on the days of the three incidents. On 18th February 2008 the Committee departed for Kafue Gorge Power Station where it visited the station and held interviews with control staff and the station manager until 20th February 2008. On 26th February 2008 the Committee visited the Copperbelt Energy Corporation Plc headquarters and were taken on a conducted tour of the control centre and the central switching station. The Committee sat at the CEC Board room and interviewed control staff and management.
On 27\textsuperscript{th} February the Committee visited Luano substation, Michelo substation and the Congo interconnector. On 28\textsuperscript{th} February 2008 the committee sat at Hotel Edinburgh and held interviews with the chamber of Mines and representatives of mining companies.

On 3\textsuperscript{rd} March 2008 the Committee visited Victoria Falls Power station and interviewed the station manager with his control staff. On 6\textsuperscript{th} March 2008 the Drafting subcommittee began drafting the report which was then reviewed by the committee on 14\textsuperscript{th} March 2008. At this meeting the Committee reviewed its progress and decided that more time than had been allowed was needed to complete the work. Therefore the Committee requested the Energy Regulation Board for an extension of time in which to submit its report, to 9\textsuperscript{th} April 2008. On the morning of 18\textsuperscript{th} March 2008 the Committee attempted to meet with ZESCO management who informed it that they were not ready to meet with the Committee and thus rescheduled the meeting to a later date. On the afternoon of 18\textsuperscript{th} March 2008 the Committee interviewed the Executive Director of the Energy Regulation Board, and the Operations Director of Lunsemfwa-Hydro Company Limited. The following day, 19\textsuperscript{th} March 2008 the Committee sat and interviewed the Managing Director of Ndola Lime Company Limited, the representatives of the Millers Association of Zambia and the station superintendent at Kabwe Substation.

Between the 24\textsuperscript{th} and 29\textsuperscript{th} March 2008 the committee sat in Siavonga where it analysed its findings, reviewed all the written submissions and began drafting its final report. On 31\textsuperscript{st} March 2008 the Committee sat at ZESCO headquarters and interviewed ZESCO management and thereafter sat to conclude its report.
APPENDIX D:

GLOSSARY

**AC:** Alternating current; current that changes periodically (sinusoidally) with time.

**Adequacy:** The ability of the electric system to supply the aggregate electrical demand and energy requirements of customers at all times, taking into account scheduled and reasonably expected unscheduled outages of system elements.

**Blackstart Capability:** The ability of a generating unit or station to go from a shutdown condition to an operating condition and start delivering power without assistance from the bulk electric system.

**Bulk Electric System:** A term commonly applied to the portion of an electric utility system that encompasses the electrical generation resources and bulk transmission system.

**Bulk Transmission:** A functional or voltage classification relating to the higher voltage portion of the transmission system.

**Bus:** Shortened from the word busbar, meaning a node in an electrical network where one or more elements are connected together.

**Capacitor Bank:** A capacitor is an electrical device that provides reactive power to the system and is often used to compensate for reactive load and help support system voltage. A bank is a collection of one or more capacitors at a single location.

**Capacity:** The rated continuous load-carrying ability, expressed in megawatts (MW) or megavolt-amperes (MVA) of generation, transmission, or other electrical equipment.

**Cascading:** The uncontrolled successive loss of system elements triggered by an incident. Cascading results in widespread service interruption, which cannot be restrained from sequentially spreading beyond an area predetermined by appropriate studies.

**Circuit:** A conductor or a system of conductors through which electric current flows.

**Circuit Breaker:** A switching device connected to the end of a transmission line capable of opening or closing the circuit in response to a command, usually from a relay.
Control Area: An electric power system or combination of electric power systems to which a common automatic control scheme is applied in order to: (1) match, at all times, the power output of the generators within the electric power system(s) and capacity and energy purchased from entities outside the electric power system(s), with the load in the electric power system(s); (2) maintain, within the limits of Good Utility Practice, scheduled interchange with other Control Areas; (3) maintain the frequency of the electric power system(s) within reasonable limits in accordance with Good Utility Practice; and (4) provide sufficient generating capacity to maintain operating reserves in accordance with Good Utility Practice.

Contingency: The unexpected failure or outage of a system component, such as a generator, transmission line, circuit breaker, switch, or other electrical element. A contingency also may include multiple components, which are related by situations leading to simultaneous component outages.

Current (Electric): The rate of flow of electrons in an electrical conductor measured in Amperes.

Demand: The rate at which electric energy is delivered to consumers or by a system or part of a system, generally expressed in kilowatts or megawatts, at a given instant or averaged over any designated interval of time. Also see “Load.”

DC: Direct current; current that is steady and does not change sinusoidally with time (see “AC”).

Distribution: For electricity, the function of distributing electric power using low voltage lines to retail customers.

Distribution Network: The portion of an electric system that is dedicated to delivering electric energy to an end user, at or below 69 kV. The distribution network consists primarily of low voltage lines and transformers that “transport” electricity from the bulk power system to retail customers.

Disturbance: An unplanned event that produces an abnormal system condition.

Electrical Energy: The generation or use of electric power by a device over a period of time, expressed in kilowatthours (kWh), megawatthours (MWh), or gigawatthours (GWh).

Electric Utility: Person, agency, authority, or other legal entity or instrumentality that owns or operates facilities for the generation, transmission, distribution, or sale of electric energy primarily for use by the public, and is defined as a utility under the statutes and rules by which it is regulated.
**Element:** Any electric device with terminals that may be connected to other electric devices, such as a generator, transformer, circuit, circuit breaker, or bus section.

**Energy Emergency:** A condition when a system or power pool does not have adequate energy resources (including water for hydro units) to supply its customers’ expected energy requirements.

**Emergency:** Any abnormal system condition that requires automatic or immediate manual action to prevent or limit loss of transmission facilities or generation supply that could adversely affect the reliability of the electric system.

**Emergency Voltage Limits:** The operating voltage range on the interconnected systems that is acceptable for the time, sufficient for system adjustments to be made following a facility outage or system disturbance.

**Fault:** A fault usually means a short circuit, but more generally it refers to some abnormal system condition. Faults are often random events.

**Flashover:** A plasma arc initiated by some event such as lightning. Its effect is a short circuit on the network.

**Forced Outage:** The removal from service availability of a generating unit, transmission line, or other facility for emergency reasons or a condition in which the equipment is unavailable due to unanticipated failure.

**Frequency:** The number of complete alternations or cycles per second of an alternating current, measured in Hertz. The standard frequency in Zambia is fifty Hertz.

**Frequency Deviation or Error:** A departure from scheduled frequency; the difference between actual system frequency and the scheduled system frequency.

**Frequency Regulation:** The ability of a Control Area to assist the interconnected system in maintaining scheduled frequency. This assistance can include both turbine governor response and automatic generation control.

**Frequency Swings:** Constant changes in frequency from its nominal or steady-state value.

**Generation (Electricity):** The process of producing electrical energy from other forms of energy; also, the amount of electric energy produced, usually expressed in kilowatt hours (kWh) or megawatt hours (MWh).
Generator: Generally, an electromechanical device used to convert mechanical power to electrical power.

Grid: An electrical transmission and/or distribution network.

Grid Protection Scheme: Protection equipment for an electric power system, consisting of circuit breakers, certain equipment for measuring electrical quantities (e.g., current and voltage sensors) and devices called relays. Each relay is designed to protect the piece of equipment it has been assigned from damage. The basic philosophy in protection system design is that any equipment that is threatened with damage by a sustained fault is to be automatically taken out of service.

Ground: A conducting connection between an electrical circuit or device and the earth. A ground may be intentional, as in the case of a safety ground, or accidental, which may result in high overcurrents.

Imbalance: A condition where the generation and interchange schedules do not match demand.

Impedance: The total effects of a circuit that oppose the flow of an alternating current consisting of inductance, capacitance, and resistance. It can be quantified in the units of ohms.

Independent System Operator (ISO): An organization responsible for the reliable operation of the power grid under its purview and for providing open transmission access to all market participants on a nondiscriminatory basis. An ISO is usually not-for-profit and can advise utilities within its territory on transmission expansion and maintenance but does not have the responsibility to carry out the functions.

Interchange: Electric power or energy that flows across tie-lines from one entity to another, whether scheduled or inadvertent.

Interconnected System: A system consisting of two or more individual electric systems that normally operate in synchronism and have connecting tie lines.

Island: A portion of a power system or several power systems that is electrically separated from the interconnection due to the disconnection of transmission system elements.

Kilowatthour (kWh): Unit of energy equaling one thousand watthours, or one kilowatt used over one hour.
**Line Trip:** Refers to the automatic opening of the conducting path provided by a transmission line by the circuit breakers. These openings or “trips” are to protect the transmission line during faulted conditions.

**Load (Electric):** The amount of electric power delivered or required at any specific point or points on a system. The requirement originates at the energy-consuming equipment of the consumers. See “Demand.”

**Load Shedding:** The process of deliberately removing (either manually or automatically) preselected customer demand from a power system in response to an abnormal condition, to maintain the integrity of the system and minimize overall customer outages.

**Lockout:** A state of a transmission line following breaker operations where the condition detected by the protective relaying was not eliminated by temporarily opening and reclosing the line, possibly several times. In this state, the circuit breakers cannot generally be reclosed without resetting a lockout device.

**Megawatthour (MWh):** One million watthours.

**Normal Voltage Limits:** The operating voltage range on the interconnected systems that is acceptable on a sustained basis.

**Operating Criteria:** The fundamental principles of reliable interconnected systems operation.

**Operating Procedures:** A set of policies, practices, or system adjustments that may be automatically or manually implemented by the system operator within a specified time frame to maintain the operational integrity of the interconnected electric Systems

**Operating Security Limit:** The value of a system operating parameter (e.g. total power transfer across an interface) that satisfies the most limiting of prescribed pre- and post-contingency operating criteria as determined by equipment loading capability and acceptable stability and voltage conditions. It is the operating limit to be observed so that the transmission system will remain reliable even if the worst contingency occurs.

**Outage:** The period during which a generating unit, transmission line, or other facility is out of service.

**Protective Relay:** A device designed to detect abnormal system conditions, such as electrical shorts on the electric system or within generating plants, and initiate the operation of circuit breakers or other control equipment.
**Power/Phase Angle:** The angular relationship between an AC (sinusoidal) voltage across a circuit element and the AC (sinusoidal) current through it. The real power that can flow is related to this angle.

**Power:** See “Real Power.”

**Power Flow:** See “Current.”

**Rate:** The authorized charges per unit or level of consumption for a specified time period for any of the classes of utility services provided to a customer.

**Rating:** The operational limits of an electric system, facility, or element under a set of specified conditions.

**Reactive Power:** The portion of electricity that establishes and sustains the electric and magnetic fields of alternating-current equipment. Reactive power must be supplied to most types of magnetic equipment, such as motors and transformers. It also must supply the reactive losses on transmission facilities. Reactive power is provided by generators, synchronous condensers, or electrostatic equipment such as capacitors and directly influences electric system voltage. It is usually expressed in kilovars (kVAR) or megavars (MVAr), and is the mathematical product of voltage and current consumed by reactive loads. Examples of reactive loads include capacitors and inductors. These types of loads, when connected to an ac voltage source, will draw current, but because the current is 90 degrees out of phase with the applied voltage, they actually consume no real power.

**Real Power:** Also known as “active power.” The rate at which work is performed or that energy is transferred, usually expressed in kilowatts (kW) or megawatts (MW). The terms “active power” or “real power” are often used in place of the term power alone to differentiate it from reactive power.

**Real-Time Operations:** The instantaneous operations of a power system as opposed to those operations that are simulated.

**Relay:** A device that controls the opening and subsequent reclosing of circuit breakers. Relays take measurements from local current and voltage transformers, and from communication channels connected to the remote end of the lines. A relay output trip signal is sent to circuit breakers when needed.

**Relay Setting:** The parameters that determine when a protective relay will initiate operation of circuit breakers or other control equipment.
Reliability: The degree of performance of the elements of the bulk electric system that results in electricity being delivered to customers within accepted standards and in the amount desired. Reliability may be measured by the frequency, duration, and magnitude of adverse effects on the electric supply. Electric system reliability can be addressed by considering two basic and functional aspects of the electric system, Adequacy and Security.

Resistance: The characteristic of materials to restrict the flow of current in an electric circuit. Resistance is inherent in any electric wire, including those used for the transmission of electric power. Resistance in the wire is responsible for heating the wire as current flows through it and the subsequent power loss due to that heating.

Restoration: The process of returning generators and transmission system elements and restoring load following an outage on the electric system.

Safe Limits: System limits on quantities such as voltage or power flows such that if the system is operated within these limits it is secure and reliable.

SCADA: Supervisory Control and Data Acquisition system; a system of remote control and telemetry used to monitor and control the electric system.

Schedule: An agreed-upon transaction size (megawatts), start and end time, beginning and ending ramp times and rate, and type required for delivery and receipt of power and energy between the contracting parties and the Control Area(s) involved in the transaction.

Security: The ability of the electric system to withstand sudden disturbances such as electric short circuits or unanticipated loss of system elements.

Short Circuit: A low resistance connection unintentionally made between points of an electrical circuit, which may result in current flow far above normal levels.

Single Contingency: The sudden, unexpected failure or outage of a system facility(s) or element(s) (generating unit, transmission line, transformer, etc.). Elements removed from service as part of the operation of a remedial action scheme are considered part of a single contingency.

Special Protection System: An automatic protection system designed to detect abnormal or predetermined system conditions, and take corrective actions other than and/or in addition to the isolation of faulted components.

Stability: The ability of an electric system to maintain a state of equilibrium during normal and abnormal system conditions or disturbances.
**Stability Limit:** The maximum power flow possible through a particular point in the system while maintaining stability in the entire system or the part of the system to which the stability limiters.

**Station:** A node in an electrical network where one or more elements are connected. Examples include generating stations and substations.

**Substation:** Facility equipment that switches, changes, or regulates electric voltage.

**Supervisory Control and Data Acquisition (SCADA):** See SCADA.

**Surge:** A transient variation of current, voltage, or power flow in an electric circuit or across an electric system.

**Surge Impedance Loading:** The maximum amount of real power that can flow down a lossless transmission line such that the line does not require any VArS to support the flow.

**Switching Station:** Facility equipment used to tie together two or more electric circuits through switches. The switches are selectively arranged to permit a circuit to be disconnected, or to change the electric connection between the circuits.

**Synchronize:** The process of connecting two previously separated alternating current apparatuses after matching frequency, voltage, phase angles, etc. (e.g., paralleling a generator to the electric system)

**System:** An interconnected combination of generation, transmission, and distribution components

**System Operator:** An individual at an electric system control center whose responsibility it is to monitor and control that electric system in real time.

**System Reliability:** A measure of an electric system’s ability to deliver uninterrupted service at the proper voltage and frequency.

**Thermal Limit:** A power flow limit based on the possibility of damage by heat. Heating is caused by the electrical losses which are proportional to the square of the real power flow. More precisely, a thermal limit restricts the sum of the squares of real and reactive power.

**Tie-line:** The physical connection (e.g. transmission lines, transformers, switch gear, etc.) between two electric systems that permits the transfer of electric energy in one or both directions.
**Time Error:** An accumulated time difference between Control Area system time and the time standard. Time error is caused by a deviation in Interconnection frequency from 60.0 Hertz.

**Time Error Correction:** An offset to the Interconnection’s scheduled frequency to correct for the time error accumulated on electric clocks.

**Transfer Limit:** The maximum amount of power that can be transferred in a reliable manner from one area to another over all transmission lines (or paths) between those areas under specified system conditions.

**Transformer:** A device that operates on magnetic principles to increase (step up) or decrease (step down) voltage.

**Transient Stability:** The ability of an electric system to maintain synchronism between its parts when subjected to a disturbance and to regain a state of equilibrium following that disturbance.

**Transmission:** An interconnected group of lines and associated equipment for the movement or transfer of electric energy between points of supply and points at which it is transformed for delivery to customers or is delivered to other electric systems.

**Transmission Margin:** The difference between the maximum power flow a transmission line can handle and the amount that is currently flowing on the line.

**Transmission Overload:** A state where a transmission line has exceeded either a normal or emergency rating of the electric conductor.

**Trip:** The opening of a circuit breaker or breakers on an electric system, normally to electrically isolate a particular element of the system to prevent it from being damaged by fault current or other potentially damaging conditions. See “Line Trip” for example.

**Voltage:** The electrical force, or “pressure,” that causes current to flow in a circuit, measured in Volts.

**Voltage Collapse (decay):** An event that occurs when an electric system does not have adequate reactive support to maintain voltage stability. Voltage Collapse may result in outage of system elements and may include interruption in service to customers.
**Voltage Control:** The control of transmission voltage through adjustments in generator reactive output and transformer taps, and by switching capacitors and inductors on the transmission and distribution systems.

**Voltage Limits:** A hard limit above or below which is an undesirable operating condition. Normal limits are between 95 and 105 percent of the nominal voltage at the bus under discussion.

**Voltage Reduction:** A procedure designed to deliberately lower the voltage at a bus. It is often used as a means to reduce demand by lowering the customer’s voltage.

**Voltage Stability:** The condition of an electric system in which the sustained voltage level is controllable and within predetermined limits.

**Watt-hour (Wh):** A unit of measure of electrical energy equal to 1 watt of power supplied to, or taken from, an electric circuit steadily for 1 hour.