PUBLIC UTILITIES REGULATORY COMMISSION (PURC)

INVESTIGATION INTO THE CAUSES OF THE THREE TOTAL SYSTEM COLLAPSES IN THE GHANA POWER SYSTEM

DRAFT FINAL REPORT OF THE FACT FINDING COMMITTEE

30th April, 2012

Contents

Composition of the Fact Finding Committee

Ing. Stephen Akuoko- Former MD ECG	-Chairman
Ing. GD Boateng-Former Director VRA(Generation)	-Member
Dr. Ferdinand Tay-Economist(Consumer Rights President)	-Member
Ing. Andrew Lawson-Former Executive Secretary Energy Foundation	-Member
Ing. Michael Odonkor-Former Director VRA(Transmission)	-Member
Ing. Emmanuel Fiati-Director Energy(PURC)	-Secretary

Executive Summary

Following the recent total system collapses, the Public Utilities Regulatory Commission (PURC) established a Fact Finding Committee (FFC) to conduct a technical and operational investigation to determine the root causes of the four[1] separate system collapses that led to nationwide power outages.

The FFC studied reports submitted by Ghana Grid Company Limited (GRIDCo) and Volta River Authority (VRA) after which further documents were requested and submitted by the two utilities. The FFC then visited GRIDCo at their Head Office at Tema where they held comprehensive discussions, first with the Chief Executive (CE) and then with the Chief Executive and Directors. The FFC proceeded to the Head Office of the VRA and had discussions with the Chief Executive, Deputy Chief Executive (Engineering and Operations), Plant Managers of the generating stations as well as key managers relevant to operation and maintenance of the generators and other plant and switchyard equipment.

The FFC visited Akosombo Generating Station (A1GS) where they discussed the total collapses with on-site personnel who were on duty on the days of the incidents. More documents were submitted by VRA staff. After studying the latter documents and reviewing the interactions at A1GS, another visit was made to A1GS. The FFC had exclusive interview with the Director of Hydro Generation (HG) who was absent during the two previous meetings with VRA. This was followed by a meeting with the Director (HG), Director, Southern Network Services (SNS) of GRIDCo and the on-site Akosombo Plant Operators, Protection and Control (P&C) Staff as well as Mechanical and Electrical Maintenance Staff on the day the first incident took place.

After further review and thorough analysis of all evidences available, the FFC submits as follows:-

A. Total Collapse on December 7, 2011.

1. The immediate cause of the total collapse was the explosion of the 1T2L2 Oil Circuit Breaker (OCB) which was being used to tie Akosombo Generating unit 1G2 to the system.
2. The root cause of the total collapse was the state of the OCBs which are aged, and subjected to rigorous impact operation since 1976.

[1] The FFC found that there were two separate system collapses on March 21, 2012.

3. VRA had recognized this problem as far back as 2006 when a decision was taken to replace the OCBs because of obsolescence. Indeed a contract was awarded in 2008 under West African Power Pool (WAPP) World Bank Project which was delayed but started in 2010 and is on-going to refurbish all equipment in the Akosombo Switchyard.

B. Total Collapse on February 26, 2012.

1. The immediate cause of the total collapse was the result of the breaking of the middle skywire for Plant Line 5 and 6 which fell across the A-Bus. Units 1G2 and 1G4 tripped to speed-no-load (SNL) because they were synchronized to the system through their A-bus breakers only. In the process the skywire contacted Plant Lines 5 and 6 hence tripping units 1G3, 1G5 and 1G6 to SNL whilst unit 1G1 tripped on overload.
2. The root cause was the snapping of the skywire at its termination on the gantry at the Plant end. As the wire contacted the Plant line a high current flowed through the Switchyard termination, melting the end and causing it to snap. The reason for the initial snapping could be attributed to mechanical failure of the termination due to ageing.

C. Total Collapse on March 21 at 19:15hrs

1. The immediate cause of the total collapse was precipitated by the partial loss of generation at Compagnie Ivoirienne d'Electricite (CIE) which resulted in the sudden power export of 72MW from Ghana to Cote d'Ivoire through the inter tie. Following this, the inter tie line tripped at Abobo at the Cote d'Ivoire end and a number of Ghana lines also tripped on frequency swings resulting in considerable load rejection. The system frequency went up and the Akosombo generators tripped on overspeed to shutdown. Other generators in the system also tripped resulting in the total system collapse. Before the collapse, the system was already running very tight with Akosombo generating units overloaded.
2. The root causes were :
    i. The absence of an appropriate relay to prevent the transfer of system disturbances from one country's system to the other.
    ii. Operating the system without spinning reserve.
    iii. Failure of Automatic Frequency Load Shedding (AFLS) relays to provide load relief and stabilize the system.

iv. Failure of System Control Centre (SCC) to manually intervene to shed some system load in order to provide relief to stabilize the system.

D. Total Collapse on March 21 at 21.17hrs

1. The immediate cause was loss of 100MW of generation. During ramping up on unit 32G2 at TAPCO, TICO back energized their transformer creating an in-rush current which caused 32G2 unit to trip on generator differential relay protection. The tripping of unit 32G2 created instability leading to another total system collapse.
2. The root cause was the lack of adequate spinning reserve during system restoration.

E. Key Recommendations

From the findings and observations the FFC makes the following key recommendations:

1. The ownership of the switchyard should remain with GRIDCo whilst the operation and maintenance are formally contracted out to VRA.
2. Current refurbishment of Akosombo Switchyard should be speeded up.
3. VRA and GRIDCo should identify critical equipment which require insurance replacement and cater for accordingly.
4. In view of the age of the skywire and other transmission hardware, GRIDCo should review their planned periodic inspections.
5. The system should be operated with adequate spinning reserve by instituting appropriate load management practices, as stipulated in Article 9.2[2] of the Grid Code and additional generation.
6. In line with articles 9.67[3] and 9.87[4] of the Grid Code, GRIDCo should ensure that the AFLS relays are always in operation in the transmission system for automatic load shedding to aid system stability.
7. Adequate demand side management including sustainable energy conservation should be put in place by GRIDCo, Electricity Company of Ghana (ECG), Northern Electricity

[2] See Appendix 1

[3] See Appendix 2

[4] See Appendix 3

Distribution Company (NEDCo) and Energy Foundation(EF) as a measure to identify and reduce the waste in the system and address growing demand and reduce line losses .This should be coordinated by the Energy Commission (EC).

8. The power system should be operated according to international norms with adequate spinning reserves, enough spare capacity to allow for regular maintenance and emergency use.
9. Whilst pursuing Demand Side Management (DSM), an accelerated programme to construct new generating plants should be implemented. For this, the Ministry of Energy should actively encourage existing generators and prospective Independent Power Producers (IPPs) to achieve 'Recommendation 8' by putting in place conducive conditions in the power sector.
10. VRA, ECG, NEDCo and GRIDCo should adhere to standard voltages, power factors and frequency to prevent overheating, reduce line losses, prevent picking of avoidable loads and improve system stability.
11. PURC should establish a long term relationship with a matured regulatory body by way of an MOU .This will enable technical staff to benefit from prompt consultation and easy access to training avenues.
12. PURC should arrange local and overseas attachment training to utilities for their technical staff.

1 Introduction

1.1 Background

Over the last four months the Ghana power system has suffered four total system collapses leading to nationwide power outages. Following these incidents which occurred on Wednesday the 7th of December, 2011, Sunday the 26th of February 2012 and Wednesday the 21st of March 2012, the Public Utilities Regulatory Commission (PURC) decided ,pursuant to Section 3(e)[5] and 10[6] of the PURC Act of 1997(Act 538) to constitute a Fact Finding Committee (FFC) to conduct a technical and operational investigation into the causes of these system failures and make recommendations towards reducing the frequency of such occurrences in future.

1.1.1 Objective of the Assignment

The objective of the assignment of the Fact Finding Committee is to conduct a technical and operational investigation to determine the root causes of the four separate total system collapses that led to nationwide power outages.

1.1.2 Duration of the Assignment

The Fact Finding Committee (FFC) was inaugurated on April 11th, 2012 and was given four weeks to submit its report on May 9, 2012.

1.2 Output of Assignment

The deliverables in accordance with the terms of reference are listed below:

a. Current technical status of all equipment at the Akosombo Switch Yard determined.
b. Root causes of the two system failures determined.
c. Critical areas/point in the NITS that can cause - system collapse determined.
d. Measures to improve technical performance identified and recommendations, including capital investment requirements in the medium to long term, made to

[5] See Appendix 4

[6] See Appendix 5

address the problems.

e. Current operational performance of the Akosombo Switch Yard determined and the recommendations, including working capital requirements made to address the issues identified.
f. Ownership, operator, age and maintenance philosophy of Akosombo Switch Yard ascertained.
g. Current generation reserve margin determined.
h. Recommendations made for capacity building of PURC staff adequately equip them for any future incident investigation

The detailed Terms of Reference is attached as Appendix 9.

1.3 Methodology

The tools used in the investigation included meetings with utilities top management, meetings with technical staff, questionnaires, interviews and site visits .The FFC reviewed reports and documents submitted earlier by the utilities to PURC. Additionally, the FFC requested for further information from the utilities which were also analyzed in the course of the investigations. A detailed list of the documents and reports studied are attached as Appendix 6 and 7.

The Committee started work after the inauguration on 11th April, 2012 at the PURC offices in Accra. The Committee reviewed the terms of reference and developed a comprehensive work plan. The detailed work plan of the FFC is attached as Appendix 8.

2 Findings and Observations

2.1 Management of Akosombo Switchyard

2.1.1 In respect of the management of the Akosombo Switchyard ,the FFC found from a letter reference number EXR/1090/029[7] from the Chief Executive of VRA to the Chief Executive of GRIDCo and confirmed by discussions with the two managements that :

a. The legal ownership of the Akosombo switchyard is vested in GRIDCo.
b. The Akosombo Switchyard is maintained and operated by VRA.
c. Even though the LI 1934 has been operationalized, the FFC found that GRIDCo is yet to take over the management and operation of the Akosombo Switchyard.

2.1.2 The FFC noted that a VRA-GRIDCo Joint Committee (VGJC) has been set up to draft the Terms of Reference (TOR) for the transfer. The VGJC has met and produced a draft TOR for approval of the two managements. The draft TOR[8] is attached as Appendix 11.

2.1.3 Both managements of VRA and GRIDCO have recognised the need for the WAPP to complete the rehabilitation of the switchyard before the transfer is effected since VRA is the World Bank recognised owner and Project Manager of the Akosombo Switchyard. WAPP is expected to complete the switchyard rehabilitation by the middle of 2013.

[7] See Appendix 10

[8] See Appendix 11

Picture of a section of the Akosombo Switchyard. Find attached Akosombo 161kV switchyard Single Line Diagram as Appendix 12.

2.2 Total System Collapse on December 7, 2011

In respect of the total system collapse of December 7, 2011, the Committee made the following findings and observations:

2.2.1 There were three separate trip incidents involving Akosombo unit 1G2. From the station log for Wednesday December 7, 2011, events leading to the system collapse are as follows:

- At 20:33hrs,unit 1G2 tripped auto to shutdown with no relay operations but with annunciation showing excessive loading,161kV breaker trip, vibration or air gap trouble.

- Operators and P&C staff carried out checks on relays, protective devices and breakers.

- At 21:37 hrs unit 1G2 was started and at 21:40, it was tied auto with 1T2A breaker and loaded.

- At 21:42hrs unit 1G2 tripped auto on 1T2A breaker to SNL

- At 21:48hrs the operators attempted synchronising 1G2 again with 1T2L2 breaker in auto mode but could not go through .The breaker exploded with fire tripping unit 1G2 and all the other units . The lines were manually tripped by SCC.

2.2.2 There was adequate generation that could meet the load demand as at the time Akosombo unit 1G2 tripped. See the tables below:

Loading of all the units at Akosombo before the trip of unit 1G2 at 20:33Hrs is shown in the table 1 below:

Table 1: Loading of Units at Akosombo GS before the Trip of Unit 1G2

Generating Unit	MW	MVAR
1G1	146	70
1G2	143	76
1G3	143	74
1G4	141	68
1G5	139	75
1G6	139	60

Source: Volta River Authority (Hydro generation Department), Memo on Complete Report on Akosombo Blackout and the recurrent Tripping of Unit 2, dated 15/12/2011

Table 2: Loading of all generating plants in service just before the system collapse

Generating Station	Unit	MW	MVAR
Akosombo GS	1G1	159	80
	1G3	158	83
	1G4	154	80
	1G5	156	86
	1G6	158	71
KPONG GS	19G1	35	12
	19G2	35	17
	19G3	34	18
	19G4	36	18
TAPCO	32G1	80	38
	32G2	80	42
TT1P1	47G1	40	28
ASOGLI	51G1	29.6	9.6
	51G2	29.8	9.3
	51G3	31.2	8.2
	51G4	29	9.5
	51G5	29.9	8.1
	51G6	30.4	9
TICO	32G4	107	52
	32G5	96	60
SIEMENS	50G1	6.8	3
	50G2	6.8	3
	50G3	6.9	3
	50G5	6.1	2.9
MRP	46G3	12	1.5

Source: Ghana Grid Company Ltd Report on power system collapse which occurred on Wednesday December 7, 2011

2.2.3 The Committee observed that even though the Protection and Control(P&C) staff carried out checks on the protective devices and other relays that could trigger the breaker operation on the first trip, they did not do any thorough inspection(took only 7 minutes) during the second trip before closing the breaker. Additionally, the Committee finds that the operators did not pay attention to the annunciations on the panel boards before reclosing the breakers.

2.2.4 The inconclusive investigations conducted by the P&C staff on the first trip resulted in their inability to identify the cause of the fault. The cause of the explosion of the breaker was a combination of the state of the breaker and poor technical judgement.

2.2.5 When the generating unit initially tripped, the relay operations were checked to determine the cause of the fault. The Committee however finds that, the inspections and investigations carried out by the operators, electrical maintenance and P&C were not exhaustive because the main auxiliary relay that operates to bring the generating units to speed-no-load SNL (94G) was not checked because it did not sound an alarm as it was not wired onto the panel.

2.2.6 The OCBs have not been taken out for maintenance for a while since the system is being operated very tight.

2.2.7 Safety was compromised in using the OCBs in their current poor state without modifying their operational procedures.

2.3 Total System Collapse on February 26, 2012

The Committee found that:

2.3.1 Skywire on plant line 5 and 6 gantries snapped at the plant end due to mechanical failure and the wire fell on the A-bus in the Switchyard which resulted in high short circuit current passing through to the switchyard end. This melted the end termination causing it to also snap.

2.3.2 The short circuit arc fires caused the B- phase lightening arrester and the B-phase insulator to shatter.

2.3.3 The shattering of the lighting arrestor drew some current through the ammeter resulting in the damage.

2.3.4 The breakers tripped at Akosombo, Kpong and Aboadze Switchyards leading to the total system collapse.

2.4 Total system collapse on March 21, 2012 at 19:15 hrs

The Committee found that:

2.4.1 There was no spinning reserve before the total system collapse. The Daily Generation Report dated 21/03/2012 submitted to PURC by GRIDCo indicates that as at 19:00hrs of the day of the collapse, the total available generation was 1629.6MW whiles the peak load was 1631.6MW showing a generation deficit of 2MW.There was therefore an unscheduled import of 2MW from CIE of Cote d'Ivoire just before the system collapse. This condition rendered the system unstable.

Tables 3 and 4 below culled from GRIDCo's report further amplify the very bad system conditions prevailing just before the incident.

Table 3: System conditions of the units before the collapse on March 21, 2012

Generating Station	Unit	MW	MVAR	pf
AKOSOMBO GS	1G1	157	100	0.843
	1G2	160	100	0.848
	1G3	162	111	0.825
	1G4	154	79	0.89
	1G5	159	116	0.808
	1G6	153	94	0.852
KPONG GS	19G1	37	12	0.951
	19G2	35	20	0.868
	19G3	39	20	0.89
TAPCO	32G2	103	45	0.916
TT1P1	47G1	104	74	0.815
ASOGLI	51G2	24	2.8	0.993
	51G3	11.8	1	0.996
	51G4	28.3	5.1	0.984
	51G5	28.5	4.3	0.989
	51G6	29	5.1	0.985
TICO	32G4	100	41	0.925
	32G5	102	61	0.858
SIEMENS	50G1	6.5	2.9	0.913
	50G2	6.6	2.8	0.921
	50G3	6.6	2.8	0.921
	50G6	8.4	3.9	0.907
MRP	46G3	14	1.4	0.995

Source: GRIDCo, Report on Nationwide Blackout of March 21, 2012 dated 26th March 2012

Table 4: Voltages at major selected sub-stations just before the system collapse on March 21,2012

STATION	VOLTAGE(Kv)
Akosombo	163
Kpong GS	163
Volta	153
Prestea	143
Aboadze	156
New Obuasi	150
Tafo	145
Achimota	152
Mallam	145
New Tema	153
Kumasi	135
Takoradi	156
Kenyasi	130
Techiman	131
Tamale	131
Bolgatanga	124

Source: GRIDCo, Report on Nationwide Blackout of March 21, 2012 dated 26th March 2012

2.4.2 The reactive power loading on the generators at Akosombo were high resulting in low power factors on the units, outside the rated power factor values of 0.95.

2.4.3 Transmission voltages before the incident were very low and well below the ±5% deviation allowed in the normal state by the Grid Code. (e.g. Volta 153kV, Bolgatanga 124kV, Techiman 131kV, Kumasi 135kV and Prestea 143kV) It is noted that even the sending end voltage at Akosombo which is usually around 167kV-169kV had reduced to 163kV

2.4.4 System frequency was also oscillating around 49.6Hzwhich is also outside the allowed range per the Grid Code at normal state of between 49.8Hz-50.2Hz. In summary the state of the transmission network just before the system collapse was very unstable.

2.4.5 At the Akosombo end too, the generators were being overloaded and beginning to overheat. The report from their log book show the following:

- 18:39hrs: System surge experienced swinging the frequency from 50.01Hz to 49.4Hz.System Control Centre advises that the surge was due to insufficient generation.

- 18:42hrs: Akosombo prompted SCC of gradual consistent system voltage decay from 164kV to 161kV
- 19:10hrs: Excitation alarms were received and as captured below the units were at this point in time exceeding their MVA ratings. The bus voltage was averaging around 161.54 kV with a frequency average of about 49.7Hz. SCC was again prompted to act to arrest the gradual but consistent decay in bus voltage.

Table 5: Loading of units at Akosombo before the system collapse at 19:10hrs

UNITS	MW	MX	MVA	RATED MVA
1G3	162	112	197	179.5
1G5	159	116	197	
1G6	155	100	184	

Source: VRA Hydro Generation Report on System Collapse of Wednesday, March 21, 2012 dated March 22, 2012.

- 19:14 to 19:15: Recorder registered 156kV by 19:15hrs followed by rapid voltage decay below 156kV resulting in complete voltage collapse and hence total system blackout.

Table 6: Unit loading before the collapse are as captured below at 19:15hrs

UNITS	MW	MX	MVA	RATED MVA	BUS VOLTAGE
1G1	157	100	186	179.5	156-160kV
1G2	160	100	188		
1G3	162	111	196		
1G4	154	79	173		
1G5	159	118	198		
1G6	153	94	179		

Source: VRA Hydro Generation Report on System Collapse of Wednesday, March 21, 2012 dated March 22, 2012.

From table 6 above, it is clearly evident that the units were generally overloaded with excessive reactive power generation and consequently overheating. Again, the range of low voltages at the sending end bus indicates a system prone to collapse at the slightest disturbance.

2.4.6 There was an unscheduled import of 72MW of power by CIE of Cote d'Ivoire worsening the system conditions

2.4.7 No AFLS relays operated.

2.4.8 Though there was a request from Akosombo plant operators to the SCC operator to intervene to grant relief to the system, the SCC operator did not meet the request.

2.4.9 The Ivorian system tripped the inter-tie line leading to wide voltage and frequency swings in the Ghana system

2.4.10 Akosombo generators tripped on overspeed protection.

2.5 Total System Collapse on March 21, 2012 at 21:17 hrs

The Committee made the following observations and findings in respect of the second total system collapse:

2.5.1 Following the system collapse at 19:14hrs restoration procedures were initiated. Four units at Akosombo had been started, synchronized and tied to the system and loaded.

2.5.2 TAPCO Unit 32G2 was started and synchronized to the system and was being ramped up on load.

2.5.3 During ramping up on 32G2, TICO back energized their transformer creating an in-rush current which caused 32G2 unit to trip on generator differential protection relay.

2.5.4 The tripping of unit 32G2 created instability leading to another total system collapse.

3 Conclusions

3.1 Technical Status of Equipment in Switchyard

The equipment at the Akosombo switchyard are functionally operative. However the Oil Circuit Breakers (OCB) have been giving problems because of their age (installed in 1976) and lack of spares for effective maintenance and are therefore in poor state . According to VRA reports, they were advised as far back as 2004 to replace the OCBs because the production of parts from the original equipment manufacturer have ceased.

Management took a decision in 2006 to replace the whole switchyard equipment and awarded the contract by 2008. However work started in 2010 after a two year delay.

As at the time of FFC's visit, the refurbishment of the switchyard which is being undertaken by WAPP with World Bank funding was in progress. About 30% of the OCBs have so far been replaced.

3.2 Root Causes of the System Failures.

3.2.1 Total Collapse on December 7, 2011.

- The immediate cause of the total collapse was the explosion of the Oil Circuit Breaker(OCB) which was being used to tie Akosombo Generating unit 1G2 to the system through 1T2L2 when 1TA2 was not successful 7 minutes earlier after both breakers had tripped 1G2 to speed-no-load(SNL) an hour before.
- The root cause of the total collapse was the state of the OCBs which are aged, and have been subjected to rigorous operations since 1976.
- VRA had recognized this problem as far as 2006 when a decision was taken to replace the OCBs because of obsolescence. Indeed a contract was awarded in 2008 under West African Power Pool (WAPP) World Bank Project which was delayed but started in 2010 and is on-going to refurbish all equipments in the Akosombo Switchyard.

3.2.2 Total Collapse on February 26, 2012.

- The immediate cause of the total collapse was the result of the breaking of the middle skywire for Plant Line 5 and 6, and falling across the A-Bus. Units 1G2 and 1G4 tripped to SNL because they were synchronized to the system through their A-bus breakers only. In the process the skywire contacted Plant Lines 5 and 6 hence tripping units 1G3, 1G5 and 1G6 to SNL whilst unit 1G1 tripped on overload.
- The root cause was the snapping of the skywire at its termination on the gantry at the Plant end. As the wire contacted the Plant line a high current flowed through the Switchyard termination melting the end and causing it to snap. The reason for the initial snapping could be attributed to mechanical failure of the termination due to ageing.

3.2.3 Total Collapse on March 21 at 19:15hrs

- The immediate cause of the total collapse was precipitated by the partial loss of generation at Compagnie Ivoirienne d'Electricte(CIE) which resulted in the sudden power export of 72MW from Ghana to Cote d'Ivoire through the inter tie. Following this, the inter tie line tripped at Abobo at the Cote d'Ivoire end and a number of Ghana lines also tripped on frequency swings resulting in considerable load rejection. The system frequency went up and the Akosombo generators tripped on overspeed to shutdown. Other generators in the system also tripped resulting in the total system collapse. Before the collapse, the system was already running very tight.
- The root causes were :
    1. The absence of a more appropriate relay to prevent the transfer of system disturbances from one system to the other.
    2. Operating the system without spinning reserve.
    3. Failure of Automatic Frequency Load Shedding relays (AFLS) to provide load relief and stabilize the system.
    4. Failure of System Control Centre (SCC) to manually shed some system load in order to stabilize it.

3.2.4 Total Collapse on March 21 at 21.17hrs

- The immediate cause was loss of 100MW of generation due to tripping of unit 32G2 at TAPCO as a result of TICO transformer energizing backlash.
- The root cause was the lack of spinning reserve during system restoration.

3.3 Critical Areas/Points in the NITS

In the current situation where the of lack of adequate power generation has led to the system being run tightly, a fault in any of the critical areas below can lead to instability and easily cause total system collapse:

- Generating station switchyards
- Volta switchyard
- ECG/NEDCo Bulk supply points
- Intertie link with CIE
- Transmission lines

It may further be noted that faults in the above mentioned areas could easily be precipitated by stormy weather conditions. Also major equipment failure in any of the above areas could lead to unstable system which could cause total system collapse.

3.4 Technical Performance

3.4.1 Measures to Improve Technical Performance

The following measures to improve technical performance may be recommended:

- Insurance spares for critical equipment should be procured.
- Routine maintenance schedules should be strictly adhered to.
- Adequate Staff training, especially Continuous Professional Development (CPD) should be put in place.
- The operation and maintenance procedures and schedules should be reviewed to reflect the age and state of the equipment.

- Stock adequate spares of all critical equipment.
- Working conditions should be enhanced for plant operators and maintenance staff to ensure efficient and effective performance at all times.

3.4.2 Periodic technical and operational audits should be performed.

Planning for capital investment renewal programme should be backed with timely funding.

3.5 Current Operational Performance of Akosombo Switchyard

3.5.1 The equipment at the Akosombo switchyard are functionally operative. However the Oil Circuit Breakers (OCB) have been giving problems because of their age (installed in 1976) and lack of spares for effective maintenance and are therefore in poor state . Management took a decision in 2006 to replace the whole switchyard equipment and awarded the contract by 2008

3.5.2 The refurbishment of the switchyard which started in 2010 is being undertaken by WAPP with World Bank funding. About 30% of the OCBs in the switchyard have so far been replaced

3.5.3 Under the proposed contract agreement for the management of the switchyard, VRA should operate and maintain the switchyard. GRIDCo should plan the capital replacement of equipment in the switchyard

3.6 Ownership and Operations of Akosombo Switchyard

3.6.1 The legal ownership of the Akosombo switchyard is vested in GRIDCo.

3.6.2 The Akosombo Switchyard is currently being operated and maintained by VRA and they should continue to operate and maintain it under the proposed contract agreement between VRA and GRIDCo.

3.6.3 Maintenance Philosophy

- Insurance spares for critical equipment should be procured
- Routine maintenance schedules should be strictly adhered to.

- The maintenance procedures and schedules should be reviewed to reflect the age and state of the equipment.
- Stock adequate maintenance spares of all critical equipment.
- Working conditions should be enhanced for maintenance staff to ensure efficient and effective performance at all times.

3.7 Generation Reserve Margin

3.7.1 The current available generation is less than the peak demand and hence there is generation deficit .In order to achieve spinning reserve, there is load shedding request by GRIDCo to ECG, VALCO and CEB from time to time. (Ref: GRIDCo Forecast Daily Peak Demand and Generating Unit's Availabilities for the week 1-7, 2012).

The current required spinning reserve margin in the system per Art 9.65 of the Grid Code should be equivalent to the single largest generating unit in the generating stations which is equivalent to 150MW. The non-spinning reserve margin will be an additional 150MW. The spinning reserve requirement can be met by a combination of demand side management and planned load shedding. This requirement does not address periods of maintenance where a unit will be taken out for maintenance and hence additional load shedding may be imposed for maintenance periods.

The FFC therefore recommends that to meet international operational standards, the required reserve margins should be planned for and implemented as soon as possible.

3.7.2 In line with articles 9.67 and 9.87 of the Grid Code, GRIDCo should ensure that the AFLS relays are always in operation in the transmission system for automatic load shedding to aid system stability.

3.7.3 Adequate demand side management including sustainable energy conservation should be put in place by GRIDCo, Electricity Company of Ghana (ECG), Northern Electricity Distribution Company (NEDCo) and Energy Foundation (EF) as a measure to slow down growing demand and reduce line losses .This should be coordinated by the Energy Commission (EC).

It will be recalled that a similar national demand side management action taken to replace incandescent filament bulbs with CFL light bulbs yielded a considerable saving of 200MW during the peak period.

A vigorous and sustained demand side management for, power factor improvement and system loss reduction coupled with punitive tariffs for high residential consumers should be undertaken to reduce demand.

The FFC expresses serious concern about the effect of air-conditioning load on the power system. A large number of air-conditioners tend to run continuously because of the environment and improper setting and hence run inefficiently.

3.8 Capacity Building of PURC Technical Staff

In respect of capacity building for PURC technical staff to handle similar investigations in the future the FFC recommends the following;

3.8.1 PURC should establish a long term relationship with a matured regulatory body by way of an MOU .This will enable technical staff to benefit from prompt consultation and easy access to training avenues.

3.8.2 PURC should arrange local and overseas attachment training to utilities for their technical staff.

3.8.3 PURC should make use of local experts to assist technical staff in their investigations and analysis of reports from utilities as well as review of external studies made on behalf of the Commission.

4 Recommendations

After analyzing all the information available, the FFC recommends the following:

4.1 Management of Akosombo Switchyard

4.1.1 The ownership of the Akosombo Switchyard should remain with GRIDCo whilst the management, operation and maintenance are formally contracted out to VRA.

4.1.2 Under the contract agreement, it is proposed that VRA stocks adequate spares and bills GRIDCo.

4.1.3 GRIDCo should plan for the capital replacement of equipment in the switchyard

4.1.4 GRIDCo should procure insurance spares for critical equipment in the switchyard.

4.2 Total System Collapse on December 7, 2011

4.2.1 To forestall future system collapses, it should be the responsibility of VRA to:

- Fund all activities in connection with switchyard maintenance with their own resources so that the delays associated with sourcing for funds will be avoided.
- Stock adequate spares of all critical equipment in the switchyard.
- Review the operation and maintenance procedures in the switchyard to reflect the age and state of the equipment.
- Conduct an independent investigation of events and reviewed by higher authority. The results of the investigations should be properly documented for institutional memory and circulated within the department to achieve staff awareness.
- Improve troubleshooting methodology and techniques for maintenance staff.
- Adhere to maintenance schedules especially functional trip tests.

NB: In addition to adhering to the maintenance schedules, all defects identified during the tests should be corrected.

4.2.2 Management should issue modified operational instructions for the OCBs operation to avoid repeated operations at very short intervals due to their age and precarious state.

4.2.3 The contact resistances of the interrupters of the OCBs should be checked more regularly until the rehabilitation of the switchyard is completed.

4.3 Total System Collapse on February 26, 2012

4.3.1 GRIDCo should synchronize their planned periodic inspections schedule for the skywire with VRA's maintenance schedule for their generators.

4.3.2 In view of the age of the plant, the inspection and maintenance regime should be modified to suit an aged plant for that purpose, modern inspection equipment (binoculars etc.) should be supplied to the operators.

4.4 Total System Collapse on March 21, 2012 at 19:15 hrs

4.4.1 The system should be operated with adequate spinning reserve by instituting appropriate load management as stipulated in Article 9.2 in the Grid Code.

4.4.2 Systems should be put in place to decouple the CIE system from the Ghana system to prevent instability from travelling across the two systems.

4.4.3 In line with articles 9.67 and 9.87 of the Grid Code, GRIDCO should ensure that the AFLS relays are always in operation in the transmission system

4.4.4 Adequate demand side management (DSM) including sustainable energy conservation should be put in place by GRIDCo, ECG and NEDCo as a measure to address growing demand and reduction in line losses

4.4.5 Whilst pursuing DSM, an accelerated plan to construct new generating plants should be implemented .For this, the Ministry of Energy should actively encourage existing generators and prospective Independent Power Producers(IPPs) by putting in place conducive conditions.

4.4.6 GRIDCo should coordinate with ECG, NEDCo and VRA to inject reactive power close to the load centres to help stabilize the system and reduce losses and overheating of VRA generators.

4.4.7 PURC should facilitate the demand side management programme of the utilities by putting in place appropriate tariffs to promote energy efficiency.

4.4.8 The Energy Commission should coordinate the efforts of Energy Foundation in DSM.

4.4.9 The migration from the current transmission voltage of 161kV to 330kV should be accelerated to enable more power to be transmitted across the NITS and reduce system losses.

4.4.10 PURC should modify their pricing model to charge consumers who cross a high threshold band of consumption to pay the highest rate for total consumption.

4.4.11 Demand limiting meters to control energy consumption should be installed in customer premises to control demand.

4.4.12 Public education about energy conservation should be carried out vigorously

4.4.13 Street lighting should be retrofitted with more efficient lamps eg CFLs and LEDs .The street light levy should be reviewed upwards by parliament to allow for more efficient and cost effective management.

4.5 Total System Collapse on March 21, 2012 at 21:17 hrs.

4.5.1 GRIDCo should revise their operating instructions to ensure that there is adequate spinning reserve during system restoration procedures.

4.6 Capacity Building of PURC Technical Staff

4.6.1 PURC should establish a long term relationship with a matured regulatory body by way of an MOU .This will enable technical staff to benefit from free consultation and easy access to training avenues

4.6.2 PURC should arrange overseas attachment to utilities similar to local utilities for their technical staff.

4.6.3 PURC should make use of local experts to assist technical staff in their investigating specialized areas and analysis of reports from utilities as well as review of external studies made on behalf of the Commission.

4.6.4 PURC should organize local attachments to the electric utilities for their technical staff.

APPENDIX

APPENDIX 1

National Electricity Grid Code Article 9.2

Types of reserves

Art 9.20 Operating Reserves are that generation capability above firm system demand that are required to meet the standards of an adequately responsive system for regulation, load forecasting error, mismatch between generation and demand, equipment forced outages and scheduled outages. Operating reserves consist of spinning reserves and non-spinning reserves.

Art 9.21 Spinning reserves consist of the unloaded generation capacity, which is synchronized and ready to automatically serve additional demand without human intervention in order to arrest a drop of system frequency due to an instantaneous mismatch between generation and demand. It shall include and consist primarily of the additional output from currently operating generating plant that is realizable in real time and can be provided steadily for at least one hour.

Art 9.22 A Non-spinning reserve is that generating capacity not operating or synchronised to the system but which is available to serve demand within thirty minutes of being requested so to do. Specifically, a Non-spinning reserve shall comprise the steady output available from a generating unit that can be synchronized to the NITS and loaded up within the specified period to respond to an unexpected demand increase or loss of generation or transmission capacity.

Determination and allocation of operating reserves

Art 9.23 The ETU shall determine and have adequate operating reserves available at all times in order to ensure the security and reliability of power supply within the NITS.

Art 9.24 The Spinning Reserve at any time shall be large enough to enable the grid withstand any one of the following events:

(a) the loss of the generating unit currently producing the highest amount of power within the NITS, or

(b) the loss of generation capacity that could result from any single transmission equipment failure, fault or other contingency, or

(c) the loss of any power in-feed from an interconnected system, whichever is the largest.

Art 9.25 The ETU shall allocate and distribute the required Spinning Reserves among the generating units operating within the NITS such that the grid is able to withstand any single contingency.

Art 9.26 The ETU shall determine the amount of Non-spinning Reserve that is required within the NITS and allocate and distribute this requirement among any available generating units provided the generating unit has not been already identified as part of the spinning reserves and can be synchronized and put on line within the stipulated time of thirty minutes.

Art 9.27 The security of supply from the NITS especially under certain contingency conditions, depends on the reliable and prompt start-up of Non-spinning Reserves whenever required. Accordingly, a generating unit designated or allocated as part of the Non-spinning Reserves shall ensure its readiness to start-up and generate its full allocated power within the stipulated period. A generating unit that fails to meet this obligation shall be in breach of the Grid Code and shall be liable for penalties as provided for under the Electricity Market Rules.

System voltage and reactive power criteria

Art 9.28 Operational planning of the grid shall assume that the reactive power requirements at all NITS nodes, feeders and substations are such that the power factor at these points is between 0.90 lagging and unity.

Art 9.29 Operations planning of the grid shall also assume that all generating units connected to the NITS are capable of continuous operation at a power factor of 0.85 lagging and 0.95 leading at rated active power output

APPENDIX 2

National Electricity Grid Code - Article 9.67

Art 9.67 The ETU shall ensure that adequate load shedding facilities that could be initiated automatically by frequency conditions are available and in service to facilitate the restoration of the power system to a Normal State following significant contingency events.

APPENDIX 3

National Electricity Grid Code - Article 9.87

Automatic Frequency Load Shedding (AFLS)

Art 9.87 An AFLS scheme shall be implemented to maintain the frequency of the NITS and to restore it to normal, following frequency deviations outside of the limits established by the Grid Code.

APPENDIX 4

Public Utilities Regulatory Commission (PURC) Act of 1997,Act 538 - Section (3e)

3. Functions of the Commission

The functions of the Commission are as follows –

e. to initiate and conduct investigations into standards of quality of service given to consumers.

APPENDIX 5

Public Utilities Regulatory Commission (PURC) Act of 1997, Act 538 - Section 10

10. Committees of the Commission

The Commission may for the discharge of its functions appoint committees of the Commission comprising members of the Commission or non-members or both and assign to any such committee such of its functions as it may determine.

APPENDIX 6

Table 7: List of documents submitted by VRA

Item No.	Date Submitted	Document Description
1	April 19, 2012	Takeover of Switchyard at VRA power Generating Stations by GRIDCo (Terms of Reference for Team that would be formed to come out with the modalities for the takeover and manage the takeover).
2	April 19, 2012	Volta River Authority Operations Department Station Log, 7/12/2011
3	April 19, 2012	Volta River Authority (Hydro generation Department) Memo on Complete Report on Akosombo Blackout and the recurrent Tripping of Unit 2 (dated 13/12/2011)
4	April 19, 2012	Volta River Authority (Hydro generation Department) Memo on Complete Report on Akosombo Blackout and the recurrent Tripping of Unit 2 (dated 15/12/2011)
5	April 19, 2012	Oil Circuit Breaker once in four years maintenance check list
6	April 19, 2012	Akosombo Generating Station Main Generator
7	April 19, 2012	Chronological event list of unit 2 governor
8	April 19, 2012	Volta River Authority (Akosombo 161 kV switchyard single line diagram)
9	April 19, 2012	Operations of 1T2A and 1T2L2 Oil Circuit Breakers from Last Maintenance Schedule
10	April 19, 2012	Volta River Authority (Hydro generation Department) Memo on inception Report on system collapse Sunday, February 26, 2012 (dated 26/2/2012)
11	April 19, 2012	Volta River Authority (Hydro generation Department) Memo on Complete Report Sunday, February 26, 2012 Blackout(dated 29/2/2012)
12	April 19, 2012	Volta River Authority Operations Department Station Log dated 21/3/2012
13	April 19, 2012	Volta River Authority (Hydro generation Department) Memo on Report on system collapse Wednesday, March 21, 2012 (dated 22/3/2012)
14	April 19, 2012	Auditing the effectiveness of the Akosombo G.S. Grounding network system dated September 2006.
15	April 19, 2012	General Problems with Oil Circuit Breakers at Akosombo GS(Hydro Electric Research Powerhouse Electrical Maintenance)
16	April 19, 2012	GRIDCo letter to VRA on Re: Request for Information Ref: SNS/100.07/5710/12.
17	April 19, 2012	Plant Capacity
18	April 19, 2012	Ghana GRIDCo Company LTD Report on power system collapse which occurred on Wednesday March 21, 2012
19	April 19, 2012	1T2A OCB recorder dated 23/7/2010
20	April 19, 2012	1T2L2 OCB Recorder dated 30/4/2009

APPENDIX 7

Table 8:List of documents submitted by GRIDCo

Item No.	Date Submitted	Documents Submitted.
1	April 20, 2012	Ghana GRIDCo Company LTD Report on power system collapse which occurred on Wednesday December 7, 2011
2	April 20, 2012	Ghana GRIDCo Company LTD Report on power system collapse which occurred on Sunday, February 26, 2012
3	April 20,2012	Ghana GRIDCo Company LTD Report on power system collapse which occurred on Wednesday March 21, 2012
4	April 20,2012	Calibration Results of AFLS relays at Kumasi Substation
5	April 20,2012	GRIDCo Memo From Director, SNS to Chief Executive on AFLS relays calibration results- SNS
6	April 20,2012	GRIDCo letter with ref no. 1001/014/724 to Deputy VRA Chief Executive on RE: Management of Switchyards at Akosombo, Kpong and Aboadze dated 29/3/2011
7	April 20,2012	VRA letter with ref no EXR/1090/250 on Re: Takeover of Switchyards at VRA Generating Stations dated 15/2/2012
8	April 20,2012	GRIDCo Memo on Revision of Automatic Requency Load Shedding (AFLS) Plan dated April 16, 2012.
9	April 20,2012	GRIDCo letter with ref no 1001/014/735 to VALCO Managing Director on AFSL Relay at VALCO dated March 23, 2012.
10	April 20,2012	GRIDCo letter with ref no 1011/001/734 to the Director of Engineering VALCO on Installation of AFLS relay at Smelter Substation dated 2/4/2012.
11	April 20,2012	GRIDCo System Frequency Chart 21/3/2012
12	April 23, 2012	RAPPORT DES TRAVAUX DE MANTENANCE PREVENTIVCE SYSTEMATIQUE
13	April 27, 2012	Installed Capacity and Available Generation Levels of Existing Plants

APPENDIX 8

FACT FINDING COMMITTEE(FFC)- WORK PLAN 11th APRIL- 9th MAY 2012

Date	Venue	Location	Activity
Wednesday 11/4/2012	PURC	Accra	1. Official Inauguration of Committee. 2. Review and analysis of TORs
Thursday 12/4/2012	PURC	Accra	Detailed discussion and analysis of each report on the total system collapse incident.
Friday 13/4/2012	PURC	Accra	1. Write letters to VRA and GRIDCo. 2. Generate probing questions and complete workplan
Monday 16/4/2012	PURC	Accra	1. Analyse the long term deliverables. 2. Analyse total generation,transmission and demand capacities. 3. Determine the total generation availabilities, spinning reserves and any bottlenecks in the power system. 4.Find out the ownership, operation and maintenance entity for the Akosombo switchyard
Tuesday 17/4/2012	PURC	Accra	
Wednesday 19/4/2012	GRIDCo	Tema	Visit GRIDCo System Control Centre and discuss CIE deloading and any other information that will aid the FFC to come out with its findings.
Thursday 19/4/2012	VRA/GRIDCo	Akosombo	Site visit to Akosombo switching and generating stations
Friday 20/4/2012	PURC	Accra	Analyse reports/documents received from VRA/ GRIDCo
Monday 23/04/2012	PURC		
Tuesday 24/4/2012	PURC	Accra	Follow up interviews with operating staff of the utilities
Wednesday 25/4/2012	PURC	Accra	Prepare the draft report
Thursday 26/4/2012	PURC	Accra	
Friday 27/04/2012	PURC	Accra	
Monday 30/4/2012	PURC	Accra	Submit the draft report
Wednesday 02/05/2012	PURC	Accra	Organise a stakeholders' workshop.
Thursday 03/05/2012	PURC	Accra	Complete analysis of stakeholder's comments and incorporate in final report
Friday 04/05/2012	PURC	Accra	
Monday 07/05/2012	PURC	Accra	Prepare the final report
Tuesday 08/05/2012	PURC	Accra	
Wednesday 09/05/2012	PURC	Accra	Present the final report

APPENDIX 9

Terms of Reference for the Constitution of a Fact Finding Committee to Investigate the Causes of Three Total System Collapses in the Ghana Power System

1. Background

PURC is the economic and quality of service regulatory body in Ghana responsible for setting and reviewing tariffs and monitoring of performance in the delivery of electricity, gas and water services. Monitoring of both technical and operational standards of the utilities are other critical functions of PURC.

The reliability and frequency of equipment failure have a direct correlation with the duration and frequency of power quality, especially the incidence of outages. As a result, the Commission is keen on investigating any major fault/failure of equipment that results in widespread power outage.

The Commission has observed that there have been three separate nationwide power outages in the country in the last four months. Initial information gathered revealed that two of these power outages which occurred on the 7th December, 2011 and 26th February, 2012 may have been due to equipment failures at the Akosombo Switch Yard. Preliminary reports by GRIDCo indicate that the third total system collapse which occurred on 21st March 2012, was as a result of decay of voltages on the bus at Akosombo due to an unscheduled import of energy from the Ghana system by CIE of Ivory Coast.

The Commission has decided to constitute a Fact Finding Committee pursuant to Sections 3(e) and 10 of the PURC Act of 1997(Act 538) to carry out a root cause analysis of the incidents that occurred in the Akosombo Switch Yard and the March 21, 2012 total system collapse.

2.0 Objective

PURC is seeking the services of a Fact Finding Committee to conduct a technical and operational investigation to determine the root causes of the three separate total system collapses that led to nationwide power outages.

3.0 Scope of work

The Fact Finding Committee will:

a. Assess and determine the root causes of the three total system collapses on December 7, 2011, February 26, 2012 and March 21, 2012 including the following:
    i. Review maintenance philosophy and procedure identifying any operational risks currently present in the Akosombo switch yards.
    ii. Identify if there are any procurement bottle necks.
    iii. Recommend steps to prevent or minimize future occurrence of similar incidents.
b. Identify critical areas/points in the National Interconnected Transmission System (NITS) that can cause total system collapse, e.g. switch yards and tie-lines
c. Ascertain ownership, operator, age and maintenance of the Akosombo Switch Yard

d. Status of transitional arrangements for assets transfer and operations between VRA and GRIDCo

e. Ascertain the current generation reserve margin of the system and its impact on the stability of the power system

f. Make recommendations for capacity building of PURC staff to adequately equip them for any future incident investigation

g. Investigate any other matters that are relevant to the assignment

The above activities should be consistent with current best-practice around the world and fine-tuned to Ghanaian circumstances.

4. 0 Duration of assignment

The Fact Finding Committee's work shall be completed within four (4) weeks from April 10, 2012 to May 9, 2012.

5.0 Composition of the Fact Finding Committee

Ing. Stephen Akuoko- Former MD ECG	-Chairman
Ing. GD Boateng-Former Director VRA(Generation)	-Member
Dr. Ferdinand Tay-Economist(Consumer Rights President)	-Member
Ing. Andrew Lawson-Former Executive Secretary Energy Foundation	-Member
Ing. Michael Odonkor-Former Director VRA(Transmission)	-Member
Ing. Emmanuel Fiati-Director Energy(PURC)	-Secretary

6.0 Reporting Obligations

The Fact Finding Committee shall be required to prepare and submit to the Technical Committee of PURC the following concise memoranda and reports:

a. A "Draft Final Report" shall be submitted on April 30, 2012. On submission of the Draft Final Report, the Fact Finding Committee in consultation with the Technical Committee of PURC may organise a stakeholder workshop to review the draft report and incorporate comments from the workshop (including MOE, EC, PURC, ECG, GRIDCo, VRA, and ECG) into the final report.

b. A Final Report shall be submitted on May 9, 2012. The Fact Finding Committee shall present six (6) copies of the Draft Final Report and Six (6) copies of the Final Report.

8.0 Fact Finding Committee's Output (Deliverables)

The Fact Finding Committee is expected to provide but not be limited to the following deliverables that shall meet the requirements of the assignment and ultimately the objectives of the PURC mandate:

a. Current technical status of all equipment at the Akosombo Switch Yard determined.
b. Root causes of the two system failures determined.
c. Critical areas/point in the NITS that can cause - system collapse determined.
d. Measures to improve technical performance identified and recommendations, including capital investment requirements in the medium to long term, made to address the problems.
e. Current operational performance of the Akosombo Switch Yard determined and the recommendations, including working capital requirements made to address the issues identified.
f. Ownership, operator, age and maintenance philosophy of Akosombo Switch Yard ascertained.
g. Current generation reserve margin determined.
h. Recommendations made for capacity building of PURC staff adequately equip them for any future incident investigation