Office of Utilities Regulation

Enquiry into JPS Power System Shutdown of July 3, 2007

Enquiry Report

OUR
OFFICE OF UTILITIES REGULATION

December 21, 2007

DOCUMENT TITLE AND APPROVAL PAGE
DOCUMENT NUMBER: Ele 2007/07
DOCUMENT TITLE: Enquiry into JPS power system shutdown of July 3, 2007
1. PURPOSE OF DOCUMENT This document sets out the Office's findings from the enquiry into the causes of the shutdown of JPS power system on July 3, 2007
APPROVAL This document is approved by the Office of Utilities Regulation and the decisions become effective as of the date hereunder. On behalf of the Office: J Paul Morgan **Director General** Date: January 11, 2008

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ENQUIRY INTO JPS POWER SYSTEM SHUTDOWN OF JULY 3, 2007
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BACKGROUND

At approximately 5:11 a.m. on Tuesday, July 3, 2007, electricity customers Island-wide experienced a power outage caused from a complete shutdown of the Jamaica Public Service Company Limited (JPS) electricity grid. This resulted in customers being out of power for periods varying between one to eleven and a half hours. Investigations conducted by JPS immediately following the incident indicated the site of the initiating fault to be in the proximity of the generator step-up transformer for Unit No. 2 steam generator at Old Harbour power station. Damage was seen on two 138 KV lightning arresters located on the high voltage side of Unit No. 2 generator step-up transformer and burning noted on a dislodged phase conductor associated with the line-side of an isolating disconnect switch.

JPS conducted a detailed internal investigation into the event as part of its standing in-house procedures and in compliance with a directive by the Office of Utilities Regulation (OUR or Office). The JPS subsequently submitted a Technical Report to the OUR which has been fully reviewed and analyzed by a panel experienced technical experts assembled by the Office. The Panel also requested answers to specific questions arising from its initial investigations, directed to JPS as well as the main Independent Power Producers (IPPs) Jamaica Energy Partners (JEP) and Jamaica Private Power Company (JPPC).

The result of the OUR investigations into the cause of the system shutdown and recommendations for corrective action to prevent a recurrence, is presented below.

JPS SYSTEM

The JPS Island-wide generation transmission and distribution system is an interconnected grid linking four (4) major power stations through 138 and 69 kV transmission lines. Details of the system are as follows:

Generation

The JPS power system is supplied from four (4) primary generating stations located at Rockfort, Hunts Bay, Old Harbour and Bogue, in Montego Bay. The total installed system capacity is approximately 870 MW comprising steam units, medium and slow speed diesels, gas turbines, hydro power plants and wind generators. The generators provide electrical energy directly into the grid at 138 or 69 kV through generator step-up transformers at an operating frequency of 50 Hz. The major IPPs which sell power to the grid under a power purchase agreement with JPS, are JEP with 124 MW on two (2) medium speed diesel barges at Old Harbour and JPPC from 2x30 MW slow speed diesels at Rockfort. Refer **Appendix 1** for generating capacity details.

Transmission and Distribution System

The transmission grid consists of an Island-wide network of over 800 miles of steel tower and wood poles lines energized at 138 and 69 kV. These are interconnected to the power stations via switchyards and also include primary bulk power substations from which distribution feeders supply customers at locations all over the country. The distribution system is an extensive overhead network constructed mainly on wood and concrete poles and is energized mainly at 24 KV. Reference **Appendix 2** – JPS Electricity System Layout and **Appendix 3** – One Line Diagram of the Existing Transmission System.

Old Harbour Switchyard

The Old Harbour switchyard which is a "breaker and a half" scheme design and energized at 138 kV connects JPS Old Harbour Units 1, 2, 3 and 4 generators and JEP Barge 1 and 2 to the grid. Single circuit 138 kV transmission lines link Duhaney and Tredegar substations and a double circuit transmission line tie Parnassus substation to the Old Harbour switchyard. Refer **Appendix 4**.

Protection and Control Mechanisms

The Old Harbour switchyard is provided with inter-bus and differential relay protection for the generator connections to the switchyard and high speed line protection for the transmission lines linkages to Duhaney, Tredegar and Parnassus sub-stations. The switchyard north and south busbars are also provided with inter-bus protection. Breaker failure protection is installed to cover various zones on the switchyard busbars and will be activated when any of the circuit breakers fail to function to clear a fault when given a trip signal to do so. Circuit breakers are expected to operate and clear a fault within a period of no more than five (5) cycles (Hz) or approximately 0.1 second. The entire scheme is also covered by local and remote system backup protection should the primary mechanism fail to function properly.

The protection system is also equipped with under-frequency relays which are designed to disconnect or shed blocks of load as the grid frequency decays, in four (4) stages at 49.2, 48.9, 48.5 and 48.1 Hz. A delayed time setting of 0.15 seconds is used to prevent spurious tripping. These relays are located to disconnect distribution feeders at various substations located across the Island.

Remote Control and Communication Systems

The JPS system is equipped with a SCADA (Supervisory Control and Data Acquisition) facility which provides real time monitoring and control of the transmission grid Island-wide. A master station is located at the system control centre with Remote Terminal Units (RTU) sited at generating stations, switchyards and substations across the country. Though this system the status of field equipment such as circuit breakers and transformers are automatically monitored, recorded and information transmitted back to the system control centre. The system also enables remote closing of the various circuit breakers and switches across the transmission grid.

The communication system comprises digital microwave as well as Power Line Carrier (PLC) linking all the generating stations, switchyards and substations. These facilitate multiple functions including SCADA, tele-protection, relay monitoring, data services, power plant monitoring, metering and an internal telephone network.

System Load and Operation

The company serves approximately 570,000 customers Island-wide with the bulk of the load (over 50%) concentrated in the Kingston and St. Catherine area. System peak demand was 629.4 MW in April 2007. The system capacity reserve margin is currently over 30% and under normal circumstances adequately meets the load peak demand which typically occurs between 6.30 - 9:00 p.m. on a week day. JPS currently operates with a spinning reserve margin of 30 MW. Voltage regulation is provided by control of the reactive power output of generators, automatic voltage regulation at substations and by fixed and switched capacitor banks located on distribution feeders. Four (4) generating stations (Bogue gas turbines, JEP, JPPC and Hunts Bay) have black-start capability which facilitates self start up after a complete Island-wide shutdown.

SYSTEM SHUTDOWN INCIDENT

On Tuesday July 3, 2007 the JPS All-Island electricity system shut down completely commencing at approximately 5:11 a.m. This caused power outages to customers for many hours, ranging from one to eleven and half hours. JPS has indicated in their technical report of the power system shutdown that the following was the situation prior to, during and immediately following the shut down incident:

Prior to Incident

At 5:00 a.m. on July 3, 2007 prior to the shutdown, twenty (20) generators were on line with a total capacity of 516 MW. The generators were serving a customer demand of 445 MW with a spinning reserve of 71 MW and the system was stable with a frequency of 50 Hz. The available generating capacity from all units was 673 MW with Old Harbour Unit No. 3 out on forced maintenance. The transmission and distribution was fully intact prior to the shutdown and the power system was operating within the normal operational limits. Fair weather was reported across the Island.

Shutdown Sequence

The sequence of system shutdown was precipitated by a two-phase to ground fault resulting from flashovers on two (2) 138 kV high voltage lightning arresters mounted adjacent to Old Harbour Unit No. 2 step-up transformer. Indications based on relay event reports obtained from Duhaney and Tredegar substations suggest that the incident started as a single line to ground fault and evolved into a two-phase to ground fault. Inspection of Unit No. 2 transformer and arresters revealed evidence of pitting and outright burn- through of the corona rings for the H3 (C-phase) and H2 (B-phase) lightning arresters. There was also a burnt ground lead connector on the C-phase Arrester, as well as other signs of scorching. A burnt B-phase down-dropper was observed on the line side of disconnect switch 9-227. Disconnect switch 9-227 is used to isolate Unit No. 2 from the 138 kV grid.

Refer **Appendix 5** for pictures of damaged 138 kV lightning arresters and dislodged switch down-dropper.

Circuit Breaker and Protection Relay Operations

Resulting from the fault, trip signals were sent from protective relays to Unit No. 2 line and generator breakers Nos. 9-220A and 9-220 respectively. Refer to Old Harbour switchyard layout diagram showing circuit breaker positions – **Appendix 6**. Circuit breaker 9-220 failed to trip within the required time because of a stuck pole mechanism (subsequent tests indicated that 1-pole of the 3-pole 138KV circuit breaker had an inherent delay in the trip operation). The stuck breaker pole was still facilitating the flow of fault current thus maintaining the fault. Breaker 9-220A appeared to have opened correctly.

However, the failure of breaker 9-220 to operate properly means that breaker failure primary and backup systems located at Old Harbour, Duhaney, Tredegar and Parnassus substations would now function to clear the fault. In consequence, all south busbar circuit breakers at the Old Harbour switchyard tripped as a result of the failure of 9-220. The circuit breaker operating sequences and initiated protective relays are shown in **Appendix 7**.

All generators at Old Harbour came off-line including JEP barges 1 and 2, due to the separation of the units from the switchyard. The remaining generators between Rockfort, Hunts Bay and Bogue were unable to carry the system load despite the operation of all four (4) stages of under-frequency load shedding, resulting in total collapse of the system. Information on the system response in respect of frequencies and busbar voltages at 69 and 138 kV is shown in the attached **Appendix 8**.

Generator Tripping Operations

Failure to promptly clear the fault at Old Harbour caused tripping of generators across the Island in the following sequence:

a) JPPC units at Rockfort
b) JEP Barge No. 2 generators
c) JEP Barge No. 1 generators
d) Old Harbour Units 1 and 4
e) JPS diesel barge at Rockfort
f) Hunts Bay Unit B6
g) Other generators still remaining on the system

Under-frequency Load Shedding

Automatic under-frequency load shedding relays located at various substations across the island and designed to trip distribution feeders operated in an effort to save the system from collapse. These are set in four (4) stages and shed blocks of load in sequence when the system frequency declines below the designated 50 Hz level. Available information indicates that the last stage (stage 4) operated at just over two (2) seconds after the commencement of the fault. The load shedding operation is set out in the attached **Appendix 9**.

Protection System Performance

Busbar protection relays at the Old Harbour switch yard as well as generator, line protection and other primary and backup relays at Old Harbour, Parnassus, Tredegar and Duhaney functioned to clear the fault. Indications are that the fault was completely isolated via circuit breaker 9-420 at Old Harbour switchyard when it tripped at 1.051 seconds after fault commencement. No major non-operation of protection relays was observed.

SCADA and Communication System

Various components of the SCADA and communication system comprising PLC, digital microwave, fiber network and remote control units located at generating stations and substations across the island were all called upon to function properly during the system shutdown. There appear not to be any major failure or nonfunctioning of these critical components given that the system shutdown proceeded according to expectation. Information was generally also available to system operators to facilitate restoration as well as to personnel carrying out post shutdown analysis.

SYSTEM RESTORATION

The system restoration began at approximately 6:15 a.m. and was completed over a period of approximately twelve (12) hours. This commenced with black-starting of systems at Bogue and Hunts Bay using Gas turbines Nos. 7 and 10. The transmission grid linking the major power stations was closed up and energized at 10:19 a.m. except for a portion of the Old Harbour switchyard where the fault had been identified. Customers were added to the system slowly as new generators were brought on-line so as not to compromise the safety or stability of the grid. However, it is noted that some obstacles were encountered during the restoration process including:

a) The following breakers at Old Harbour could not be closed due mainly to charging air problems: 89/9-530, 9-630, 9-830 and 8-130.
b) The following breakers at Parnassus were unable to close remotely: 26/8-170, and 26/8-410.
c) Some generators at (JPPC, Rockfort, Old Harbour) took longer than normal to come on-line following energizing of the stations.
d) Bogue GT3 tripped and GT12 & 13 were restricted to 25MW to facilitate ST14 coming on line, JEP sets tripped at various times during the process.
e) JPPC took longer than normal to ramp up to full load.

Electricity supplies to the last set of customers took place at 4:09 p.m. on July 3, 2007.

QUESTIONS TO BE ANSWERED

Following an initial analysis of the system shutdown, the OUR posed a number of questions to the company, in order to fully brief itself on the situation and be in a position to carry out a technical review. These questions are set out in **Appendix 10**.

SEQUENCE AND ANALYSIS OF SHUTDOWN

An Enquiry Panel constituted by the OUR carefully reviewed all the technical information provided voluntarily by JPS and the main IPPs, JEP and JPPC. After review, the Panel has arrived at the following opinion concerning sequence of the system shutdown:

1. The system shutdown was initiated when a line-to-ground flash-over occurred on two (2) lightning arresters mounted adjacent to Old Harbour generator No. 2 step-up transformer.
2. The flash-over most likely occurred because the surface of the lightning arresters which are glazed ceramic may have been polluted by the saline environment at the station, which is located in very close proximity to the sea (location of station near to sea is necessary as sea water is used to cool the steam Units 1-4 at Old Harbour)
3. The salt pollution would have facilitated electrical tracking and then arcing on the surface of the lightning arrester during the dawn hours when moisture will

condense on the ceramic surface (it is noted that the flash-over in fact occurred at 5:11 a.m.).

4. The salt and water comprise a weak electrolyte which would enable the conduction of electricity because of the very high voltage (138 kV system which the lightning arrester is attached).
5. Protective relays in the switch yard operated correctly and initiated trip signals to two (2) 138 kV Oil Circuit Breakers (OCB) as designed for the purpose of quickly isolating the fault on the two (2) lightning arresters.
6. These relays were required to operate within 0.1 seconds (or 5 cycles) in order to prevent the system from going into unrecoverable instability caused from transient swings in generator rotor speeds.
7. However, while one of the connecting circuit breakers operated correctly the second circuit breaker (9-220) failed and only tripped after a full four (4) seconds. This failure is attributed to the sticking of one pole of the three-pole breaker as verified by subsequent inspection.
8. The delay in clearing the fault caused breaker failure and other backup relays at the switch yard to operate and trip the next in sequence 138 kV circuit breakers.
9. Line distance relays and other backup protection systems located at Parnassus, Tredegar, and Duhaney sub stations also operated properly to isolate the failure at the Old Harbour switch yard.
10. The falling system frequency initiated the operation of all four (4) stages of under frequency relay causing shedding of some 57% of the system load.
11. At this point the Critical Fault Clearing Time for the system was already exceeded and therefore the system was in a state of unrecoverable instability.

In consequence of the above events, all generators tripped off in sequence resulting in a total shutdown of the entire Island's electricity grid.

TECHNICAL COMMENTS AND RECOMMENDATIONS

In conducting the investigation, the OUR noted a number of items, particularly relating to the protective relaying system at the Old switchyard which need follow-up by the company. These are listed in **Appendix 11** and framed under the captioned of Comments, Observations and Recommendations. These matters should be accorded consideration and priority by JPS since the reliability of the protection system is of primary importance to system stability and the Old Harbour switchyard is clearly the most sensitive to failure given the siting of over 300 MW of the Islands generating capacity at that location.

It is noted that the company has already recognized some of these problems and have already focused attention on specific items, details of which are listed in **Appendix 12**

CONCLUSIONS FROM SHUTDOWN OF JULY 15, 2007

The investigations have lead to a number of specific conclusions. The summary of major conclusions following the OUR's reviews of the shutdown are as follows:

a. The system shutdown was initiated by the development of a flash-over (electrical arcing) on the external ceramic surface of two (2) 138 kV lightning arresters mounted adjacent to generator No. 2 step-up transformer at Old Harbour.

b. The flash-over initiated protective relays which designed to quickly isolate the fault and thereby prevent system instability caused from the high short circuit current flow.

c. However, one of two circuit breakers located at the switchyard which should have operated delayed in its opening sequence.

d. The delay caused other local and remote protective relays which serve as backup in the event of a breaker failure, to operate but the system critical fault clearing time had already exceeded.

e. All generators attached to the grid independently disconnected as a result of initiation of generator protective relays due to frequency swings which were outside governor tolerances.

f. In the circumstances, the full shutdown of the JPS system was inevitable.

FINDINGS AND RECOMMENDATIONS

The OUR's investigation of the system shutdown has identified a number of matters which require attention. The OUR has also reviewed its Findings from the previous system shutdown which occurred on July 15, 2006 and have restated those items which it considers pertinent to this particular shutdown. These are indicated below for follow-up action by the company.

1. It is imperative that the general maintenance of all major substations and switchyards in particular those associated with the major generating stations located at Rockfort, Hunts Bay, Old Harbour and Bogue be given every priority.

2. The contamination of insulators in the switch yard and on step up transformers and related equipment should be given special attention and routinely cleaned to remove saline pollution.

3. The maintenance of equipment in the above mentioned switchyards must be given priority attention and routine maintenance cycles rigidly adhered to, given that the failure of just one single device can result in a total system shutdown has evidenced by the current incident.

4. High voltage circuit breakers located in these switchyards are now of advanced stage and the company must conduct a review of all such device in switchyards across the island for the purpose of assessing their reliability and for the intention of making replacements based on the achievement of the useful life of the device.

5. The company must proceed quickly with the development of a transmission and distribution code which covers the design operations and proper maintenance of the system including switch yards and service stations.

The following findings are also relevant from the last system shutdown of July 15, 2006, approximately one year ago and are repeated below:

6. The overall system relay coordination scheme should be reviewed by appropriate experts (The Office considers that this activity is of fundamental importance to continued system stability in instances of faults occurring on transmission lines and at substations/switchyards and must be given absolute priority).

7. The non-operation of under-frequency relays during a system stability crisis requires further examination. JPS recommendation that a voltage load shedding scheme be incorporated as well to enhance system stability, is supported by the OUR.

8. The company's spinning reserve and under-frequency load shedding policies must be critically reviewed to ensure dynamic stability of the generating system under normal operating conditions and probable contingency scenarios.

9. All JPS generating stations, IPP plants and JPS System Control Centre must be time synchronized as a matter of urgency.

10. The sequence of events recorders for all power stations and generators must be made fully functional and kept in a state of serviceability at all times.

In addition, the Office further recommends that action be taken by JPS in respect of upgrading its current operating practice and procedures, particularly in respect of the inspection and maintenance of the system infrastructure and equipment, where presently deficient.

Several of the above matters form the basis of further specific recommendations by the PORT Study conducted as a result of the July 2006, system shutdown, which have been identified for implementation.

The Office is of the view that the outage has again precipitated a number of problems which would have remained undetected but which have surfaced only because of the system collapse. It also underscores the requirement for further action on the company's side to promptly deal with certain items which are fundamental in instigating a system collapse such as the Critical

Fault Clearing Time and the coordination of relevant protective relays. Also, the need to inspect and maintain the system infrastructure and equipment is clearly highlighted.

A number of these recommendations will form the basis of a separate Directive to be issued to JPS, requiring the strict implementation of specific items.

<u>APPENDIX 1</u> - Generating System Capacities

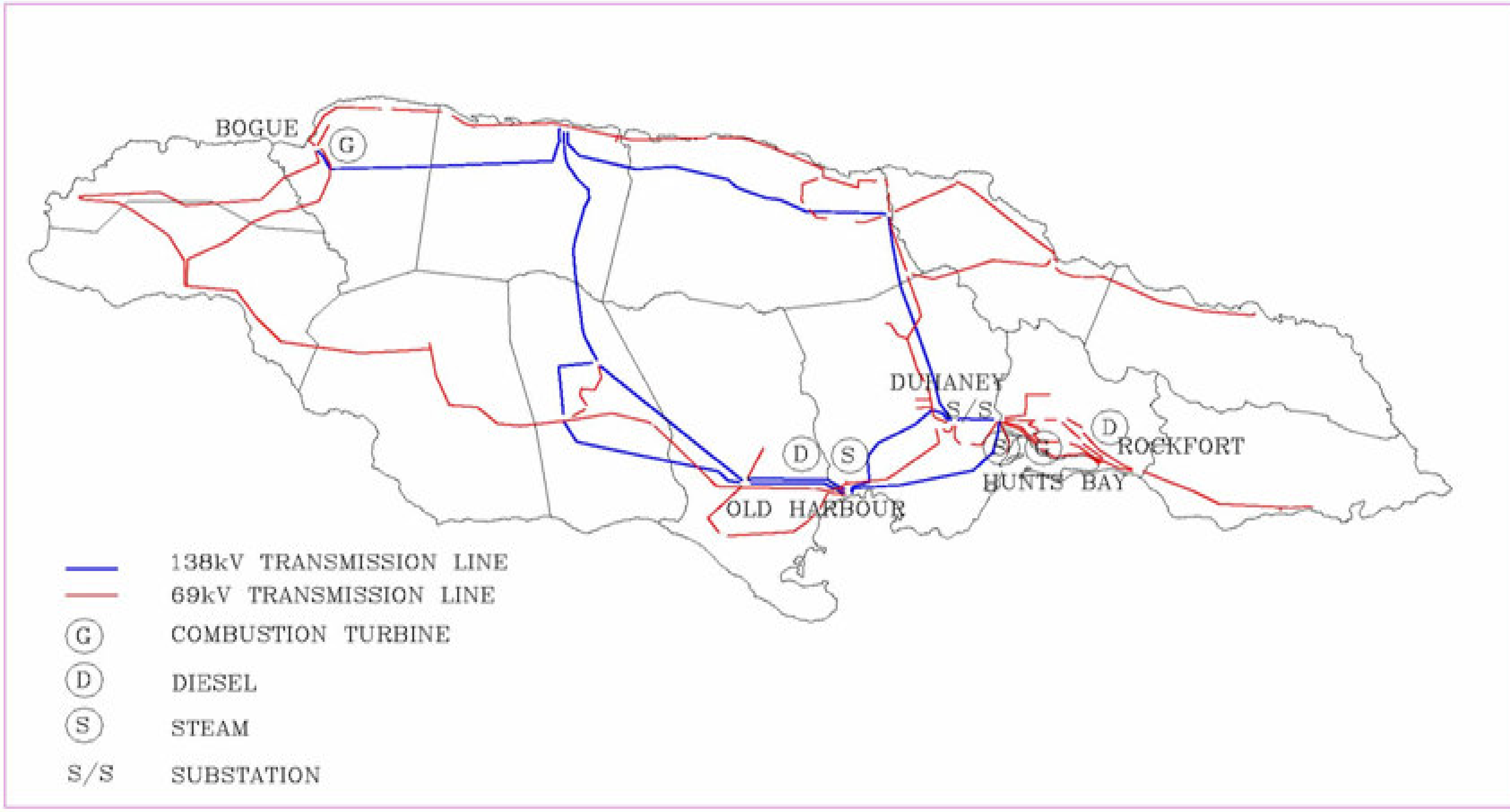
JPS Power Plants

Site	Type	Name Plate (MW)	Maximum Continuous Rating (MW)
Old Harbour	Steam	230.0	223.5
Rockfort	Diesel	40.0	36.0
Hunts Bay	Steam	68.5	68.5
Hunts Bay	GTs	55.0	54.0
Bogue	GTs	247.8	217.5
Hydros*	Hydro	22.9	21.6
Total		664.2	621.1

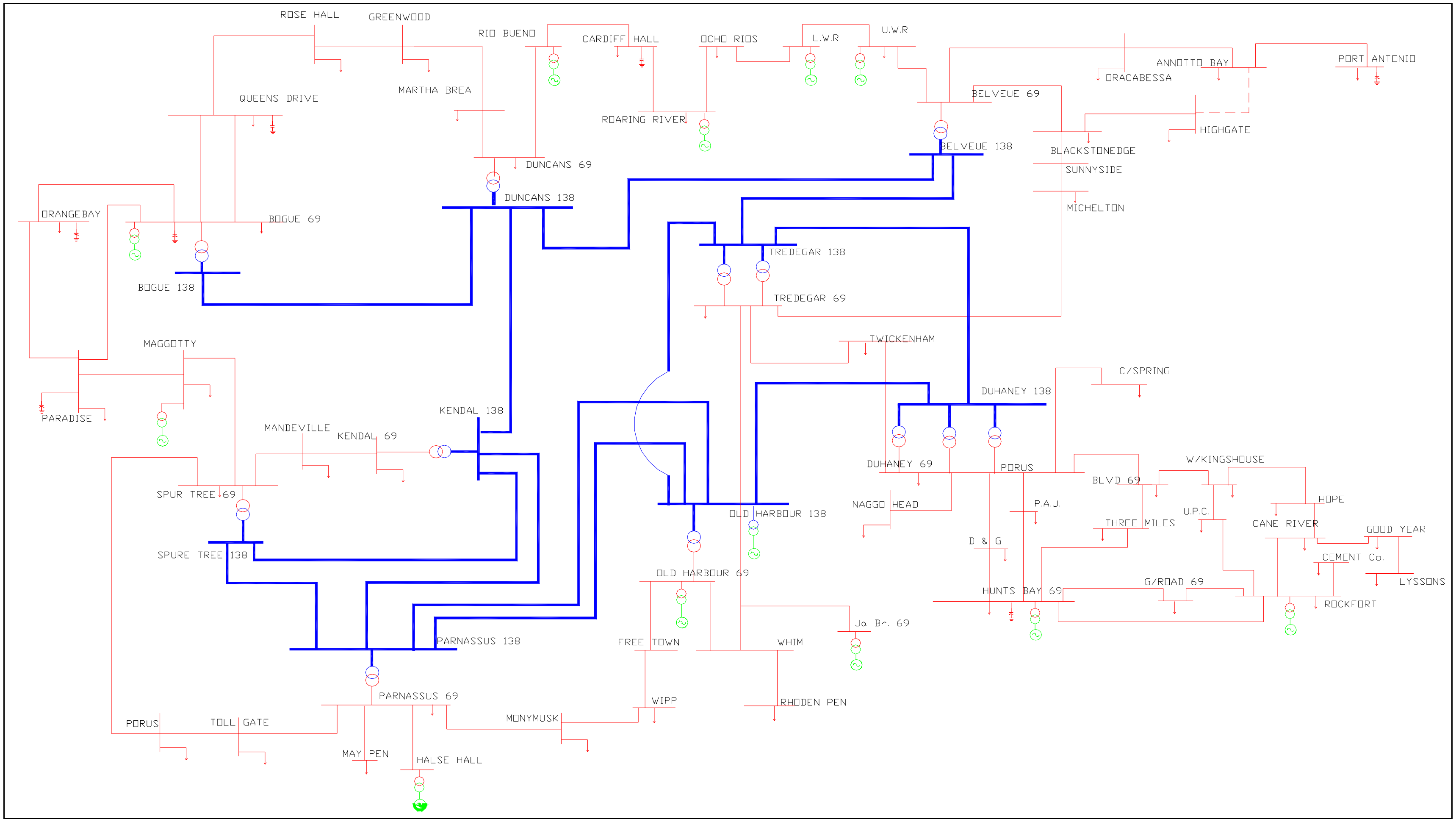
Independent Private Power Plants

Plant	Type	Name Plate (MW)	Maximum continuous Rating (MW)
Jamaica Energy	Medium Speed	124.36	124.36
Partners	Diesel		
Jamaica Private Power Company	Slow speed Diesel	61.30	59.2
Jamalco	Cogeneration	11.00	11.00
Wigton	Wind	20.00	As available
Firm Total		216.66	196.66

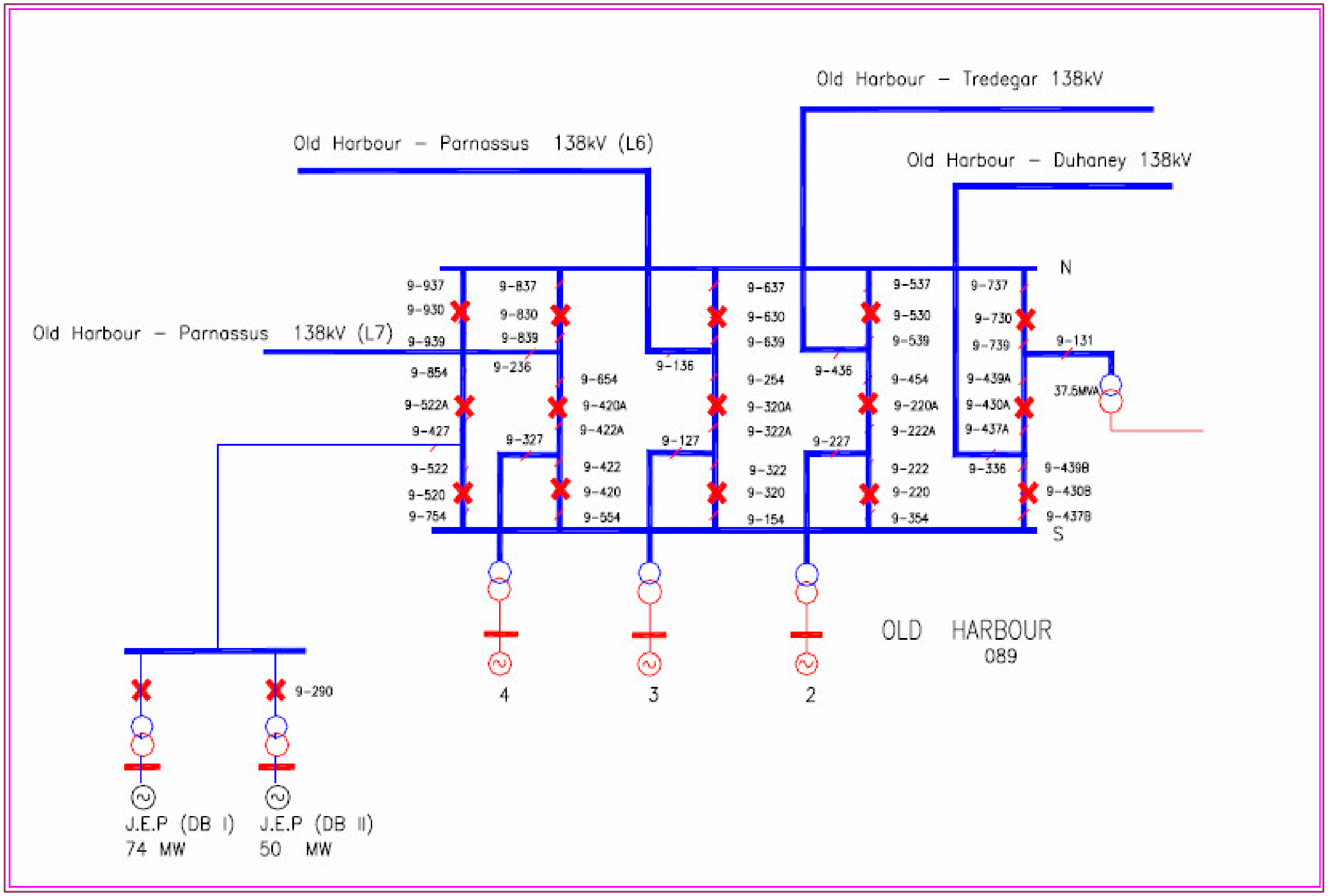
APPENDIX 2 – JPS Electricity System Layout



APPENDIX 3 - One Line Diagram of the Existing Transmission System



APPENDIX 4 - Old Harbour 138KV Switchyard Layout Diagram



APPENDIX 5 - Pictures of Lightning Arresters and Burnt Conductors at Old Harbour Switchyard

Inspection of Old Harbour Unit No. 2 transformer and arresters revealed evidence of pitting and outright burn-through of the corona rings for the H3 (C-phase) and H2 (B-phase) lightning arresters. There is also a burnt ground lead connector on the C-phase Arrester, as well as, and other signs of scorching.

A burnt B-phase down-dropper was observed on the line side of disconnect switch 9-227. Disconnect switch 9-227 is used to isolate Unit No. 2 and its generator step-up transformer from the 138 kV grid.

Photo #1: Burnt ground conductor connector at base of outer phase arrester

Photo #2: Burnt outer phase arrester base

Photo # 3: Scorching on middle phase arrester

Photo #4: Burn-through of corona ring at top of arrester – middle phase

Photo #5: Dislodged down dropper on middle phase of disconnect switch 9-227

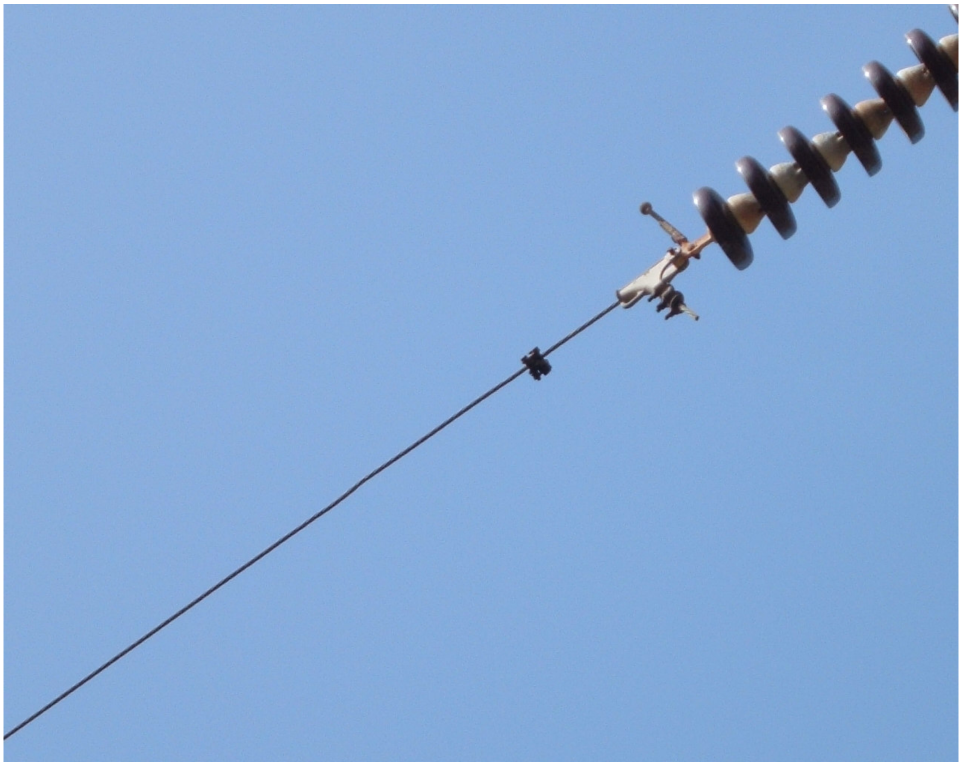
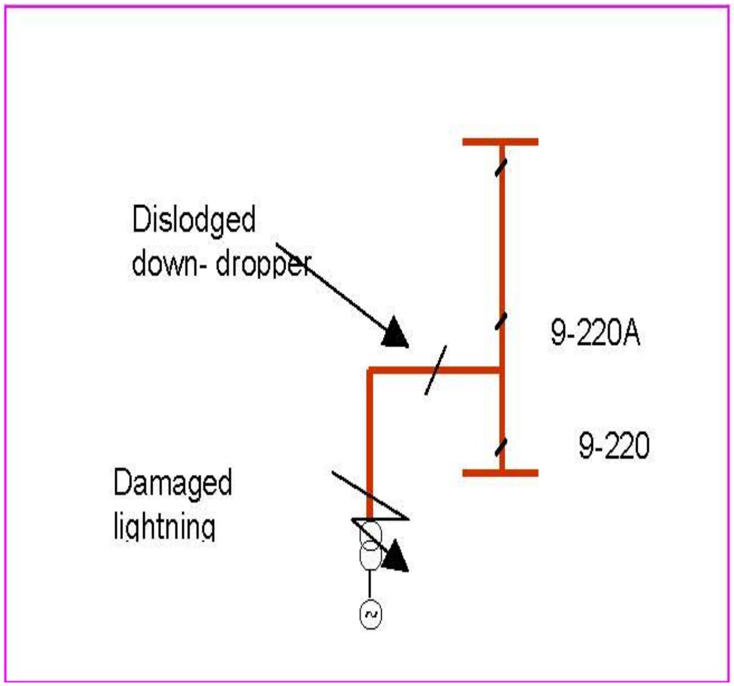


Photo #6: Connector for the dislodged down dropper for disconnect switch 9-227

APPENDIX 6 - Old Harbour Switchyard Layout Diagram Showing 138KV Circuit Breaker Positions



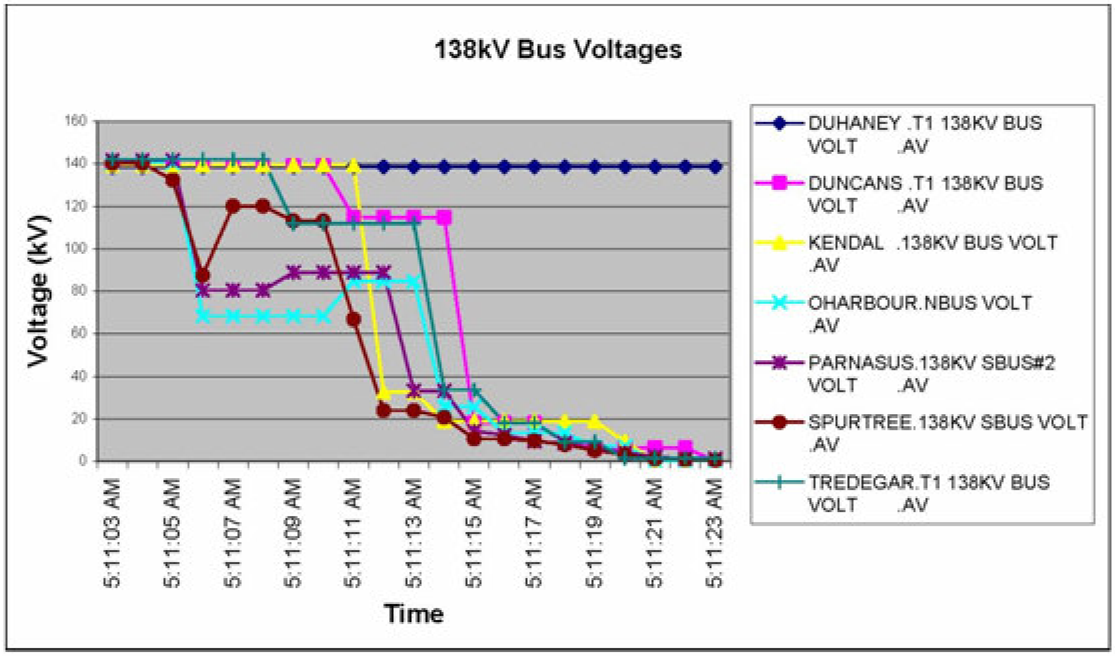
Section of the single Line Diagram

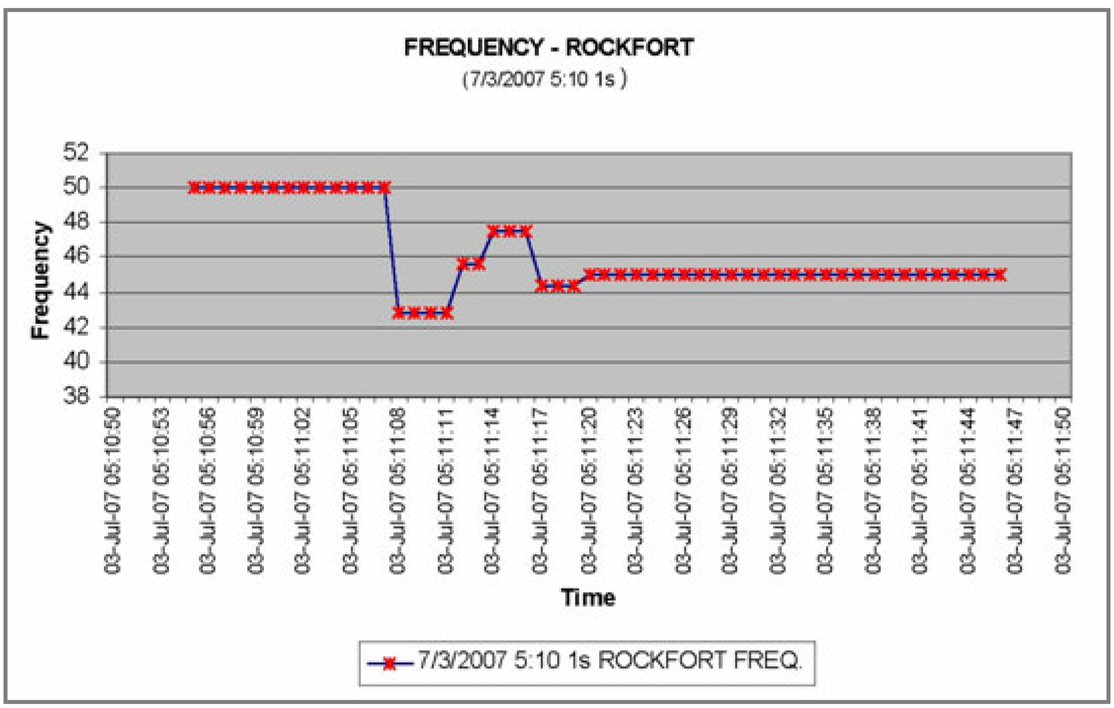
For the damaged lightning arresters and the dislodged down-dropper on disconnect switch 9-227, breakers 9-220 and 9-220A are required to trip along with the generator.

APPENDIX 7 – Major Protective Relay Operations Tripping 138KV Circuit Breakers to Clear the Fault

No	Station	Breaker(s)	SOE Time	Elapsed Time (ms)	
				Actual	Design
(0)	Old Harbour		5:11:05.608	0.00	Fault inception
(1)	Old Harbour	Unit 2 (9-220A)	5:11:05.820	212	80
(2)	Old Harbour	Unit 2 (9-220)	5:11:09.958	4350	80
(3)	Old Harbour	South Bus (9-520)	5:11:06.591	983	330
(4)	Old Harbour	South Bus (9-430B)	5:11:06.613	1005	330
(5)	Old Harbour	South Bus (9-320)	5:11:06.655	1047	330
(6)	Old Harbour	South Bus (9-420)	5:11:06.659	1051	330
(7)	Duhaney	Old Harbour (9-830)	5:11:06.079	471	470
(8)	Tredegar	Old Harbour (9-930)	5:11:06.306	698	470
(9)	Tredegar	Old Harbour (9-430)	5:11:06.317	709	470
(10)	Parnassus	Old Harbour L7 (9-1230)	5:11:06.371	763	470, 730 *
(11)	Parnassus	Old Harbour L7 (9-250)	5:11:06.372	764	470, 730 *
(12)	Parnassus	Old Harbour L6 (9-730)	5:11:06.376	768	470, 730 *
(13)	Parnassus	Old Harbour L6 (9-150)	5:11:06.378	770	470, 730 *

<u>APPENDIX 8</u> – System Voltages and Frequencies





APPENDIX 9 – Under Frequency Relay Operations

Stage 1		Stage 2		Stage 3		Stage 4	
Substation	**% of total Load Shed**	**Substation**	**% of total Load Shed**	**Substation**	**% of total Load Shed**	**Substation**	**% of total Load Shed**
Bogue	-	Hunts Bay	1.30%	Three Miles	3.22%	Greenwich Road	2.04%
Hunts Bay	0.26%	New Twickenham	4.99%	Cane River	0.45%	Hunts Bay	-
Orange Bay	1.38%	Washington Blvd	4.8%	Duhaney	1.73%	Naggos Head	-
Paradise	1.10%	Hope	1.1%	Greenwich Road	2.05%	Rockfort	1.61%
Spur Tree	1.46%			Hope	1.55%	Tredegar	4.49%
Up Park Camp	-			Kendal	1.12%	West Kings House	3.95%
Washington Blvd	1.74%			May Pen	1.64%		
				Parnassus	3.11%		
Total % per Stage	5.93%		12.19%		14.89%		12.10%

Total % Shed 45.11%

APPENDIX 10 - Information and Questions for Enquiry

OFFICE OF UTILITIES REGULATION

Information and Questions for Enquiry – JPS System Shutdown of July 3, 2007

1. The system status prior to the commencement of the system shutdown incident.
2. Operating sequence of the system shutdown with indication of circuit breakers which operated and at what time.
3. Generators which came off-line, including IPP units, at what time and the reason for the separation from the system grid.
4. Any partitioning of the transmission system, location and time.
5. In respect of Old Harbour switchyard, all circuit breakers and relays which operated, in what sequence, inclusive of times.
6. Remote backup relays external to Old Harbour switchyard which operated and time alignment with the Old Harbour switchyard incident.
7. Any SOE recordings from the System Control Center or generating plants relevant to the incident which would serve as confirmation of items (2) to (6) above.
8. Any eye witness account pertinent to the event.
9. Information on currents, voltages and frequencies which may have been recorded on bus-bars across the island, particularly at Old Harbour.
10. The cause attributed to the delayed or non-tripping of any circuit breaker at Old Harbour switchyard.
11. Cause attributed to flash-over of two (2) 138 KV lightning arresters on Old Harbour generator Unit #2 step up transformer.
12. Cause attributed to damage to the Old Harbour switchyard isolating switches for generator Unit #2 step up transformer, including burning of jumpers.
13. Whether any circuit breaker, switch, protective relay or any other major item of equipment in the Old Harbour switchyard was found defective or otherwise out of service.
14. Whether there is any indication that a fault occurred at any point on the 138 KV system external to the Old Harbour switchyard.
15. The date or dates of the last general service carried out in relation to Old Harbour switchyard.

16. Specifically, the date or dates when the switchyard insulators, including lightning arresters and transformer and circuit breaker insulator bushings were last cleaned (of dust and saline contamination).
17. Specifically, the date or dates when the relevant circuit breakers involved in this incident at the Old Harbour switchyard was last inspected and maintained.
18. Specifically, the date or dates when the key protection relays involved in this incident at the Old Harbour switchyard were last inspected and maintained.
19. Availability of the SCADA remote monitoring and control and telecommunication systems.
20. Black-start capability of generating units.
21. Information on the sequence of system restoration, time lines and any incidents or issues resulting from the close-up exercise.
22. Single line diagram for Old Harbour switchyard.
23. Electrical diagram of Old Harbour switchyard, showing protective relay types and locations.
24. Tripping logic for Old Harbour switchyard.
25. Island transmission grid net-work.
26. JPS' opinion as to the primary initiating event leading to the system collapse.

JULY 5, 2007

APPENDIX 11 – OUR Additional Technical Comments and Recommendations

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Comments and Observations

The following observations and comments are made on the JPS Technical Document submitted to the OUR –

1. Executive Summary, Page 3:

    a. The breaker operation speed is stated to be 100 ms. Elsewhere in the document, it appears that the breakers are rated for 3 cycle interruption, which indicates that the operating time after receiving a trip signal is in fact 2 cycles (40 ms on a 50 Hz basis). This point needs clarification here and elsewhere in the document.

2. Paragraph 3.4.1, page 24:

    a. The statement is made that the relays were "… in good working order and within calibration". On reviewing the calibration records presented in Appendix B, this does not appear to be supported, based on the following examples -

        i. **Relay 50BF-G2**: Pickup As found/As left – upper unit 4.9/3 A, middle unit 6.6/3.98 A (spec 3 A), lower unit 2.1/.55 A (spec 1.0 A) – test 16 July 2007

        ii. **Relay 50BF-G3**: Pickup As found/As left –upper unit 4.44/4.09 A, middle unit 7.16/4.07 A (spec 4 A), lower unit 4.22/2.07 A (spec 2.0 A) – test 16 July 2007

        iii. **Unit Aux Xfmr DDT-12 relay (presumably 87T?) -** Pickup As found/As left (spec 2.5 A) – R 1.80/1.83 A, Y 2.3/2.3 A, B 2.00/2.10 A – test 6 July 2006

        iv. **Generator Overcurrent Protection CDV22 relay-** Pickup As found/As left (spec 5 A) – R 4.2/5 A, Y 4.9/4.2 A(??), B 4.4/4.9 A – test 28 July 2006

    b. No timing tests were recorded for the 50 BF relays or the differential relays – these are needed to confirm satisfactory operation.

    c. No mention has been made of Integrity Tests having been done on the circuits subsequent to the shutdown.

3. Paragraph 3.4.2, Page 26:

a. The results of the timing tests on the other circuit breakers were not included in Appendix C. This information is critical to determining the overall condition of the equipment at the station and is necessary data for the report.

b. No indication is given as to the method and equipment used to measure the circuit breaker timing – this is required to assess the adequacy of the results.

c. It is noted that many other circuit breakers of the same general type and vintage as the Old Harbour breakers (3-tank, bulk oil) were installed at other JPS substations. A listing of similar breakers still in service should be provided, together with a summary of their maintenance history, including timing tests.

4. Paragraph 3.5, Page 26:

a. Noted that the weather was reported as clear, but the results of the observations on contamination made in Appendix D must be highlighted in the main report – this appears to be a significant contributing factor to the initial fault condition.

5. Paragraph 5.3.4, Page 43:

a. It is reported that the JEP Barge I generators tripped due to overcurrent. It is not clear why the Barge I step-up transformer ground fault protection did not operate similar to the Barge II protection. Advise the settings of the two sets of ground fault relays.

6. Paragraph 5.4.1, Page 45:

a. The operating time of the 87T relay is stated as 10 mS. It is noted that this relay has a time dial setting of 1.5. Need to know the significance of this setting – is the relay in fact instantaneous? Provide information on this.

b. According to the relevant ANSI standard, the circuit breaker interrupting time of 3 cycles consists of the following – 1 cycle for relay operation to energize the breaker trip coil, 2 cycles for the mechanism to open and the fault current to be interrupted.

c. Overall operating time for BF clearance should be as follows –

    i. 87TB+A86V+B86V time = 10 mS (see above query on 87T); 50BF-G2 should operate concurrently with these (also 10 mS)

    ii. 62BF-G2 delay = 250 mS

    iii. 86BF relay time = 10 mS

    iv. Breaker clearing time after trip coils energized = 40 mS

    v. Total clearing time from fault inception = 310 mS (ideal, should also allow for inaccuracy of 62 BF)

d. The breaker clearing time needs to be corrected elsewhere in the document as well, in the interest of strict accuracy.

Recommendations

The following general recommendations are made –

1. The protection schemes for the major generating units in service at JPS should be evaluated for urgent upgrade to modern microprocessor based equipment.
    - Based on a review of the test results, the original electromechanical relays are subject to drift in their settings between the unspecified calibration intervals.
    - Operating speed and accuracy need to be carefully maintained so as to achieve the design goals that JPS has set.
    - Keeping equipment in service after nearly 50 years is a difficult proposition, given the lack of available spares and the effort in terms of man hours to calibrate and maintain the equipment.
    - Strongly recommend that these schemes should be updated (all units > 15 years old).
2. The condition of all 138 kV bulk oil circuit breakers should be evaluated and consideration should be given to developing a plan for replacing any breakers found to be in marginal condition.
    - Operation of these circuit breakers is critical to satisfactory operation of the protection systems in achieving the goal of maintaining system stability.
    - Strongly recommend that this condition evaluation be done on an urgent basis
3. If not already in place, institute a program for insulator cleaning at Old Harbour that is based on insulator condition, rather than a time-based program.
4. JPS to provide the following additional information –

- Confirm that the test sheets provided were in fact for the Generator 2 main step up transformer differential relays.
- Perform timing tests on the Generator 2 transformer differential relays.
- Perform timing tests on the 50BF relays (specifically 50BF-G2).
- Advise whether integrity tests were performed on the Generator 2 protection circuits subsequent to the shutdown and advise the results of any CT tests performed; otherwise, submit the latest CT test data available.
- Provide the results of the timing tests performed on all circuit breakers at Old Harbour.
- Advise details of the test equipment and method used to perform the timing tests.
- Provide a list of circuit breakers still in service on the JPS system that are similar in design and age to breaker 9-220 at Old Harbour.

- Also provide a summary of the maintenance history, including timing tests, for these breakers.
- Provide details of the settings of the JEP Barge I and Barge II step-up transformer 138 kV ground fault protection schemes.
- Provide information clarifying the time dial setting of the type DDT –12 differential relays

APPENDIX 12 - JPS ACTIONS SINCE SYSTEM SHUTDOWN

JPS reported that they took the following actions after the system shutdown of July 3, 2007.

OLD HARBOUR

1) Replaced lightning arresters for Unit No. 2 generator step-up transformer.
2) Timing verification performed for breakers 9-220, 9-520, 9-320, 9-830, 9-630, 9-420A & 9-320A.
3) Performed timing tests on breaker fail timers for 9-220, 9-320, 9-420, 9-520 and 9-430B
4) Repaired jumper for disconnect switch 9-227
5) Accelerated contamination mitigation programme (insulator cleaning)
6) Accelerated general maintenance of Old Harbour switchyard.
7) Replaced circuit breaker 9-220 with SF-6 type circuit breaker.

PARNASSUS

8) Reviewed and implemented 50M (LOP block) distance relay settings at Parnassus for Old Harbour lines 6 & 7.