Office of Utilities Regulation

Enquiry into JPS Power System Shutdown of July 15, 2006

Final Report

OFFICE OF UTILITIES REGULATION

September 19, 2006

DOCUMENT TITLE AND APPROVAL PAGE

DOCUMENT NUMBER: Ele 2006/04.1

DOCUMENT TITLE: Enquiry into JPS power system shutdown of July 15, 2006

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 15, 2006

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:

OFFICE OF UTILITIES REGULATION

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J. Paul Morgan
Director General
Date 19 Sept 2006

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Attachments

Office of Utilities Regulation

ENQUIRY INTO JPS POWER SYSTEM SHUTDOWN OF JULY 15, 2006
Final Report

INTRODUCTION

Electricity supply to customers island-wide was disrupted on Saturday July 15, 2006, commencing at 4:16 pm, following the complete collapse of the Jamaica Public Service Company Limited (JPS) system. A "*Preliminary Technical Report*" on the system shutdown prepared by JPS, dated July 27, 2006 was subsequently submitted to the Office of Utilities Regulation (OUR). The OUR conducted an initial investigation into the system shutdown and submitted its "*Preliminary Findings*" in a Report dated August 11, 2006.

In its Preliminary Report, the OUR made a number of observations and comments and posed some eighteen (18) questions to which the JPS was required to submit a response. Also, several interim recommendations were made following the work of the preliminary investigations. JPS followed up its initial report with a *"JPS Final Report"* comprising a number of detailed technical reports, together with other attachments and documentation dated August 17, 2006, all of which were submitted to the OUR.

The OUR has carefully reviewed the submissions and after consultations with JPS and other relevant stakeholders to the system shutdown, now presents its completed findings contained herein in the OUR Final Report.

JPS PRELIMINARY AND FINAL REPORTS

In the JPS preliminary report, assumptions had been made in regard to a number of the events which took place. Also, key field information was not available on which to properly arrive at conclusions.

In the JPS Final Report, a number of the outstanding technical issues were addressed and relevant details presented. In addition, reports were submitted from the various areas of JPS operations, namely:

- generation
- system control centre
- transmission system
- protective relaying

- communications
- Supervisory control and data acquisition (SCADA)
- System planning

Also, reports from the Independent Power Producers (IPPs), Jamaica Energy Partners Ltd. (JEP), Jamaica Private Power Company Ltd. (JPPC), Jamalco and Wigton were included. The Company had also carried out computerized simulations of the system collapse addressing the issue of short term stability, frequency, voltages as well as fault current levels at various points on the island-wide electric grid.

SUMMARY OF JPS FINAL REPORT

Situation Prior to the Shutdown

i) In its report, JPS indicated that of the total installed system generating capacity of 817 MW, only some 613 MW was available due to a number of units being out of service on forced and planned maintenance. Capacity on-line at the time was 497.3 MW supplying a load demand of 465.6 MW and providing a spinning reserve of 31.7 MW. The recorded system frequency was 50 Hz and system bus bar voltages were within the normal operating limit of ± 5 percent.

ii) The transmission system was largely intact, except for planned maintenance on 3 transmission lines and a distribution substation in the Corporate Area and eastern side of the island.

iii) The National Weather Service reported rain and lightning in the northern areas of the island.

iv) Some 47 substations are monitored and remotely controlled by the Company’s SCADA system; however, at the time of the shutdown 14 were not under SCADA supervision due to communication problems.

v) The Company has indicated that between 2003 and 2006 wherein 1586 interruptions took place on the transmission system, there was a 97% correct clearance by the relay protection system and no incident of a system-wide collapse of the grid. In respect of the Duncans/Bogue 138 kV transmission line, 16 outages took place since 2002, all of which were correctly cleared without disturbance of the system’s integrity.

Cause of Shutdown

vi) The Company states that a three-phase transient fault on the Duncans/Bogue 138 kV transmission line that was caused by a lightning strike at Tower #75, initiated the occurrence that led to the system shutdown.

vii) Primary protective relays located at the Bogue substation side of the line tripped and isolated the fault. However, the corresponding primary protection relays at the Duncans substation end of the line did not clear the fault as designed thereby initiating the system collapse. As well, the back up protection scheme at that location and those located remotely at Bellevue and Kendal substations did not operate.

viii) Failure of the primary, as well as, the backup protection to operate was due to the absence of a DC voltage supply because a 125V breaker had previously tripped taking both circuits out of service. Remote status alarms which would have alerted system controllers to the situation were not in place.

ix) Despite the transient nature of the fault, the system went into unrecoverable instability and started cascading because the critical clearance time for the system (approximately 0.54 seconds) was exceeded and took place before system backup relays (set to operate within 0.8 second) could operate to isolate the fault.

x) The system shutdown occurred approximately 10 seconds after the fault took place.

Sequence of Shutdown

xi) The three-phase fault on the Duncans/Bogue 138 kV transmission line triggered sequential tripping of:

- JEP Barge #1 and #2
- Bogue combined cycle ST14
- JPPC Units 1 and 2
- Old Harbour Units 1 and 4
- Hunts Bay Unit B6
- Bogue combined cycle 14 and 13
- Separation of the north west 69 kV grid at Queens Drive and Spur Tree
- Other generating units which may have been on line

System Restoration

xii) Restoration of the system was completed at 12:47 a.m. on Sunday, July 16, 2006 covering a period of 8 ½ hours. Customers started to receive return of supply within the first hour and within five hours, supply was returned to 25% of customers, with 50% restoration within six hours and 75% within seven hours. The exercise was carried out on a phased-basis but was slowed due to unexpected difficulties in bringing some of the generators on-line and the trip-off of others which had previously been put back in service.

Analysis of Shutdown

xiii) Stability stimulations were carried out by JPS in order to assist in determining the sequence of events and to identify the critical areas leading to the shutdown. It was noted that the automatic under-frequency load shedding system stage 1 only may have operated while other stages did not, due to the fact that the system frequency did not vary significantly during the system collapse. On the other hand, major low voltage situations would be seen at both the generator terminals and on substation bus bars. The severely depressed bus bar voltages could have had a major impact on generating plants, resulting in the tripping of a number of generators.

Corrective Actions

xiv) Lastly, the Company advises that following its own analysis of the event and findings they have taken or will take, within a short period, a number of actions to remedy the identified problems in order to prevent a recurrence of the situation. These include:

1. Replacement of failed protection relay at the Duncans substation and separation of supply source between backup and primary protection.
2. Remedy problem with JEP Power Barge #2.
3. Review generation dispatch philosophy to improve system stability and security.
4. Remedy problems with Bogue combined cycle plant
5. Conduct fault study of transmission system and review relay settings.
6. Review under-frequency load shedding scheme and examine whether a voltage load-shedding system should be added to improve system response to disturbances.
7. Ensure GT5 black-start capability.

OUR PRELIMINARY FINDINGS

The OUR had previously issued its Preliminary Report dated August 11, 2006 setting out its findings in respect of the shutdown. This was based on a preliminary technical report dated July 27, 2006 submitted by JPS and following its own investigations and review of the available records, data and other documents and reports, together with interviews conducted with JPS and JEP operating personnel. Copy of the OUR's *Preliminary Findings* report is attached hereto as APPENDIX 1.

A number of questions were raised by the OUR in the *Preliminary Findings* report for which JPS was required to provide a response. These questions together with the responses submitted, are attached hereto as APPENDIX 2.

REVIEW OF ISSUES

1. **Initiating Cause**

   Based on the available evidence namely a) the recording of the fault by the Duncans/Bogue 138 kV transmission line distance relay at Bogue and b) the burn marks on 3 insulator strings at Steel Tower #75 (refer APPENDIX 3), it is concluded that the initiating cause of the incident was a lightning strike to the line or tower on the Duncan/Bogue 138 kV transmission line, resulting in a three-phase ground fault.

2. **System Shutdown Sequence**

   It is accepted that the primary and backup protective relaying system at the Duncans substation failed to operate and promptly clear the fault. Also, that backup relaying systems at Bellevue and Kendal substations did not function as expected.

   The subsequent collapse of the system was inevitable because the critical clearing time of under 0.6 seconds had been exceeded due to the non-clearance of the fault. The resulting low voltages on the south coast bus bars at substations and generating stations are logical and consistent based on the simulation reports done by JPS.

   The OUR views the sequence of system collapse wherein generators came off-line over a period of 10 seconds as expected, given that the loads exceeded the capability of the system which had become unstable. Also, that only Stage 1 of the under-frequency relaying system operated to shed some of the load.

The sequence of system separation and generator disengagements identified by JPS in their final report is accepted. It is felt that even if the sequence was in fact different than suggested, the collapse would nevertheless have occurred.

3. Relay and Protection Systems

The explanation for the non-operation of the relay and protection systems at Duncans, Bellevue and Kendal substations are plausible. The absence of a DC voltage supply to the relays at Duncans would have prevented their function.

The tripping of the DC supply circuit because of a defective relay seems logical since the system operated correctly once the defect was subsequently remedied. The remote alarm for this system however, was not functional and therefore system controllers were not alerted to the fact that the relays would not work.

The non-functioning of backup relays elsewhere on the grid could have been due to a number of reasons and further studies are needed to establish that proper relay coordination is indeed in effect.

4. Generation Issues

The system collapse has raised several generation issues, all of which were brought to light by the incident. JEP, JPPC and some of the JPS generators all came off-line in an incorrect manner.

In respect of JEP Barge #1 low voltage appears to have affected the governor controls. JEP Barge #2 disengaged because of the incorrect operation of relays protecting the step-up transformer/generator system.

Bogue combined cycle steam unit ST14 disconnected early because of problems with the controls.

Although the reason for Old Harbour Unit #4 disengagement is not known, it is suspected that the unit auxiliaries initiated the trip because of low voltage on the bus bars. A similar situation occurred with Old Harbour Unit #1.

5. System Stability and Load Shedding

The under-frequency load shedding scheme operated for Stage 1 only. Simulation studies conducted by JPS, as well as actual observations and records of the frequency variation during the event, validates this situation.

The frequency variation was indeed not sufficient to initiate some of the other under-frequency stages which are set at a lower level frequency than Stage 1. Given the unstable situation existing during the incident, it is unlikely that the non-operation of the under-frequency relays would have made a difference in preventing the shutdown.

6. **Communication and SCADA Systems**

Communication links with 14 of 49 substations and generating stations were not functional at the time of the collapse. While this situation would not have prevented the shutdown it would nevertheless, have prevented system controllers from being able to effectively analyze the situation following the disturbance and to facilitate earlier restoration of the system and supplies to customers.

This is considered unacceptable and for the future, among other things JPS must ensure that defective communication and SCADA systems are promptly restored to service.

7. **Sequence of Events Recording**

The evaluation of the sequence of system collapse and cause of some of the generator disengagements from the system was impaired due to the non-functioning of some of the sequence of events (SOE) recorders located at power stations. Also, there is no link existing between the various stations and system control center to ensure time synchronizing of events.

The alignment of timing between various locations is crucial to the overall analysis of events and must be remedied as a matter of priority.

GENERAL OBSERVATIONS AND COMMENTS

The north coast which is the location of much of the island's tourism is vulnerable to power outages. The Tourism Industry is also at a stage of very strong growth. This means that the security of electricity supply to the north and western sections of the island has to be reviewed. At this time, loss of the Duncans/Bogue transmission link and any attendant power outage will have a negative impact on the island's tourism. Accordingly, there is need to study the options to strengthen the JPS infrastructure to avert any such event, as well as to cater for contingencies.

CONCLUSIONS

The summary of major conclusions following the OUR's analysis of the situation, are set out as follows:

a) The system shutdown was initiated by lightning striking steel tower #75 or the adjacent lines on the Duncans/Bogue 138 kV transmission link, precipitating a three-phase ground fault.

b) The subsequent system collapse occurred for the reason that protective relays at the Duncans substation side of the line did not operate to clear the fault. This was caused from the absence of DC voltage supply to the relay circuits. The system controllers were not aware of the situation because the remote alarm system was not in place.

c) The system subsequently became unstable because the critical clearing time for system stability was exceeded, due to of non-clearance of the fault.

d) Remote relay backup systems did not operate, possibly due to relay coordination problems or early dissipation of the fault, which could have been transient in nature.

e) Several generators, inclusive of some at JEP, JPPC and JPS Old Harbour and Bogue plants, were affected by the instability particularly the very low bus bar voltages and disengaged from the system incorrectly. JEP Barge #2 had a problem with relays which mal-operated, while the other generators seem to have been negatively impacted by the low voltage situation.

f) The non-functioning of a number of important communication and SCADA circuits at the time of the shutdown, affected the early analysis of the problem and therefore delayed restoration activities.

RECOMMENDATIONS

Interim recommendations were made following the OUR's preliminary investigation. Some of these recommendations remain unchanged after completion of the enquiry and are therefore repeated below. Also a number of other recommendations have been included. These are being submitted to JPS for implementation and also, to the independent power producers namely, JEP and JPPC for remedy as appropriate.

1. The overall system relay coordination scheme should be reviewed by appropriate experts. Particular attention should be paid to the early clearance

of generators and the probability of low fault currents occurring on the transmission infrastructure in specific contingency situations.

2. A review of the linkage of the 138 kV grid to the northwest transmission system must be undertaken. The feasibility of establishing link at 138kV between Kendal/Spur Tree and Bogue substations should be determined and steps taken to include the desired solution in the company's investment programme.

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

4. The early and incorrect tripping of generators operated by JPS, JEP and JPPC respectively must be corrected as soon as possible (it is noted that the entities have already taken steps to rectify the problems identified with the particular generating units).

5. 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.

6. The non-functioning of highly important communication links and SCADA monitoring systems to facilitate vital remote control operations, is completely unacceptable. The maintenance of this system must be accorded immediate and first priority in order to effect full operating status at all times.

7. Also, backup systems for the communication network is crucial and must be put in place where not now existing.

8. Comments under items 5 & 6 above, also apply in general to the primary relaying system for the 138 kV and 69kV transmission grid.

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.

The Office is of the view that the island wide shutdown of July 15, 2006 has precipitated a number of problems which would otherwise continue to remain as potential instigators of system outages. It has also highlighted the need for further studies to identify any other problem areas. 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.

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.

APPENDIX 1

OUR *Preliminary Findings* Report Dated August 11, 2006

Office of Utilities Regulation

Enquiry into JPS Power System Shutdown of July 15, 2006

Preliminary Findings

August 11, 2006

Office of Utilities Regulation

ENQUIRY INTO JPS POWER SYSTEM SHUTDOWN OF JULY 15, 2006
Preliminary Findings

BACKGROUND

The Jamaica Public Service Company Ltd. (JPS) power system suffered an island-wide shutdown on Saturday, July 15, 2006 commencing at 4:16 p.m. The Office of Utilities Regulation (OUR) is in receipt of a "*preliminary technical report*" on the power system shutdown which was provided to the OUR by JPS on July 27, 2006. An initial Report on the outage was earlier submitted to the OUR on July 17, 2006.

The *preliminary technical report* sets out the status of the operating conditions prior to the shutdown and outlines the company's reconstruction of the events during the system failure. In addition, the Company's analysis of the probable cause which initiated the shutdown together with voltages, frequency, loadings and functioning of communications, sequence of events recording and protective relaying systems, are indicated.

Prior to the shutdown, the generation and transmission systems were stable with 497.7 MW of generating capacity on-line supplying a system demand of 465.7 MW and a spinning reserve of approximately 32.0 MW. The total generating capacity available was 613.5 MW. Bad weather accompanied by lightning was reported on the northern side of the island.

The Company's conclusions arising from the preliminary report are summarized as follows:

1. The Duncans/Bogue 138 kV transmission line was struck by lightning at about 4:16 p.m. on July 15, 2006. The incident resulted in a three-phase fault as evidenced by tracking/damage to insulator strings on steel towers (either tower No.75 or No. 90).

2. The fault caused the 138 kV line breaker at Bogue to trip on distance protection. However, the Duncan's end did not clear as designed due to non-functioning of the DC trip circuit which was out of service.

3. The backup relays on the 138 kV system located at Bellevue and Kendal substations consisting of remote zone distance and over-current relays did not operate to clear the fault as designed.

4. JPS assumes that despite the non-isolation of the fault, the fault nevertheless cleared as it was only transient in nature and disappeared in a short time.

5. The disturbance caused immediate tripping of JEP generators on barges #1 and #2, as well as Bogue combined cycle steam unit ST14.

6. JPPC generators at Rockfort also came off-line.

7. This is followed in sequence by the operation of stage 1 under-frequency relays which would have shed a block of system load.

8. Also, other generators in the system and 69 kV breakers at Queens Drive, Halse Hall and Spur Tree substations eventually tripped.

9. Severe voltage fluctuations on the 138 kV bus bars at Old Harbour and Duhaney were recorded.

10. System frequency decay was also recorded, however, only stage 1 under-frequency relays operated due to the voltage restraint settings of the relays which would have prevented other stages from functioning.

11. The sequence of generator and circuit breaker operations caused the system to collapse island-wide.

12. The timing of Old Harbour Unit 4 generator which was on-line is not stated.

13. Also, it is noted that due to the failure or non-functioning of the communications/SCADA system across the island, remote control activities and status and telemetry data were impaired.

QUESTIONS

The OUR Investigating Team has examined the JPS preliminary technical report in detail. In addition, it is in receipt of some records and data provided by both Jamaica Energy Partners Limited (JEP) and Jamaica Private Power Company Limited (JPPC) as to system operations prior to and during the outage, in respect of their generators. The OUR conducted interviews with JPS and JEP operating personnel. In addition, other relevant items of materials and documents, such as, the under-frequency relaying scheme, reports on prior system failures, etc were reviewed by the OUR. Photographs of the insulator strings and maintenance report for the Duncans/Bogue 138 kV transmission circuit, assumed by JPS to be the initiating cause of the problem, were also examined and the extent of damage noted.

As a consequence of the preliminary reviews and examination of the information specified above, a number of technical observations and other questions arise, to which a response is required. These are as follows:

a. JPS has aligned the timings of JEP and JPS operations during the outage through the linkage of identified similar events. However, the result suggest that JEP barge #1 came off-line instantaneously with the occurrence of the line fault and tripping of the Bogue 138 kV breaker. This instantaneous trip is questionable given that there should be a discernable time lag designed into the system to avert spurious tripping of generators for system faults.

b. JEP barge #2 over-current earth fault relay operated. This is a backup relay in the event that there is failure of the grid protection system. This operation appears incorrect unless the settings are wrong or the line fault was in fact sustained for some time before clearance. Please confirm whether the relay type is instantaneous over-current (50N) or a time delayed over-current (51N). Also, please indicate the CT connections on the step-up transformer for this relay.

c. What is the operating state of the sequence of events (SOE) recorder for the Old Harbour power station? Is it functioning and if not why not?

d. What time did Old Harbour Unit 4 trip and what was the reason for the generator disconnecting itself from the system? Report from an independent witness would suggest, based on the noise made by the blowing of the steam valve that JEP barge #1 and this unit tripped almost simultaneously.

e. Did the Old Harbour 2.3 kV auxiliary bus bars disengage on the occurrence of the low voltage recorded on the 138 kV bus bars?

f. Does the Old Harbour station have the capability to monitor and record voltages on the 138 kV bus bars and if so, is this information available for the incident?

g. JEP barge #1 tripped on the governor control limits being exceeded. However, the initiating cause is not clear. Please indicate whether a bus bar low voltage condition affecting the control system for the generators could have been a factor and therefore a weakness which require remedy to avert future incidents of tripping.

h. The JPPC generators appear to have come off-line due to problems with the auxiliary controls. Please indicate exactly what caused the JPPC units to trip and whether there has been a history of sensitivity to system and line faults.

i. What is the JPS spinning reserve policy for generation dispatch? What is the expected system response when loss of the largest unit on the system is experienced, particularly in respect of the under frequency load shedding?

j. Please confirm the operational setting of the governor controls for Hunts Bay Unit B6 and Old Harbour Unit 4, during the shutdown. Were they on "manual only" operation during the shutdown?

k. What exactly caused GT12 and GT13 to trip, given that loads were being served independently after separation from the grid?

l. Key SCADA and communication systems links were not in operation during the shutdown. Please indicate why and when this was known. Are the systems being adequately inspected and maintained given their importance? Please provide appropriate documentation in support of inspection and maintenance activities.

m. Please indicate why the DC circuit for the tripping relay at Duncans substation was out of service, when was this known and why did the "trip circuit supervision" remote alarm at the System Control Centre not operate to alert the system Controllers to the situation, given that a primary relay system was non-functional. As well, advise what other circuits and relays supplied from this particular DC circuit were also affected by it being out of service?

n. Why did the backup protection relays at Duncans substation not operate following failure of the primary protection?

o. Please provide micro processor oscillograph recordings for 1) Duncans/Bogue 138 kV line at Bogue 2) Duncans/Queens Drive 69 kV line at Queens Drive 3) Magotty/Spur Tree 69kV line at Spur Tree. Also, explain reason for distance relay on the Magotty/Spur Tree line, operation on zone 3 at Spur Tree substation.

p. What is the history in respect of reliable operation and clearance of the Duncans/Bogue 138 kV line, for the SEL distance relaying scheme?

q. What is the critical fault clearing time for a three-phase fault on the Bogue/Duncans 138kV line section? Is this time within the clearance time of back-up relays at Bellevue and Kendal?

r. Would the earlier than expected trip of major generators have worsened or precipitated a relay coordination problem?

OBSERVATIONS AND COMMENTS

It is recognized that the investigation is still at a preliminary stage and that further work will likely unearth other items which will contribute to the diagnosis of the shutdown. Nevertheless, the OUR feels constrained to make a number of observations and comments. These are as detailed below.

The insulator strings on the Duncans/Bogue 138 kV transmission line reflect relatively minor damage and would be indicative of a flash-over which is not sustained or if sustained, the fault current would have to be of comparatively low level. A high current sustained fault would probably have melted or shattered some of the insulators, assuming that this is indeed the initiating cause of the incident. However, the severe voltage depression noted throughout the transmission system does suggest that the fault was indeed maintained for several seconds.

Indeed, preliminary calculations carried out by the OUR Investigating Team indicates that the level of fault current on the Duncans/Bogue 138 kV line would be significantly low when the JEP and Old Harbour #4 generators are disconnected from the grid, together with no power being available from the Bogue end of the line. This situation could prevent the proper operation of key backup protection, which depends on optimum levels of fault current to ensure correct relay coordination and reliable clearance of faults.

The alignment of timings between JPS and JEP operations is in question and should be carefully reviewed. The absence of common time synchronism between JPS System Control and the various generating plants is a major handicap to effective operation of the system and to subsequent diagnosis of system failures.

It appears that some of the generators did not meet the full-load rejection capability standards during the shutdown. This requires further examination.

The control circuits for the Old Harbour generators should preferably be supplied from a reliable DC battery source. The feasibility of converting the controls from AC to DC should be investigated.

A study should be undertaken and consideration given to operating sections of the 69 kV grid in a radial configuration. This would entail opening existing loops not essential for systems stability, on the 69 kV grid and supplying loads radially away from 138/69 kV substations. The enactment of automatic reclosing feature on the radial lines should also be looked at.

The OUR has observed that JPS experienced problems in its efforts to restore the system following the shutdown. The concern arises as to whether JPS have a comprehensive System Restoration Plan inclusive of policies and procedures to respond to a major outage crisis and the level of preparedness of the System Controllers to enact its implementation.

While the “shutdown” will require further study with one objective being to precisely establish the sequence of events and identify problems, based on the information submitted and currently available to the OUR, it is probable that the scenario of the system shutdown occurred in the following manner and for the causes indicated:

- Lightning struck either a tower or overhead shield wire(s) on the Duncans/Bogue 138 kV steel tower line causing critical voltage uplift on one tower which resulted in a three-phase flashover of insulators.

- The three-phase flashover may or may not have been transient. However, the probability is that is was in fact sustained for some time.

- The Bogue end of the line tripped but protective relays on the Duncans side did not operate due to a DC supply failure.

- Backup protection relays at Duncans, as well as at Kendal and Bellevue substations did not operate. The clearance for the backup relays at these locations may have exceeded the critical fault clearing time for a three-phase fault on the Duncans/Bogue 138 kV line, which would led to instability of the generating power grid before the backup relays could operate.

- JEP barges and Old Harbour Unit 4 came off line almost simultaneously, JEP barge #2 from an improper earth fault relay operation and the Old Harbour Unit probably due to tripping of the auxiliaries from under-voltage.

- The loss of major units at Old Harbour carrying over 150 MW would have severely depressed the 138 kV grid feeding power into the Corporate Area.

- Stage 1 under-frequency relays operated to shed some of the load following a frequency decay, however, additional stages were inhibited by the voltage restraint setting on the relay devices.

- In the absence of additional under-frequency protection operation, overload on the remaining generators at Old Harbour, Hunts Bay and Rockfort resulted in a complete shutdown of power supplies.

- The 69 kV lines linking Bogue and the northwest transmission infrastructure to the rest of the island grid had earlier separated at various points.

- The resulting overload of gas turbines 12 and 13 which had remained on-line caused both units to trip eventually on overload.

INTERIM RECOMMENDATIONS

Arising from the OUR's preliminary investigation, the following recommendations, which are general in nature, are being submitted to JPS:

1. A system stability study which takes into account the various operating conditions of the system, as well as contingency failures, should be commissioned as soon as possible. This should include simulation of the shutdown event establishing current flows, fault levels and voltages for various scenarios of generation on-line.

2. The overall system relay coordination scheme should be reviewed by appropriate experts. Particular attention should be paid to the early clearance of JEP and JPPC generators and the probability of low fault currents occurring on the transmission infrastructure in specific contingency situations.

3. A review of the linkage of the 138 kV grid to the northwest transmission system should be undertaken. The question as to whether investment should be made in establishing a 138 kV line between Kendal/Spur Tree and Bogue substations should be determined.

4. The non-operation of under frequency relays during a system stability crisis requires remedy. Consideration should be given to relocating the relays to the 69 kV bus bars and/or providing supply from a DC source which will prevent spurious tripping caused from the distribution side.

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

6. The non-functioning of highly important communication links and SCADA monitoring systems to facilitate vital remote control operations, is completely unacceptable. The maintenance of this system must be accorded immediate and first priority in order to effect full operating status at all times. Also, backup systems for the communication network is crucial and must be put in place where not now existing.

7. Comments under (6) above, also apply in general to the primary relaying system for the 138 kV and 69kV transmission grid.

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

9. The sequence of events recorders for all power stations and generators should be make fully functional and kept in a state of serviceability at all times.

10. JPS should have in place complete and detailed procedures for the step by step restoration of the system in the event of a major shutdown of the grid, in whole or in part and System Controllers should be fully trained in the restoration process.

The OUR expects that as the investigation progresses and other facts emerge, it will be in a position to put forward additional recommendations in order to mitigate or avert the risk of the recurrence of an island-wide power system shutdown and to minimize the restoration periods if such system failures should in fact recur in the future.

August 11, 2006

APPENDIX 2

JPS RESPONSE TO QUESTIONS RAISED IN THE OUR *Preliminary Findings* REPORT

JPS System Shutdown of July 15, 2006
JPS Response to OUR Questions from Preliminary Findings
September 13, 2006

QUESTIONS

The OUR Investigating Team has examined the JPS preliminary technical report in detail. In addition, it is in receipt of some records and data provided by both Jamaica Energy Partners Limited (JEP) and Jamaica Private Power Company Limited (JPPC) as to system operations prior to and during the outage, in respect of their generators. The OUR conducted interviews with JPS and JEP operating personnel. In addition, other relevant items of materials and documents, such as, the under-frequency relaying scheme, reports on prior system failures, etc were reviewed by the OUR. Photographs of the insulator strings and maintenance report for the Duncans/Bogue 138 kV transmission circuit, assumed by JPS to be the initiating cause of the problem, were also examined and the extent of damage noted.

As a consequence of the preliminary reviews and examination of the information specified above, a number of technical observations and other questions arise, to which a response is required. These are as follows:

a. JPS has aligned the timings of JEP and JPS operations during the outage through the linkage of identified similar events. However, the result suggest that JEP barge #1 came off-line instantaneously with the occurrence of the line fault and tripping of the Bogue 138 kV breaker. This instantaneous trip is questionable given that there should be a discernable time lag designed into the system to avert spurious tripping of generators for system faults.

JPS does not have any data on the JEP governor control system and its operating characteristics.

The Bogue breaker tripped five cycles after fault inception, presumably, the governor trip could occur within this time.

Note JEP Barge 2 relay operated in 194 ms.

b. JEP barge #2 over-current earth fault relay operated. This is a backup relay in the event that there is failure of the grid protection system. This operation appears incorrect unless the settings are wrong or the line fault was in fact sustained for some time before clearance. Please confirm whether the relay type is instantaneous over-current (50N) or a time delayed over-current (51N). Also, please indicate the CT connections on the step-up transformer for this relay.

JEP barge 2 earth fault relay is located on the 11 kV side of the GSU and should only respond to earth faults within its 11 kV zone.

The relay is set with a definite time delay characteristic.

The CT connection is a toroidal arrangement enclosing all phase cables. The arrangement delivers the summation of the phase currents and should be zero under balanced condition and produces zero sequence currents under ground fault condition.

c. What is the operating state of the sequence of events (SOE) recorder for the Old Harbour power station? Is it functioning and if not why not?

Historic Files on 3&4 became corrupted and no recording took place. The Recorder on Unit 1 & 2 side was functioning OK.

d. What time did Old Harbour Unit 4 trip and what was the reason for the generator disconnecting itself from the system? Report from an independent witness would suggest, based on the noise made by the blowing of the steam valve that JEP barge #1 and this unit tripped almost simultaneously.

Old Harbour 4 tripped at 16:16:05 based on corrected time. The initiating event was not established.

e. Did the Old Harbour 2.3 kV auxiliary bus bars disengage on the occurrence of the low voltage recorded on the 138 kV bus bars?

NO. There is no record to suggest that

f. Does the Old Harbour station have the capability to monitor and record voltages on the 138 kV bus bars and if so, is this information available for the incident?

Power Relays, PPMS, readings were also obtained from JEP which is connected to the Old Harbour 138kV busbars.

g. JEP barge #1 tripped on the governor control limits being exceeded. However, the initiating cause is not clear. Please indicate whether a bus bar low voltage condition affecting the control system for the generators could have been a factor and therefore a weakness which require remedy to avert future incidents of tripping.

JEP is addressing the protection of the generator and in particular the overcurrent

h. The JPPC generators appear to have come off-line due to problems with the auxiliary controls. Please indicate exactly what caused the JPPC units to trip and whether there has been a history of sensitivity to system and line faults.

JPPC units apparently tripped due to an undervoltage condition on their 460 bus.

i. What is the JPS spinning reserve policy for generation dispatch? What is the expected system response when loss of the largest unit on the system is experienced, particularly in respect of the under frequency load shedding?

Economic Load Dispatch is done with a 29 MW spinning reserve. It is expected that with the loss of the largest unit, Stage 1 & 2 Under-frequency should relieve the system.

j. Please confirm the operational setting of the governor controls for Hunts Bay Unit B6 and Old Harbour Unit 4, during the shutdown. Were they on "manual only" operation during the shutdown?

Both B6 & OH4 were in governor control

k. What exactly caused GT12 and GT13 to trip, given that loads were being served independently after separation from the grid?

GT 12 and GT13 tripped on exciter undervoltage. The reactive power demand for the Western sub-system could not be supported by these two generators

l. Key SCADA and communication systems links were not in operation during the shutdown. Please indicate why and when this was known. Are the systems being adequately inspected and maintained given their importance?

Please provide appropriate documentation in support of inspection and maintenance activities.

We were having technical problems with our Data Acquisition Servers (RDAS) earlier in the week of the shutdown; some transfers of the unavailable circuits were done on the evening before the shutdown to restore the majority of the circuits that were unavailable.The RDAS are now operational again and the circuits normalized.

m. Please indicate why the DC circuit for the tripping relay at Duncans substation was out of service, when was this known and why did the "trip circuit supervision" remote alarm at the System Control Centre not operate to alert the system Controllers to the situation, given that a primary relay system was non-functional. As well, advise what other circuits and relays supplied from this particular DC circuit were also affected by it being out of service?

A tripped dc moulded type breaker that supply auxiliary power to the primary and back-up distance relays (SEL321 and ABB REL512), as well as, dc supply for a separate tripping relay was found during subsequent field investigations. The secondary main distance relay (ABB REL512) was found to be defective and may have caused the tripping of the moulded type breaker. The trip circuits of the Bogue 138 kV circuit breakers at Duncans were intact and no trip circuit alarm would have been activated.

The primary SEL321 relay-fail condition remained undetected as the monitoring circuit was not in place (the wires were not connected).

n. Why did the backup protection relays at Duncans substation not operate following failure of the primary protection?

Both primary and secondary distance relays were powered down with the tripping of the dc breaker. The other back-up ground overcurrent relay would not respond to the balanced three-phase fault condition.

o. Please provide micro processor oscillograph recordings for 1) Duncans/Bogue 138 kV line at Bogue 2) Duncans/Queens Drive 69 kV line at Queens Drive 3) Magotty/Spur Tree 69kV line at Spur Tree. Also, explain reason for distance relay on the Magotty/Spur Tree line, operation on zone 3 at Spur Tree substation.

See appendix ix(b) – Protection Data of the final report

p. What is the history in respect of reliable operation and clearance of the Duncans/Bogue 138 kV line, for the SEL distance relaying scheme?

Prior to July 15, 2006, sixteen faults were recorded since 2002 and all sixteen were correctly cleared.

q. What is the critical fault clearing time for a three-phase fault on the Bogue/Duncans 138kV line section? Is this time within the clearance time of back-up relays at Bellevue and Kendal?

For the July 15 fault, the critical fault clearing time for a fault on the Duncans 138 kV bus was 0.54 sec. The minimum operating time for remote distance relay zone 3 operations at Bellevue and Kendal is 0.8 sec.

Local back-up distance protection (secondary main protection) is used at various locations to reduce the operating times for back-up protection operation.

r. Would the earlier than expected trip of major generators have worsened or precipitated a relay coordination problem?

To the extent that the fault dissipated before Old Harbour Unit 4 tripped, relay coordination would not come into question. The loss of generators during a disturbance, however, will result in reduced infeeds to faults and consequent longer operating times for IDMT overcurrent relays.

APPENDIX 3

INSULATOR STRINGS WITH BURN MARKS AT TOWER # 75 ON THE DUNCANS/ BOGUE 138kV TRANSMISSION LINE

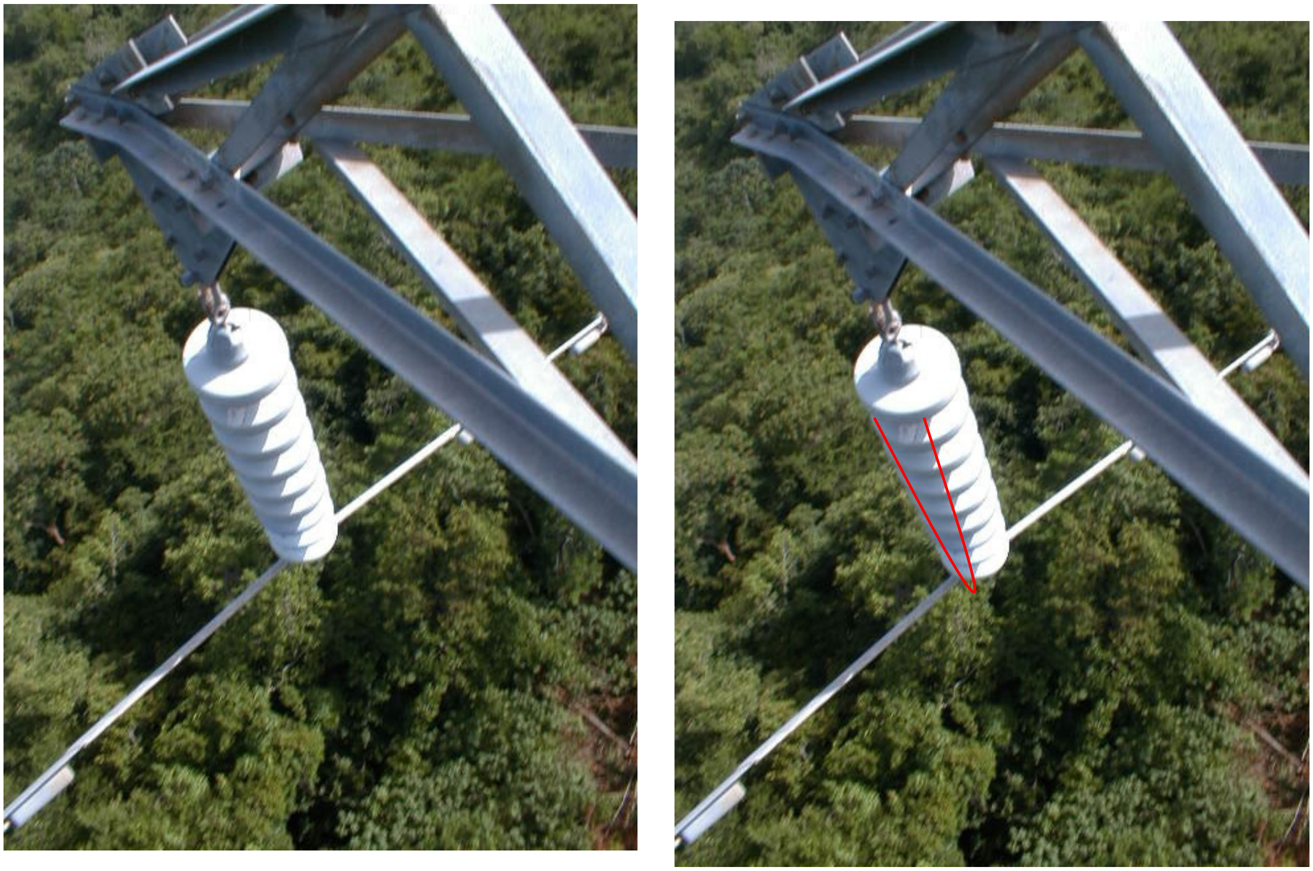

Figure 1: DUNCANS/BOGUE -T75_OUTER PH1_060715

Figure 2: DUNCANS/BOGUE -T75_MIDDLE PH_060715

Figure 3: DUNCANS/BOGUE -T75_OUTER PH3_060715

APPENDIX 3

PHYSICAL AND ELECTRICAL LAYOUTS OF JPS TRANSMISSION SYSTEM

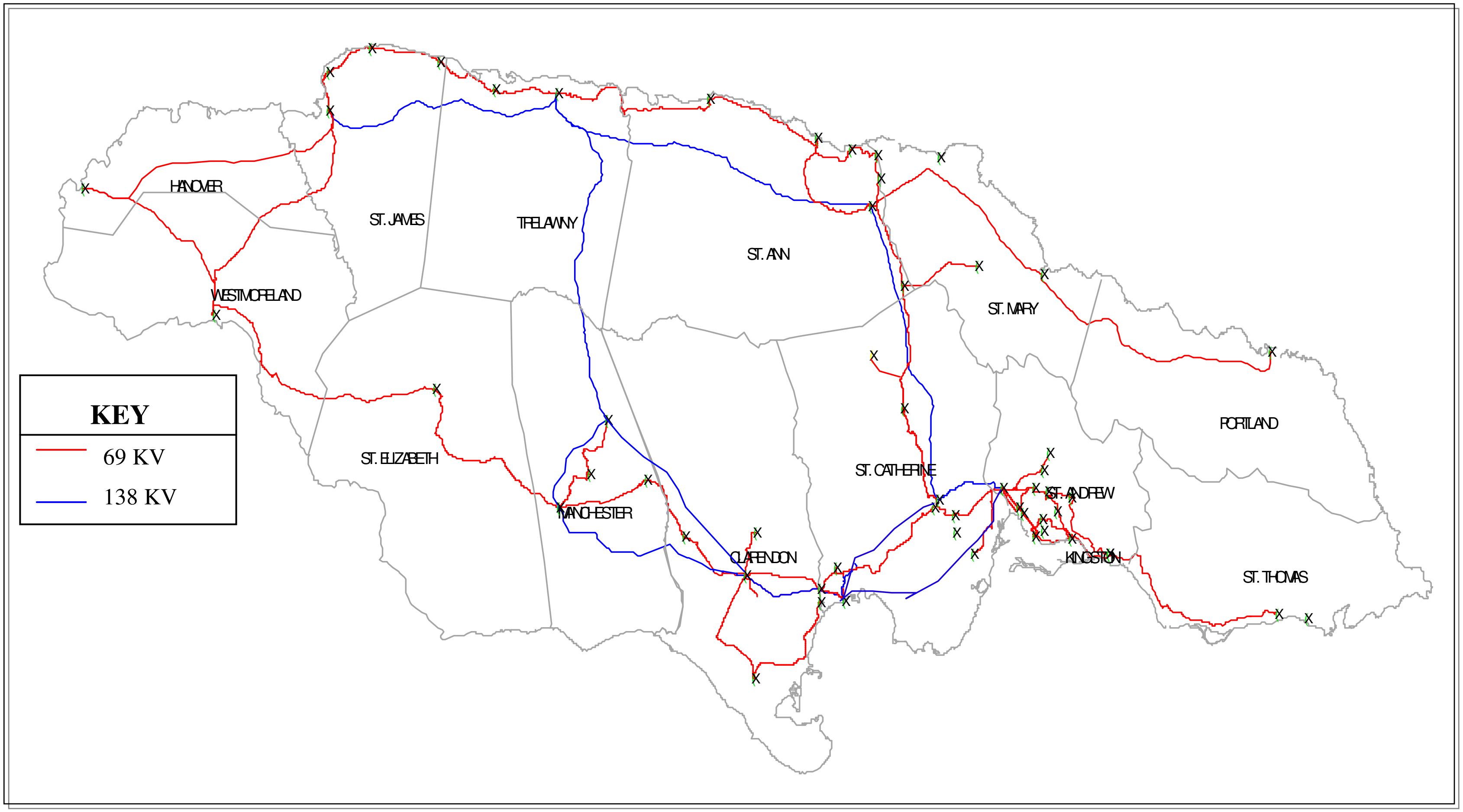

Figure 1: Geographical Layout of JPS Transmission System

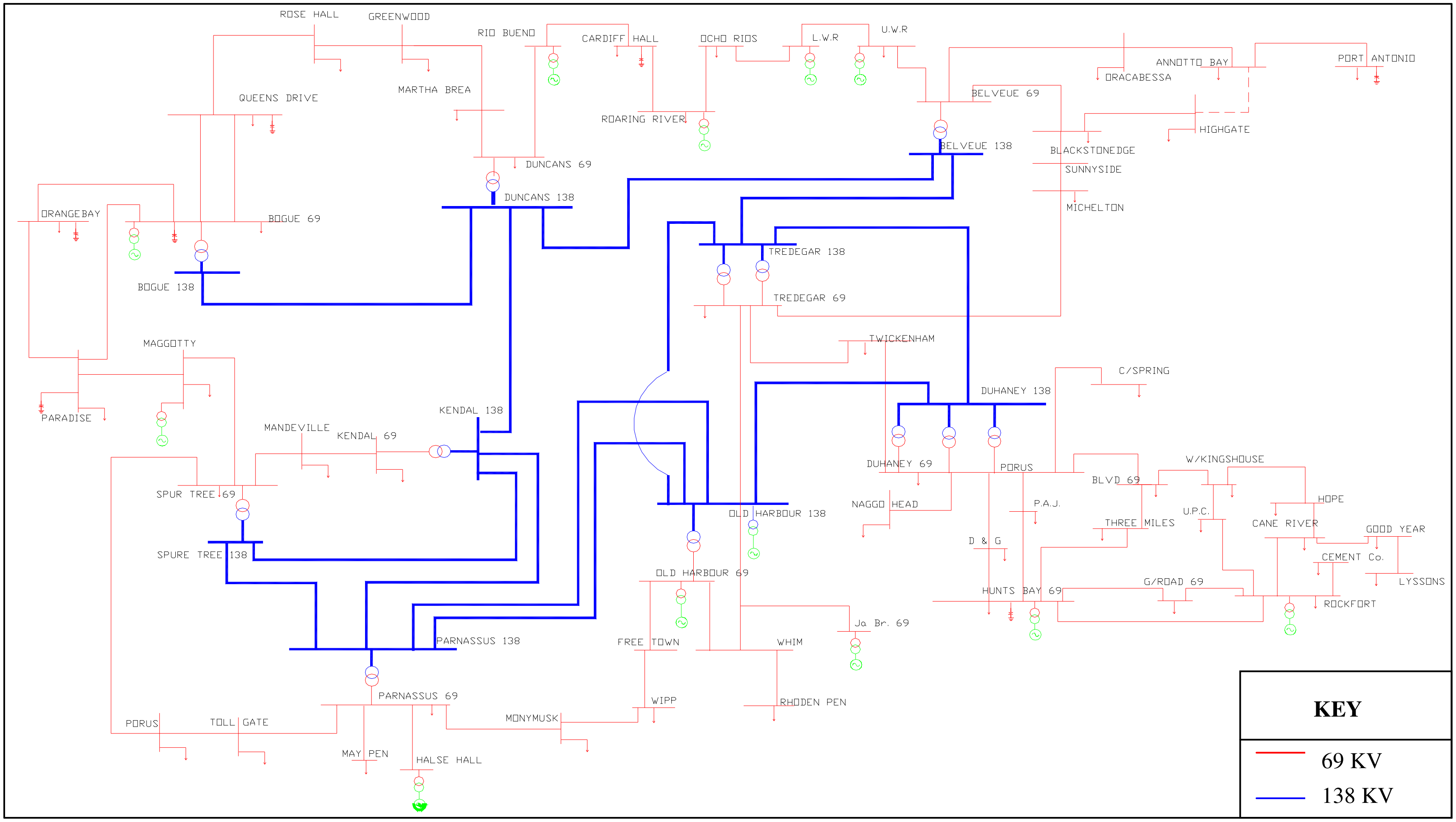

Figure 2: One Line Diagram of JPS Transmission System