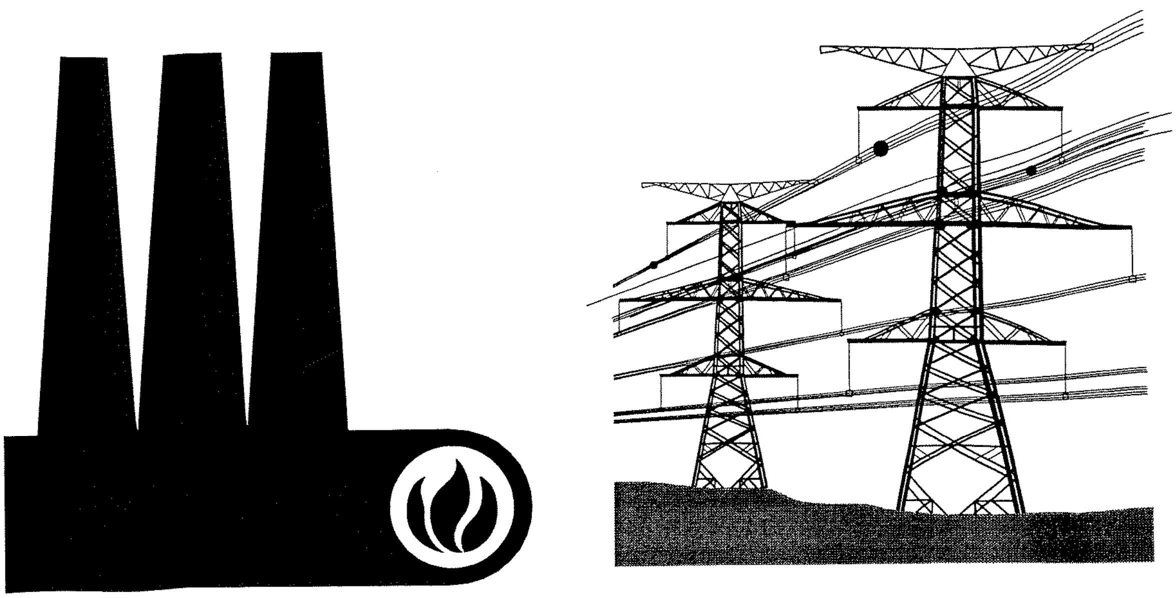
TAB 2

Newfoundland & Labrador Hydro

HYDRO



# Holyrood Generating Station
# Units 1 & 2 EHC Study

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# 1.0 INTRODUCTION

## 1.1 Background

Units 1 and 2 at Holyrood Thermal Generating Station were constructed in 1969 to generate 150MW with an upgrade to 175MW in 1990/91. The present turbine control installed on Units 1 and 2 is electro-hydraulic and is a General Electric Mark II System which incorporates 1960's technology. Electro-hydraulic means that electrical signals from the controller go to actuators that allow hydraulic oil to operate the valves. Limitations in operating flexibility with the existing turbine controls have been identified and spare parts are becoming increasingly difficult to obtain. A study was requested to determine the need and time for replacement of the systems. Only the electrical portion of the electro-hydraulic controls (EHC) will be presented in this report. It is not anticipated that many changes are needed to the hydraulic section.

Among the most important functions that steam turbine generator controls must perform are: speed control, load control and steam pressure control. The EHC system controls the turbine by positioning the turbine's stop valve, control valves, reheat stop valves and intercept valves to meet operating conditions.

## 1.2 Purpose of Study

The purpose of the study is to present an analysis of the electrical portion of the electro-hydraulic control system used on Units 1 and 2 steam turbines at Holyrood and to discuss the need and feasibility of upgrades or replacement.

The report is divided into six sections:

1. General discussion of the steam turbines at Holyrood and their control.
2. Availability of spare parts and General Electric Field Personnel to support the existing electro-hydraulic controls.
3. Failures and Maintenance of the existing turbine control system.
4. The inability of the existing controls to provide full governor control of the turbines throughout the full range of loading.

5. Replacement systems for the electro-hydraulic controls and the advantages / disadvantages of each.

6. Points of interest and recommendations.

### 1.3 Methodology

The steps taken to provide input for this study were:

1. Discussion with Plant Personnel on operating experience.

2. Request to the Plant for maintenance information.

3. Request to the Plant for spare parts on site.

4. Discussion with potential suppliers.

5. Presentations and budget quotations from these suppliers.

6. Discussion with personnel in other companies having similar EHC systems.

7. Request to the original supplier (General Electric) for spare parts availability.

8. Search for suppliers who can repair or replace components of the existing system.

This information is presented in the report and recommendations are given for future action.

## 2.0 TURBINE CONTROL SYSTEM

### 2.1 Steam Flow

To understand the control of a steam turbine a brief description of the steam flow path through the unit is helpful. As shown in Figure 1, steam from the boiler is fed to the high pressure (HP) section of the turbine through the main stop valve. The steam admission to the turbine is controlled by six inlet control valves - three on the top steam chest and three on the bottom steam chest. These valves throttle steam into the HP turbine as instructed by the EHC System. Once in the HP section the steam expands and exhausts to the reheater section of the boiler. After being

**DIAGRAMMATIC ARRANGE[illegible]T OF STEAM FLOW & VALVE LOCATION FOR REH[illegible] CONDENSING TURBINE**

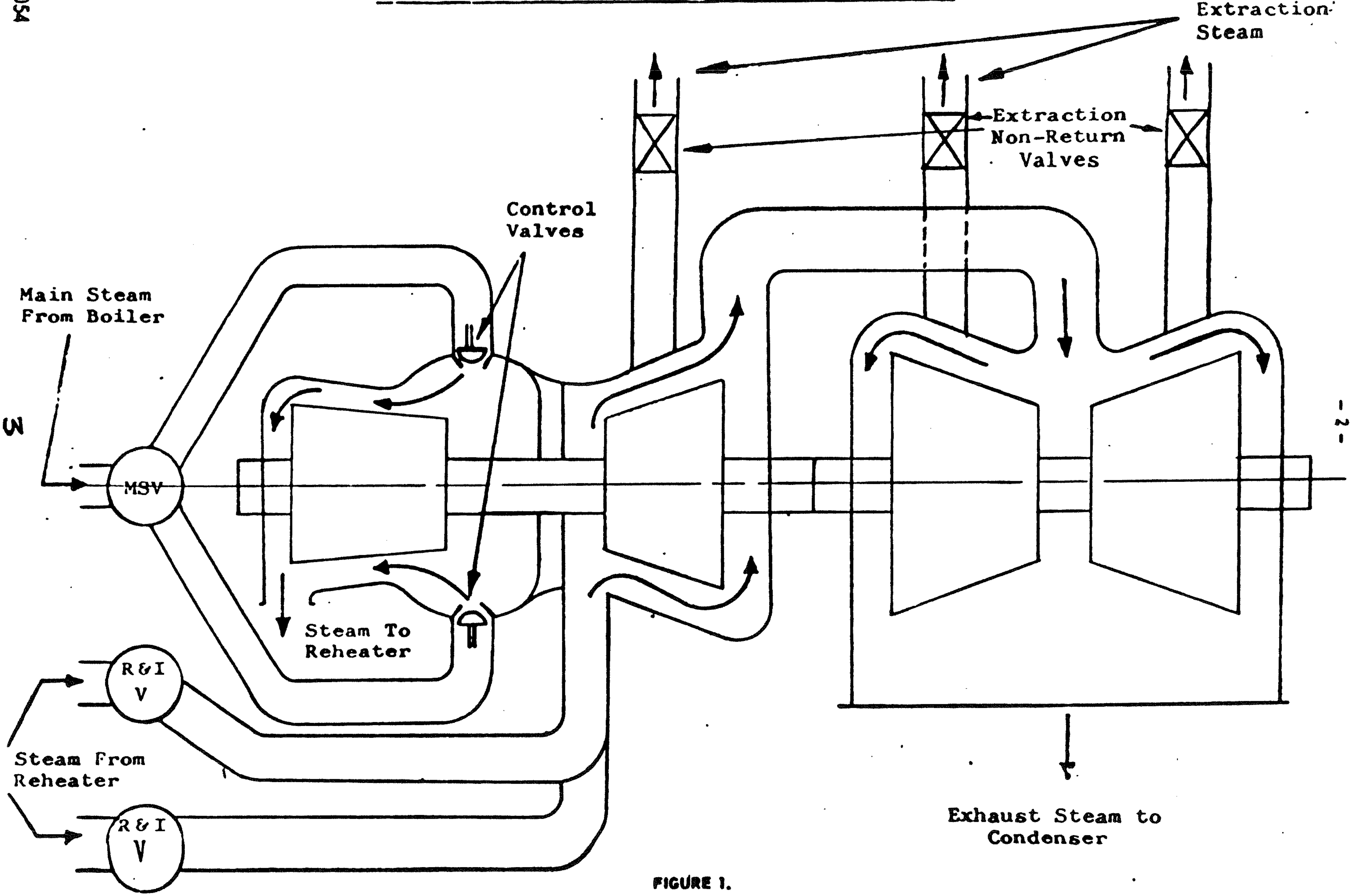


FIGURE 1.

reheated in the boiler the steam exits and passes to the intermediate pressure (IP) section of the turbine through two combined reheat and intercept valves which are open during normal operation. Again the steam expands, gives up energy to the IP section and passes to the low pressure (LP) section of the turbine. In the LP section the steam expands and exits to the condenser. The condensate is cycled through the feedwater heaters and eventually back into the boiler to complete the cycle.

## 2.2 EHC System Operation

The steam is admitted to the HP section through a main stop valve and subsequently through a set of six control valves. Each of these control valves admits steam through a different set of nozzle sections. Since these sections are distributed around the periphery of the high pressure section, they divide the steam admission into partial arcs. If only a portion of the control valves are open, steam is being admitted along a partial arc of the high pressure section turbine rather than through all 360 degrees of the circumference. This mode of operation is called **"partial-arc admission"** and is the normal in service mode.

During the start-up process thermal stresses on the HP cylinder can be reduced by symmetrically admitting steam to all nozzle sections of the high pressure turbine. Turbine control, up to 30MW, is achieved by fully opening the control valves and controlling the steam flow manually with the main stop valve. This mode of operation is called **"full-arc admission"**.

The EHC also has the responsibility for controlling overspeed on the turbine. It does this by controlling the intercept and main control valves over specific speed ranges. The turbine also has a mechanical overspeed trip bolt.

## 2.3 Present Electro Hydraulic Controls

The control function is maintained by a high pressure hydraulic system which consists of a hydraulic power unit, valve servomotors and the emergency trip system. High pressure hydraulic fluid is the operating medium. The basic features of the EHC system include speed control, load control with full arc / partial arc admission transfer and steam pressure control.

Load control implies control of the load throughout the full range of the machine. Once the machine has reached it's operating speed and temperature, control is accomplished by controlling the position of the main stop valve, for loads 30MW and below. Above 30MW control is achieved by positioning the inlet control valves. The speed sensor is a permanent magnet generator (PMG) on the turbine rotor. The speed control system compares actual turbine speed obtained from the PMG with a speed/load reference and provides command signals to the turbine control valves.

If the generator circuit breaker opens when the control valves are open, the entire driving torque becomes available to accelerate the turbine rotor. Under these conditions the turbine can accelerate 15 to 30 percent of rated speed per second. Closing of the intercept and inlet control valves constitute the first line of defense against overspeed and start to close quickly to prevent a speed increase that would trip the unit. If this line of defense fails and the turbine speed increases to 105% of rated speed, a pre-emergency overspeed system will close the reheat and intercept valves completely and will also position the inlet control valves at about 90% closed. The last line of defense is the emergency overspeed governor. The emergency overspeed governor is a mechanical speed bolt on the turbine shaft which is calibrated to move away from the shaft and strike a trip finger thereby closing the main stop valve and tripping the turbine at approximately 3950 RPM. These safety devices are only called upon to act if the normal control devices fail to function properly.

The EHC System controls output to maintain certain pressure conditions within acceptable limits. This is accomplished on the units at Holyrood by two methods:

1. Initial Pressure Unloading
2. Low Vacuum Unloading

The initial pressure unloading system will start to unload the machine in response to a 10% drop in turbine inlet pressure by closing the main control valves. Another drop of 10% and the EHC System will unload the unit down to a pre-set base load. The function of this system is to protect the turbine against water carryover from the boiler. Low vacuum unloading is similar to initial pressure unloading except increasing pressure is monitored in the low pressure turbine instead of low pressure in the high pressure turbine. The EHC System will unload the machine proportionally as the back pressure in the LP Turbine increases. The purpose of this system is to protect the turbine from operating under abnormal stress conditions which would be caused by poor vacuum.

## 3.0 AVAILABLE PARTS AND SERVICE FOR EXISTING EHC SYSTEM

The existing electro-hydraulic controls are nearly thirty years old and the technology used is dated. There are concerns that parts are not readily available to replace failed components within the system. Appendix 1 indicates a parts list for the MARK II System installed at Holyrood.

## 3.1 Holyrood Warehouse EHC Parts Inventory

The following is a list of EHC parts stocked at Holyrood:

**Table 1**

| Description | General Electric Part Number | Warehouse Part Number | Quantity |
|---|---|---|---|
| *Computer Rack Assembly* | | | |
| Speed Translator Function | 748D91G1 | 81200174 | 1 |
| Speed Translator Sensing | 7486091G2 | 81200175 | 1 |
| 3 KC Oscillator | 7486D52G1 | 81200171 | 1 |
| 3 KC Output | 7486D52G3 | 81200172 | 1 |
| 3 KC Power | 7486D52G2 | 81200173 | 2 |
| LH & RH ICV Function | 817D666G1 | 81200027 | 2 |
| 1 CV Summer Function | D4011J24G1 | 81200166 | 1 |
| *Miscellaneous Components* | | | |
| Motor and Gear | 1112J40-1 | 65000097 | 1 |
| Potentiometer (20K) | 654A692-5 | 81000981 | 1 |
| Potentiometer (1K) | 654A692-1 | 81000982 | 1 |

As can be seen by comparison of the above list and that in Appendix 1 several parts are not kept in inventory at the Plant. The parts stocked at Holyrood are 30 years old and have never been tested. In fact, many of the circuit boards were only catalogued by the Instrumentation Supervisor when Stores Personnel found them in a box in the Warehouse. There is no guarantee that these circuit boards will work properly if called on to do so.

## 3.2 Parts and Technical Support from General Electric

The electronic circuit boards within the existing MARK II EHC System have not been available for purchase from General Electric since January 1997. General Electric now supports an "Exchange Program" and a "Repair & Return Program". In the exchange program Hydro can return failed boards and GE will exchange them for working ones. In the repair & return program the failed boards are sent to GE and the same board is sent back when repaired. Both of these programs indicate the importance of having at least one spare board of each type in

Holyrood Stores inventory. General Electric emphasizes that these programs will only continue as long as they can get components for the boards and the programs are economically sound. GE has stated that they no longer maintain an inventory of these cards and so they may or may not be available when required. If a board in the MARK II should fail GE would provide another through the exchange program if they had one in their inventory or could locate one through their network of distributors. They do not guarantee being able to provide boards of every kind.

On the following pages is a complete list of EHC parts installed in the MARK II System at Holyrood and the replacement cost of each through the exchange program.

MARK II EHC Systems were installed in the 1960's and early 1970's. Over the past 30 years most of General Electric's Technical Personnel familiar with these systems have retired. Technical support staff at GE is very limited.

## Table 2 - Computer Rack Assembly

| Description | General Electric Part Number | Warehouse Part Number | Cost |
|---|---|---|---|
| Speed Translator Function | 748D91G1 | 81200174 | $20,282.00 |
| Speed Translator Sensing | 7486091G2 | 81200175 | $19,275.00 |
| Speed Summer Function | 4008J80G1 | Not Stocked | N/A |
| DC Amp | 784E661G2 | Not Stocked | $15,192.00 |
| Initial Pressure Translator | S0817D616G1 | Not Stocked | $12,481.00 |
| MCV Servo Amp Power | S07486D76G2 | Not Stocked | $16,925.00 |
| MCV Servo Amp Function | S07486D76G1 | Not Stocked | $19,274.00 |
| Aux. Function A | S0818D610G1 | Not Stocked | $17,036.00 |
| Card Module **(Repair Only)** | S0819D349G1 | Not Stocked | $13,333.00 |
| 3 KC Oscillator | 7486D52G1 | 81200171 | $14,393.00 |
| 3 KC Output | 7486D52G3 | 81200172 | $11,027.00 |
| 3 KC Power | 7486D52G2 | 81200173 | $11,027.00 |
| Oscillator | 817D634G1 | Not Stocked | $21,770.00 |
| Aux. Function A | 4008J81G1 | Not Stocked | N/A |
| CB-DC Amp Function | S0819D353G1 | Not Stocked | $10,559.00 |
| Servo Amplifier CD | 07486D84G2 | Not Stocked | $17,396.00 |
| Card Servo Power Amplifier | 07486D84G1 | Not Stocked | $19,371.00 |
| 1 CV Summer Function | 4011J24G1 | 81200166 | N/A |
| LH/RH ICV Func.**(Repair Only)** | 817D666G1 | 81200027 | N/A |
| LH ICV Servo Amp Power | S07486D82G2 | Not Stocked | $16,421.00 |
| Board Servo Amp Power | S07486D82G1 | Not Stocked | $11,996.00 |
| Pressure Translator PWB Neg. | S0817D617G1 | Not Stocked | $18,428.00 |
| DC Amp (B) CB | S0821D380G1 | Not Stocked | $12,481.00 |

## Table 3 - Auxiliary Rack Assembly

| Description | General Electric Part Number | Warehouse Part Number | Cost |
|---|---|---|---|
| +30 VDC Power Supply | S0819D384G1 | Not Stocked | $14,700.00 |
| - 22 VDC Power Supply Redund | S0819D384G2 | Not Stocked | $15,139.00 |
| Board Power Supply Monitor | 817D664G1 | Not Stocked | $18,732.00 |
| Aux. Relay | 818D312G1 | Not Stocked | $17,196.00 |
| Aux. Relay | 818D315G1 | Not Stocked | $20,398.00 |
| Card Lamp Supply | 818D313G1 | Not Stocked | $38,199.00 |
| Card Lamp Supply | 818D314G1 | Not Stocked | $29,480.00 |
| -22 VDC Power Supply | U6028CPXP0001 | Not Stocked | $18,138.00 |
| Power Supply | U6028CNXP0001 | Not Stocked | $24,157.00 |
| Exhaust Fan | 1085J83-1 | Not Stocked | $68.00 |
| Fan (Recirc.) | 1085J86-1 | Not Stocked | $2069.00 |
| Relay | 1085J66-1 | Not Stocked | $125.00 |
| Hi Fidelity Relay | 1085J66-2 | Not Stocked | $185.00 |

**Table 4 - Miscellaneous Components**

| Description | General Electric Part Number | Warehouse Part Number | Cost |
|---|---|---|---|
| ***Control Panel Assembly*** | | | |
| -Potentiometer (5K) | 7603-4062-0 | Not Stocked | $4442.00 |
| -Motor & Gear | 1112J40-1 | 65000097 | $20,876.00 |
| ***Main Stop Valve Position Control*** | | | |
| -Potentiometer (5K) | 120A561-3 | Not Stocked | $6188.00 |
| -Motor & Gear | 1112J40-1 | 65000097 | $20,876.00 |
| ***Vacuum Unloading Control*** | | | |
| -Potentiometer (20K) | 654A692-5 | 81000981 | $6188.00 |
| -Motor & Gear | 1112J40-1 | 65000097 | $20,876.00 |
| ***Initial Pressure Control*** | | | |
| -Potentiometer (Helipot) | 654A692-5 | 81000981 | $6188.00 |
| -Motor & Gear | 1112J40-1 | 65000097 | $20,876.00 |
| ***Load Limit Cont. LH & RH Controls*** | | | |
| -Potentiometer (5K) | 120A561-3 | Not Stocked | $6188.00 |
| ***Aux. Control Panel*** | | | |
| -Potentiometer (5K) | 120A561-3 | Not Stocked | $6188.00 |
| -Potentiometer (1K) | 654A692-1 | 81000982 | $3809.00 |

After discussions and interviews with Plant Personnel it was determined that if a circuit board failed within the EHC System, and there was no spare in the warehouse, the affected Unit would be down until the failed board was replaced or repaired. GE claims that if the board was in their inventory they could have one to Holyrood in less than a week but if it needed to be repaired it could take as much as a month. This situation seriously compromises the reliability of Units 1 & 2 at Holyrood and could leave Hydro unable to provide power to all of its customers if the failure occurred in mid winter when the system load is highest.

### 3.3 Parts and Technical Support from Other Sources

There is a company in Fort Collins, Colorado called Novatech which provides parts and service support for GE MARK II Systems. The company is headed up by two ex-General Electric Start-up Engineers who left to form Novatech. Novatech performs upgrades to MARK II Systems, repairs failed circuit boards, performs on site field engineering services and on site technical training. This company claims they can repair failed MARK II circuit boards for $950.00 US. In discussion with Plant Personnel it was learned that Novatech had been contacted in the past to repair a failed board. The results were not acceptable in that the turnaround time was far too long and Novatech never did repair the board because they did not have the proper drawings. The Plant feels Novatech is unable to provide satisfactory support in lieu of GE and should be considered as a source for parts and repairs for the MARK II Systems at Holyrood only in emergency situations.

## 4.0 FAILURES AND MAINTENANCE

Holyrood Staff were interviewed to determine the extent of failures and maintenance with the existing EHC System.

### 4.1 Failures

Plant personnel feel that the MARK II System installed at Holyrood is one of the most reliable and trouble free systems in the Plant. Discussions with Plant Maintenance, Operating and Engineering Staff revealed that no one could recall a failure ever occurring within the system. A thorough search through MAXIMO records confirmed that no failures had occurred with the MARK II System since records had been kept on the subject.

Failures which have occurred in the past that relate to the EHC System, either electrical or mechanical, have been within the front standard of the turbine. The equipment in the front standard is soaked with hydraulic oil and much of the wiring is not marked. This, coupled with the close quarters of the front standard compartment, makes troubleshooting difficult and, at times, lengthy. Devices which have failed in the front standard are solenoids and relays and have, on occasion, resulted in taking down the turbine to make repairs.

### 4.2 Maintenance

Yearly maintenance on the existing system consists of the following:

- cleaning the cabinet, cards, fans and filters
- checking power supply voltages / card power supply voltages and making adjustments if necessary.
- complete alignment of all functions:
  - valve strokes and feedback
  - overspeed settings
  - pre-emergency settings
  - valve tests
  - speed load and load limit settings

This maintenance would be reduced and much easier to perform if the system were replaced with a new EHC System since all functions and settings would be in software.

## 5.0 LIMITATIONS OF THE EXISTING CONTROLS

The existing EHC System on Units 1 and 2 at Holyrood is not capable of using the units to black start a de-energized system unless they are operated outside their normal operating parameters. The controls are set up in such a way that the units must be run up to operating speed and synchronized to an energized, stable frequency system. The system must have sufficient capacity to accept an increase in generation or load that is automatically compensated for by governor control of the other units on the system. This is due to the fact that when Units 1 & 2 operate at less that 30MW there is no automatic governor control of steam admission.

These turbines have six inlet control valves that operate in sequence, during loading, to admit increasing amounts of steam to the HP section and hence increase generator output. At loads under 30MW, damaging thermal stresses can be set up in the HP turbine because the steam flow is insufficient to provide uniform heating of the HP cylinder with the control valves operating in this sequence. To provide uniform heating it is necessary to start-up the unit with the control valves wide open and manually control the positioning of the turbine main stop valve in an effort to govern steam admission. If we are in a blackout condition on the Avalon Peninsula, such as December 1994, and are isolated from the main grid it is difficult to get these units back on line and pick up load. Below 30MW the main stop valve cannot be manually controlled quickly enough to pick up blocks of load from customers and hence the units trip when load is applied in quantities of about 15MW.

To start these units under black start conditions with the governor in control of the main stop valve would require a substantial upgrade to the MARK II System or the installation of a new EHC System. After discussions with General Electric it was determined that the cost to upgrade the existing MARK II System would be just as much as the cost of a new replacement system.

# 6.0 POSSIBLE REPLACEMENTS FOR THE MARK II ELECTRO-HYDRAULIC CONTROLS.

## 6.1 General

The two driving forces for replacing the MARK II System at Holyrood are the lack of spare parts available and the inability of the MARK II to provide full governor control to the main stop valve and main control valve thereby giving full flexibility during startup and loading. There are several state of the art EHC Systems on the market by General Electric, ETSI (Elsag Bailey), Woodward and Westinghouse which would alleviate these problems. All four manufacturers were asked to give a presentation on their proposal for replacement of the MARK II System at Holyrood. GE, Woodward and Bailey responded with presentations during the month of October 1997. Westinghouse, although asked to meet with Hydro Staff on several occasions, have not responded with a confirmed date for a presentation. Westinghouse is in the process of being sold to Siemens and this may have affected their ability to come to Hydro Place to deliver a presentation. The new systems have several benefits to consider:

- The MARK II System at Holyrood is one of only about 100 such systems installed worldwide for this size of turbine and this has resulted in a lack of spare parts. The new systems are "off the shelf" standard turbine controls which are installed on new turbines today. There are a large number of these systems installed (GE has 3000 MARK V units installed on steam and gas turbines to date) so the customer base is much larger than the MARK II System and therefore parts and technical support should be consistent for a number of years to come; longer than the support which has been made available to the MARK II System.

- All of the new EHC Systems will provide full governor control of steam admission over the full range of loading thereby making it possible to black start a dead system. This would make it possible for the units at Holyrood, operating at low loads (less than 30

MW), to accept blocks of load from customers in times when the Avalon Peninsula is isolated from the Main Grid.

- New software for retrofit applications is derived from standard control and protection algorithms used on steam turbines and is modified only slightly, where necessary, for compatibility with existing site conditions.

- With the new systems a direct interface is provided for all turbine sensors and actuators. This would eliminate interposing instrumentation in the turbine front standard such as solenoids, relays and timers and therefore eliminate the potential for failures associated with these interposing devices.

- Modifications to the turbine front standard include removal of the existing PMG and the installation of a toothed wheel complete with magnetic pick-ups for speed control and overspeed protection. Also, since the new system provides a direct connection to turbine sensors, much of the interposing instrumentation such as solenoids, relays, timers and associated wiring would be removed. This would improve the reliability of the machine and reduce maintenance and troubleshooting in the front standard.

- Magnetic pick-ups in the front standard are used for speed control and primary overspeed protection of the unit. The pick-ups are also used for emergency overspeed protection. The units at Holyrood have a mechanical speed bolt which is now used for emergency overspeed protection. This speed bolt would be left in place to provide a third overspeed protection. On-line and off-line overspeed tests are provided by all systems equivalent to the existing controls at Holyrood.

- Diagnostics are provided for failures including a sequence of events log. Diagnostics locate electronics problems to the circuit board level. Having no interposing devices external to the controls cabinet makes it possible for the system to perform all system diagnostic functions.

- The operator interface for these systems will consist of a CRT screen and keyboard for each turbine located in the control room very similar to that installed at Holyrood now for WDPF Boiler Controls. There will also be one industrial grade PC located in the relay room next to the EHC Control Cabinets to be used by Instrumentation Technicians for editing software such as revisions to I/O assignments, sequencing, control, protection, tuning constants and graphic displays. In addition there will also be a backup operator interface for each main operator interface in the event that the main interface fails. It will be a small liquid crystal or LED display of control parameters and alarms and can be used to issue operator commands. It is generally mounted in the control cabinet door with an emergency stop push-button. This panel can be located on the operator control panel if so desired.

- Discussions with other Plants that have done similar replacements conclude that the replacement systems can be installed, commissioned and started within a four week outage on the unit in question if much of the cabling and cabinet installation is done prior to the outage. This means that the system can be installed during a minor outage.

- Power supply for these systems consists of redundant 120vac sources from the UPS.

## 6.2 Simplex vs Triple Redundant Turbine Controls

The turbine controls proposed by General Electric and Woodward are available in two versions: Simplex and Triple Modular Redundant (TMR).

The Simplex version is a single channel controller capable of controlling, protecting and monitoring medium sized steam turbines like Holyrood. Redundant power supplies and triple redundant overspeed protection are included in the Simplex systems. If a circuit board fails within the main controller of this system the unit will trip. With adequate spares on site, it is estimated that the circuit board could be replaced and the unit returned to service within four hours provided there aren't any start-up problems.

The Triple Redundant steam turbine control systems have all the features of the Simplex but three independent main controllers are provided for all turbine control loops. Each controller contains all the necessary hardware and software to run the turbine and therefore any controller can be taken out of service for repair while keeping the turbine on line. TMR systems have the following features: three independent field sensing devices, two out of three software voting on the field sensing device outputs, three independent servos for each valve in the field. Since the existing system installed at Holyrood is a Simplex one there would be significant cost to upgrade to a TMR system not only because of the extra hardware inherent to the controls cabinet for TMR but also because of the increased field equipment required. Triple Redundant systems have traditionally been installed on units in nuclear plants or units providing power to dedicated customers where a process disruption can cause large losses and a long downtime.

In general Triple Redundant systems cost about 50% more than Simplex systems to buy and install. In comparing the Simplex with the Triple Redundant system the ability to repair problems and quickly return to service is a prime consideration. Processors are highly reliable but failures do occur. With the Triple Redundant systems, if there is a failure of two controllers, the unit will be tripped because two out of the three controllers have voted to do so.

The Bailey and Westinghouse Systems are based on a Distributed Control System Platform in the same way as the existing boiler control system for these units and therefore provide the option of dual redundant digital process controllers (DPUs). Dual controllers are used throughout the boiler control system. One controller is the primary DPU while the other is a hot standby which takes control in the event of a failure of the primary DPU. If both processors fail the unit will be tripped.

It is felt that a Simplex System, which General Electric and Woodward can supply, will provide adequate protection and control for the units at Holyrood. Bailey and Westinghouse can also provide single processor control. However, since the cost to provide redundant controllers in these systems increases the purchase price by only 2-3 %, the extra hot standby controllers proposed by Bailey and Westinghouse provide the best overall system for the cost and stay in line with the boiler control system redundancy.

### 6.3 General Electric MARK V - Simplex

General Electric Controls are jointly designed and manufactured in Salem, Virginia and Fitchburg, Massachusetts. GE, a certified ISO 9001 company, ships approximately 300 EHC Systems each year with about 20% of these being shipped for retrofits. The MARK V Simplex Turbine Control, developed in 1991, is the newest version of GE's series of EHC Systems for steam turbines. There are roughly 3000 MARK V EHC Systems in service worldwide. With such a large customer population GE expects to provide parts and technical support for the MARK V much longer than it has for the MARK II Systems. The limiting item in supporting spare parts on a long term basis is the availability of outside vendor equipment, i.e. circuit board electronics. GE guarantees the availability of spare parts for the MARK V for ten years after the MARK V is taken out of production.

The MARK V can provide full governor control of the main stop valve and main control valve thereby giving full flexibility during startup and loading. This system can also interface with the existing Westinghouse WDPF Boiler Controls and Bentley Nevada TSI System to transmit information to and accept information from each. Even though there is only one main controller for turbine control loops there are triple redundant controllers for trip protection which GE claim can "ride through" a failure in either the electronics, the sensors and actuators or the interconnecting wiring. In addition to the two 120 vac redundant power supplies for the MARK V, a third 125VDC source is recommended from the station batteries.

A thermal plant in Alabama (LOWMAN - 86 MW GE Machine) replaced a MARK II System with a MARK V 18 months ago and was contacted for a reference for General Electric. The situation at this plant was very similar to ours in that they had not had many problems with the

MARK II but were having trouble obtaining spare parts. They did have some problems with the PMG on the unit and were unable to run on Automatic Generator Control (AGC) due to noise to the controls from the MARK II power supplies. If Hydro was to implement AGC for the units at Holyrood, with the existing MARK II Systems in place, we would likely encounter similar problems. The Plant Engineer at LOWMAN gave GE a good reference in that they provided excellent technical support both from their manufacturing plant in Virginia and on site. The job was done on schedule, within budget and with the exception of a few software glitches during start-up the project went very smoothly.

### 6.4 Woodward MicroNet TCS100 - Simplex

Woodward is a certified ISO 9001 company which designs and manufactures Turbine Controls in Loveland, Colorado. The Micronet System is a repackaging of an older controller manufactured by Woodward called Netcon which Hydro has installed on the Happy Valley Gas Turbine. This repackaging was done by the company to reduce the cost of the system. The Micronet, introduced in 1996, has the same processor as the Netcon and also 90% of the modules used in the Micronet were used in the Netcon. Woodward has successfully applied it's Digital Turbine Control System in over 30 utility turbine retrofits but only one of these has used the new Micronet System. The company's policy is to support there control systems for as long as they can buy components from outside vendors. They buy the last batch of these components just before they go off the market in an effort to maintain service to their customers as long as possible. Also, Woodward will guarantee replacements-in-kind for as long as the system is in service.

Like the MARK V, the TCS100 can provide full governor control of the main stop valve and main control valve thereby giving full flexibility during startup and loading. This system can also interface with the existing Westinghouse WDPF Boiler Controls and Bentley Nevada TSI System to transmit information to and accept information from each.

A plant in Lansing, Michigan (ECKERT - 165 MW GE Machine) replaced a MARK II with a Woodward System 30 months ago and was contacted for a reference for Woodward. Again, this plant had not had many problems with the MARK II but were having trouble obtaining spare parts and could not afford lengthy shutdowns since they provided power to a General Motors manufacturing facility. The switch to Woodward from General Electric was based purely on financial considerations with General Electric's bid for new controls being 33% higher than Woodward's. The Operations Superintendent at ECKERT gave Woodward a good reference. The project came in on schedule, within budget and with the exception of some noise and feedback problems after start-up the project was a success. Woodward provided excellent technical support and field service.

### 6.5 ETSI (Bailey) - Dual Redundant Controllers

ETSI Turbine Control Systems are designed and manufactured in Burlington, Ontario. ETSI, a certified ISO 9001 company, is 100% owned by Elsag Bailey and was created in 1984 by six ex-Westinghouse Turbine Control Engineers. The ETSI turbine controls are based on a Bailey INFI 90 Distributed Control System (DCS) similar to that installed on the Hibernia Rig and being installed at Hydro's Hardwoods Gas Turbine Facility. ETSI has shipped approximately 350 EHC Systems since 1984 but there is an installed base of 16,000 Bailey INFI 90 Systems worldwide. The DCS modules proposed for the application at Holyrood are the same as those being installed at Hardwoods with the addition of some specialized modules for steam turbines. This is beneficial in that many spare parts for these systems are common. The modules of the ETSI System are upward and downward compatible. This means, for example, that modules installed in units back in 1984 can be installed in new 1997 systems with no upgrade cost and similarly 1997 modules can be installed in 1984 systems. The software used is also upward compatible.

The ETSI System can provide full governor control of the main stop valve and main control valve thereby giving full flexibility during startup and loading. ETSI's Turbine Protection System consists of three turbine protection modules cabled to a common termination unit. All electronic overspeed related protective functions are monitored and initiated in the modules and termination unit. This means that the turbine is protected even if the main control processors should fail. The ETSI system can also interface with the existing Westinghouse WDPF Boiler Controls and Bentley Nevada TSI System to transmit information to and accept information from each.

BOSWELL Station in Minnesota used ETSI to retrofit a boiler feed pump steam turbine EHC System six years ago and was contacted for a reference for ETSI. The Senior Engineer at BOSWELL gave ETSI a good reference in that they provided excellent technical support, on site commissioning and start-up assistance. ETSI completed the project on schedule, within budget and BOSWELL would not hesitate to use ETSI again for future projects.

### 6.6 Westinghouse WDPF - Dual Redundant Controllers

Westinghouse WDPF Turbine Control Systems are designed and manufactured in Pittsburgh, Pennsylvania. All correspondence and sales are handled through Westinghouse Canada in Richmond Hill, Ontario. Westinghouse has had considerable experience in Holyrood in that they supplied all of the boiler controls for all three units at Holyrood and also the burner management system on Unit #3. Westinghouse turbine controls are based on a WDPF Distributed Control System (DCS), the same as that installed for the boiler controls and burner management with the additions of some specialized modules for steam turbine control. This is beneficial in that many spare parts for these systems are common.

The Westinghouse System can provide full governor control of the main stop valve and main control valve thereby giving full flexibility during startup and loading. This system already exists at Holyrood and would mean that another two drops on the existing WDPF data highway would have to be incorporated into the present system for turbine controls. The existing WDPF System presently interfaces with the Bentley Nevada TSI System to accept information from each and display it to the operators in the control room. Engineering, Maintenance and Operating Personnel are all familiar with the existing WDPF Systems at Holyrood so training costs are all but eliminated.

No other Plants were contacted for references for Westinghouse since our own experience speaks for itself.

## 6.7 Advantages & Disadvantages of Manufacturer's Products

### General Electric

*Advantages*

1. GE has been in the turbine controls business for several years and have the most experience among the manufacturers discussed.

2. GE have the most experience in retrofitting MARK II Turbine Controls as well.

3. GE is the original manufacturer of the turbines to be controlled and the existing turbine controls.

4. GE has a great depth of knowledge and technical support for turbine control.

5. The MARK V System proposed by GE is a proven system with over 3000 units installed on steam and gas turbines worldwide.

*Disadvantages*

1. GE is expensive - see Appendix 2.

**Woodward**

*Advantages*

1. Woodward is the least expensive system - see Appendix 2.

*Disadvantages*

1. Woodward have the least experience in retrofitting MARK II Turbine Controls.

2. The Woodward Micronet is a repackaged Netcon 5000. The unit was repackaged to cut costs and has not been thoroughly tested in industry.

3. Woodward has only sold one Micronet system - the system they are proposing for Holyrood.

4. A service panel, mounted inside the controls cabinet door, has to be used to interigate programming since Woodward's Engineering Console Software is unable to do so. This service panel is a two line display which is not user friendly and can only step through the program two lines at a time.

**Elsag Bailey**

*Advantages*

1. The System proposed by Bailey is based on a Distributed Control System (DCS) which offers dual redundant processors in the same manner as the WDPF Boiler Controls.

2. The Bailey System is state of the art 1990's technology which is upward and downward compatible.

3. There is presently a Bailey System being installed at Hardwoods Gas Turbine which could share spare parts with Holyrood if Bailey was chosen to replace the MARK II System there.

4. Bailey's experience with DCS is vast and they are considered by many to be the benchmark for Distributed Control. With an installed base of 16,000 units worldwide they are on the leading edge of the technology.

5. Bailey has had considerable experience in retrofitting turbine controls on steam turbines.

*Disadvantages*

1. Different DCS architecture than the existing WDPF Boiler Controls will require training for Instrumentation Technicians and Engineers.

**Westinghouse**

*Advantages*

1. The System proposed by Westinghouse is based on their WDPF Distributed Control System (DCS) which offers dual redundant processors in the same manner as the existing WDPF Boiler Controls. This proposal offers the possibility of having a completely integrated boiler and turbine control system at Holyrood.

2. All personnel are familiar with the WDPF System and would require very little additional training.

3. Spare parts would be compatible between the boiler controls and turbine controls if all systems were Westinghouse.

*Disadvantages*

1. The WDPF system is an early 1980's technology which is already almost twenty years old. This may impair the Plants ability to obtain spare parts in the near future.

2. Westinghouse is unable to supply a backup operator interface for each main operator interface in the event that the main interface fails.

### 6.8 Cost for Replacement of EHC System

The tables in Appendix 2 indicate cost comparisons between the four manufacturer's proposed systems discussed in sections 6.3 through 6.6.

# 7.0 POINTS OF INTEREST & RECOMMENDATIONS

## 7.1 Points of Interest

1. General Electric considers the technology used in the MARK II EHC System to be obsolete by modern standards. The circuit boards in the MARK II System are no longer manufactured and therefore, for all intents and purposes, no longer available. GE does have a program to exchange or repair these boards in the event of failures but the cost is excessive. The programs emphasize the urgency of having one of each type of circuit board in stock at Holyrood but as can be seen in Tables 2, 3 and 4 of section 3.2 the cost to buy these boards exceeds the cost to replace the system. The spare parts that Hydro does have in Stores are very limited in supply, thirty years old, and have never been tested. This situation seriously compromises the reliability of Units 1 & 2 and could result in lengthy outages.

2. Plant Personnel feel that the MARK II System is one of the most reliable systems in the Plant and could not recall a failure ever occurring. A search through MAXIMO records confirmed that no failures had occurred with the MARK II System.

3. Some problems have been experienced with the equipment in the front standard. A new EHC System provides a direct connection to turbine sensors so much of the interposing instrumentation such as solenoids, relays, timers and associated wiring would be removed. This would improve the reliability of the machine and reduce maintenance and troubleshooting in the front standard.

4. Maintenance would be reduced and much easier to perform if the system were replaced with a new EHC System since all functions and settings would be in software.

5. The MARK II EHC System cannot provide full governor control over the full range of loading for these units. The cost to upgrade the present controls is comparable to the cost to install a new state of the art EHC System at Holyrood. New systems can provide full governor control of the units thereby allowing them to black start a de-energized system in times of isolation from the main grid as was the case in the December 1994 Blackout.

## 7.2 Recommendations

1. Due to the limited supply of critical spare parts in Stores inventory, the lack of parts available form GE, the high cost of those parts that are available, the limited technical support for MARK II Systems, limitations on governor control of the MARK II and the increasing potential for lengthy forced outages in the event of failures with the system it is recommended that a budget be prepared in 1998 for the EHC System on Units 1 & 2 to be replaced in 1999.

2. The new EHC System should be based on a Distributed Control System Platform in the same way as the existing boiler control system for these units and provide dual redundant digital process controllers (DPUs).

3. Two new Operator Interfaces (one for each unit) should be installed in the Control Room.

4. One new industrial grade PC should be installed in the Relay Room ( if the Westinghouse System is installed this PC will not be necessary) for the Instrumentation Technicians for editing software such as revisions to I/O assignments, sequencing, control, protection, tuning constants and graphic displays.

5. There should be a backup operator interface for each unit mounted on the turbine control board in the event that the main interface fails.

6. New cables should be installed from field sensing devices to the new EHC Cabinets.

7. The mechanical speed bolt should be left in place to provide an extra level of overspeed protection.

APPENDIX 1

| PART NO. | DESCRIPTION | DRAWING NO. | QUATITY | | LOCATION | BOARD NO. |
|---|---|---|---|---|---|---|
| | COMPUTOR RACK ASSMY. | | | | | |
| 696 | Speed Translator Function | 748D91G1 ✓ | 1 | | Computer Rack Assembly | B1 |
| 697 | Speed Translator Sensing | 7486091G2 ✓ | 1 | | " | B3 |
| 698 | Speed Summer Function | D4008J80G1 ✓ | 1 | | " | B4 |
| 699 | D.C. Amp | 817D605G1 ✓ | 8 | | " | B5, 11, 18, 36, 38, 46 |
| 700 | Initial Pressure Translator | 817D616G1 ✓ | 1 | | " | B8 |
| 701 | IP Control Amplifier Function | 821D380G1 ✓ | 1 | | " | B10 |
| 702 | MCV Servo Amplifier Power | 7486D76G2 ✓ | 1 | | " | B14 |
| 703 | MCV Servo Amplifier Function | 7486D76G1 | 1 | | " | B16 |
| 704 | Auxiliary Function A | 818D610G1 | 1 | | " | B19 |
| 705 | Auxiliary Function B | 819D349G1 | 1 | | " | B20 |
| 706 | 3 KC Oscillator | 7486D52G1 | 1 | | " | B21 |
| 707 | 3 KC Output | 7486D52G3 | 1 | | " | B23 |
| 708 | 3 KC Power | 7486D52G2 | 1 | | " | B24 |
| 709 | 1 KC Oscillator | 817D634G1 | 1 | | " | B26 |
| 710 | Auxiliary Function A | D4008J81G1 | 1 | | " | B28 |
| 711 | MSV Function | 819D353G1 | 1 | | " | B30 |
| 712 | MSV Servo Amplifier Power | 7486D84G2 | 1 | | " | B32 |
| 713 | MSV Servo Amplifier Function | 7486D84G1 | 1 | | " | B34 |
| 714 | 1 CV Summer Function | D4011J24G1 | 1 | | " | B37 |
| 715 | LH&RH ICV Function | 817D666G1 | 2 | | " | B41, B49 |
| 716 | LH ICV Servo Amplifier Power | 7486D82G2 | 1 | | " | B42 |
| 717 | LH ICV Servo Amplifier Function | 7486D82G1 | 1 | | " | B44 |
| 718 | RH ICV Servo Amplifier Power | 7486D82G2 | 1 | | " | B50 |
| 719 | RH ICV Servo Amplifier Function | 7486D82G1 | 1 | | " | B52 |
| 720 | VAC Translator | 817D617G1 | 1 | | " | B55 |
| 721 | VAC Control Amplifier | 821D380G1 | 1 | | " | B57 |
| | | | | | | |
| | | | | | | |
| | | | | | | |

| PART NO. | DESCRIPTION | DRAWING NO. | QUATITY | | LOCATION | BOARD NO. |
|---|---|---|---|---|---|---|
| | AUXILIARY RACK ASSEMBLY | | | | | |
| 722 | +30 VDC Power Supply Redund | 819D384G1 | 2 | | Aux. Rack Assy. | AB1, AB4 |
| 723 | -22VDC Power Supply Redund | 819D384G2 | 2 | | " | AB7, AB10 |
| 724 | (+30 -22) Power Supply Monitor | 817D664P1 | 1 | | " | AB13 |
| 725 | Auxiliary Relay | 818D312P1 | 1 | | " | AB15 |
| 726 | Auxiliary Relay | 819D315P1 | 1 | | " | AB16 |
| 727 | Lamp Supply (60CPS) | 818D313P1 | 1 | | " | – |
| 728 | Lamp Supply (PMG) | 818D314P1 | 1 | | " | – |
| 729 | Power Supply (-22VDC) | 838B589P1 | 2 | | " | – |
| 730 | Power Supply (+30VDC) | 838B590P1 | 2 | | " | – |
| 731 | Exhaust Fan | A1085J83P1 | 3 | | " | – |
| 732 | Recirculating Fan | A1085J86P1 | 1 | | " | – |
| 733 | Auxiliary Relay AC Dist Panel Relay | A1085J66P1 | 9 | | " | – |
| 734 | Auxiliary Relay AC Dist Panel Relay | A1085J66P2 | 1 | | " | – |
| | | | | | | |
| | CONTROL PANEL ASSEMBLY | | | | | |
| 735 | Speed Load Control Potentiometer (5K) | 655A752P3 | 1 | | Cont. Panel Assy. | – |
| 736 | Motor & Gear | B1112J40P1 | 1 | | " | – |
| | MAIN STOP VALVE POSITION CONT. | | | | | |
| 737 | Potentiometer (5K) | 120A561P3 | 1 | | – | – |
| 738 | Motor & Gear | B1112J40P1 | | | – | – |
| | | | | | | |
| | VACUUM UNLOADING CONTROL | | | | | |
| 739 | Potentiometer (20K) | 654A692P5 | 1 | | – | – |
| 740 | Motor & Gear | B1112J40P1 | | | – | – |
| | | | | | | |
| | INITIAL PRESSURE CONTROL | | | | | |
| 741 | Potentiometer (20K) | 654A692P5 | 1 | | – | – |
| 742 | Motor & Gear | B1112J40P1 | 1 | | – | – |
| | | | | | | |

13 ITEMS

| PART NO. | DESCRIPTION | DRAWING NO. | QUATITY | | LOCATION | BOARD NO. |
|---|---|---|---|---|---|---|
| | LOAD LIMIT CONT. LH & RH CONTROLS | | | | | |
| 743 | Potentiometer (5K) | 120A561P3 | 3 | | – | – |
| | | | | | | |
| | AUXILIARY CONTROL PANEL | | | | | |
| 744 | Speed Reg. Control Potentiometer (5K) | 120A561P3 | 1 | | – | – |
| 745 | Vacuum Unload Lev Control Potentiometer (1K) | 654A692P1 | 1 | | – | – |
| | | | | | | |
| | POWER ACTUATORS | | | | | |
| 746 | Servo Valve (ICV50Gal.) | 200A227P1 | 2 | | – | – |
| 747 | O Ring | 655A770P214 | 8 | | – | – |
| 748 | O Ring | 655A770P11 | 2 | | – | – |
| | | | | | | |
| 749 | Servo Valve (ICV) 15 Gal. | A1071J70P1 | 2 | | – | – |
| 750 | O Ring | 655A770P11 | 8 | | – | – |
| 751 | O Ring | 655A770P10 | 2 | | – | – |
| | | | | | | |
| 752 | Servo Valve (MCV) 50 Gal. | 200A227P1 | 1 | | – | – |
| 753 | O Ring | 655A770P214 | 4 | | – | – |
| 754 | O Ring | 655A770P11 | 1 | | – | – |
| | | | | | | |
| 755 | Servo Valve (MSV) 15 Gal. | A1071J70P1 | 1 | | – | – |
| 756 | O Ring | 655A770P115 | 3 | | – | – |
| 757 | O Ring | 655A770P10 | 2 | | – | – |
| 758 | O Ring | 655A770P11 | 4 | | – | – |
| | | | | | | |
| | | | | | | |
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# APPENDIX 2

# TABLE 1
## COST COMPARISON TO RETROFIT ONE UNIT
### ( Direct Costs Only)

| COST ITEM | General Electric | Woodward | ETSI (Elsag Bailey) | Westinghouse |
|---|---|---|---|---|
| Control System c/w cabinet, operator interface, one industrial PC, on site assistance. | $394,200.00 | $226,910.00 | $395,076.00 | $305,250.00* |
| Other Material | $25,000.00 | $25,000.00 | $25,000.00 | $25,000.00 |
| On Site Training | $20,000.00 | $20,000.00 | $20,000.00 | $8,000.00 |
| Installation (Internal) | $88,000.00 | $88,000.00 | $88,000.00 | $56,080.00 |
| Engineering | $40,000.00 | $40,000.00 | $40,000.00 | $30,000.00 |
| TOTAL | $567,200.00 | $399,910.00 | $568,076.00 | $424,330.00 |

* Price does not include Backup Operator Interface which Westinghouse cannot provide.

**Notes:**

1. Prices based on 1997 estimates. Escalated costs shown in Table 2.
2. *Other Material* refers to cable, cable tray, conduit, relays, metalwork, etc.
3. *On Site Training* is the cost charged by the Manufacturer to put off a one week course at Holyrood for Engineers, Technicians and Operators.
4. Installation costs for Westinghouse are less because Instrumentation Technicians are familiar with the WDPF System and therefore installation and commissioning should be less. Training time will also be less if this System is installed.
5. Engineering time for Westinghouse System is less because of familiarity of the WDPF System.

# TABLE 2
## COST COMPARISON TO RETROFIT ONE UNIT IN 1999
### ( Total Escalated Costs)

| COST ITEM | General Electric | Woodward | ETSI (Elsag Bailey) | Westinghouse |
|---|---|---|---|---|
| Control System c/w cabinet, operator interface, one industrial PC, on site assistance. *33,000 | $394,200.00 | $226,910.00 | $395,076.00 | $305,250.00* |
| Other Material | $25,000.00 | $25,000.00 | $25,000.00 | $25,000.00 |
| On Site Training | $20,000.00 | $20,000.00 | $20,000.00 | $8,000.00 |
| Installation (Internal) | $88,000.00 | $88,000.00 | $88,000.00 | $56,080.00 |
| Engineering | $40,000.00 | $40,000.00 | $40,000.00 | $30,000.00 |
| Corporate O/H | $37,000.00 | $26,000.00 | $37,000.00 | $27,000.00 |
| IDC | $7,800.00 | $5,800.00 | $7,800.00 | $5,900.00 |
| Contingency | $56,700.00 | $40,000.00 | $56,800.00 | $42,400.00 |
| Escalation | $36,300.00 | $25,700.00 | $36,400.00 | $26,900.00 |
| TOTAL | $705,000.00 | $497,410.00 | $706,076.00 | $526,530.00 |

* Price does not include Backup Operator Interface which Westinghouse cannot provide.

**Notes:**

1. Prices are 1999 escalated prices.
2. *Other Material* refers to cable, cable tray, conduit, relays, metalwork, etc.
3. *On Site Training* is the cost charged by the Manufacturer to put off a one week course at Holyrood for Engineers, Technicians and Operators.
4. Installation costs for Westinghouse are less because Instrumentation Technicians are familiar with the WDPF System and therefore installation and commissioning should be less. Training time will also be less if this System is installed.
5. Engineering time for Westinghouse System is less because of familiarity of the WDPF System.

# TABLE 3
## COST COMPARISON TO RETROFIT BOTH UNITS 1 & 2
## ( Direct Costs Only)

| COST ITEM | General Electric | Woodward | ETSI (Elsag Bailey) | Westinghouse |
|---|---|---|---|---|
| Control System c/w cabinets, operator interfaces, one industrial PC, on site assistance. | $788,400.00 | $385,080.00 | $702,500.00 | $610,500.00* |
| Other Material | $50,000.00 | $50,000.00 | $50,000.00 | $50,000.00 |
| On Site Training | $20,000.00 | $20,000.00 | $20,000.00 | $8,000.00 |
| Installation (Internal) | $140,800.00 | $140,800.00 | $140,800.00 | $102,080.00 |
| Engineering | $60,000.00 | $60,000.00 | $60,000.00 | $45,000.00 |
| TOTAL | $1,059,200.00 | $655,880.00 | $973,300.00 | $815,580.00 |

* Price does not include Backup Operator Interface which Westinghouse cannot provide.

**Notes:**

1. Prices based on 1997 estimates. Escalated Costs shown in Table 4.
2. *Other Material* refers to cable, cable tray, conduit, relays, metalwork, etc.
3. *On Site Training* is the cost charged by the Manufacturer to put off a one week course at Holyrood for Engineers, Technicians and Operators.
4. Installation costs for Westinghouse are less because Instrumentation Technicians are familiar with the WDPF System and therefore installation and commissioning should be less. Training time will also be less if this System is installed.
5. Engineering time for Westinghouse System is less because of familiarity of the WDPF System.

# TABLE 4
## COST COMPARISON TO RETROFIT BOTH UNITS 1 & 2 IN 1999
## ( Total Escalated Costs)

| COST ITEM | General Electric | Woodward | ETSI (Elsag Bailey) | Westinghouse |
|---|---|---|---|---|
| Control System c/w cabinets, operator interfaces, one industrial PC, on site assistance. | $788,400.00 | $385,080.00 | $702,500.00 | $610,500.00* |
| Other Material | $50,000.00 | $50,000.00 | $50,000.00 | $50,000.00 |
| On Site Training | $20,000.00 | $20,000.00 | $20,000.00 | $8,000.00 |
| Installation (Internal) | $140,800.00 | $140,800.00 | $140,800.00 | $102,080.00 |
| Engineering | $60,000.00 | $60,000.00 | $60,000.00 | $45,000.00 |
| Corporate O/H | $68,000.00 | $41,000.00 | $64,000.00 | $53,000.00 |
| IDC | $14,700.00 | $9,600.00 | $13,500.00 | $11,000.00 |
| Contingency | $105,900.00 | $65,600.00 | $97,300.00 | $81,600.00 |
| Escalation | $67,600.00 | $41,800.00 | $62,300.00 | $52,100.00 |
| TOTAL | $1,315,400.00 | $813,880.00 | $1,210,400.00 | $1,013,280.00 |

*Price does not include Backup Operator Interface which Westinghouse cannot provide.

**Notes:**

1. Prices are 1999 escalated prices.
2. *Other Material* refers to cable, cable tray, conduit, relays, metalwork, etc.
3. *On Site Training* is the cost charged by the Manufacturer to put off a one week course at Holyrood for Engineers, Technicians and Operators.
4. Installation costs for Westinghouse are less because Instrumentation Technicians are familiar with the WDPF System and therefore installation and commissioning should be less. Training time will also be less if this System is installed.
5. Engineering time for Westinghouse System is less because of familiarity of the WDPF System.