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THERMAL POWER DIVISION, MONTREAL, CANADA

REPORT

NALCOR

FEASIBILITY STUDY OF HTGS UNITS 1&2 CONVERSION TO SYNCHRONOUS CONDENSER - AN EVALUATION OF RUN UP OPTIONS FOR GENERATORS

ORIGINAL

Contract No.
503743
Revision 02

February 2011

Certified ISO 9001

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SNC-LAVALIN Thermal Power

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February 2011

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TABLE OF CONTENTS

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FIGURE LIST

APPENDIX LIST

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EXECUTIVE SUMMARY

SNC-Lavalin (SLI) received a mandate from NALCOR to prepare a study of the modifications necessary to allow Holyrood units 1 & 2 to operate as synchronous condensers in anticipation of implementation of the Lower Churchill Hydroelectric Project. Since Holyrood would also be required to provide generation for several years to come during the winter period, the machines would have the flexibility to operate either as synchronous condensers or in generation mode (as unit 3).

SLI carried out a review of proven modern technology available for starting the machines as synchronous condensers and accelerating them to synchronous speed. Available options included electric motor drives at either constant or variable speed with various coupling arrangements, and variable speed drives acting directly on the generator stator.

Since both units 1 & 2 were to be modified, and NALCOR expressed interest in modernizing the drive system currently used on unit 3, a system using two static starter systems was recommended. Each system could be used to start any of the three machines, and the provision of two systems gives the necessary redundancy. The static starters would require new excitation transformers as well as integration with the existing excitation, control, and protection systems.

Each generator must be de-coupled from the steam turbine, and a new stub shaft is required at the outboard end of the generator to locate a new thrust bearing and turning gear assembly. During operation as a generator, either the stub shaft could be removed, or the thrust pads of the new thrust bearing would be removed. It is not completely clear that the main shaft coupling provides sufficient clearance for synchronous condenser operation. A detailed inspection of one of the couplings is required to confirm this point, as GE have not seen fit to confirm the coupling details.

Preliminary equipment arrangement drawings and single line diagrams have been prepared. Budgetary prices were received from qualified international suppliers for all major items.

A capital cost estimate has been prepared indicating an estimated installed cost of approximately $5,748,000. This cost includes an allowance for inflation through 2014 and a contingency for items which cannot be defined at this stage. The estimate meets AACE class 4 definitions and accuracy.

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1.0 INTRODUCTION AND MANDATE

SNC-Lavalin Thermal Power was mandated to prepare a screening study and cost estimate for the implementation of the capability of operating as synchronous condensers for generators 1 and 2 at the NALCOR Holyrood generating station. These two machines have a rating of 194,445 kVA (PF 0.90) and were supplied by General Electric Canada.

Holyrood is an active generating station in the winter months, but remains largely unused in the summer, and NALCOR is considering using units 1 and 2 more effectively. Once phase 1 of the Lower Churchill power generation project is completed, Holyrood would be converted from a generating station to synchronous condenser operation.

A team from SNC-Lavalin Thermal Power (Montreal) visited the Holyrood GS on August 5/6 2010 and met with members of the plant staff and NALCOR Engineering in St. John's.

The SNCL team has proceeded to investigate the technical and commercial implications of adapting units 1 and 2 to operate synchronous condensers while maintaining the capability to operate in generation mode.

One intermediate progress report presentation was made by SNC-Lavalin personnel to NALCOR staff in St. John's. The final meeting where the major results of the study were presented to NALCOR staff was held in St. John's on October 26th, 2010.

This report presents the detailed findings including both technical and cost comparisons, and provides a recommendation for the type of equipment optimally suited for the conversion to synchronous condenser operation at Holyrood.

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2.0 TECHNOLOGY REVIEW

The existing unit 3 generator utilizes a pony motor acceleration system and is decoupled from the steam turbine once per year and re-coupled once per year for the generating season (winter). This conversion operation takes approximately 15 days, during which time the unit is not operational.

Units 1 and 2 require an acceleration system to bring the uncoupled generator to synchronous speed for synchronous condenser operation plus decoupling the generator from the steam turbine. Provision of a thrust bearing is also required.

The installation of an overrunning clutch between the steam turbine and generator for units 1 and 2 is not feasible due to insufficient space for installation. Creating the necessary space would only have been possible if the generator was moved axially on its foundation, which was not considered.

Several types of generator acceleration systems are available, including various types of acceleration drives (skidded) connected to the decoupled generator using either constant speed or VFD drive, or a static frequency drive acting directly on the generator stator.

Note that whichever type of generator acceleration system is ultimately selected, the steam turbine/generator lube oil system and generator cooling system will need to remain operational. The existing systems may require a small low-power bypass circulation system installed that would operate only during the reduced cooling and lube oil needs of synchronous condenser operation.

SNC-Lavalin identified five different types of acceleration or starting systems for review, which are described in more detail in the following sections.

SNC-L was informed that a spare medium voltage circuit breaker was available on each unit board for synchronous condenser auxiliaries. In synchronous condenser mode the large drives used in the generating mode such as cooling water pumps and boiler feed pumps will not be operating. In the synchronous condenser mode, the station service load will be much less than at present when operating in the generating mode. However, for the static start option the excitation system has to be fed from the medium voltage bus. Since the units still will have to operate in the generating mode for some years the excitation system load is fed from the medium voltage bus It was confirmed the capacity of the bus is sufficient to cover the excitation load.

2.1 Unit 3 Existing System (Option 1)

The existing acceleration system used for unit 3 is provided by Philadelphia Gear (PGC model HL60/9HS). It consists of a constant speed 1800 RPM pony motor, a variable speed hydro-viscous clutch with integrated step-up gearbox, and SSS over-running clutch. It also includes an oil and hydraulic system and accessories to operate the gearbox, and clutches. For the equipment list of this acceleration system arrangement, please see Appendix A. Budget quotes for new equipment for units 1, 2 were received from PGC.

This system was designed to accelerate the unit 3 generator rotor from zero to full speed in 18 minutes. In speaking with NALCOR about the system, it often takes longer in practice to accelerate and synchronize the generator, and the existing system once included a brake, which was subsequently removed.

There is no thrust bearing included in this arrangement, and when synchronized, the rotor axially positions itself according to the magnetic center of the generator. This drive unit does not have a turning gear, the turning gear for the steam turbine/generator is located at the main shaft coupling.

The generator, while operating in synchronous condenser mode, has experienced vibration issues over the years, which has caused spider cracks in the concrete foundation. NALCOR believe that this may be related to the lack of a thrust bearing on unit 3, and the installation of a thrust bearing has been considered in talks with Mel Giberson from TRI.

Figure 1 Photograph of unit 3 acceleration skid PGC model HL60/9HS

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2.2 Motor Drive with Magnetic Coupling (Option 2)

This acceleration system consists primarily of a drive-train including a generator main thrust bearing, an over-running clutch, a step-up gearbox, a magnetic coupling and a constant speed pony motor. For the budgetary equipment list of this acceleration system, please see Appendix A.

For this study, a unit supplied by [redacted] a leader in this technology was considered. The largest [redacted] coupling available is rated 1750 HP at 1800 RPM (a maximum rating of only 275 HP is available at 3600 RPM), therefore a step-up gearbox is required in this arrangement. This unit requires water cooling.

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Figure 2 Illustration of [redacted] unit in housing

[redacted]

Figure 3 Side view of typical [redacted] coupling

[redacted]

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2.3 Motor Drive with Hydraulic Coupling (Option 3)

This acceleration system consists primarily of a drive-train including generator main thrust bearing, a hydraulic torque converter and a constant speed pony motor. For the budgetary equipment list of this acceleration system arrangement, please see Appendix A.

Two vendors were considered, [redacted]. The [redacted] arrangement consists of a constant speed motor (3600 RPM) and hydraulic coupling as shown below. Decoupling of the drive is done by removal of the fluid in the coupling. The TRI [redacted] arrangement uses an 1800 RPM motor and a step-up gearbox, and includes a disconnect coupling, a turning gear and a thrust bearing.

Figure 4 [redacted] hydraulic torque converter starter skid model [redacted]

[redacted]

Figure 5 [redacted] arrangement

[redacted]

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2.4 Variable Speed Drive with Overrunning Clutch (Option 4A, 4B)

This acceleration system consists primarily of a drive-train including a generator main thrust bearing, an over-running clutch, a step-up gearbox, and an 1800 RPM pony drive motor with a VFD (one VFD for each unit). This is considered Option 4A, and is shown in the diagram below.

Option 4B is the same as 4A, but using a 3600 RPM motor and no step-up gearbox.

For the budgetary equipment list of this acceleration system arrangement, please see Appendix A.

Figure 6 Pony motor c/w step-up gearbox & over-running clutch (typical)

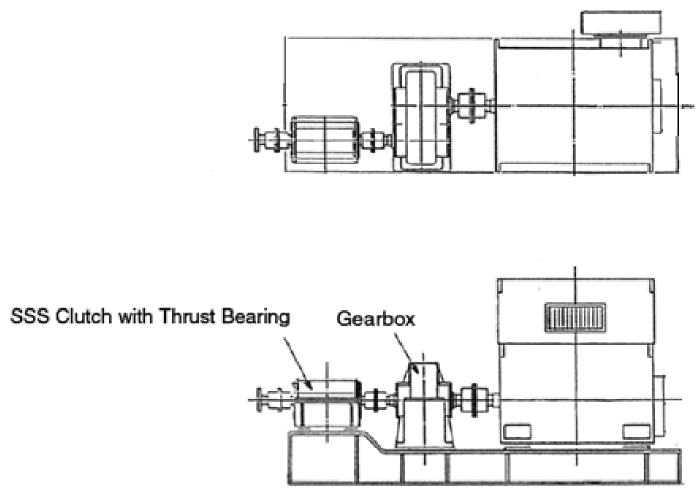

Figure 7 A typical 4.16 kV adjustable speed drive (Eaton)

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2.5 Static Frequency Converter Generator Start(Option 5)

2.5.1 System Description

A static frequency converter (SFC) start system is connected to the generator which is soft started as a synchronous motor. The SFC is disconnected just before the generator is synchronized for a bumpless transfer to the grid.

With this option one SFC can be used to start one or more units by switching the output to the unit being started using additional switches/contactors. However, for reliability reasons redundancy is recommended so that one SFC should be supplied for each unit with the ability to start either unit from either SFC. If, in the future, it is decided to convert unit 3 to the same system, the two SFCs could be connected to unit 3.

Available SFC technologies such as Load commutated inverter (LCI) or Voltage Source Inverter (VSI) units are selected by suppliers based on their assessment of alternatives, previous experience and cost.

All drive alternatives typically comprise an incoming breaker or switch/contactor, an input/isolation transformer, a rectifier, a dc link reactor and an inverter which operates as a variable voltage and frequency output. In addition to an output filter and disconnect there is HMI (Human Machine Interface) and PLC based diagnostics, protection and control circuits. The power plant’s designed control architecture will establish the I/O configurations and communication protocols. The SFC power requirements and ratings are dependent on the breakaway torque, inertia of the rotating system, windage, friction and the starting time.

Only one circuit breaker per machine is presently available for synchronous condenser auxiliaries. A new switchgear will be installed for each unit and will be fed from the spare circuit breaker. Two feeders will connect to the SFC and to the excitation systems. The new switchgear will be located next to the SFC units.

Since two SFCs would be installed with the ability to feed both units and possibly three units, switchgear is required to switch the output of an SFC to any unit. New switchgear will be installed for each unit to do this switching. The switchgear will be located next to the SFC units

Two approaches are possible to connect the SFCs to the generators. One is to connect the SFCs to the generator output busduct using the taps now used for the excitation transformers. In this case the output switchgear and connecting cables would have to be 17.5kV class or higher. The second method is to connect the SFCs to the low voltage side of the station service transformer. In this case the switchgear and connecting cables would be 5kV class

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In SLD (Single Line Diagram) 0001 ([redacted]) the SFC is connected to the isolated phase busduct through the secondary of the unit station service transformer using a remotely operated disconnect/contactor.

In SLD 0002, the SFC is fed directly to the terminals of the generator through a remotely operated disconnect switch or circuit breakers. The connection to the Synchronous Condenser will be at the isolated phase busduct tap used for the excitation transformer.

A new excitation transformer is necessary since excitation power from the MV (4.16 kV) station auxiliary service bus is required during start up. An alternative approach would be to procure a system that combines a static excitation system and a static frequency converter which could provide space and installation cost savings and simplify the control system integration.

The excitation transformers would have to be replaced with units fed from the medium voltage bus since excitation is required during start-up. If the bus duct taps are used to connect the SFCs to the generators, the new transformers will have to be located at the other end of the excitation line-up and a low voltage busduct will be used to connect the transformer to the rectifier. If the busduct taps are not used, the new transformer would be located in the same location as it is currently. The transformers would have side mounted bushings for power cables. The busduct taps would be sealed off. There are several stages to the starting run-up. Initially between standstill and a chosen speed the acceleration takes place at constant torque where the terminal voltage of the machine rises in proportion to the speed until the inverter's rated voltage is reached. Acceleration continues with constant power while the excitation unit adjusts the machine voltage until the SFC unit is turned off a few percents above synchronous speed while operating at full line voltage. During the coasting down phase the generator breaker is closed after a successful synchronizing to the grid.

Information received from suppliers based on estimated data shows the proposed two configurations in Single Line Diagrams (SLDs) 503743-0000-47D1-0001 and 0002

The two types of Static Starter Units proposed are the Load commutated inverter (LCI) and the Voltage Source Inverter (VSI) units. The operation for both is similar in that the SC (Synchronous Condenser) would be accelerated from standstill or a few rpm to synchronous speed where the Static Start Unit would be disconnected and the SC synchronized to the grid using the high voltage circuit breaker.

The Static Starter Unit control system has to be integrated with the excitation system controls so as to adjust and monitor the machine's voltage. The Static Starter Unit incorporates the generator protection required during starting.

The transformers and SFC cubicles will be located in the Mezzanine area as shown on drawing 503743-0000-47D3-0001.

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2.5.2 Synchronous Condenser Starting Sequence

The starting procedure is a routine sequence that involves properly timed operations as well as the automatic checking of many mechanical and electrical conditions best done by the supervisory and control PLCs and DCS.

1) Prior to a unit start-up the different switching equipment will be in the following position:
    a) Synchronous Condenser unit's 230 kV breaker is open.
    b) Unit station service transformer circuit breaker is open.
    c) Unit station service is connected to the start-up supply from the 69kV Switchyard.
    d) Static Frequency Start Unit (SFC) 4.16 kV supply circuit breaker is open.
    e) Static Exciter 4.16 kV supply circuit breaker is open.
    f) Shaft turning motor 600 V auxiliary supply starter is open.
    g) Lock-out relay has been reset.
    h) Supply voltages normal.

2) Energizing of the Auxiliaries:
    a) Start oil lift pumps and check of oil pressure.
    b) Hydrogen and oil coolers operational.
    c) Energize shaft turning motor and rotate shaft to approx. 5 rpm.

3) Synchronous Condenser (SC) Start-up:
    a) Stop shaft turning motor.
    b) Close the Exciter 4.16 kV breaker in the supply switchgear.
    c) Close the SFC Start Unit 4.16 kV breaker in the supply switchgear.
    d) Start of the Static Frequency Start Unit locally or from the DCS which will initiate the field excitation and energize the stator winding by closing the respective motorized switches or circuit breakers. Rotation is initiated.
    e) All critical operating conditions and values are checked continuously by the control system as to whether they remain within the permissible operating limits. Any abnormality will cause a lock-out.
    f) In the initial acceleration phase the machine terminal voltage rises in proportion to the speed with a constant excitation.
    g) The acceleration to slightly over synchronous speed is achieved by the SFC controls regulating the voltage/current and the exciter so as to achieve the required acceleration within the V/Hz limits.
    h) The excitation adjusts the machine terminal voltage to the nominal voltage.
    i) Motorized switch or circuit breakers disconnects the SFC from the Synchronous Condenser.
    j) SFC unit circuit breaker opened.
    k) In the coasting down phase, the machine/exciter controls are transitioned to the plant's controls (DCS).
    l) Upon a successful synchronization the unit's 230 kV breaker is closed.
    m) Unit is loaded to required VARS.

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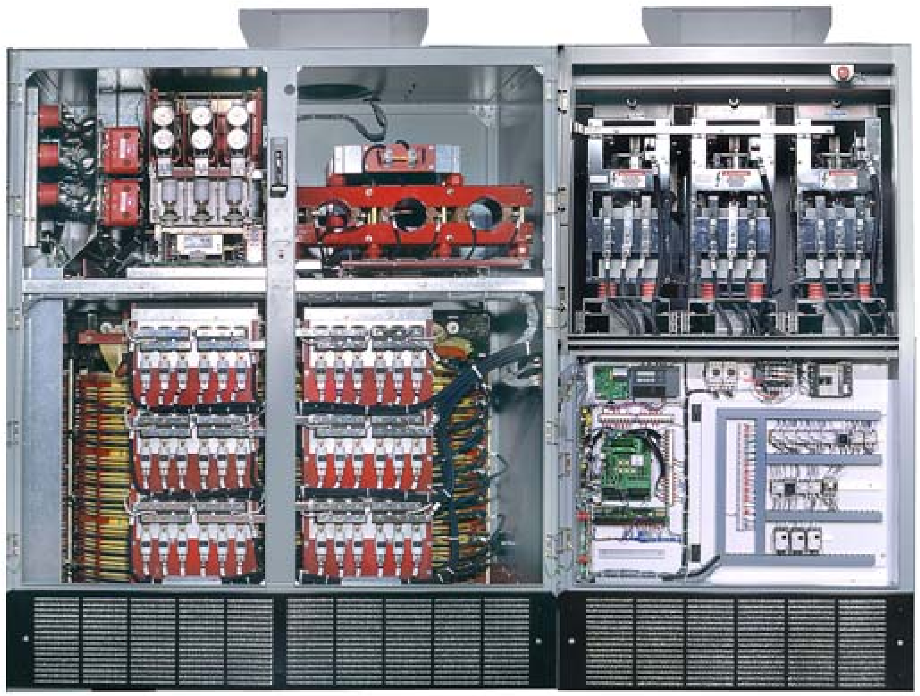
Unit 4.16kV auxiliary board is transferred from station supply to unit transformer supply.

2.5.3 Typical SFC Hardware

Figure 8 Typical Static Start Unit with incoming disconnect/contactor and transformer [redacted]



[redacted] proposes an air cooled 24 pulse IGBT - VSI (Insulated Gate Bipolar Transistor – Voltage Source Inverter) which is packaged in a footprint comparable to the LCI (Load Conmutated Inverter) units proposed by the other suppliers. Their mean time between failures (MTBF) is specified as a minimum of 16 years with a mean time to repair (MTTR) of 15 min. The interfaces allow for communicating with ABBs Exciter open control system.

[redacted] proposed LCI (load Comutated Inverters) units, Fig. 11 & 12, which are typically used in these applications due to their simplicity and lower cost. [redacted] can readily integrate the Exciter and SFC controls with one HMI (Human Machine Interface) platform.

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Figure 9 Typical Static Start Unit from [redacted]

Figure 10 Typical Static Start Unit from [redacted] (note this unit is containerized)

For the budgetary equipment list of this acceleration system arrangement, please see Appendix A.

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3.0 RFP AND BUDGETARY PROPOSALS RECEIVED

3.1 Acceleration Skids

Equipment Supplier	Budget Spec/Inquiry submitted	Proposals Submitted - Comments
[redacted]	Verbal discussions held in Aug/Sept	Submitted budget proposal for Option 1
[redacted]	Request for budgetary proposal (RFBP) sent 2010-8-10	MagnaDrive does not package it's own equipment. We have been unable to find a vendor who would supply an engineered package based on the Magnadrive coupling acting as a clutch.
[redacted]	RFBP sent 2010-10-8	Submitted budget proposal for Option 3
[redacted]	RFBP sent 2010-10-8	Submitted budget proposal for Option 3
[redacted]	RFBP sent 2010-10-8	Submitted budget proposal for Option 4A

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3.2 Static Start Units

Equipment Supplier	Budget Spec/Inquiry submitted	Proposals Submitted - Comments
[redacted]	Oct. 8, 2010	Proposal is for two complete systems, equipment only, including new excitation systems. [redacted] have not justified the inclusion of the new excitation systems.
	Oct. 7, 2010	Proposal is for Static starter only, equipment only. Other components have to be added to complete system.
	Oct. 20,2010	Proposal is for Static starter only, equipment only. Other components have to be added to complete system.

3.3 Other Potential Suppliers for Static Start Units

Although three vendors were contacted for budget pricing and information for static start options, other suppliers also provide this equipment, and may be approached when a formal RFP is issued by NALCOR:

- [redacted];
- [redacted]
- [redacted].

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4.0 ADVANTAGES AND DISADVANTAGES OF TECHNOLOGY OPTIONS

Variable speed hydro-viscous clutch (PGC model HL60/9HS)	Variable speed coupling with permanent magnet	Hydraulic torque converter coupling	Electric motor with VFD (1800 RPM)	Electric motor with VFD (3600 RPM)	Static Frequency Converter
1	2	3	4A	4B	5
Pros	Pros	Pros	Pros	Pros	Pros
Known, proven technology	Magnetic coupling relatively insensitive to alignment, will not transfer vibration through air gap	Hydraulic coupling is proven technology, potential supplier [redacted]	Known, proven technology	Known, proven technology	Known, proven technology, used for starting high capacity (> 100 MW) gas turbines
Reported +/- 0.5% variability on speed control	Low cost variable speed	Low cost variable speed	Smooth speed and torque control over the generator acceleration	Smooth speed and torque control over the generator acceleration	One frequency converter, requires no drive motor and coupling to generator rotor
	Simple mechanical speed control	Built-in disengaging from the generator (does not need an overrunning clutch)	Higher speed range than the base speed	Higher speed range than the base speed	Smooth speed and torque control over the generator acceleration
		Good track record for these units	Low starting current	Low starting current	Higher speed range than the base speed
		Smooth speed and torque control over the generator acceleration	Minimal maintenance in normal use	Minimal maintenance in normal use	Low starting current
			Reduces mechanical and thermal stresses	Reduces mechanical and thermal stresses	Minimal maintenance in normal use
					Reduces mechanical and thermal stresses
					Disengaging clutch not required
Variable speed hydro-viscous clutch (PGC model HL60/9HS)	**Variable speed coupling with permanent magnet**	**Hydraulic torque converter coupling**	**Electric motor with VFD (1800 RPM)**	**Electric motor with VFD (3600 RPM)**	**Static Frequency Converter**
Cons	Cons	Cons	Cons	Cons	Cons
Significant footprint – requires space behind generator exciter	Significant footprint – requires space behind generator exciter	Significant footprint – requires space behind generator exciter	Significant footprint – requires space behind generator exciter	Significant footprint – requires space behind generator exciter	
Somewhat complicated	Gear increaser has to be added after the coupling because Magnadrive currently only makes high power couplings (1800 BHP) for 1800 RPM applications	Gear increaser has to be added to unit	Use of 1800 RPM motor requires use of step-up gearbox	Use of 3600 RPM motor requires higher capacity motor to provide breakaway torque required at start-up	Requires connection to generator main bus duct or to station service feeder with a circuit disconnect switch.
	Generator disengaging clutch required to prevent continuous running of gearbox at no load		Generator disengaging clutch required	Generator disengaging clutch required	
	Additional shaft and bearings alignment and maintenance	Additional shaft and bearings alignment and maintenance	Additional shaft and bearings alignment and maintenance	Additional shaft and bearings alignment and maintenance	

5.0 MODIFICATIONS REQUIRED TO UNITS 1 & 2 GENERATOR ROTORS.

In order to convert the existing unit 1 and 2 generators to synchronous condensers and operate independently of the steam turbines, several circumstances and modifications need to be considered.

5.1 Available Space Footprint Behind Generator Exciter

The space available behind the generator exciter housing and the control room wall is approximately 15 feet (See Fig. 13, 14). Any acceleration drive system would be required to fit into this space. Alternatively the exciter housing could be removed and the brush rings relocated on a shorter stub shaft.

Figure 11 Exciter housing, rear of generator, unit 2

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Figure 12 View of space available behind unit 2

5.2 Decoupling Generator From Steam Turbine

The main shaft coupling between the generator and steam turbine must be uncoupled for the generator to rotate independently of the steam turbine. The drawing below, provided by GE Canada, indicates that there is no spacer in the coupling. This would make it impractical to decouple the two shafts unless material was removed from either shaft to allow clearance for relative rotation between the shafts (i.e. the generator turning, the steam turbine immobilized). However, after some discussion between SNC-Lavalin and GE's site representative it is understood that a spacer was installed between the shaft coupling flanges when modifications were implemented during the 1980's. This is addressed in Item 10 of this report.

GE has not confirmed the modifications, and a visual inspection is still required to definitively establish the current mechanical arrangement. The plant will carry out an inspection during the next maintenance season (May/June 2011).

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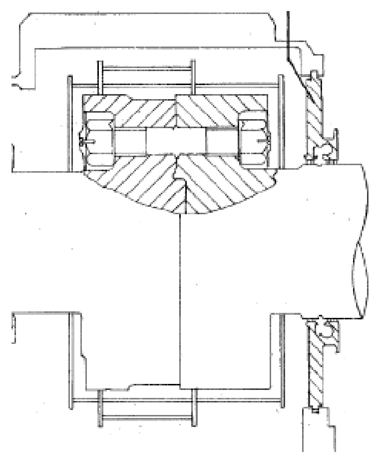
If a spacer is not found to be installed between the two shafts, there may significant implications. In order for the generator rotor to turn unimpeded under all operating conditions, it is possible that some in-situ machining of the shaft flanges may be required. There is also the possibility that with the steam turbine shaft thrust bearing located at the hot end, and the disconnected steam turbine shaft in the cold and unexpanded condition, sufficient clearance might already exist. If machining is required, this might or might not preclude the eventual re-connection of the two shafts. More detailed engineering will be required to resolve this situation pending results of the visual inspection.

Figure 13 Sketch of generator/turbine coupling as provide by GE



5.3 Installation of Generator Thrust Bearing

In order for the generator to be positively located during SC operation, an independent thrust bearing will be required and would be installed at the outboard end of the generator. When the unit is switched back to generation mode either the generator thrust pads would be removed, or the entire stub shaft could be removed, with the axial position maintained by the turbine thrust bearing.

5.4 Barring System

A barring system to start rotation of the generator by reducing breakaway torque and additionally to prevent bow from occurring in the generator rotor is required unless the acceleration system can operate from zero RPM. This barring system would be integrated into any thrust bearing assembly.

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5.5 Conversion Process

The conversion from generator to synchronous condenser operation requires the previously outlined modifications followed by an automatically controlled starting and synchronizing sequence that ensures that all preconditions are met.

As presented in the previous sections, synchronous condenser rotor acceleration torque can be obtained by an induction motor connected to the condenser shaft or by self-starting using a static frequency converter (SFC) source.

The issues encountered when a synchronous condenser is brought up to speed with an induction motor and then put on line, are exactly the same as when a generator is synchronized and put on line i.e.: the machine must be brought to synchronous speed, the voltage matched and synchronized to the line voltage followed by closing the running breaker. The transients are minimized when closing the breaker by matching closely the voltage and phase.

A static frequency converter (SFC) system accelerates synchronous machines using the interaction of the stator and the rotor fields, where the rotor field must be energized and set from the SFC from standstill to running speed so as to generate the necessary acceleration torque. Note that the exciter and machine controls must be designed to transition from being controlled by the SFC drive to being controlled by the utility operation controls after synchronization.

Functions such as breaker/contactor interlocking, field reference control, synchronizing supervisory logic, operator control / HMI (Human Machine Interface) and overall DCS or plant interface must be integrated in the System Logic and Drive Control. These functions will be divided between the drive's PLC and the synchronous condenser/generator DCS controls.

5.6 Auxiliary Systems

Modification of the turbine lube oil distribution piping is expected to be required. Based on the changes made on unit 3, some additional valving will be required to isolate the turbine bearings during synchronous condenser operation, and flow orifices will be needed to limit the flow to the generator.

Cooling water for unit 3 generator is supplied by an auxiliary pump during synchronous condenser operation. It is not expected that this pump will have sufficient capacity for an additional unit, however some additional capacity could be realized by increasing its operating speed. An additional pump is expected to be required and together the two pumps could serve all three units.

No modifications are foreseen to the generator hydrogen gas system.

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6.0 BUDGETARY EQUIPMENT COSTS

For full details of the budgetary equipment costs of all options considered, please refer to Appendix B.

Summary Table of budget costs for all options

	1	2	3	4A	5
Technology	Variable speed hydro-viscous clutch (PGC model HL60/9HS)	Variable speed coupling with permanent magnet	Hydraulic torque converter coupling	Electric motor with VFD (1800 RPM)	Static Frequency Converter
Equipment Supply	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Cabling/Misc	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Thrust Bearing c/w turning gear	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Total	$4.6 million	Not available	$1.8 - $2.2 million	$2.6 million	$1.8 - $2.6 million

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7.0 RECOMMENDATION FOR TECHNOLOGY

7.1 Recommendation

SNC-Lavalin recommends the Static Frequency Converter technology for this application for the following reasons:

- Ease of conversion:

  Due to the self starting feature no other equipment is required to be installed at the generator/synchronous condenser floor space. The mechanical modifications are limited to the turbine coupling spacer and bearing pads, please refer to section 5.

- High reliability:

  The inherent availability of Static Frequency Converters or Variable Speed Drives is excellent due to mature/reliable components and modular construction e.g.: IEEE standard #493 Appendix Q, provides an inherent availability 0.999958 for Variable Speed Drives; (inherent availability being MTBF/(MTBF+MTTR) where MTBF is the Mean Time Between Failures and MTTR is the Mean Time To Repair. [redacted] publishes for their proposed unit a MTBF of 16 years and a MTTR of 15 minutes i.e.: an inherent availability of 0.999998. Note that inherent availability considers down time for repair of failures only, no logistics time allowance.

- Soft start capability:

  The acceleration amperage drawn initially from the auxiliary supply is low (magnetization) and increases with speed where the stator voltage and current are regulated to provide the torque required for the chosen acceleration.

- One unit can be used for multiple machines.

  One SFC can be used to start one or more units by switching the output to the unit being started using additional output switches/contactors. However, for reliability reasons redundancy is recommended.

- New equipment can be installed remotely

  Unlike the acceleration skids, the majority of the equipment is not located on the generator floor.

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The selection of the Static Frequency Converter supplier must be based on the following in order of priority:

- Experience integrating similar installations;
- Long term record of support for their supply;
- Price.

A condition assessment including specialized testing of the generator and associated equipment condition as discussed during the presentation meeting must be done to verify the condition of the generator windings and insulation prior to implementing the SC modifications. Extent of repair and/or rewind would be determined by the results of the condition assessment.

7.2 Single Line Diagram (SLD)

Two single line diagrams have been prepared to illustrate the proposed electrical design and arrangement (drawing no. 503743-0000-47D1-0001 Rev 01). An alternative arrangement has also been considered in SLD drawing no. 503743-0000-47D1-0002 Rev 01. Both SLD's are presented in Appendix D of this report.

7.3 Proposed Equipment Location

The proposed location for the static starter units is on floor level 24'-2", North of the battery room, East of the unit 3 generator bus ducts. They will be situated between columns U-S and columns 8-9. Please see Drawing 503743-0000-47D3-0001 Rev 01 in Appendix E. The existing floor would be extended for this purpose.

Note that the new excitation transformers will be located in the same area as the existing units. See drawing 503743-0000-47D3-0002 Rev 00 in Appendix E

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8.0 COST ESTIMATE FOR RECOMMENDED OPTION

8.1 Direct Costs

The capital cost estimate has been prepared based on budgetary price information provided by [redacted] The price for the generator thrust bearing, turning gear and stub shaft assembly was provided by [redacted].

Unit pricing for standard equipment and bulk material was taken from SNCL's in-house database. Installation costs include labor and direct supervision with labour rates for 2010 in Newfoundland.

The capital cost estimates includes the following equipment and services:

- 2 static starter systems (prices based on most competitive received);
- 2 excitation transformers;
- 2 static starter output switchgears, each with 2 circuit breakers;
- 2 static starter input switchgears, each with 2 circuit breakers;
- 2 generator thrust bearing, stub shaft and turning gear assemblies;
- Allowance for modifications to units 1 & 2 turbine lube oil distribution piping;
- Allowance for an additional CW supply pump and capacity increase of existing pump;
- Integration of the static starting system with the existing STG controls, excitation and protection;
- Cabling, trays, and terminations;
- Installation by qualified contractor.

8.2 Indirect Costs

Indirect costs have been estimated based on typical percentages of the project Direct Costs

Engineering includes detail engineering services and engineering support during installation. It was assumed that NALCOR would be maintain responsibility for construction site management and cost control given that Holyrood would remain in operation during the conversion.

A separate amount has been allocated for integration of the new equipment with the existing ABB excitation. This amount covers both commissioning of the new equipment and any necessary interfacing between the two systems.

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The Contractors' indirect costs include mobilization and demobilization, construction facilities, fees, liability insurance, warehouse, stores, first aid, etc

A contingency is included to cover items which cannot be defined given the engineering completed to date. The contingency amount is expected to be needed as the project is more closely defined and detail items are identified. It is not intended to cover over-budget costs.

The cost estimate is given in 2010 Canadian Dollars, with an allowance of 2% per year for inflation to 2014 implementation.

8.3 Exclusions

The following items are not included in the estimate:

- Owner's project development and management, legal fees, environmental studies, permitting fees etc.;
- Owner's salary costs during project implementation;
- Financing fees;
- Interest during construction;
- Initial Plant Costs including O&M preparation, staff training, initial spare parts;
- Working Capital;
- Cabling for unit 3 and modifications to the excitation system;
- Modifications to existing CW distribution piping and intake;
- Partition walls to facilitate selective heating once conversion to SC operation is complete.

	Qty	Equipment ($)	Material ($)	Installation ($)	Total ($)
DIRECT COSTS					
Thrust Bearing incl. Stub Shaft & Turning Gear	[redacted]				
Static Starter Output Switchgear each unit with 2 circuit breakers					
Static Starters					
Excitation Transformers					

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	Qty	Equipment ($)	Material ($)	Installation ($)	Total ($)
Supply Switchgear each unit with 2 Circuit Breakers	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
MV Cables & Terminations	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Control Cables & Terminations	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Cable Trays & Hardware	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Allowance for turbine lube oil system valving additions	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Allowance for additional CW pump and capacity increase	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Expansion of platform floor adjacent to unit 3 at El 24'-2"	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
System Integration (Vendor)	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Total Direct Costs		[redacted]	[redacted]	[redacted]	$4 252 795
INDIRECT COSTS					
Engineering	10.0%				$425 280
Escalation Allowance (2% per year)	2.0%				$350 567
Contractor Indirect Costs					$294 190
Contingency (10%)	10.0%				$425 280
Total Indirect Costs					$1 495 316
ESTIMATED TOTAL COST					$5 748 111

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8.4 Alternative Configuration

[redacted] has provided a budgetary estimate for a full scope Synchronous Condenser conversion which includes a separate SFC system for each machine, new [redacted] control, new excitation systems and auxiliaries, and the generator thrust bearing and integrated turning gear. NALCOR may wish to consider this alternative, however it is based on a considerably enlarged scope of work than the cost estimate presented above. [redacted] budget price for two units is [redacted] plus cabling, cable trays, and all indirect costs.

8.5 Estimate Accuracy

The cost estimate is based on vendor budget prices for all equipment and SLI database information for bulk material and labour costs. As such the estimate meets the criteria for AACE class 4 and carries an expected accuracy of ±25%.

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9.0 PRELIMINARY PROJECT SCHEDULE

A preliminary project schedule has been prepared to outline the various steps required to engineer, procure and install the proposed static starter system for Holyrood, and the estimated timeline to do so.

The overall project length from internal initiation at NALCOR is estimated to be approximately 22 months, with the first three months used internally at NALCOR for the preparation of the RFP for Engineering services and selection of the Engineer.

Upon initiation of the project with the Engineer, the Engineering is anticipated to take approximately six months, with a further seven months of Engineering support during the construction and installation period.

The purchase orders for the main equipment would be issued between 2 and 3 months from initiation of Engineering, and the delivery lead time is anticipated to be between eight and twelve months depending on the supplier.

The contractor would be mobilized at month twelve from initiation of Engineering, about two months before receipt at site of the main equipment, and the construction and installation period will be approximately seven months.

Please refer to the project implementation schedule in Appendix G for more details.

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10.0 ITEMS TO BE INCLUDED IN NEXT PHASE

Should NALCOR decide to proceed with the implementation of a static frequency converter system for Holyrood, the following issues will need to be addressed as the next step in the implementation sequence:

1) As discussed in section 5.2 of this report, the details of the coupling between the generator shaft and steam turbine shaft as it exists today must be firmly established.

2) The technical compatibility of the new SFC with existing systems, in particular the existing ABB exciters must be confirmed. Any RFPs to suppliers would specify compatibility as a requirement, but only upon receipt of actual bids can this be fully reviewed.

3) The generator rotor inertia information should be reviewed in detail (some initial information is provided in the report in Appendix C) and an Engineering review of the capacity of the SFC required for an acceptable acceleration rate of the generator shall be carried out.

4) Thorough review of all systems, sub-systems, and auxiliaries.

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APPENDIX A

Equipment List for all Options

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Appendix A - Equipment List for all Options

Acceleration system	Variable speed hydro-viscous clutch (PGC model HL60/9HS)	Variable speed coupling with permanent magnet	Hydraulic torque converter coupling	Electric motor with VFD (1800 RPM)	Electric motor with VFD (3600 RPM)	Static Frequency Converter
System No.	**1**	**2****	**3**	**4A**	**4B*****	**5**
Base	Skid/base-frame with oil sump	Skid/base-frame with oil sump	Skid/base-frame	Skid/base-frame with oil sump	Skid/base-frame with oil sump	
Driver	Drive motor 1500 HP	Drive motor 1500 HP	Drive motor 2500 HP	Drive motor 1500 HP	Drive motor 2500 HP	
Driver speed	1800 RPM	1800 RPM	3600 RPM	1800 RPM	3600 RPM	
Specialized mechanical equipment	Gear-Pak hydro-viscous transmission with integrated step up gearing (Ratio 2.167)	Magnadrive Coupling WH-2500 used in clutch-like operation (1800 BHP capacity for power transmission)	Hydraulic torque converter coupling [redacted]			
Couplings	Couplings	Couplings	Couplings	Couplings	Couplings	
Gearbox	Integrated	Independent Step-up gearbox (Ratio 2.167)	Included in [redacted] system only, not required by [redacted]	Independent Step-up gearbox (Ratio 2:1 required because of VFD)		
Disengaging clutch	SSS overrunning clutch 60T with brake and small thrust/location bearing	overrunning clutch with brake and small thrust/location bearing		overrunning clutch with brake and small thrust/location bearing	overrunning clutch with brake and small thrust/location bearing	
Water system	Oil system water cooled in this specific application	Water system for cooling coupling				
Oil system	Lube oil system for operation of clutch and transmission above	Lube oil system for overrunning clutch and step-up gearbox	Hydraulic drive fluid system	Lube oil system for overrunning clutch and step-up gearbox	Lube oil system for overrunning clutch gearbox	

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Acceleration system	Variable speed hydro-viscous clutch (PGC model HL60/9HS)	Variable speed coupling with permanent magnet	Hydraulic torque converter coupling	Electric motor with VFD (1800 RPM)	Electric motor with VFD (3600 RPM)	Static Frequency Converter
System No.	1	2**	3	4A	4B***	5
Oil cooling	Oil/water heat exchanger	Required	Required	Required	Required	
Hydraulic/control oil	Hydraulic actuation system for variable speed transmission		Required			
Electric Motors other than prime mover	Hydraulic and lube oil system	Lube oil system	Lube oil system	Lube oil system	Lube oil system	
Control system	Electronic control system	Electronic control system	Electronic control system	Electronic control system	Electronic control system	Control system for SS start-up system
Circuit Breakers	4.16kV Generator circuit breaker* two units	4.16kV Generator circuit breaker* two units	4.16kV Generator circuit breaker* two units	4.16kV Generator circuit breaker* one unit	4.16kV Generator circuit breaker* one unit	4.16kV Generator circuit breaker* two units
VFD				VFD (two units)	VFD (two units)	
Static starter						Static Starter (SS), two units
Excitation transformer						Replace excitation transformer with switchgear fed unit
(2) circuit breakers to feed excitation transformer						5kV circuit breakers
Other electrical						MV cables between circuit breaker and SS and SS to generator
Other electrical	MV cables between circuit breakers and pony motors	MV cables between circuit breakers and pony motors	MV cables between circuit breakers and pony motors	MV cables between circuit breakers and pony motors	MV cables between circuit breakers and pony motors	

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Acceleration system	Variable speed hydro-viscous clutch (PGC model HL60/9HS)	Variable speed coupling with permanent magnet	Hydraulic torque converter coupling	Electric motor with VFD (1800 RPM)	Electric motor with VFD (3600 RPM)	Static Frequency Converter
System No.	**1**	**2****	**3**	**4A**	**4B*****	**5**
Other electrical	LV cables to small motors	LV cables to small motors	LV cables to small motors	LV cables to small motors	LV cables to small motors	
Other electrical	Modify generator protection for SC operation	Modify generator protection for SC operation	Modify generator protection for SC operation	Modify generator protection for SC operation	Modify generator protection for SC operation	Modify generator protection for SC operation
Generator thrust bearing	Install generator thrust bearing	Install generator thrust bearing	Install generator thrust bearing (TRI proposal includes thrust bearing)	Install generator thrust bearing	Install generator thrust bearing	Install generator thrust bearing

* Circuit breakers available in existing switchgear

** Option 2 was not pursued seriously as an option after not being able to find an Engineered package

*** Option 4B was not pursued, in favour of option 4A (for which a budget quote was received)

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APPENDIX B

Budget Costing for all Options

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APPENDIX C

Rotor Inertia

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Appendix C – Rotor Inertia

The inertia of the rotor of each generator has now been established. This information was not included in the GE generator data and drawings, but has been determined based on NALCOR's systems modeling (which itself was based on the CGE Contract Data obtained in April 1968). This data used in the stability model was received from NALCOR at the meeting in St. John's of Oct 27, 2010.

H = 229.9 (MW) / 194.445 (Rated MVA) = 1.182

H = (0.231 * WK**2 * RPM) / (KVA * 10E6) therefore

WK**2 = 76,790.50 (lb ft**2)

The GE rotor weight is given on the drawings/manuals as 66,500 lbs

For a solid cylinder WK**2 = 1/2 WR**2 which results in an approximate R = 1.55 or a Diameter = 3.10 ft (or approx. 37 inches).

Although the GE Generator Assembly Drawing 593E724AJ implies that the rotor would be less than 3 ft, NALCOR has confirmed that the diameter is in fact 37.25 inches.

Therefore, the rotor inertia for each generator is WK**2 = 76,790.50 (lb ft**2).

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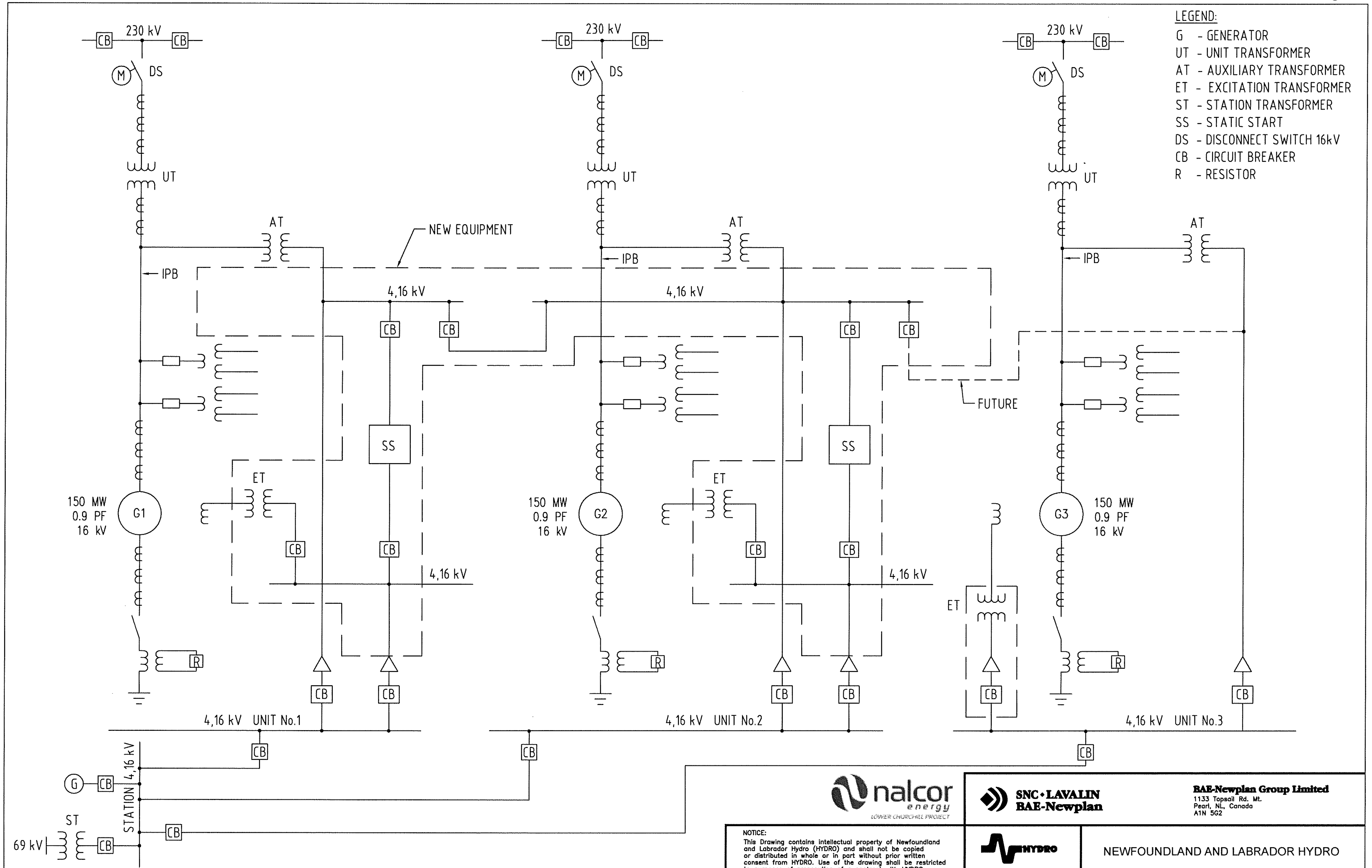
APPENDIX D

Single Line Diagrams (SLD)



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BAE-Newplan Group Limited
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A1N 5G2

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HYDRO — NEWFOUNDLAND AND LABRADOR HYDRO

HOLYROOD THERMAL POWER PLANT
SINGLE LINE DIAGRAM
SYNCHRONOUS CONDENSER

ELECT.	SCALE: –
CIVIL	DESIGNED: A. MACDONALD
TRANS.	DRAWN: E. GORALSKA
MECH.	DATE:
P&C	CHECKED:
TELC.	APPROVED:

W.O. NO.
DWG. NO. 503743-0000-47D1-0001
REV. 01

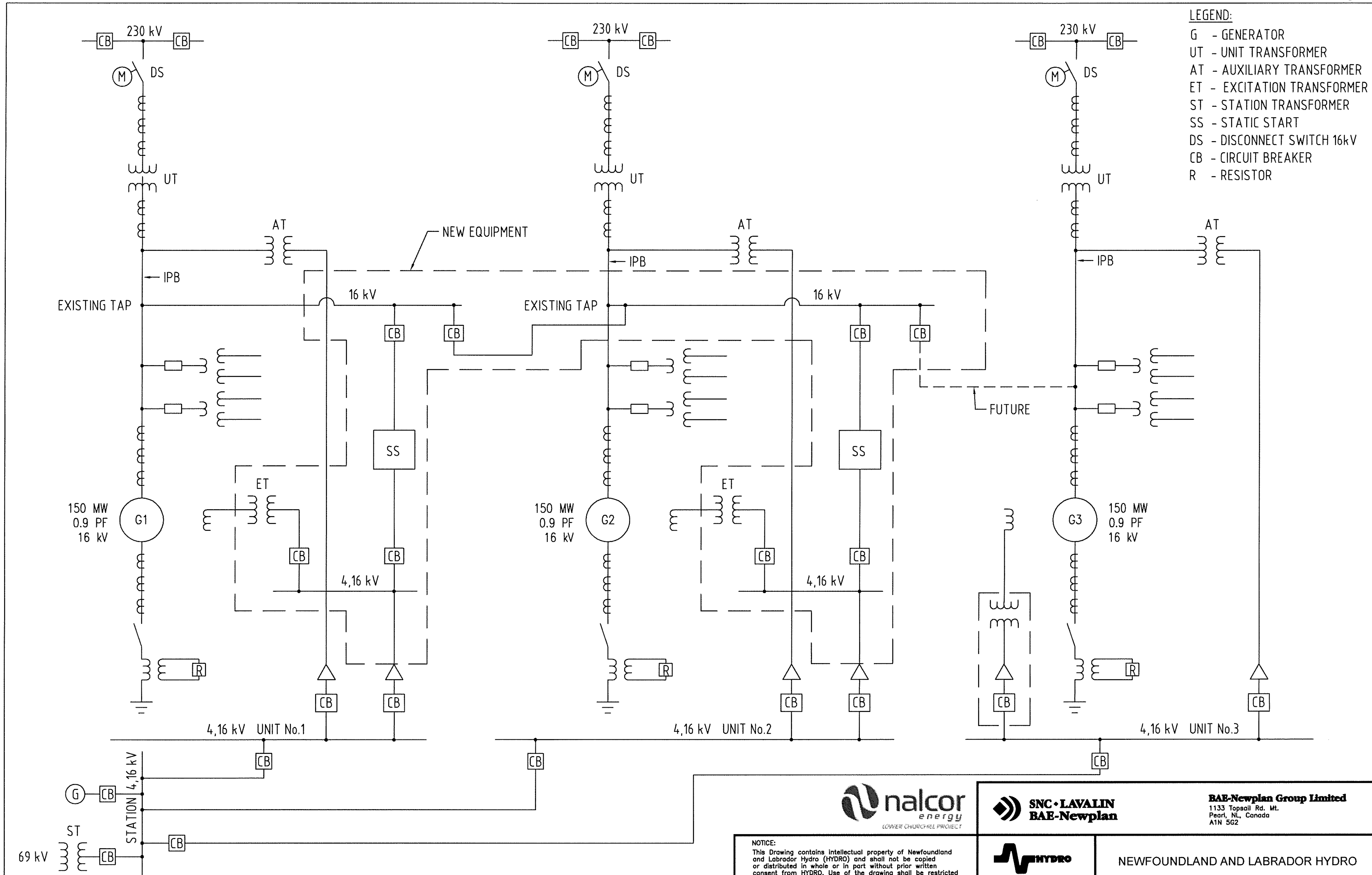
DWG.NO.	TITLE
	REFERENCE DRAWINGS

NO.	DATE	DESCRIPTION	DWN.	DESIGN.	CHK.	APP'D
01		FOR REPORT				

REVISIONS

Feb 03, 2011 – 1:10pm

C.A.D.



nalcor energy
LOWER CHURCHILL PROJECT

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HYDRO

NEWFOUNDLAND AND LABRADOR HYDRO

HOLYROOD THERMAL POWER PLANT
SINGLE LINE DIAGRAM
SYNCHRONOUS CONDENSER
ALTERNATIVE No. 1

ELECT.	SCALE: –
CIVIL	DESIGNED: A. MACDONALD
TRANS.	DRAWN: E. GORALSKA
MECH.	DATE:
P&C	CHECKED:
TELC.	APPROVED:

W.O. NO.

DWG. NO. 503743-0000-47D1-0002

REV. 01

DWG.NO.	TITLE

REFERENCE DRAWINGS

NO.	DATE	DESCRIPTION	DWN.	DESIGN.	CHK.	APP'D
01		FOR REPORT				

REVISIONS

Feb 03, 2011 – 1:10pm

C.A.D.

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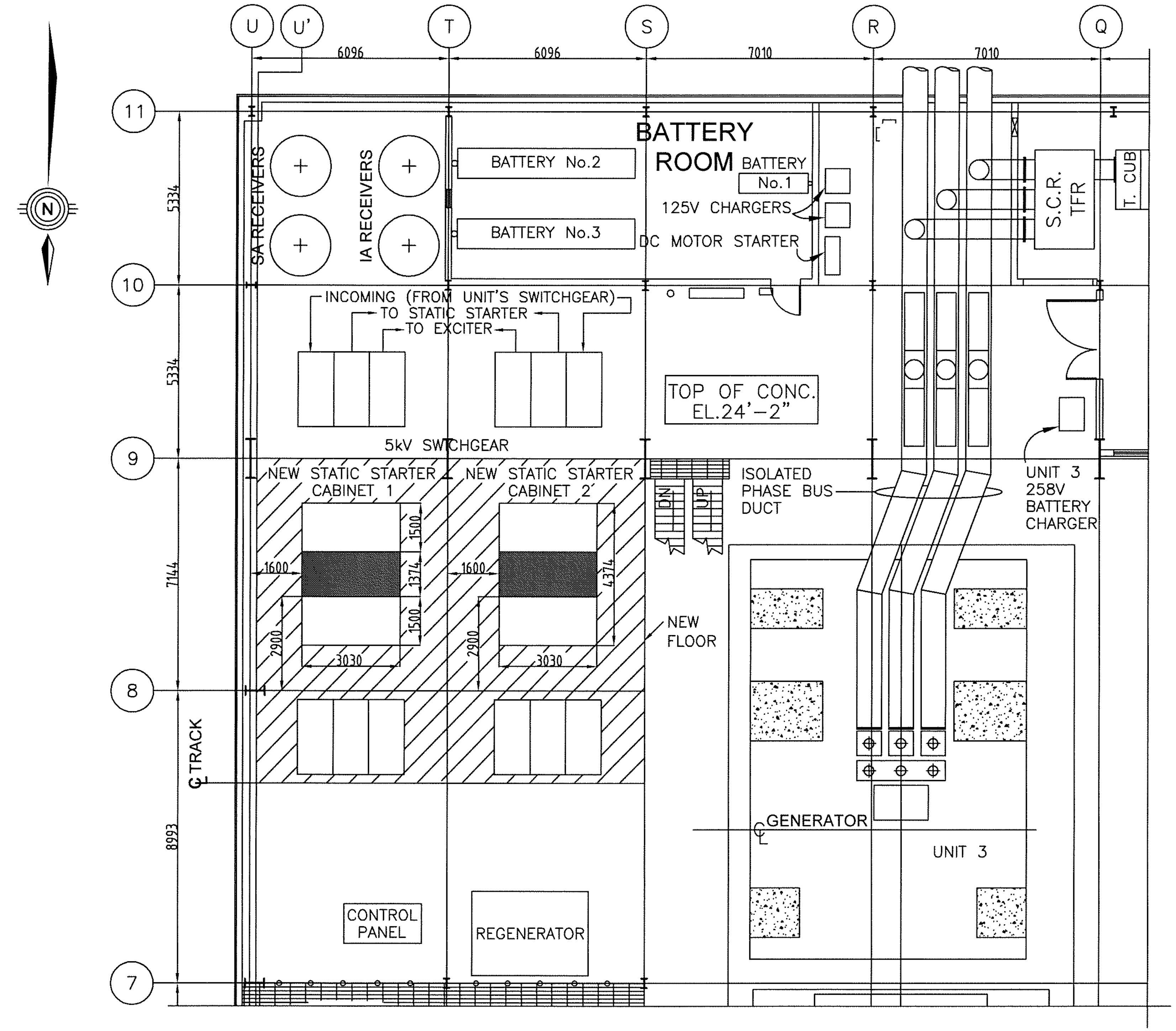
APPENDIX E

General Layout and Alternatives Layouts for Excitation System



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HOLYROOD THERMAL POWER PLANT
GENERAL EQUIPMENT LAYOUT
SYNCHRONOUS CONDENSER
STARTING EQUIPMENT

ELECT.	SCALE: 1:150
CIVIL	DESIGNED:
TRANS.	DRAWN:
MECH.	DATE:
P&C	CHECKED:
TELC.	APPROVED:

W.O. NO.
DWG. NO. 503743-0000-47DD-0001
REV. 01

DWG.NO.	TITLE
–	

REFERENCE DRAWINGS

NO.	DATE	DESCRIPTION	DWN.	DESIGN.	CHK.	APP'D
01		FOR REPORT				

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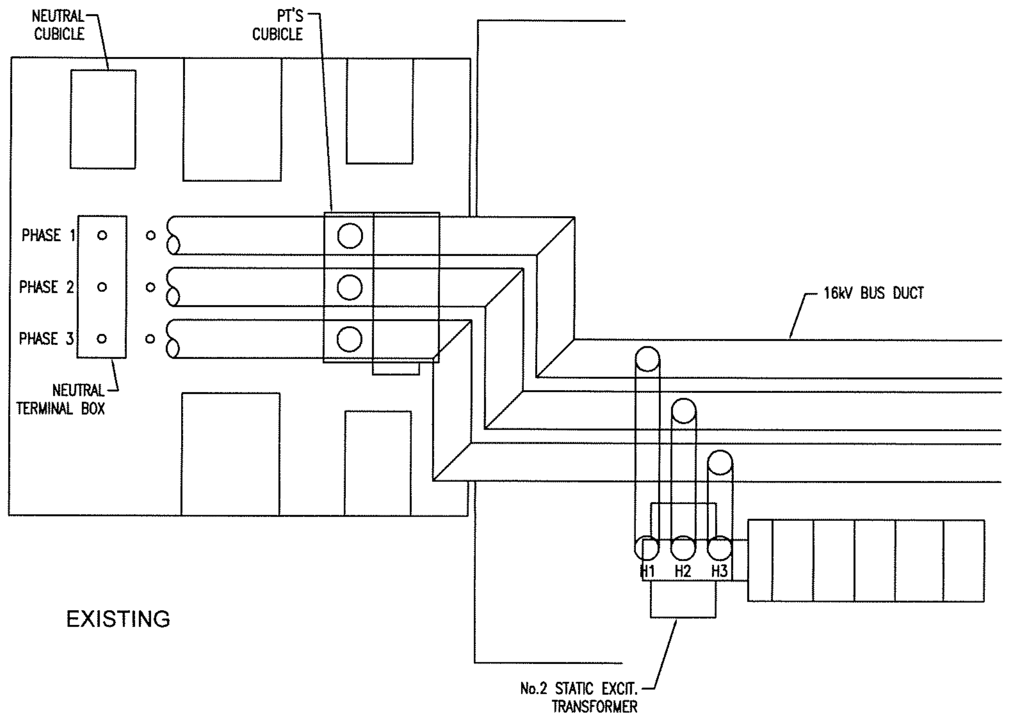

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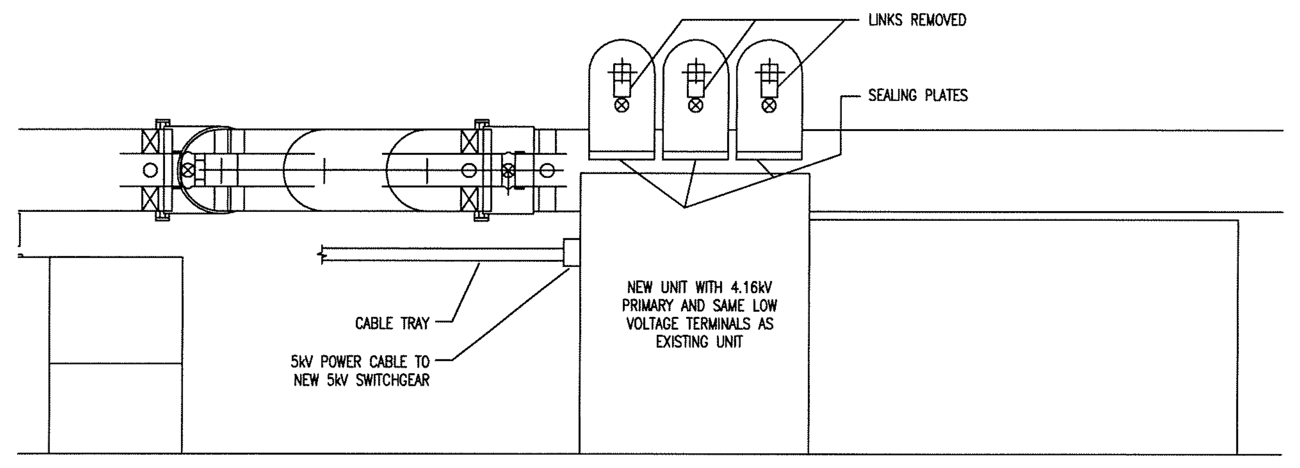
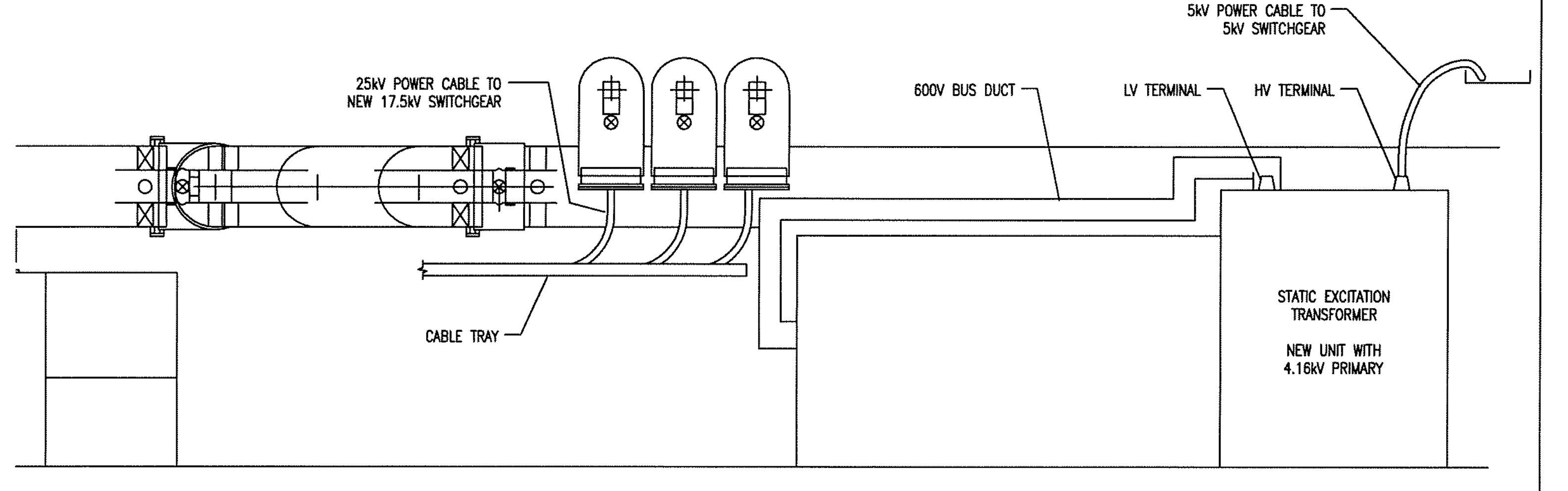


ALTERNATIVE No. 1



ALTERNATIVE No. 2

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00		FOR REPORT				

REVISIONS

ELECT. CIVIL TRANS. MECH. P&C TELC.

SCALE: _
DESIGNED: A. MACDONALD
DRAWN: E. GORALSKA
DATE:
CHECKED:
APPROVED:

HOLYROOD THERMAL POWER PLANT
MODIFICATIONS TO EXCITATION SYSTEM
FOR
SYNCHRONOUS CONDENSER OPERATION

W.O. NO.

DWG. NO. 503743-0000-47D3-0002

REV. 00

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APPENDIX F

Quotes from Static Start Unit Suppliers

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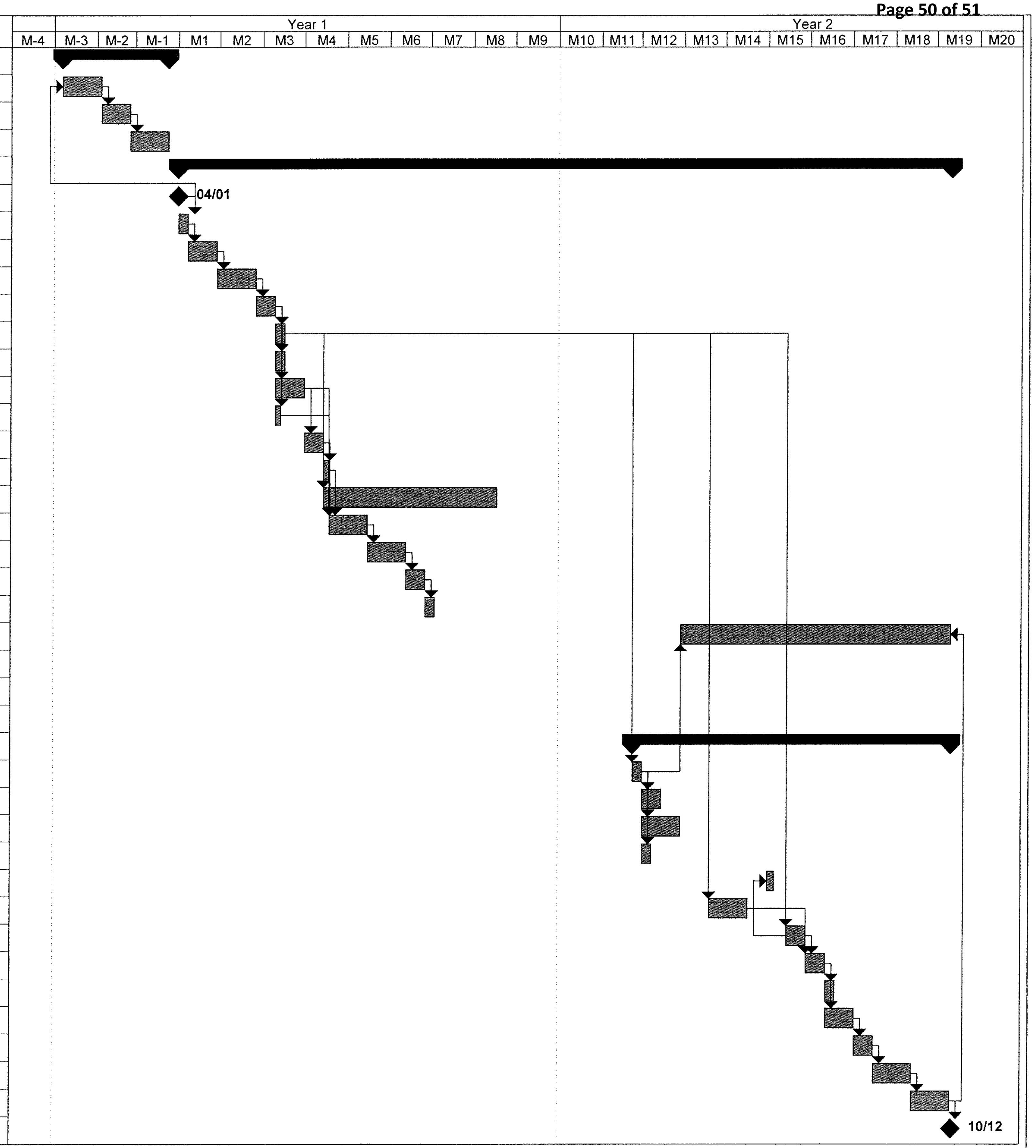
APPENDIX G

Preliminary Project Schedule

ID		Task Name	Duration	Start	Finish	Predecessors
1		**Pre-project activities by NALCOR**	**55 days**	**Fri 11/01/07**	**Thu 11/03/24**	
2		NALCOR RFP for engineering services prep & issue	20 days	Fri 11/01/07	Thu 11/02/03	6FS-60 days
3		preparation of engineering proposals (selected bidders)	15 days	Fri 11/02/04	Thu 11/02/24	2
4		evaluation & award of engineering mandate	20 days	Fri 11/02/25	Thu 11/03/24	3
5		**engineeering**	**400 days**	**Fri 11/04/01**	**Thu 12/10/11**	
6		award contract for engineering	0 days	Fri 11/04/01	Fri 11/04/01	
7		verify single line diagram & SFC capacity	5 days	Fri 11/04/01	Thu 11/04/07	6
8		prepare detailed equipment specifications & issue	15 days	Fri 11/04/08	Thu 11/04/28	7
9		vendor proposal preparation	20 days	Fri 11/04/29	Thu 11/05/26	8
10		evaluate proposals & recommendation	10 days	Fri 11/05/27	Thu 11/06/09	9
11		issue PO's for main equipment	5 days	Fri 11/06/10	Thu 11/06/16	10
12		prepare equipment list	5 days	Fri 11/06/10	Thu 11/06/16	10
13		prepare detailed arrangement drawings	15 days	Fri 11/06/10	Thu 11/06/30	10
14		prepare cable lists	2 days	Fri 11/06/10	Mon 11/06/13	10
15		prepare cable tray layouts	10 days	Fri 11/07/01	Thu 11/07/14	13
16		detail modifications to existing bus duct	2 days	Fri 11/07/15	Mon 11/07/18	15
17		review vendor drawings as required (PT as req'd)	90 days	Fri 11/07/15	Thu 11/11/17	11FS+20 days
18		prepare installation specifications & issue	20 days	Tue 11/07/19	Mon 11/08/15	13,14,15,16
19		contractor bid preparation	20 days	Tue 11/08/16	Mon 11/09/12	18
20		evaluate bids & recommendation	10 days	Tue 11/09/13	Mon 11/09/26	19
21		award construction contract	5 days	Tue 11/09/27	Mon 11/10/03	20
22		field technical support	140 days	Fri 12/03/30	Thu 12/10/11	27,39FF
23						
24						
25						
26		**construction**	**165 days**	**Fri 12/02/24**	**Thu 12/10/11**	
27		contractor mobilization (2 months before equip delivery)	5 days	Fri 12/02/24	Thu 12/03/01	11FS+180 days
28		prepare cubicle base and cutouts as req'd	10 days	Fri 12/03/02	Thu 12/03/15	27
29		install cable trays & pull cable	20 days	Fri 12/03/02	Thu 12/03/29	27
30		prepare existing bus duct for mod'ns	5 days	Fri 12/03/02	Thu 12/03/08	27
31		remove existing excitation transformer	3 days	Fri 12/06/01	Tue 12/06/05	33SS-10 days
32		receive & install SFC cubicles	20 days	Fri 12/04/20	Thu 12/05/17	11FS+220 days
33		receive & install new excitation transformers	10 days	Fri 12/06/15	Thu 12/06/28	11FS+260 days
34		install new circuit breakers	10 days	Fri 12/06/29	Thu 12/07/12	33,32
35		terminate power cabling	5 days	Fri 12/07/13	Thu 12/07/19	34
36		install control wiring & loop checks	15 days	Fri 12/07/13	Thu 12/08/02	34
37		energize excitation transformer & verify operation	10 days	Fri 12/08/03	Thu 12/08/16	36
38		energize SFC system & test	20 days	Fri 12/08/17	Thu 12/09/13	37
39		Owner test & verification	20 days	Fri 12/09/14	Thu 12/10/11	38
40		**project complete**	**0 days**	**Fri 12/10/12**	**Fri 12/10/12**	**39FS+1 day**



Project: SC Conversion Implementatic
Date: Mon 10/11/22

Task		Progress		Summary		External Tasks		Deadline
Split		Milestone		Project Summary		External Milestone	

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