Cogeneration power plant.

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UMI®
COGENERATION POWER PLANT

by

Manohar Velyuthan

A Thesis
Submitted to the Faculty of Graduate Studies through the
Department of Electrical Engineering in Partial Fulfilment
of the Requirements for the Degree of
Master of Applied Science
at the
University of Windsor

Windsor, Ontario, Canada
1997.
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ABSTRACT

Cogeneration involves the production of more than one form of energy and is defined as, “The sequential production of necessary heat and power (topping) or the recovery of low-level energy for power production.” However, the topping cycle is the major focus of current cogeneration projects due to its applicability in large cogeneration power plants.

To ensure that a cogeneration plant will operate safely, reliably, and economically a study of the protection, control and reliability of the power system is required at the planning and conceptual design stages of the project. Power system studies can result in capital and operating savings as well as improvement in the overall safety and reliability of the plant. The impact of the studies on the design process and plant system reliability is discussed. The guidance, structure, and refinement needed for meaningful reliability measurements and reliable warranties are provided.

Electrical studies are required to ensure the proper integration of a gas-turbine generator facility into a utility grid. Typical utility requirements are reviewed, the basis for their formulation is explained, and practical ways for the industrial cogenerator to satisfy them are suggested. For inter-ties between a cogeneration plants and an existing host utility power systems, special considerations must be given to protection systems. The importance of the protection scheme requirements during the conceptual design stage of a cogenerating plant is demonstrated.

The design of the electrical auxiliary system in a power plant requires a considerable amount of data handling. When the major mechanical equipment
have been determined, single line diagrams are drawn as well as switchgear line-ups and other electrical assemblies are determined. Loads, transformers, switchgear, and fault duties are estimated before the start of the design of the installations.

Guidelines are given on methods to streamline the sizing process using computer generated, standardized tables for feeders, motors and transformers. These tables not only reduce design time but assure increased quality control in the design process.

The control systems are configured using the Bailey INFI 90 distributed control system. The configuration details of plant control systems are described. Integration of the manufacturers controls system with the Bailey system is explained. Merits and demerits of using standard discrete device logic systems (Macro) are discussed. Reduction in design cycle time and savings in engineering, training and maintenance are demonstrated.

Windsor cogeneration power plant supplies 50 MW of base electrical power to Ontario Hydro and steam to Chrysler Windsor assembly plant. Power is generated in the plant at 13.8 kV, and stepped up to 115 kV and exported by overhead line to Ontario Hydro transmission station. Design of plant electrical systems with different voltage levels, such as 115 kV, 13.8 kV, 4.16 kV, 600 V, 120 Vac and uninterruptible power supply are analyzed and presented. The importance of standby supply at 600 V level has been examined.

A survey of the available literature on the design of cogeneration power plant design was carried out. A number of IEEE published papers related to cogeneration, different issues of Power engineering and EC & M magazines,
and the General Electric cogeneration design manuals were studied and relevant important data have been highlighted in the appropriate sections of this thesis.

This thesis also describes contributions to the recently completed, successful cogeneration power plant in Windsor. Engineering design, equipment procurement, construction and commissioning of the electrical and control portions of the power plant require many person-hours to complete the project. Only a representative portion of my work is included in the thesis. Included therein typical engineering equipment specifications, calculation sheets and engineering drawings for the purpose of discussion and reference.
DEDICATION

TO MY LOVELY FRIENDS RANI AND KARTHI

AND

MY SWEET GIRLS MALINIE, VIVI AND SHALINI
ACKNOWLEDGEMENTS

I would like to express my sincere gratitude and appreciation to my supervisor Dr. R. Hackam, for his invaluable guidance and constant encouragement throughout the progress of this thesis. His enthusiasm and innovatory approach were strong sources of inspiration.

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Appendix - B: Typical electrical drawings

Appendix - C: Typical calculation sheet

Appendix - D: Electrical equipment specifications (Typical)

Appendix - E: Controls typical logic diagrams

References
## ABBREVIATIONS

<table>
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<tr>
<td>CPP</td>
<td>Cogeneration Power Plant</td>
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<tr>
<td>DCS</td>
<td>Distributed Control System</td>
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<tr>
<td>HRSG</td>
<td>Heat Recovery Steam Generator</td>
</tr>
<tr>
<td>Nox</td>
<td>Nitrous Oxide</td>
</tr>
<tr>
<td>HP</td>
<td>High Pressure</td>
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<tr>
<td>LP</td>
<td>Low Pressure</td>
</tr>
<tr>
<td>DLE</td>
<td>Dry Low Emission</td>
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<tr>
<td>GT</td>
<td>Gas Turbine</td>
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<tr>
<td>IP</td>
<td>Intermediate Pressure</td>
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<tr>
<td>HVAC</td>
<td>Heating, Ventilation and Air Conditioning</td>
</tr>
<tr>
<td>UPS</td>
<td>Uninterruptible Power System</td>
</tr>
<tr>
<td>GTG</td>
<td>Gas Turbine Generator</td>
</tr>
<tr>
<td>STG</td>
<td>Steam Turbine Generator</td>
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<tr>
<td>WUC</td>
<td>Windsor Utilities Commission</td>
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<tr>
<td>OH</td>
<td>Ontario Hydro</td>
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<td>PT</td>
<td>Potential Transformer</td>
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<td>MMI</td>
<td>Man Machine Interface</td>
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<td>CRT</td>
<td>Cathode Ray Tube</td>
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<td>MCC</td>
<td>Motor Control Center</td>
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<td>HV</td>
<td>High Voltage</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>TS</td>
<td>Transmission Station</td>
</tr>
<tr>
<td>DGP</td>
<td>Digital Generator Protection</td>
</tr>
<tr>
<td>SOE</td>
<td>Sequence Of Events</td>
</tr>
<tr>
<td>FRC</td>
<td>Full Rated Current</td>
</tr>
<tr>
<td>WSAC</td>
<td>Water Surface Air Condenser</td>
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<tr>
<td>RTU</td>
<td>Remote Terminal Unit</td>
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<tr>
<td>BMS</td>
<td>Burner Management System</td>
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<tr>
<td>SLC</td>
<td>Strategic Loop Controller</td>
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<tr>
<td>PLC</td>
<td>Programmable Logic Controller</td>
</tr>
<tr>
<td>CEMS</td>
<td>Continuous Emission Monitoring System</td>
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<tr>
<td>ESD</td>
<td>Emergency Shutdown</td>
</tr>
<tr>
<td>FMEA</td>
<td>Failure Mode and Effects Analysis</td>
</tr>
<tr>
<td>EPR</td>
<td>Electrical Power Research Institute</td>
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</table>
CHAPTER - 1

INTRODUCTION
INTRODUCTION

1.1 Evolution of the Regulation:

1996 was a landmark year in what is becoming a long transition period for Canada’s electric utility industry. In Alberta an Electric Utilities Act took effect in 1996 that moved Alberta’s electric industry away from vertically integrated utilities. A new an open-access power pool came into existence, through which the province’s electric energy began to trade.

The intent of the act was to provide for a gradual entry into a competitive marketplace for future generations. The act allows for all new generations produced in the province to be sold into a deregulated environment. This movement toward deregulation in the electricity sector is further compounded by the activity in the already deregulated gas industry. Other jurisdictions, like Ontario Hydro, New Brunswick Power and many others are continuing their preparations for future deregulation.

This new deregulation removes all the stringent regulatory requirements from the cogenerators, which makes cogeneration more efficient than the commonly used fossil-fired systems. It is common knowledge that the cost of cogenerated electrical power is less than the cost of central-station power. But the key to that economy is the ability to tie in with the electric utility network and strike a balance between the electrical needs and the process-heat needs of the industrial plant.
Interconnection with the utility network makes this lower cost possible by allowing the sale of excess power to or the purchase of supplementary power from the utility. The possibilities for cogeneration are greatest in process industries such as chemicals, steel pulp and paper, and petroleum refining. Each of these is a consumer of high levels of electrical energy, usually on a round the-clock basis, and of steam that can also be used to generate electricity.

1.2 Scope of Thesis

Objectives of the thesis are:

- To show how the cogeneration power plant (CPP) was put together.
- To describe how a CPP functions.
- To show how the efficiency of the CPP can be increased.
- To describe the Windsor CPP.
- To review the engineering design of the electrical system and control system of the Windsor CPP.
- To show how to design efficiently and manage the electrical and control systems for the CPP.
- To identify areas of improvements in the engineering design of the CPP.
- To identify new aspects of CPP where further detailed and useful studies can be carried out.
1.3 Thesis Organization

*Chapter - 2* presents the background material required to understand the basis of CPP. It begins by introducing the theory behind the cogeneration system and then proceeds to Windsor CPP design criteria, site conditions and Windsor plant design description.

*Chapter - 3* presents the complete details of the electrical system of the Windsor power plant. It covers the design description of the electrical system and discusses the electrical protection and control design. Implications on the design of protection are emphasized.

*Chapter - 4* presents the guidelines to carry out all the required power system calculations related to cogeneration plant and also emphasized the importance of electrical studies.

*Chapter - 5* presents the background of the distributed control system (DCS) which was implemented in the Windsor power plant. It gives details of the control design description, control system architecture and the important features of DCS.

*Chapter - 6* briefly presents the requirements for the start-up and commissioning of the CPP.
Chapter - 7 summarizes the electrical and control functions of the plant and identifies the areas of improvements.

Appendix - A includes Windsor cogeneration plant overview and simple single line diagram.

Appendix - B presents all the key electrical drawings that were produced for the Windsor cogeneration plant.

Appendix - C presents a few samples of the power system calculations that were produced for the project.

Appendix - D presents a few samples of the electrical equipment specifications that were produced to procure the equipment.

Appendix - E presents a few examples of the control system logic diagrams.

Finally a reference list of literature, manufacturer’s design manual and documents that were used on this thesis is identified.

1.4 Survey of literature:

A survey of the available literature on the cogeneration power plant design, electrical studies and utility grid / cogeneration inter-
tie protection scheme configurations were carried out in order to observe the applicability of the method described. Considerable attention has been given to power system studies for cogeneration by many authors.

Philip A. Nobile [1] identified the type of electrical studies to be carried out during the feasibility study stage of the project to define system and equipment parameters. Philip A. Nobile has stated that the type of study performed varies depending upon the size and complexity of the power system.

Some of the basic electrical design considerations have been discussed by Edward E. Hogwood and David E. Rice [2,3]. The essential aspect of cogeneration for the electrical design engineer to have in mind is the necessity for high reliability and availability. The industrial process is dependent on a steady steam supply, and the return on investment of the cogenerator is dependent on the steam flow as well as on the maintenance of kWh sales to the utility.

Richard L. Doughty, Louise Gise, Edward W. Kalkstein and Ronald D. Willoughby [4] have discussed and examined the impact of the studies on the design process and plant system reliability [2]. The studies that are required to assure the proper integration of a gas-turbine cogeneration facility to the utility grid are presented in detail. The electrical studies benefit the cogeneration project in many ways[5].
1. Project engineers will be able to predict the performance of the combustion gas-turbine generator and associated plant electric stress under normal and adverse operating conditions.

2. Design deficiencies can be discovered and corrected before the start up of the cogeneration facility.

3. Studies develop management confidence in the cogeneration system design and assure that the plant electric system availability would not be adversely affected.

4. Studies make possible the design of the utility isolation and load-shed system, an electric system operating availability enhancement.

Most electric utilities have adopted a standardized protection scheme to interface with a cogenerating industrial system. Customarily, protection systems are not major components of overall cogeneration capital expenditures. However, overlooked complications in these protection systems can cause unexpected growth in system costs, sufficient to affect the economical viability of the facilities. Rasheek M. Rifaat, James M. Daley and Louise J. Powell have emphasized the implications on the design of protection system [6,7,8]. Also they have discussed in detail the application and characteristics of modern controls and protection technique as they apply to cogeneration.

Richard A. Fuselier has analyzed the ampacity tables and the method of sizing the circuit. He has given examples and guidelines to generate standardized tables for feeders, motors, and transformers [ 9 ]. These tables not only reduce design time but assure increased quality control in the design process.
A. Jack Williams, and M. Shan Griffith have presented several methods for analyzing motor starting problems [10]. Each type of study has an appropriate use, and the selection of the correct type of study is as important a step in the solution process as the actual performance of the study itself.

Reliability guarantees, backed by liquidated damages' clauses, are becoming more the rule rather than the exception. But the power generation industry does not have a universally accepted set of reliability measurement. Thomas E. Ekstrom has provided the guidance, structure, and refinement needed for meaningful reliability measurements and reliability warranties [11].
CHAPTER - 2

BASIS OF COGENERATION POWER PLANT
2.1 Introduction to Cogeneration power plant

2.1.1 Cogeneration design:

The name "Cogeneration combined cycle" is derived from the integration of a gas turbine cycle and a steam cycle into one system that is used to generate electricity and heat for process or district heating. These two cycles are integrated in such a way that they complement each other. The waste gases from the gas cycle provide the energy used in the water / steam cycle. This translates into one of the most efficient methods of power and heat production on the market today.

The combined cycle principle can be described as follows: Air is drawn from the atmosphere, through a filter system, into the compressor stages of the gas turbine. Here it is compressed before entering the combustion chamber. Fuel sprayed into the chamber through nozzles mixes with the compressed air to enhance the combustion process. The pressurized gases drive the power part of the gas turbine to provide electrical output at the generator terminals.

Hot waste gases leave the gas turbine through the exhaust ducting and enter a heat recovery steam generator (HRSG). The purpose of the HRSG is to recover the available energy from the hot gases by transferring it to a water / steam cycle. The cooled gases are then released to the atmosphere through the stack.
The HRSG consists of a combination of three different types of heat exchanger sections. Pressurized water enters the cold end of the HRSG through an economiser where it is heated to a temperature slightly below the saturation temperature before being converted into steam in an evaporator loop. The saturation steam is further heated in a superheater from where live steam is fed to the steam turbine. The steam expands in the turbine stages, converting thermal energy into electrical power.

On leaving the steam turbine, the low grade steam is condensed back to water in a condenser where a cooling system is used to remove the latent heat. The condensate is now being pumped through condensate pumps to a deaerator / feedwater storage tank. Here any incondensible gases are removed by heating with steam from a steam turbine extraction. The feed water storage tank also serves as a water buffer for the water / steam cycle. Water leaves the feedwater storage tank through the feed water pumps which pressurizes it before it is returned to the HRSG.

Combining the gas turbine cycle with a waste heat steam cycle achieves major thermodynamic advantages over conventional power plants. This is possible due to the high temperature difference between the gas cycle working fluid and the low temperature heat dissipated in the steam cycle. The difference between these two temperature levels is related to the cycle efficiency. Apart from thermodynamic advantages, combined cycle plants have several additional benefits. It can be used not only for pure power production, but also for cogeneration, by extracting
process steam from either the boiler or steam turbine at the required conditions.

The amount of cooling required for a combined cycle plant is less than for a conventional plant of the same rating. This is because only about one third of the power in the combined cycle plant is generated by the steam turbine which largely determines the cooling requirements. This reduces the cost of cooling water and the heat discharged to the environment.

2.1.2 Selection Process Overview:

The following aspects need to be given thorough consideration during the selection process of a cogeneration plant. These matters will have direct impact on the plant efficiency and the cost of the plant.

- **Customer Requirements:**

  The design of the cycle is affected by the operating philosophy. Combined cycles are intended for different uses such as the base load plant will have a higher earning potential than a stand-by plant because a greater number of operating hours can be billed out. It is therefore worth investing more capital to improve the efficiency of the base load plant.
• **Site Related Factors:**

Some site conditions will affect the gas turbine’s performance. For instance, a gas turbine operating at 0°C will generate approximately 20% more electrical output than the same gas turbine operating at 30°C.

Emission requirements are usually set by local legislation. There is normally a limit on the level of nitrous oxide (NOx) emissions. Water or steam injected into the combustor can control this level but will affect the gas turbine performance and increase the water consumption and consequently the cost of the cycle.

Fuel is a key factor for both technical and economic reasons. The fuel type and composition have a direct effect on the gas turbine performance and the emissions produced. The sulphur content of the fuel determines the temperature at which the water is allowed to enter the HRSG.

• **Cooling System:**

The design of the cooling system depends on the availability of cooling water at the site. If it is available at a reasonable cost, typically from the sea or a river, then a direct cooling water system is installed. If water is limited or expensive, it may be necessary to reduce the water requirements by installing indirect cooling water using a cooling tower. Plants without cooling water use air cooled condensers or dry cooling towers which need no water supply but use more auxiliary power and are expensive.
2.2 Windsor plant design criteria

The design of the Windsor CPP was based on the following basic criteria and its general block diagram (fig.1 in the appendix-A).

2.2.1 Plant Operation

The plant operates in two basic modes:

- On-peak the plant will generate 67 MW
- Off-peak the plant will generate 50 MW

The additional 17 MW required during peak periods will be generated by the steam turbine. The additional steam flow to produce this 17 MW will be supplied in two ways:

- Supplementary duct burner firing (up to 760°C (1400°F) exit temperature of the duct burner) to increase the HP turbine throttle flow in the summer (warm ambient) periods.
- Supplementary duct burning combined with additional steam production in the peaking boilers in the winter (cool ambient) periods. The duct burners increase the high pressure (HP) turbine throttle flow. The steam production from the peaking boilers flows to the customer (Chrysler Corp.) and displaces extraction from the steam turbine. This allows more steam to pass through the low pressure (LP) section of the steam turbine to produce electricity.

2.2.2 Gas Turbine / Generator Systems

The plant utilizes a single General Electric LM6000 gas turbine / generator package. The package is designed for outdoor
installation and single fuel natural gas operation. The package is self-contained and includes the following:

- Generator
- Gas turbine complete with dry low emission burners
- Air inlet system
- Washing system
- Manufacturer’s control system
- Associated auxiliary equipment

**Generator**

The gas turbine generator is driven from the cold end of the unit to enable axial exhaust to flow into the HRSG. The generator is a synchronous, air cooled machine with a minimum gross capacity of 43,000 kW. This rating is based on a power factor of 0.9 lagging at the rated terminal voltage of 13.8 kV.

**Emissions Control System**

The LM6000 is equipped with dry low emissions (DLE) combustors capable of reducing NOx emission to 25 parts per million volumes (ppmv) at 15% oxygen (O2).

**Air Inlet System**

The LM6000 performance is dependent on the combustion air temperature. The optimum combustion air temperature range for a
LM6000 with DLE is between -12.2°C (10°F) and +8.3°C (47°F). The combustion air will be filtered and conditioned to maintain its temperature within optimum range. Ventilation air for the gas turbine package will be filtered and heated to prevent icing when necessary.

The combustion air conditioning coils are installed outside of the first stage inlet air filters. A twelve row coil bank is supplied with the gas turbine package.

A glycol heating loop from the HRSG will supply heated glycol to the combustion air conditioning coils. This will be used to heat the combustion air to -12.2°C when ambient air temperatures are below the optimum range.

The gas turbine combustion air will be chilled to 8.3°C when the ambient air temperature is above the optimum temperature range. This will be accomplished by circulating chilled water through the package's combustion air conditioning coils.

2.2.3 Chilling System

The gas turbine combustion air will be chilled to 8.3°C when the ambient air temperature is above this limit of the optimum temperature range.

Chilled water will be supplied to the conditioning coils from an absorption chilling system. The system will include:
• Two absorption chillers
• Chiller cooling system
• Cooling water circulation pumps
• Chilled water circulation pumps and surge tank

The absorption chillers will utilise steam from the 0.24 MPa (35 psi) LP steam system.

2.2.4 Fuel

The fuel, natural gas, is distributed to the site by Union Gas at a pipeline pressure of approximately 1.98 MPa (275 psig).

A pressurized pipeline with natural gas will be supplied to:
• Fuel gas compressors
• Boiler duct burners
• Peaking boilers
• Heating, ventilation and air-conditioning (HVAC) system

The manufacturer of the LM6000 package recommends that the fuel be supplied at a minimum pressure of 4.7MPa (675 psig). This pressure limit may be higher than necessary. Gas compressors will be utilized to boost fuel gas from the pipeline pressure to this level. Preheating of the fuel improves the efficiency of the gas turbine. The manufacturer currently limits the fuel gas temperature to 200°C (400°F). A fuel gas preheater will be used to raise the temperature of the gas turbine (GT) fuel gas to the maximum allowed by the manufacturer. High temperature HP feedwater that is extracted from the boiler will be utilized in the preheater.
2.2.5 *Steam System*

The Heat Recovery Steam Generator is designed to generate steam at three conditions. HP steam is used to supply turbine throttle flow, intermediate pressure (IP) steam is used to supply Chrysler and LP steam is used in the GT air inlet chillers and for feedwater deaeration.

The three pressure levels of steam cycle are:
- **HP - 7.3 MPa (1065 psia), 482°C (900°F)**
- **IP - 1.06 MPa (155 psia), Saturated, 178.3°C (353°F)**
- **LP - 0.24 MPa (35 psia), Saturated, 126°C (259°F)**

The HRSG generates steam at the three steam system pressures. The exhaust temperature of the gas turbine is expected to be 475°C (888°F). The HRSG duct burners will be required to fire continuously, year-round, to maintain power and steam generation capacities. Firing temperatures range from 510°C (950°F) to 787°C (1450°F). The HP steam conditions were chosen to best utilize the energy available in the gas stream when the duct burners are ON.

The HP, IP and LP pinches for the boiler design were all specified at 6.6°C (20°F) to maximize the efficiency of the plant. Tight boiler approaches were also chosen to optimize plant efficiency.
2.2.6 Steam Turbine

The steam turbine is capable of augmenting the gas turbine output to achieve 62 MW under the worst possible degradation conditions.

Throttle steam will enter the HP turbine inlet valve at 7.3 MPa (1065 psia) and 482°C (900°F). Steam will be extracted for Chrysler as required through a controlled extraction at 1.06 MPa (155 psia). When Chrysler's demands are low, IP steam generated in the HRSG is admitted into the turbine. There will be an uncontrolled 0.24 MPa (35 psia) extraction / admission port in the LP turbine. Steam will be admitted into this port when the plant auxiliary load is low and extracted when the auxiliary load is high. The remaining steam will exit the LP steam turbine at 6.89 kPa (1 psia) and flow to the condenser.

Sufficient flow is maintained through the steam turbine at all times to provide blade cooling. Steam extraction will be limited to ensure flow through the remaining sections.

Sliding pressure, LP turbine design, and control methods will be evaluated further with the turbine supplier to optimize the plant efficiency.

2.2.7 Condenser

The condenser design pressure will be 6.89 kPa (1 psia). The peak condensing load will be 75,000 Kg / hr (165 Mlbs / hr). Steam flow duration for the condenser is equal to the flow through the LP
section of the steam turbine. The condensing system will be a wet evaporative type.

The major sources for condensate will be:

- condenser
- condensate returns from Chrysler
- returns from the water treatment plant
- returns from plant HVAC unit space heaters
- returns from absorption chiller system

The condensate will be collected in surge vessels and pumped into the boiler feedwater tank. The condensate collected from Chrysler and the plant auxiliaries will be polished at the cogeneration plant.

2.2.8 Water Systems

The raw water system will supply all the water requirements of the CPP. The raw water supply will be from the Windsor Utilities Commission municipal filtered water system. Raw water will supply:

- All the cooling water make-up
- Utility water
- Potable water, and
- Water treatment plant

The raw water system includes:

- Raw water main
- Raw water storage tank, and
- Raw water feed pumps

The water treatment plant will filter and demineralize makeup boiler feedwater. The quality of the boiler feedwater will meet the HRSG and steam turbine manufacturers' requirements. The treated water system will include:

- Carbon and multimedia filters
- Filter backwash system
- Cation - anion demineralizer
- Condensate polishing system
- Neutralization tanks
- Chemical Storage tanks and feed system
- Resin regeneration system, and
- Feedwater tanks

Waste water will be collected from all sources in the cogeneration plant and discharged to the Windsor Utilities Commission sanitary sewer system. The major sources of waste water within the plant will be:

- Demineralizer regeneration waste
- Filter backwash waste
- HRSG blowdown,
- Condenser blow down, and
- Plant utility water

2.2.9 Electrical System
The two generators will generate power at 13.8 kV. This will be transformed in the plant substation to 115 kV. It will then be transmitted to the Essex transformer station north-west of the plant site. Station loads will be supplied from the 13.8 kV bus. Step down transformers will reduce the voltage to 4160 V, 600 V and 120 V, as required.

Chapter 3 describes the electrical system in the plant.

2.2.10 Control Systems

A plant distributed control system (DCS) integrates the manufacturers' control systems and controls the balance of plant. The plant is equipped with a suitable un-interruptible power supply (UPS) system. Chapter 5 deals with the control system in detail.

2.3 Site Conditions

The plant is located on a 5.5 acre site owned by Transalta Energy Corporation, south of Chrysler's Assembly Plant and west of Ontario Hydro's Sussex transformer station.

The site elevation is 186.5 m (600 feet) above sea level. Ambient range is from -24°C to 37°C.

Precipitation:
15 minutes rainfall: 28 mm
One day rainfall: 78 mm
Annual total precipitation: 849 mm
Seismic Requirements: Zone 0, Non-seismic

Area Electrical Classification:
The site is generally non-hazardous, except for the following areas:
Gas Compressor Room: Class 1, Division 2, Group D
Gas Metering Building: Class 1, Division 1, Group D

2.4 Plant Design Description

The TransAlta Windsor CPP is designed to provide reliable steam supply to Chrysler's Windsor Assembly Plant and 50 MW of base electrical power to Ontario Hydro and up to 17 MW of peaking electrical power in reserve.

The CPP is configured around a General Electric LM-6000 DLE gas turbine exhausting into a Heat Recovery Steam Generator (HRSG), with supplementary natural gas firing, to produce steam at three pressure levels: High Pressure (HP), Intermediate Pressure (IP) and Low Pressure (LP). The HRSG is equipped with low emission duct burners capable of heating the LM-6000 exhaust gas to a temperature of 816°C (1500°F). The HP steam supplies the throttle flow to the steam turbine. The HP steam flow requirements will vary depending on Chrysler's steam demands and the electrical generation requirement (on-peak or off-peak). IP steam is supplied to Chrysler via a pipeline from the CPP for facility heating, and a small amount for process heat exchange. LP steam supplies de-aeration, combustion air heating, demineralizer regeneration steam and building heating requirements. The IP and
LP steam, as well as being generated in the HRSG, can be both induced or extracted as required from the steam turbine to match flow requirements.

The present plant equipment is sized and arranged to accommodate one LM-6000 DLE gas turbine generator (GTG), one HRSG and one steam turbine generator (STG).

The plant is designed to meet the heating load which varies from no steam required by Chrysler when the Assembly Plant is shut down during the non-heating season, to a maximum of 170.097 kg/hr steam heating load. The process load is approximately 11,340 kg/hr and the heating load varies with outdoor temperatures.

Because of equipment limitations, the CPP is designed to export the following steam flow to Chrysler:
- 174,633 kg/hr @ 50 MW
- 121,109 kg/hr @ 62 MW

The plant and equipment are designed in accordance with applicable regulatory and safety requirements, the electrical power output requirements, the export steam requirements, "good utility practice", a serviceable life of 20 years, and TransAlta's requirements.

Chrysler condensate is collected at the Chrysler powerhouse and pumped back to the CPP as feedwater for the auxiliary boiler. Surplus condensate is forwarded to the raw water tank to be treated and used as feedwater for the HRSG.
Natural gas is supplied to the CPP via the union gas system terminating at the north-west corner of the cogeneration site.

Power is produced by two generators in the plant at 13.8 kV which is stepped up to 115 kV in the plant substation. The station is serviced from the 13.8 kV bus, stepped down to 4.16kV for the large plant loads. A backup electrical supply is provided at the 600 V level from the Windsor Utility Commission’s 27.6 kV system.

The control packages supplied with the gas and steam turbine generators are linked with a DCS system which also control the balance of plant.
CHAPTER - 3

PLANT ELECTRICAL SYSTEM
3.1 **INTRODUCTION**

The plant electrical systems mainly comprise the following:

a) 115 kV system  
b) 13.8 kV system  
c) 4.16 kV system  
d) 600 V system  
e) 125 V dc and Un-interruptible Power Supply (UPS) system  
f) 125 V ac Un-interruptible Power Supply (UPS) system

Power is generated in the plant at 13.8 kV, and stepped up to 115 kV and transmitted by an overhead line to an adjacent Ontario Hydro (OH) transmission station via OH line "Z1E". The plant auxiliary loads are supplied from the 13.8 kV bus and the station service transformer. The essential electrical system of the plant is supported by a standby supply from Windsor Utilities Commission (WUC) Walker Transformer Station during the absence of both generators and 115 kV Ontario Hydro power supply.

The power supply from WUC is stepped down from 27.6 kV to 600 V. The 600 V standby supply is used to commission the process system during the initial start-up stage and supports the essential loads during the plant shutdown. This transformer is star connected at both the primary and the secondary sides.

The plant is not designed to run in parallel condition at the 600 V side with the regular station service power supply and the WUC
power supply. The plant is not provided with black start-up capabilities.

In the event of a loss of the normal 4 kV bus voltage there is an automatic transfer scheme which will transfer the MCC 1 600 V bus #1 from the WUC standby power. The scheme is designed to block the automatic restoration to normal supply in the event that normal supply is restored. This must be achieved manually. The overall system is shown in appendix-A on Diagram No. 10601-FE-1A: One-line Diagram. Only a few electrical equipment specifications and calculations are attached and are described in detail for reference purposes.

3.2 **ELECTRICAL SYSTEM DESIGN CRITERIA**

3.2.1 *Functional Requirements*

The CPP is required to generate power for export to Ontario Hydro, as well as to supply power to all auxiliary loads (house loads). The plant is designed to deliver and absorb reactive power between 0.85 power factor out and 0.95 power factor in. On a day to day basis the plant adjusts the reactive power flows as required by the Ontario Hydro load dispatching centre. Under normal system conditions, OH will usually require the plant to operate between 0.9 power factor out and 0.95 power factor in. Under emergency, outage or other abnormal system conditions, the plant must adjust the excitation level as required by OH subject to equipment limitations and capabilities.
Under base load conditions 50 MW will be available for export. However, the system is designed to handle the peak load conditions up to 67MW.

Plant auxiliary loads are estimated at 4.2 MVA.

3.2.2 Design Requirements

Primary Plant Generation Voltage:

- 13.8 kV, 3 Phase, 60 Hz resistance grounded.

System Voltages in Plant facilities:

- 13.8 kV, 3 Phase, 60 Hz grounded via a PT primary and relay 59g with no in-plant generation.
- 4.16 kV, 3 Phase, 60 Hz resistance grounded for distribution and 4 kV motors' loads.
- 600 V, 3 Phase, 60 Hz, resistance grounded for distribution and 575 V motors' loads.
- 120/208 V, 3 Phase, 4-wire, 60 Hz solidly grounded for low voltage lighting, process and instrumentation.

Direct current at 125 V will be supplied by storage batteries and battery charger and will be used for:

- Closing and tripping of medium voltage switchgear
- Fire alarm and annunciation
- Steam turbine emergency lube oil pump motor
120 Vac UPS power will be supplied for DCS and other essential loads.

Interconnection of Windsor CPP to the OH system will be at 115 kV and the design conditions are as follows:

115 kV system:

- nominal voltage 115 kV
- nominal voltage range 110 kV to 127 kV
- system frequency 60 Hz
- maximum 3-phase fault 5,135 MVA

3.2.3 Codes and Standards

All equipment, material and installation will be in accordance with the latest edition of the following:

- CSA Standards
- EEMAC Standards
- ANSI Standards
- IEEE Standards
- IEC (International Electrotechnical Commission)

Where applicable to equipment manufactured outside of Canada.

- Local codes, standards and practices
- Further details are described in equipment and installation specifications
3.2.4 Quality Program Standard

All system equipment and materials are manufactured in accordance with the requirements of CSA Quality Standard Z 299.3.

3.2.5 Seismic Requirements

The requirements of the National Building Code of Canada are met. This stipulates Zone 0, Non-Seismic.

3.2.6 Noise Abatement

Equipment sound levels do not exceed 90 dba at a distance of 1 m from any component part of system or its accessories.

3.2.7 Future Requirements

With the future addition of another gas turbine unit, an additional main transformer and associated controls and protection system are required. Space is provided both in the switchyard and an electrical room for this. An additional auxiliary power transformer is not foreseen.
3.3 **ELECTRICAL SYSTEM DESIGN DESCRIPTION**

The man machine interface (MMI) units for control and monitoring the plant are located in the main control room along with steam turbine and gas turbine generator control panels.

The MMI is via CRT screens. The screens interface with a Distributed Control System manufactured by Elsag Bailey (INFI 90) Bailey INFI-90 panels and interposing panel are located in the DCS Room.

The MCC Room contains the two units 600 V substations each with its associated motor control centre. Each 600 V substation contains a 4.16 kV/600 V transformer and incoming main breaker. A tie breaker is provided between the 600 V substations. In addition, a standby supply is provided from the WUC. The WUC supply panel is also located in the MCC Room. 120 V ac UPS panel and its battery unit and the 125 V dc battery and battery charger 0EI-UJX-1 for the STG are also located in the MCC Room.

The Switchgear Room contains the 13.8 kV switchgear, 4.16 kV motor control centre, generator protection panels, transformer and breaker fail protection panel, Ontario Hydro interfacing panel and 125 V dc and 120 V/208 V ac distribution panels. Ontario Hydro revenue metering devices are located inside a 13.8 kV switchgear cell. The 125 V dc batteries and battery charger 0EI-UJX-2 is located in the Switchgear Room.
3.3.1 **115 kV System**

The main output transformer 0EA-XFMR-1 steps up the 13.8 kV generator output to 115 kV. The transformer is rated at 60 MVA.

The output of the transformer is fed via a 115 kV (SF6) breaker and a disconnect switch to the Ontario Hydro System by means of an overhead transmission line designated Z1E. See 1-Line diagram 10601-FE-1A for details.

3.3.2 **13.8 kV System**

The plant consists of two generating units. The nominal terminal voltage of each is 13.8 kV. The gas turbine generator 1RB-GEN-1 is capable of producing 40.6 MW at 13.8 kV and the steam turbine generator 0TB-GEN-1 is capable of producing 31.3 MW at 13.8 kV. Both the generators are connected to 13.8 kV switchgear 0EA-SWGR-1 via its own dedicated generator breaker. See 1-Line diagram 10601-FE-1A for details.

The 13.8 kV bus ground protection (59G) will be in service only when the breakers of both generators G1 and G2 are open.

13.8 kV switchgear bus is braced for short circuit currents of 63 kA symmetrical. Circuit breakers are rated to interrupt the system short circuit currents at the high X/R ratios, 63 kA symmetrical value. BIL level is 95kV. Switchgear enclosure is rated for EEMAC type 1 general purpose.
Each circuit breaker has three definite and distinctive positions within the circuit breaker cell:

a) Operating (connected) position
b) Test position
c) Withdrawn position

Each breaker is provided with a position indicator and local control switches. The specifications of the electrical equipment for 15KV switchgear have been described in detail in Appendix-D.

The station service load is via the station service transformer OEB-1SS 13.8/4.16 kV of 5/6.6 MVA capacity. The station service transformer is also located in the switchyard near to the main output transformer.

3.3.3 4.16 kV System

This indoor metalclad switchgear OEB-SWGR-1SS is provided for use on the 4160 V, three phase, three wire, high resistance grounded 60 Hz system. The main incoming breaker is of removable element vacuum breaker type which has a basic impulse rating of 60 kV and a short circuit current of 63 kA.

H.V. grouped class E2 contactors feed all 4160 V motors and feed supply to 4160/600 V transformers.

Controllers are of the fused type employing current limiting power fuses that give the controller an interrupting rating of 350 MVA, 3
phase symmetrical rating at 4200 V, 60 Hz. All starters employ vacuum line contactors rated 400 A, 5000 V, and have an interrupting capacity of 40 MVA, 3 phase symmetrical.

The Motor control centre is of two-high construction with NEMA 1 enclosure.

Vacuum line contactors are of the draw-out type and the controllers can be isolated by an externally operated isolating switch.

3.3.4 600 V System

The system consists of two secondary unit substations and associated motor control centre.

Each secondary unit substations' consists of:

a) Incoming 4160V line section

The HV air interrupter switch is manually operated and rated at 600 A continuous. The switch mechanism provides quick closing and opening, independent of the handle speed.
b) **Transformer section**

Dry type transformer 1,500 kVA, 4.16 kV/600 V mounted in an indoor NEMA 1 ventilated enclosure.

c) **Outgoing low voltage section**

The low-voltage metal enclosed switchgear consists of a stationary structure assembly and air circuit breaker units fitted with disconnecting devices and other necessary equipment.

The removable element consists of an air circuit breaker equipped with the necessary disconnecting contacts, wheels, and interlocks for draw-out application. The removable element has four-position features and permits closing the compartment door with the breaker in the `connected`, `test`, `disconnected`, and `remove` positions.

Each breaker is equipped with position indicators and local switches, with a solid state trip unit consisting of long time, short time, instantaneous, and ground fault pick-ups.

d) **A 600 V motor control centre**

The 600 V motor control centre enclosure is of EEMAC Type 1 (general purpose). The MCC consists of a vertical power section and accommodates different sizes of starters and breakers' units. Units of the same size and rating are interchangeable. See 1-Line diagrams
10601-FE-1F, 10601-EE-1C and 10601-EE-1D for details in appendix-B.

Each vertical power section is designed to accommodate front mounting of starter control units. All units are front wired, with all connections and terminals readily accessible from the front.

Service entrance panel housing metering unit and incoming breaker 0EC-52-ES provides standby power to motor control centre 0EC-MCC-1 via breaker 0EC-52-ESA. Standby power is supplied via WUC transformer 0EC-XFMR-3SS 1000 kVA, 27.6 kV/600 V.

3.3.5 **Uninterruptible Power Supply**

The UPS unit 0EE-UJX-1 of capacity 20 kVA is normally powered from 0EC-MCC-1, 600 V, 3 phase. 240 V dc battery system is used for the UPS system. An alternative 600 V, 1 phase supply from 0EC-MCC-2 is used to by-pass the UPS during UPS maintenance. Refer to UPS 1-Line diagram 10601-FE-1F. The specifications of the electrical equipment for the uninterruptible power system, 125 Vdc and 120 Vac have been described in detail in appendix-D.

Output from the UPS system is fed to two distribution panels of 100 A capacity. All the essential loads are connected to the UPS distribution system. A common "UPS trouble" alarm is provided in the DCS for status monitoring purposes.

240 V dc UPS batteries are located in an individual cabinet 0EE-BTRY-1 for ease of operation and maintenance.
All operations related to the UPS system are to be carried out from the local panel. There are no remote operation provisions made.

The battery back-up for this UPS is capable of supplying the loads for 30 minutes on loss of the utility ac input power.

3.3.6 125 V dc System

There are two dc systems available. One dc system OEl-UJX-1 is dedicated to supply power to the steam turbine emergency oil pump and the other OEl-UJX-2 is used to provide control supply to all electrical breakers and protection circuits. Refer to 125 dc 1-Line diagram 10601-FE-1F.

The dc system OEl-UJX-1 houses both the battery rack and the battery charger in the same cabinet. The other dc system OEl-UJX-2 has separate cabinets for the battery rack OEl-BTRY-2 and the battery charger OEl-BYC-2.

The battery back-up for the dc system OEl-UJX-1 is capable of supplying 3.7 kW to the motor of the emergency lube oil pump of the steam turbine for 60 minutes.

The battery back-up for dc system OEl-UJX-2 is capable of supplying constant and intermittent loads for 30 minutes on loss of utility ac input power.
Common "battery charger trouble" alarm is provided in the DCS for status monitoring purpose.

3.4 ELECTRICAL PROTECTION AND CONTROL DESIGN

3.4.1 13.8 kV System

The gas turbine generator and steam turbine generator and their auxiliaries are controlled from the control room via their dedicated control panels. All the devices/instruments related to the synchronising system and excitation systems are located in and on the control panels.

Generator breakers can be closed only through the respective synchronizing system. It cannot be closed from the DCS. Tripping of the breaker could be achieved from both the DCS and control panel. In general, solid state protection relays have been used for the generator protection. The status of the generator and the breaker is monitored via the DCS. Refer to Elementary Wiring Diagram 10601-CE-2DE and 10601-CE-2DF.

Multi-function power meters have been provided to measure the CTG and plant output and are linked into the DCS via soft link also pulse outputs of kW hr/MW hr are provided via the DCS for logging-in purposes. Refer to metering diagram 10601-BE-2DC for details.

OH revenue metering has been provided at the export level of 13.8 kV. Transformer load losses have to be deducted to obtain the actual power exported. Since the power is measured before the
transformer, OH will have to adjust for this loss for billing purposes. See in section 3.2 for calculation details.

In addition, a power output transducer is provided to measure the net power exported to OH. The 4-20 mA output signal of the transducer is connected to the DCS, and used as the measured value for the plant load control loop.

3.4.2 115 kV System

The plant power is exported to Ontario Hydro after stepping up to 115 kV from 13.8 kV using the output transformer 0EA-XFMR-1. The transformer is protected by a ground fault relay (64), gas relay, oil/winding temperature, phase overcurrent (B50/51) and differential relay (87T).

115 kV breaker 0FK-52-L1 is operable from both the remote (in the control room via the DCS) and from local position. This breaker is not provided with synchronizing capabilities. This breaker is interlocked to block closing if either generator breakers G1 and G2 are closed. Status of the breaker is monitored via the DCS. Breaker-fail protection is provided for this breaker.

The Output of the breaker is tied into the OH line via the motor operated disconnect switch OFK-89-L1.

The switch OFK-89-L1 can only be operated from a local switch. The disconnect switch will be opened automatically on operation of line fault protection scheme. The transmission line protection consists of
impedance relay, under/over voltage relay, under/over frequency relays.

115 kV line protection also includes OH telecommunication protection system consisting of the following:

1) Remote transfer trip to Essex and Lauzon TS using DC signal.
2) Blocking to Essex TS using tone signal.
3) Blocking to Lauzon TS using tone signal.
4) Common alarm to Walker TS (monitoring the status of 115 kV breaker, generator breakers and 13.8 kV station service breaker).

3.4.3 Station Service System

The system is designed such that 13.8 kV supply is stepped down to 4.16 kV using the station service transformer OEB-XFMR-1SS. 13.8 kV station service breaker OEA-52-1SS is designed to operate either from the DCS or local. Breaker status is monitored via the DCS. Refer to elementary wiring diagram 10601-CE-2CZ.

The transformer is protected by phase overcurrent relay, ground overcurrent relay and winding temperature. The Ground overcurrent relay is used only to "alarm."

The 4.16 kV breaker OEB-52-1SS can be operated from the DCS as well as locally. The status of the breaker is monitored via the DCS. The incoming 4.16 kV supply is monitored by electronic power meter and it is tied into the DCS communication loop for remote
monitoring purposes. This is shown in the elementary wiring diagram 10601-CE-2DA.

The 4.16 kV supply is used to power the fuel gas compressors, HRSG feed pumps, centrifugal chillers and to feed power to the 600 V motor control centres via the two 4.16 kV/600 V transformers. All 4 kV feeders are protected by Multilin relays. The motor current is monitored by a Multilin relay and 4-20 mA signal used for monitoring on the DCS. The Multilin relay and the motor contactor status are monitored in the DCS. The motor space heaters are powered from a separate 120 V ac distribution circuit.

The 4.16 kV/600 V transformer 0EC-XFMR-1SS and 0EC-XFMR-2SS are the dry type and their ground current is monitored by a resistor network unit and used to alarm fault condition.

The MCC-1 and MCC-2 power is measured by an electronic power meter and is linked to the DCS through soft link.

The tie-breaker 0EC-52-2A between MCC-1 and MCC-2 is normally in the open condition. The WUC feed breaker 0EC-52-ESA is also normally in the open position. The system is not designed to operate with MCC 1 and MCC 2 paralleled. The emergency standby power from WUC cannot be paralleled with MCC 1 or MCC 2.

A Kirk-key interlock has been provided between breakers 0EC-52-2, and 0EC-52-2A. An electrical interlock has been provided between the breakers 0EC-52-1 and 0EC-52-ESA in such a way that at no time can both breakers be in the closed condition. This is shown in the 1-
line diagram 10601-FE-1A and Elementary wiring diagrams 10601-CE-2CV, 10601-CE-2CW, 10601-CE-2CX, and 10601-CE-2CY.

A loss of normal power at MCC#1 will initiate an automatic transfer operation - the breaker 0EC-52-1 will open and the breaker 0EC-52-ESA will close. With emergency power in service the auxiliary boiler can be operated to supply steam to the Chrysler Plant.

The 600 V tie-breaker cell 0EC-52-2A is wired for electrical operation. The cell is left empty. The breaker 0EC-52-2 is taken out of its present position and inserted into 0EC-52-2A cell to achieve paralleling of the buses EE-1D and EE-1C. This is not a normal operation but is used only as a maintenance tool or when supplies are available only from WUC via the breaker OEC-52-ESA.

3.4.4 Trip Tone Protection

The CPP is tapped off OH 115 kV circuit Z1E. The Z1E terminal stations for line Z1E are Essex TS and Lauzon TS with the circuit terminating in a ring bus configuration in both cases. Three other stations are tapped from circuit Z1E; Ford EEP and Walker TS Nos. 1 and 2. This is shown in Fig.2 for operating control 1-line diagram and Fig.3 for “Z1E” protection zone scheme in the appendix-A.

In the event that abnormal conditions occur, such as over or under voltage, over or under frequency or, voltage imbalance, and the plant personnel cannot contact the J.C. Keith Operator, then personnel will separate the plant from the OH system. Appendix - A
provides a simple single line diagram and the Z1E protection diagram.

Both Lauzon and Essex TS employ A and B protections. Each has overcurrent supervised single zone distance relays (reach of 250% and 150% of circuit impedance respectively), ground directional overcurrent and overcurrent line test protection. Impedance protections overreach the protection zone at the terminal stations but do not 'see through' the power transformers at the tapped stations (although provision allows the plant to momentarily block tripping of the terminal stations, permitting instantaneous clearing of, in zone faults only, timed clearing (400 ms) occurring only if the adjacent protection zone fails to clear the fault. A permissive echo is provided at each terminal station to permit instantaneous clearing of line faults when either terminal is open.

The tapped stations are tripped via dual channel dc remote trip of which there are two separate schemes: one between Lauzon TS and Ford EEP, the other serving the remaining stations with the cascading of both schemes occurring at Lauzon TS. Each station has its air break switch of the line transformer interlocked with the sending and receiving of remote trips. Failure of the remote trip circuits serving Ford EEP or the Lauzon TS Position Unit is detected at Lauzon TS.

All alarms are transmitted to the OH Keith TS control room. Failure of remote trip circuits being monitored at Essex are communicated to the CPP via the Essex Plant Positron Unit. Failure of a single remote
trip introduces a 50 ms delay in clearing time while under normal conditions zone clearing is essentially instantaneous.

3.4.5 **Generator Protection and Control**

*Protection:*
The protection requirements of a generator that is connected to the utility network are much more complex than those of a stand-alone generator.

Protection is needed against possible damage that the massive utility network can cause to the in-plant generator and the generator to the network. As yet, there is little consensus as to how much protection is prudent, and most utilities have slightly different published requirements, which are constantly under review.

Synchronism or a synchronism check relay must be used to ensure that the in-plant generator cannot be connected to the utility system when out of phase.

Over-frequency and under-frequency relays indicate that utility power has been interrupted. The main breaker must open before power is restored.

The under / over-voltage relay indicates when the in-plant generator voltage differs from the network voltage, a condition that causes excess flow of reactive power when the breaker is closed.
The power directional relay indicates whether the power is flowing from the utility to the customer or vice versa.

Isolation of the customer’s generation occurs if the utility breaker opens for any reason (such as for clearing a fault). This leaves the customer’s generator coupled to the full plant load and to any adjacent customers that are connected downstream of the tripped breaker. If the customer’s generator is feeding power to the utility at the time of the trip, it may over-speed when the utility disconnects. Thus, in any interconnected system, the customer’s main breaker must trip whenever the utility power is interrupted.

Usually under- or over-frequency relays are suitable to cause this trip. Typically these are set at 59 and 61 Hz so that, when the generator output reaches these frequency limits, the breaker trips. But it’s just possible that the customer’s governor works better than expected, so that the generator maintains exactly 60 Hz for a few seconds after being isolated. For this reason, over and under-voltage or power directional relays are also specified to guard against this possibility. Some or all of these relays may be equipped with a time delay to prevent unnecessary operation during a transient.

A General Electric Digital Generator Protection (DGP) relay is used. The DGP is a multifunction relay and is a microprocessor-based digital relay system that uses wave-form sampling of current and voltage inputs to provide protection, control and monitoring of the generator. These samples are used to compute current and voltage phasors that are used for the protection function algorithm.
DGP system uses a man-machine interface (MMI) and communication software.

**Control:**

An in-plant generator provides the possibility of an additional control over the kilowatts purchased from the electric utility and the KVARs drawn from the utility network. The VARs represent power, which is not useful but is necessary for the excitation of the electric motors in the plant. The utility charges for VARs are drawn from its system. This charge is normally expressed in terms of the power factor.

Two types of generators are used for the in-plant generating system: the induction generator and the synchronous generator. There is a large difference in the degree of control available from these two machines.

*The induction generator* consists of a conventional induction motor, which is connected to the utility network driven above its synchronous speed by a prime mover. The more mechanical power that is applied to the induction generator's shaft, the more kilowatts are fed into the utility network. Note, however, that the induction generator works only when connected to an energized network. This is because it needs to draw VARs from the network for its own energization. Once the induction generator is disconnected from the live network, it causes it to generate power. Reactive power for the excitation of the induction generator can be supplied by the user if static capacitors are installed at the generator terminals. However,
this introduces the problem of self-excitation of the generator when disconnected.

_The synchronous generator_

When the generator breaker is open, the torque from the prime mover is controlled by adjusting the fuel input to maintain constant speed and frequency. The generator voltage is controlled by varying the brush-less exciter.

When the generator breaker is closed, the generator is placed in parallel with an infinite bus, that is, a bus whose voltage and frequency are not affected by the output of this one generator. Now the control problem changes completely. The governor on the prime mover no longer controls the speed because the generator is locked into the synchronous speed of the bus. The governor controls the real power output of the generator. Likewise, the voltage regulator no longer controls the voltage because the voltage is the same as that of the infinite bus. Instead, the voltage regulator controls the flow of the reactive power.

_A governor with a droop_ characteristic does not control the generator speed precisely. Rather, it allows the speed to droop slightly as the load is increased. Thus, a governor with a 5% droop characteristic allows the prime-mover speed to drop 5% as the load changes from 0 to 100%.

_The iso-chronous_ governor is the type used in a utility power plant to maintain a precise speed and a precise frequency at any load level.
3.4.5 Local Override of Electrical Motors

The motors controlled from the DCS are each fitted with a 'local/remote' selector switch and a local 'stop' push-button. When switched to 'local' the operator may locally 'start' and 'stop' the motor, but the DCS cannot 'start' or 'stop' the motor under this condition. This feature provides the operator with a local override of all interlocks associated with these motors.

The status of the 'local/remote' selector switch is not wired to the DCS. The DCS does monitor the state (on/off) of the motor from its respective MCC and compares it to the last command. It generates a 'drive fault alarm' in the event the motor is locally started or stopped. If a drive fault is received, the DCS start signal will be tripped off. Therefore, if a motor has been started in "local" and is then re-selected to 'remote,' it will stop and have to be restarted via the DCS.

3.5 SEQUENCE OF EVENTS

The sequence of events' data logger (SOE) is a high speed data logger dedicated to specific hard-wired digital inputs. Each of the dedicated digital inputs is acquired every millisecond and compared to the previous values. If there is a change in one or more inputs, the new value is stored in an internal buffer with its own time stamp. The
time stamping is synchronized on a regular basis with the DCS console clock.

An SOE log is automatically triggered when one or more of the dedicated Digital Inputs to the SOE changes from its normal state to its triggered state. The trigger state can be from 0 to 1, 1 to 0, or both and is defined on an individual input basis in the "Input Channel Interface" function block.

An SOE digital input trigger will cause a regular alarm followed by an automatic SOE log printout. There are 24 retained SOE logs. The retained SOE logs can be viewed or printed through the DCS console.

The following points are monitored in DCS as sequence of events' points with time stamp.

3.5.1 *Process Related SOE Points:*

STG stop valve closed
HP feedwater pump 1 status
HP feedwater pump 2 status
Gas compressor 1 alarm status
Gas compressor 2 alarm status
IP-HI steam pressure
IP-HI steam temperature
GTG shutdown status
STG shutdown status
Duct burner shutdown status
HP drum level HI trip
HP drum level LO trip
IP drum level HI trip
IP drum level LO trip
HRSG HI duct temp
STG ECV valve closed

3.5.2 Electrical System SOE Prints:

13.8/121 kV XFMR 'A' diff. protection relay activated
13.8/121 kV XFMR 'B' current protection relay activated
GTG 13.8 kV BRKR fail protection activated
STG 13.8 kV BRKR fail protection activated
115 kV line BRKR fail protection activated
115 kV line protection remote transfer tone trip ch.1
115 kV line protection remote transfer tone trip ch.2
115 kV line BRKR trip relay activated
ST Generator protection trip 'A' activated

3.6 KEY DRAWINGS
All the key drawings listed below are included in the appendix-B for reference purposes.

10601-FE- 1J       Plant shutdown logic

10601-CE- 2DB       Hardwired emergency shutdown
                      Elementary wiring diagram
<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10601-CE-2CV</td>
<td>600 V MCC-1&lt;br&gt;Main incoming breaker (0EC-52-1)&lt;br&gt;Elementary wiring diagram</td>
</tr>
<tr>
<td>10601-CE-2CW</td>
<td>600 V MCC-2&lt;br&gt;Main incoming breaker (0EC-52-2)&lt;br&gt;Elementary wiring diagram</td>
</tr>
<tr>
<td>10601-CE-2CX</td>
<td>600 V MCC-2&lt;br&gt;Tie breaker (0EC-52-2A)&lt;br&gt;Elementary wiring diagram</td>
</tr>
<tr>
<td>10601-CE-2CY</td>
<td>600 V MCC-1&lt;br&gt;Emergency incoming breaker (0EC-52-ESA)&lt;br&gt;Elementary wiring diagram</td>
</tr>
<tr>
<td>10601-CE-2DA</td>
<td>4.16 kV switchgear&lt;br&gt;Main incoming breaker (0EB-52-1SS)&lt;br&gt;Elementary wiring diagram</td>
</tr>
<tr>
<td>10601-FE-2DC</td>
<td>Power metering scheme&lt;br&gt;13.8 kV, 4.16 kV, 600 V SWGR&lt;br&gt;General block diagram</td>
</tr>
<tr>
<td>10601-CE-2CZ</td>
<td>13.8 kV switchgear&lt;br&gt;0EA-52-1SS breaker&lt;br&gt;Elementary wiring diagram</td>
</tr>
</tbody>
</table>
10601-CE-2DE  13.8 kV switchgear
               1RB-52-G1 breaker (GTG)
              Elementary wiring diagram

10601-CE-2DF  13.8 kV switchgear
               0TB-52-G2 breaker (STG)
              Elementary wiring diagram

10601-FE-2B   HRSG Boiler Feed Pump
               4.16 KV Motor/OSJ-P-1MO
              Elementary Wiring Diagram

10601-FE-2CT  4.16 KV/600 V Transformer Feeder
               0EC-XFMR-1SS
              Elementary Wiring Diagram

10601-FE-4AA  Communication Loop
              Cable Block Diagram
CHAPTER-4

POWER SYSTEM ELECTRICAL CALCULATIONS FOR
COGENERATION PLANT
4.1 **GENERAL:**

To ensure that the power plant will operate safely, reliably, and economically, power system calculations were carried out during the planning stages of the project. These were refined during the design stages as concepts matured. The following calculations were carried out:

- The load estimate of the station service
- Short circuit current
- Cable sizing
- Voltage drop of motor starting
- Load loss curve of the output transformer

4.1.1 *The load estimate of the station service:*

The first calculation needed was the estimation of station service loads. It helps in determining the real and reactive loads that will be supported by the generator and it is important for determining the optimum design and operation for the facility. This is based on the mechanical equipment list which is normally issued by the mechanical group as a preliminary engineering design. It is safer to add 10 to 15% to the total load value to cover possible design changes.

Estimation of load is done in the form of an Electrical Load List. It is very important to identify all the load's duty cycle (operating condition) such as Continuous load, Intermittent load (Random load) and Stand-by load. This is done because, not all the connected loads on the switchgear and the motor control center are going to be operating at the same time. There is a certain sequence and logic behind each load as to when it is supposed to be
“ON” or “OFF”. Sequence/Logic is determined by the system process design.

Once the load list is established, the total running load on every bus has to be calculated on the basis of their duty cycle using the following equation:

\[
A \quad \text{Sum of Running load in KVA} = \frac{\text{Total of all Continuous load in kW} \times \text{Diversity factor}}{\text{for category “C” (continuous)}} \times \text{Efficiency} \times \text{Power factor}
\]

\[
B \quad \text{Sum of Running load in KVA} = \frac{\text{Total of all Random loads in kW} \times \text{Diversity factor}}{\text{for category “R” (random)}} \times \text{Efficiency} \times \text{Power factor}
\]

\[
\text{Total Running load KVA on a Bus} = A + B
\]

The addition of the loads of all buses gives the total estimated station service load. A sample page of load list is attached for reference in appendix-C.(Calculation No:10601-E1)

Notes:

- Diversity factor is assumed to be 0.8 for continuous load
- Diversity factor is assumed to be 0.2 for random load
- Stand-by load is not considered in the calculation of total running load
- Unless the load power factor is known, a power factor of 0.85 is assumed for all the loads
- Unless the load efficiency is known, an efficiency is assumed as follows:
  1. Motor rated less than 1.0 kW -- 70%
  2. Motor rated between 1kw and 25 kW -- 80%
  3. Motor rated between 26 kW and 150 kW -- 90%
  4. Motor rated above 150 kW -- 95%
  5. Motor operated valves -- 95%
6. All panels, heater and lighting loads -- 100%

**Transformer sizing of the station service:**

The size of the station service transformer is based on the load estimate of the station service and taking the future growth into consideration. The calculation sheet (Calculation No: 10601-E2) in appendix-C explains in detail the method of calculation.

**Generator step-up transformer:**

The size of the generator output transformer is usually based on the generator capacity and taking into account any future growth. The generator step-up transformer used on this project is a self-cooled OA (oil to air) rating. Increased in capacity rating of the transformer was accomplished by forced cooling above the OA rating. The use of radiator fans (FA) yields an additional 33-percent increase over the OA rating for each stage of cooling. In addition, significant kVA increases can be obtained by utilizing a 55 / 65°C rated unit, which at 65°C yields a 12-percent increase over the OA rating of 55°C rise.

However, when the maximum generator sizes are in the low 100 - MVA range, as with gas turbine cogeneration units, the self-cooled type of transformer becomes more attractive on a comparable cost and efficiency basis.

The generator step-up transformer is sized on a larger, more conservative basis for a number of reasons, which include:
1. The desire to be able to carry full generator kVA with one bank of fans
2. The desire to allow for possible future turbine-generator updates, i.e., not to make the transformer the limiting item in the generator package
3. The desire to extend the transformer life and enhance reliability by running the transformer below rated temperature
4. Since load losses go up as the square of current, and auxiliary fans also consume energy, more efficient operation with reduced transformer loading
5. A lower per-unit transformer impedance resulting in a lower voltage rise at the generator terminals, lower reactive drop, and better transient stability performance
6. All of the above, reinforced by the economic fact that additional transformer kVA is inexpensive relative to the investment in the turbine-generator

Based on the above factors a prudent basis for sizing is to make use of the additional kVA from a 55/65°C rating and one stage of forced cooling. This results in a transformer rating equal to the generator rated MVA and rated power factor divided by 1.5, (i.e., 1.33 * 1.12).

4.1.2 Short circuit current:

Having established the required loads and the transformer size, it is important to carry out the short circuit analysis to find out the momentary and interrupting short circuit currents at the switchgear and the motor control centres. This calculation was carried out using the computer program “Electrical Transient Analyser Program” ETAP 7.301. Refer to 1-Line diagram 10601-FE-1A for load distribution details.
The short circuit program analyses the effects of a three-phase fault on the electrical distribution system. The program calculates the fault current contributions of motors, generators and utility ties in the system. Fault duties are in compliance with the latest edition of the ANSI standard (C 37 series) and IEEE -- recommended procedures. For efficient, fast and reliable computation, the program uses the bus impedance matrix with the node injection method.

Note that ETAP ignores all bus loading (Motor & Static Load) for short circuit calculations. For example, if bus #1 has a 1MVA motor connected to it and the motor is loaded 80% at unity power factor (Motor load = 0.8MW), the short circuit program uses the 1 MVA motor rating for fault contributions and ignores the 0.8MW loading. Refer to the short circuit calculation sheet in appendix-C for further details.(Calculation No: 10601-E3)

4.1.3  *Cable sizing:*

Cable sizing is an important task that has to be carried out as part of the detailed engineering work. If it is done incorrectly, which often happens in a fast track project, we may not be able to energize the plant electrical system without the electrical inspection. Net savings are achieved by decreasing feeder $I^2R$ losses through oversizing the conductor. The use of tables to oversize for voltage drop or energy conservation, or a combination, saves time and money, provide more uniformity, simplify construction, and provide increased reliability, safety, and code compliance.

The sizing of the circuit conductors is basic, but there is considerable confusion, misunderstanding, ignorance, and misinformation in its
implementation. With the increase of code requirements and the number of ampacity tables, this function has become increasingly complex. Use of customized tables simplifies the process and reduces the possibility of errors. Cable sizing in general involves 3 major steps that are:

- Calculating the short circuit withstand capability of the cables
- Calculating the maximum loading capacity
- Calculating the voltage drop of the cable and limiting it to the predefined value

**4.1.3.1 Short circuit current withstand capability:**

The short circuit withstand capability of the power cables (copper) is determined using the assumption that the duration of the short circuit is so short that the heat generated is contained within the conductor and taking into consideration the temperature limit of the insulation. The following equation was provided by the cable manufacturer (Philips.):

\[
[I/A_1]^2 \cdot t = 0.0297 \log [(T_2 + 234)/(T_1 + 234)]
\]

\[ I = \text{Short circuit current, A} \]

\[ A_1 = \text{Conductor cross sectional area, in circular mills} \]

\[ T_2 = \text{Maximum short circuit temperature, °C (250°C for XLPE/EPR cable)} \]

\[ T_1 = \text{Maximum normal operating temperature, °C (90°C for XLPE/EPR cable)} \]

\[ t = \text{Short circuit duration, s} \]

Substituting the \( T_1 \) and \( T_2 \) value, the equation -(1) become:

\[ I = (0.07195 \cdot A_1) / t^{1/2} \text{ for copper conductor, A} \]

High voltage power cables usually have a copper shield in contact with the auxiliary insulation shield and a thermoplastic jacket, the maximum shield
short circuit temperature, $T_2$, is 150°C and the normal operating temperature, $T_1$, is 75°C. Substituting the value 150 and 75 for $T_2$ and $T_1$ respectively, in equation-(1) to obtain the maximum shield short circuit current, we get:

$$I = (0.05294 \ A_1) t^{1/2}, \text{ A}$$

$A_1$ is the area of the shield in circular mills

The short circuit current is further limited by increasing conductor resistivity due to the rising temperature.

4.1.3.2 *Maximum load capacity (current)*:

The maximum running current for any load is determined from the load list. An additional factor is added as a safety margin so that the maximum current for:

1. Motor /Generator is 125% of full rated current (FRC)
2. MCC is the running current less FRC of the largest motor + 125% of the largest motor FRC
3. Switchgear is the maximum rating of the supply transformer

The following multiplying factors have to be calculated and taken into consideration while determining the maximum running current. This is based on IEEE/ICEA publication no:S-135.

- Cable deaerating factor to be calculated if multiple conductors per phase are used. This is to be done to overcome the unbalanced current in the phases.
- Ampacity correction factor for ambient temperature difference.
- Ampacity correction factor for multiple cable grouping (no space between cables).
• Ampacity correction factor for three-single conductors run in Triplex configuration.

4.1.3.3 Steady state voltage drop:

Once the required size of the cable is established to withstand the available short circuit current level, size and no. of cables required for limiting steady state voltage drop to an acceptable level can be calculated using the following equation (provided by the cable manufacturer-Philips). Usually the acceptable voltage drop level is 3% for the motor feeder cables and 2% for the main feeder cables.

\[ dV = 1.732 \times I \times L \times [ R \cos \phi + X \sin \phi ], \ V \]

\[ dV = \ \text{Voltage drop}, \ V \]
\[ I = \ \text{Maximum running current}, \ A \]
\[ L = \ \text{Length of the cable}, \ m \]
\[ R = \ \text{Resistance of the cable}, \ \text{ohms} / \text{km} \]
\[ X = \ \text{Reactance of the cable}, \ \text{ohms} / \text{km} \]
\[ \cos \phi = 0.85 \ (\text{assumed}) \]

In the case of single conductor cables installed in Triplex configuration, the value of ‘X’ is calculated as follows:
\[ X = 0.17362 \log(\text{GMD} / \text{GMR}), \ \text{ohms/km} \]
GMD = Geometric mean distance between conductor, mm
GMR = Geometric mean radius of conductor, mm

Note: Refer to the attached calculation sheet for further details. (Calculatio No: 10601-E4)
4.1.4 Voltage drop of motor starting:

The motors used in modern industrial systems are becoming increasingly large in size. Starting these large motors, especially across-the-line, will produce transient voltage depression that can substantially reduce the motor output torque while severely influencing the operation of other locally connected, as well as loads served by buses electrically remote from the point of the motor. Motors with special starting equipment may reduce the motor inrush current and the associated voltage dip, but the starting performance of the motor may be unacceptably altered.

Assuming that a reduced voltage provides adequate accelerating torque, it should also be verified that the longer starting interval required at the reduced torque available during a voltage dip does not result in exceeding the permissible $I^2t$ damage of the motor. Besides using standard impedance values for transformers and cables, it is often necessary to use typical or assumed values for other variables when making calculations of the voltage drop of starting motors. Some common assumptions that are often used in the absence of more precise data are as follows:

- **Inrush current**: Usually, a conservative multiplier for motor starting inrush current is obtained by assuming the current of the locked rotor is equal to approximately six times the full-load current with full voltage applied at the motor terminals.

- **Starting power factor**: The power factor of a motor during starting determines the amount of reactive current that will be drawn from the system, and thus to a large extent the maximum voltage drop. For motors under 746 kW (1000 HP) power factors value of 0.20 and for over 746 kW (1000 HP) 0.15 are assumed.
When the voltage drop is the only concern, the end product is the calculation at the point in time when all the system impedances are at their maximum value and all sources are at their minimum voltage level. The voltage drop can be calculated either from the Impedance method or from the Load flow method.

**Impedance method:** This method essentially involves a reduction of the system to a simple voltage divider network where the voltage at any point in a circuit is found from the known voltage times the ratio of the impedances to the point in question over the total circuit impedance.

\[ V = E \left( \frac{Z_1}{Z_1 + Z_2} \right), \text{V} \]

The locked rotor impedance for 3φ motor is:

\[ Z_{LR} = \frac{[\text{rated volts}(L-L)]}{(\text{LRA})(3^{1/2})}, \text{ in ohms} \]

Where LRA is the locked rotor current at rated voltage. This value in per unit is equal to the inverse of the inrush multiplier on the motor rated KVA base.

\[ Z_{LR} = \frac{1}{(\text{LRA}/\text{FLA})} \text{ in per unit} \]

Since the motors that are starting can be accurately represented as a constant impedance, the impedance method is very convenient for calculating the system bus voltages during motor starting.

**Load flow solution method:** Bus voltages and the voltage drop can be determined by a conventional load flow program. By modelling the
starting motor as a constant impedance load, the load flow calculation yields the bus voltages during starting.

4.1.5 **Load loss curve of the unit output transformer:**

As the metering is done on 13.8 kV side before the unit output transformer, the value of the transformer load loss needs to be taken into account for the correct revenue billing. Considering the manufacturer’s load loss and the impedance test report of the main transformer, the load loss curve has been created which will be used as a function block in the DCS to obtain the Net Export to Ontario Hydro. Refer to the load loss curve calculation sheet in the appendix-C for further details.
CHAPTER - 5

CONTROL SYSTEM
5.1 **INTRODUCTION**

The plant control systems are configured using specialized pre-packaged sub-systems interconnected mechanically and electrically to achieve the final plant configuration. In most cases the pre-packaged systems have been supplied with the vendors' standard controls for equipment operation and protection.

An Elsag Bailey INFI 90 Distributed Control System (DCS) is provided as a unifying platform for the Man Machine Interface (MMI) for the plant operator centred in the Control Room.

Steam Turbine Generator (STG), Heat Recovery Steam Generator (HRSG), Wet Surface Air Condenser (WSAC), Balance of Plant Systems is configured to be controlled from the DCS.

Packaged systems utilizing Programmable Logic Controllers (PLC) are "soft linked" via RS-485 Modbus RTU protocol to the DCS to provide additional monitoring information to the operator; however, only hardwired signals to and from the DCS are used for control and trip functions on the plant.

With the DCS as the hub, operators are provided with monitoring, control, alarm, log reporting and trend information from the entire plant. This controls architecture provides the plant operator with access to the total plant from a single central location.
5.2 CONTROL SYSTEM DESIGN CRITERIA

Functional Requirements

An integrated, centralized plant control system is required to operate and control equipment and systems including start-up and shutdown; status information including alarms and plant protection, and data collection.

The plant controls are divided into ten sub-systems which are distributed throughout the plant with specific equipment packages.

The systems consist of:

× The balance of plant DCS and operator consoles.

× The gas turbine NetCom 5000 and generator protection.

× The steam turbine Woodward 505E HP/IP governor control and generator protection.

× The auxiliary boiler burner management system (BMS) and modulating controls utilizing Bailey strategic loop controllers (SLC).

× Water treatment control, GE Fanuc PLC.

× Fuel gas compressor, Modicon PLC.
HRSG duct burner management, Modicon PLC.

Continuous emissions monitoring system (CEMS), GE Fanuc PLC.

Electrical power monitoring.

Glycol chiller, load management panel.

All of the above programmable logic controllers (PLC) and controllers are connected via Modbus serial communication links to the plant DCS with the exception of the steam turbine, auxiliary boiler and glycol chillers. Although the PLCs and controllers are linked to the DCS, it is not intended that control be performed through the serial link. Therefore, any information that is displayed on the operator console via the serial link, is for information only. Associated control functions have either been hardwired or performed locally via the associated PLC and/or controllers. The exception to this is the connection to the auxiliary boiler SLCs (analogue loop controllers) which are directly connected to the DCS thereby allowing the operator to raise and lower the auxiliary boiler steam pressure setpoint.

The DCS allows the operator control, sequencing, alarming, trending and logging functions for operation of the plant. The DCS consists of the following major components:
× Redundant Operator Display Consoles complete with alarm printer each.

× Engineering Workstation/Console complete with colour printer.

× Electronic Cabinets in the DCS Equipment Room which contains redundant controllers.

× Sequence of Events Monitor with up to 48 points.

× General Purpose Interface which allows communication to the PLCs and other controllers.

5.3 CONTROL SYSTEM DESIGN DESCRIPTION

Operator Overview

The objective of this section is to describe the control of the plant from the Elsga Bailey operator consoles via the Distributed Control System (DCS).

The consoles have been configured as redundant client/server machines allowing the operator access to all functions from either machine. These consoles use the QNX and QWindows real-time operating systems and behave very similar to Microsoft’s Windows 95 and 3.1. Though similar, there are some differences, specifically the use of the mouse and operation of the windows. Generally, the left mouse button is used to select items and to control the plant,
while the right button is normally used to control the windows and select system properties. The engineering work station supplied can also be operated as an additional client console with all the above functionality.

Each console allows up to eight windows to be opened simultaneously to view and operate the plant. All the windows can be moved and arranged on the screen as required, except for the Executive Window that is always located along the top of the screen. The Executive Window shows the system status, which alarm groups have active (solid yellow) or new (flashing yellow) alarms, and provides access to the "Main" and "Sign In/Out" menus.

From the main menu, the operator may open one or more of the "Process Graphic" windows. Each Process Graphic window allows the operator to view and/or operate the plant via one of the "Plant Graphics." Each Plant graphic represents a specific plant area and/or view. There are approximately 35 different graphics that have been arranged in a Graphic hierarchy.

The graphic hierarchy depicts how the graphics have been arranged with respect to paging and control functions.

The graphic hierarchy shows how the graphic paging has been set up. To move "up" in the hierarchy, the operator hits the ESC key; to move "left" or "right," the PREV, NEXT keys; to move down in hierarchy, the operator touches and clicks the area on the overview graphic or the area from the graphic menu located on the bottom line of the graphic.
Motion (paging) between graphics is controlled by either using the mouse, keyboard or Function/ADP keys.

There are three layers to the graphics:

- Overview Level
- Control/Operational Level
- Detailed Level

At the top of the graphic hierarchy is the OVERVIEW (ovv) which is a pictorial representation of the major plant components. See fig.4 in the appendix-E for details. Each of the components is set up as a touch area, which means the operator can move to a more detailed representation of the area simply by moving the mouse pointer on top of that component and clicking with the left mouse button.

Below the overview is the Control/Operational Level which provides a detailed representation of each area in a graphic display and allows control of the equipment in that area.

Below the Control Operational Level is the Detailed Level which provides further detail of equipment in that area as well as control of any auxiliary equipment not represented at the control level.

Each graphic is assigned a unique number in addition to a title.

**Alarm Description**

All alarms brought into the system can be grouped and sorted in several different ways. An alarm page is set up for each area which shows the alarms for that area sorted chronologically with the most
recent alarm at the top of the screen. The following alarm graphics have been set up:

Each of the alarm groups has been set up in a similar one-line format:

*Key, Priority, Time, Tag Name, Current State, Alarm Limit, Tag Description, Alarm Code, Group*

The following provides a typical example of an alarm:
D 2 08:37:01 OSD-LT-0120 101.20 mm 95.00 mm COND RECEIVER TANK LVL H 4

"D" is the primary display select. By depressing the "D" key, the primary display (plant graphic) associated with this alarm is selected.

"2" is the priority of this alarm - "1" is the Highest, "99" the Lowest, "0" is not Alarmed. The alarms may also be sorted by priority and then chronologically. Only 2 alarm priorities have currently been configured. Priority "1" alarms need quick attention, while Priority "2" alarms generally are to make the operator aware of a change of state that may become critical.

"08:37:01" is the time of occurrence of the alarm.

"OSD-LT-0120" is the Tag Name associated with the alarm point.

"101.20" is the current value of the point. This value will continue to change showing the current value of the point.
"95.00 mm" is the alarm limit violated. This value is tuned as part of the tag and may be increased or decreased as required to provided earlier warning or prevent spurious alarms.

"COND RECEIVER TANK LVL" is the description of the point being alarmed.

"H" is the alarm type. In this case, it is High alarm.

"4" is the alarm group associated with the point. There are 11 alarm groups.

5.4 **DCS Logic**

The DCS control has been set up in building block style using a standard combination of control logics commonly referred to as macros. These are pre-configured software logics of frequently used control loops/functions (e.g. motorized valve control, three-element drum level control) which have been previously tested, proven, standardized. Two different styles of macros are used: the S-series or sequential logic type (on/off) and the M-series or modulating analog control.

The standard macros used include the following sets:

- M002  Station Interface
- M005  Advanced Pid Control Loop
- M016  Temperature Compensated Flow C/W Squarer Root
- M019  2-Transmitter Average
- M070  3-Element Drum Level Control
× M075 Cascade Steam Temperature Control
× M076 Desuperheater Control
× M091 Temperature and Pressure Compensated Flow
× S302 2-Speed Drive
× S320 Generic Push-button Interface
× S331 Start/Auto/Stop Push-button
× S333 Open/Auto/Close Push-button
× S334 Open/Stop/Close Push-button
× S336 High/Low Speed Select Push-button
× S400 Trip Coil Breaker/Drive
× S401 MCC Drive
× S402 Single Coil Solenoid C/W Status
× S403 Single Coil Solenoid No Status c/w Open/Auto/Close Push-button
× S406 Motor-Operated Valve

Examples of macro building:

When used for control of a drive, S401 (fig.7) and S400 (fig.6) are used with S331 (fig.5) to monitor the status only of a drive in which no push-button interface is provided (figures 4 to 9 are included in the appendix-E).

When used for control of a valve, S402 (fig.9) and S406 (fig.10) are used with S333 (fig.8).

Both the sequential and modulating macros are hierarchical in nature and set up to allow individual control of the drives when in manual and group/loop control when in automatic. As an example, when a pump is in manual, the operator can start or stop it individually as required, provided there is no interlock preventing the operation.
When the same pump is in automatic, it will start and stop as required by the plant conditions.

**Graphic Faceplates or Pop-ups**

Each sequential drive, if controlled from the DCS, is generally provided with a "pop-up" or faceplate on the console screen. The "pop-up" is the DCS equivalent of the 2- or 3-position handswitch or push-button with status lights used for operation of electrical drives. The faceplate has several components which include:

- **Tag Description**, HP STEAM ISOL VL OPN/ A/CLS.

- **Tag Name**, 1AE-MOV-5180.H.

- **Push-button Descriptor** (to the left of the squares, e.g., OPEN/AUTO/CLOSE) which describes the function of each push-button.

- **Feedback State Indicators**, OPEN’D/CLSD of which only one mode is displayed at a time.

- **Feedback Status Indicator**, N’PERM, FAULT, provides indication whether the drive is permitted to start or stop and if there is a fault condition associated with the drive.

*Note:* The faceplate or "pop-up" are activated by touching the drive symbol with the mouse or using the key select (the red two-digit number located to the left of the drive symbol). For
modulating valves/drive, the "pop-up" shows the control variable, the setpoint, the valve demand and the tracking/mode status.

**Automatic Controls and Interlocks**

The plant automatic controls and interlocks are set up with the following levels of local overrides, trips, interlocks and automatic functions in terms of ascending orders of priority:

× **Automatic Logic.** This level logic is configured in the DCS and requires that the drive be in automatic to function. The operator may override this logic by manually starting or stopping the drive.

× **Trip Logic.** This level of logic is configured in the DCS and functions when the drive is in auto or manual. The operator cannot override the trip logic. Generally, this logic requires that the drive local control station local/remote selector switch be in remote position.

× **Local Logic.** This level of logic is configured external to the DCS and functions independently of the DCS. Normally, there is a local start/stop switch which is part of this logic. When operated locally, the equipment is not protected by the DCS logic.

The operation of the interlocks vary slightly when applied to On/Off and Open/Close drives as opposed to modulating valves such as the
HRSG Gas Flow Control Valve. There is no provision made for local control of modulating valves which are controlled from the DCS.

**On/Off and Open/Close Drives**

These drives are typically two state (on/off), with the exception of the WSAC fans which are three state (high/low/off).

The majority of these drives have also been wired with local hand switches which allow the operator to locally start/stop drives or place them in remote for control from the DCS. Normally, control is expected to be via the DCS. Therefore, the local start/stop functions are considered override-type functions and will be alarmed. The DCS is only in control when in remote mode and, as a consequence, any interlock configured as part of the DCS is disabled (not active) when in local mode.

**Local Override**

Most of the equipment has generally been wired back to the DCS with a local/remote selector switch and a local stop push-button. When in Local, the operator may locally start and stop the drive, but the DCS cannot start or stop the drive at that time. This feature gives the operator a local "override" of these drives.

The state of the remote/local selection switch is not wired to the DCS. The DCS monitors the state (On/Off or Open/Closed) feedbacks of the drives from its respective MCC and compares it to the last command. It generates a drive fault alarm in the event the
drive was locally started or stopped. In this case, a drive fault due to a local start or stop will cause the DCS start signal to be tripped off. Therefore, once the drive is placed back in remote, it will have to be restarted from the DCS.

**Trips and Interlocks**

Within the DCS, all drives have been set-up with individual Start/Auto/Stop or Open/Auto/Close push-buttons. In parallel to these push-buttons, trip logic may have been configured to start or stop the drive. From the DCS, the operator cannot override the trip logic while it is present. Therefore, in the context of the DCS, the term "trip" means that it will trip the drive irrespective of whether it is in manual or auto mode.

**Manual/Automatic**

Provided there is no trip condition present, the operator may manually Start or Stop a drive as required. Alternatively, the operator may place the drive in Auto and the drive will start or stop based on the auto logic.

A drive is returned to manual by the operator initiating either the start or stop push-button.

**Lead/Standby (Base/Lead/Standby)**

In addition to the Auto/Man selection for parallel drives, such as Feedwater Pumps or the WSAC Basin Circulating Water Pumps, the
operator can select which drive will act as standby and as lead (or Base, in the case of a 3-drive combination).

The Lead/Standby provides two functions: it automatically starts and stops the drives as the load/demand changes; and it will also automatically start the standby if the lead drive trips.

The Lead/Standby logic is only enabled when a drive is placed in automatic and acts as follows:

× With both drives in manual, neither drive is Lead nor Standby.

× If one drive is placed in automatic, it will act as the Standby drive.

× Once the second drive is placed in automatic, it will become the Standby and the first drive will be elevated to Lead, (i.e., the first drive in auto becomes the Lead; the second drive in auto becomes the Standby).

× To switch the selection of Lead and Standby, simply place both drives in manual and then change the order in which they are placed in auto (i.e., place the desired Lead in auto first).

The Base/Lead/Standby logic, although similar to the Lead/Standby logic, differs only in that it offers more combinations of ordering. It follows the same basic rules with the exception that, if
all drives are in manual and off, the first drive must be manually started and, therefore, declared the Base. The other two drives may be started or simply placed in automatic, and the Lead/Standby selection will be set based on the order in which they were placed in auto. Also, if a drive is in manual, on and is selected as Base, and no other drive is manually on, then it will remain Base if placed in automatic. If the Base pump is required and trips, the Lead will start (if not already started) and will become the Base. The Standby will then become the Lead and start, if required.

Motor Running Hours

All electric motor drives monitored or controlled by the DCS are configured with a running hour totalizer. These are continuously displayed on the graphic, adjacent to the drive symbol. This feature is for the benefit of the operator or maintainer in evaluating the life span of the drive. The run hour register is resettable from the DCS.

Duty Cycle Equalization for Multiple Drives or Trains

Wherever there are multiple drives such as two 50% boiler feed pumps or three 40% demineralized water treatment trains, means have been provided so that the operator can select the lead (master) train and has the ability to rotate the lead so the running hours on the three different trains can be equalized. The motor on standby will start automatically when called upon by the control system.

The operator will be alerted to any abnormal condition because of increased demand such as a trip, but in cases where the standby
pump starts automatically, only the status change will be indicated on the CRT display. However, in the case of drives that are designated as emergency equipment starting automatically, the operator will be alerted to the event.

**Power Demand Reduction**

In order to reduce the "peak electrical demand" charges from Ontario Hydro, the start-up and shutdown of plant equipment are staggered in such a way, that the use of large power consumption motors is minimized during these periods when both plant generators are off line.

In addition, to minimize these charges, it is important that all unnecessary electric motors and loads are shut down when neither generator is operating.

**Hardwired ESD Panel**

A hardwired emergency shut down pull button is provided on the ESD panel in the control room. This button will shut down all gas valves, trip duct burners and STG. In addition, hardwired dedicated push buttons are provided for individual tripping of the HRSG, auxiliary boiler and STG. See drawing 10601-CE-2DB for further details about logic implementation.
**Plant Shutdown Logic**

There is logic resident in the DCS, and elsewhere, to initiate shutdown of any drive in cases where plant safety is involved. This logic is shown on the Plant Shutdown Logic Diagram (10601-FE-1J).

If the GTG/HRSG is supplying steam to the steam turbine and the GTG trips, the STG will not be tripped immediately, after a delay of 30 s, it will run back and trip on reverse power.

On Steam Turbine Trip the Gas Turbine will run back automatically to hold station service and steam output.

On power demand reduction, the fuel gas compressor is left running for 2 minutes to allow for gas turbine re-synchronization. If the gas turbine is re-synchronized, the compressor will continue to run. Lube oil pumps and cool down fans will continue to run.

Tripping of STG or GTG will result in trip of HRSG duct burners.

5.5 **PLANT METERING AND LOG REPORTS**

**Fuel Gas Metering**

The Plant Daily Fuel Gas Consumption is carefully monitored and projected. The monitoring and protection will allow the operator to adjust the plant output throughout the day so as not to exceed the daily gas limit.
Monitoring and projection of the total plant gas flow usage is displayed on a trend graphic titled: Fuel Flow Trends, and on which the following points are trended:

<table>
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<th>Description</th>
<th>Tag Name</th>
</tr>
</thead>
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<tr>
<td>Daily Fuel Gas Consumption (reset at start of day)</td>
<td>0DG-FQ-0303.D</td>
</tr>
<tr>
<td>Current Plant Gas Flow</td>
<td>0DG-FT-0303.F</td>
</tr>
<tr>
<td>Daily GTG Fuel Consumption (reset at start of day)</td>
<td>0DG-FQ-0330.D</td>
</tr>
<tr>
<td>Current GTG Gas Flow</td>
<td>0DG-FT-0330.F</td>
</tr>
<tr>
<td>Current HRSG Gas Flow</td>
<td>0DG-FT-0316.V</td>
</tr>
<tr>
<td>Projected Daily Plant Gas Consumption</td>
<td>0DG-FQ-0303.P</td>
</tr>
<tr>
<td>Total Plant Megawatts</td>
<td>0AE-JT-0001.I</td>
</tr>
<tr>
<td>STG Megawatts</td>
<td>0TA-XT-5002</td>
</tr>
</tbody>
</table>

An operator alarm "Projected Fuel Usage greater than Limit" is initiated in the DCS to pre-warn the operator in the event that the fuel usage is foreseen to be heading to exceed the allowable daily quota.

**Plant Megawatt Reporting**

The megawatt production for the GTG, STG and Total Plant Output to Ontario Hydro grid is individually totalized and logged on an hourly, daily, weekly and monthly basis. Because the total plant output measurement is made before the output transformer, the transformer loss factor is not included in this DCS reading and compensation is made for this loss. The load loss curve has been defined in the Calculation section of this thesis.
The Ontario Hydro megawatt value from its metering system is also logged and available as a comparison with the plant metering. A comparison between the two metering systems is made and a deviation alarm activated in the event of greater than 0.5% deviation.

By contract agreement between Ontario Hydro and TransAlta, Ontario Hydro will pay a capacity payment for energy from 7 am to 11 p.m., Mondays to Fridays, if a defined minimum amount of energy is delivered each month. It is therefore important to track the energy delivered during this period each month. These parameters are automatically built into the calendar for the report logs, however because public holidays vary from year to year, it is an operator action at the beginning of each calendar year to define the public holidays into the report log programme.

**Plant Log Reports**

Plant log reports are created in the DCS to provide the station with permanent records on fuel gas consumption and megawatts produced on a daily, weekly and monthly basis. The log reports are automatically accrued in the DCS report programme and can be readily accessed and printed out by the operator.

Fuel gas flows to the GTG, HRSG and total gas flow to the plant are integrated and individually totalized on the report. In addition, the total gas supply from Union Gas meters is also recorded on the report for comparison purposes with the individual plant gas consumption.
5.6 Conclusion

The Discrete Device Logic Systems (Macros) enhance operator information and operating safety for discrete devices: motor-operated valves, solenoid-operated valves, reversing and non-reversing motor starters, and switchgear starters or breakers. Within the processor, each motor, digital valve, or breaker to be controlled has its own dedicated logic system that is configured from the common template.

The logic systems integrate discrete device information from the operator console, other controller logic, and the motor control centre. Thus they provide the foundation for all control strategies for the discrete devices.

The following points are the benefits of using Macros:

- Common template for discrete device logic that reduces engineering, training, and maintenance costs
- Standard alarm functions and optional interlocks and overrides that enhance operating safety
- A solution that can be both expanded and customized to meet client needs
- Ergonomic presentation of process information from overview displays to process detail displays, trend displays and help displays
- Reduced client-incurred expense and less design cycle time associated with specification of control displays and logic
CHAPTER - 6

START-UP AND COMMISSIONING
6.1 **General**

Cogeneration plants normally are fast-track projects. It takes 18 to 20 months to complete from engineering to commercial operation. This demands a very aggressive test engineering effort and start-up program.

The first major start-up activity is energizing the plant. Transmission line is used to back-feed the main transformer to supply power for plant checkout and start-up.

The plant control system (DCS) is the next major system to come on because it controls all plant equipment and in some cases, the equipment cannot be run without it. After power and controls are available, the normal plant start-up sequence of cooling water systems, air compressors, feedwater, boiler and turbine system can follow. The table shown below describes the normal sequence of a small power plant.

<table>
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<tr>
<th>Start-up Sequence order</th>
<th>System Description</th>
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<tr>
<td>1</td>
<td>Checkout electrical and energize plant</td>
</tr>
<tr>
<td>2</td>
<td>Start-up water treatment system</td>
</tr>
<tr>
<td>3</td>
<td>Start-up air compressor</td>
</tr>
<tr>
<td>4</td>
<td>Water available</td>
</tr>
<tr>
<td>5</td>
<td>Chemical clean HRSG</td>
</tr>
<tr>
<td>6</td>
<td>Gas turbine controls checkout</td>
</tr>
<tr>
<td>7</td>
<td>Gas turbine oil flush</td>
</tr>
<tr>
<td>8</td>
<td>Synchronise gas turbine</td>
</tr>
<tr>
<td>9</td>
<td>Gas turbine initial operation with HRSG</td>
</tr>
<tr>
<td>10</td>
<td>Tune controls and resolve problems</td>
</tr>
<tr>
<td>11</td>
<td>Performance testing, Resolve punch list items and Commercial operation</td>
</tr>
</tbody>
</table>

It is important that water treatment plants start as soon as possible to make water available for other start-up activities. Safety systems, such as fire protection, should also be among the first systems in service. Cogeneration
plant in the range of 10 - 50 MW, the checkout and start-up program duration is approximately three months.
CHAPTER - 7

CONCLUSIONS
7.1 CONCLUSION

In general, The CPP project is a fast track project; the following points need to be kept in mind:

1) The engineering design has to be very well thought out in the beginning stage and planned accordingly
2) The electrical studies ensure the proper integration of a gas-turbine generator facility into a utility grid
3) The reduction in design cycle time is achieved using standardized tables for sizing the electrical equipment and cables
4) The discrete device logic system (Macros) enhance operator information and operating safety for discrete devices
5) The use of Macro reduces engineering, training, and maintenance costs
6) Doing engineering smarter and more efficiently save time and money. Implementing the creative engineering ideas described in the Plant electrical and controls chapter is the key for success
7.2 Areas for Exploration

The cost of a new combined-cyle generating capacity has dropped from $600/kW to $350/kW in recent years. Gas turbine capacity is increasing much faster than steam turbine capacity. It is worth looking into the area of reliability and availability of gas turbine units which will increase the operability and maintainability of the CPP.

Reliability

The only cloud on the gas turbine horizon is reliability. The rapid pace of technical advancement has led to inevitable, debugging-type problems associated with all new technology. Gas turbine inlet temperature, a key feature of the improving technology, has risen from less than 1093°C (2000°F) in the 1980s to about 1260°C (2300°F), with currently installed machines, and will move up to 1426.6°C (2600°F) in the next generation of gas turbines.

Availability

To increase the availability, the use of advanced design and analytical methods such as Failure Mode and Effects Analysis (FMEA) should be implemented. FMEA looks at the possible failures of the engines before they occur and attempts to identify the areas or components that will be affected by the failures.

Electrical Power Research Institute (EPRI) began a long-term program to study performance, operation and maintenance track records of advanced gas turbines. One of EPRI’s main focus areas is on-line monitoring of hot
blade temperatures. The increase in inlet temperatures requires the use of more advanced materials and thermal coatings.

7.3 Suggestion for Efficiency Improvement

The following options can be explored to increase the efficiency:

- Increasing gas turbine inlet temperature
- Advancement in gas-turbine cooling techniques
- Reducing auxiliary power consumption rate
- Hydrogen cooled generators
- Multiple pressure steam cycle with reheat
- Better HRSG design
- Fuel pre-heating

It is worthwhile to remember the term “Fuel Parity” and “Output parity” and what they stand for.

Fuel parity is the fuel saved when gaining one extra kilowatt by an efficiency improvement with constant fuel consumption.

The Output parity indicates what it is worth to the customer, to have one additional kilowatt of electricity generating capability, to increase the rating of the plant by 1 kw keeping the efficiency constant.
**TransAlta Energy Corporation**

**WINDSOR COGENERATION PLANT**

**HARDWIRED EMERGENCY SHUTDOWN ELEMENTARY WIRING DIAGRAM**

**STONE & WEBSTER CANADA LIMITED**

**TORONTO - ONTARIO**

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**Legend:**
- **TERMINALS IN ODCS-RLYPL-1**
- **GREEN INDICATION FOR BKR OPEN**
- **RED INDICATION FOR BKR CLOSED**
- **INTERRUPTED DIGITAL INPUT TO DCS**
- **DIGITAL OUTPUT FROM DCS**

**Notes:**
1. All wires and devices shall be prefixed with system no. OES-ESD- unless otherwise specified.
2. HS-1000, HS-1001, HS-1002 & HS-1003 located at ESD console.
3. Relays ESD-1, ESD-2, ESD-3 & ESD-4 located at aux. relay cubicle in OCS room.
4. Relays ESD-1 to 4 are normally in deenergized condition.
5. For ref. vendor Dwg.No. see Bd. 95709 W07002 (BAILEY CANADA)/10601-CL-66 (SWCL).

**Scale:**

Do not scale this drawing.

This drawing is not to be used for certified construction unless certified and dated, date.

---

**TransAlta Energy Corporation**

**WINDSOR COGENERATION PLANT**

**HARDWIRED EMERGENCY SHUTDOWN**

**ELEMENTARY WIRING DIAGRAM**

**STONE & WEBSTER CANADA LIMITED**

**TORONTO - ONTARIO**

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**Drawing:**

CJ-10601

**Issue:**

10601-CE-2DB

**Issue:**

4

**Designed by:**

Des. Chkd by:

**Drawn by:**

Chkd by:

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**Scale:**

Do not scale this drawing.

This drawing is not to be used for certified construction unless certified and dated, date.

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**TransAlta Energy Corporation**

**WINDSOR COGENERATION PLANT**

**HARDWIRED EMERGENCY SHUTDOWN**

**ELEMENTARY WIRING DIAGRAM**

**STONE & WEBSTER CANADA LIMITED**

**TORONTO - ONTARIO**

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**Drawing:**

CJ-10601

**Issue:**

10601-CE-2DB

**Issue:**

4

**Designed by:**

Des. Chkd by:

**Drawn by:**

Chkd by:

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**Scale:**

Do not scale this drawing.

This drawing is not to be used for certified construction unless certified and dated, date.
SEE VENDOR DRAWING FOR COMPLETE BREAKER CONTROL DETAILS

DWG. 10601-E-10-90

STRUCTURE: 1 CELL: A (SWGR)

1ADW-8
1ADW-9
1ADW-10
1ADW-11

120V AC "PT POWER TO "2ADW" DWG. 10601-CE-2CV

STRUCTURE: 1 CELL: C (SWGR)

1CDW-1
1CDW-2

120/240V AC "PT POWER TO "2CDW" DWG. 10601-CE-2CK

0950 "MCC-1 INCR. XFRMR. GROUND FAULT"
0951 "MCC-1 INCR. XFRMR. GROUND FAULT"

ISSUE DESCRIPTION CHG Date
3 AS BUILT. 2

INTEGRATIONS FOR J6-SL

UNIT: 0 10 20 30 40 50 60 70 80 90 100 mm

INCH: 0 1 2 3 4
1. INTERPOSING RELAYS R1 & R2 AND CONTROL CIRCUIT MONITORING RELAY 27A SUPPLIED AND FACTORY INSTALLED WITHIN THE SWITCHGEAR BY VENDOR.
2. THIS DRAWING HAS BEEN CREATED TO SHOW EXTERNAL INTERFACING POINTS, BASED ON VENDOR DRAWINGS.
SEE VENDOR DRAWING FOR COMPLETE BREAKER CONTROL DETAILS
DWG. 10601-E-10-81
REFERENCE DRAWINGS:
GENERAL BREAKER CONTROL DIAGRAM (VENDOR) 10601-E-10-78 THRU 81

NOTES:
1. INTERPOsing RELAYS R3 & R4 AND CONTROL CIRCUIT MONITORING RELAY 27C SUPPLIED AND FACTORY INSTALLED WITHIN THE SWITCHGEAR BY VENDOR.
2. THIS DRAWING HAS BEEN CREATED TO SHOW EXTERNAL INTERFACING POINTS, BASED ON VENDOR DRAWINGS.

TRANSALTA ENERGY CORPORATION
WINDSOR COGENERATION PLANT
600V MCC-2
TIE BREAKER(0EC-52-2A)
ELEMENTARY WIRING DIAGRAM

STONE & WEBSTER CANADA LIMITED
TORONTO - ONTARIO
SEE VENDOR DRAWING FOR COMPLETE BREAKER CONTROL DETAILS

DWG. 10601-E-10-90

STRUCTURE: 1 CELL: B (SWGR)

100OW-10
100OW-11
100OW-12
100OW-13
100OW-14
100OW-15

169 (2BDJ)
170 (2B3F)
162 (2C3E)
163 (2CFJ)
161 (2C3D)
164 (2C3H)

FROM "2CDW" DWG. 10601-CE-2CX

STRUCTURE: 1 CELL: D (SWGR)

100OW-46
100OW-49
100OW-50
100OW-51
100OW-52

192 (1C5F)
191 (1C5G)
199 (1C5H)
200 (1C3J)
201 (1C5P)

ESD AUX. RELAY DWG. 10601-CE-2DB

FROM "2CDW" DWG. 10601-CE-2CX
SWR TERMINALS
TERMINALS IN LINE & KFMR PROTECTION PANEL EA-PL-1B
TERMINALS IN DCS TERMINATION UNIT
GREEN INDICATION FOR BKR OPEN
RED INDICATION FOR BKR CLOSED
DIGITAL INPUT TO DCS
DIGITAL OUTPUT FROM DCS
SOLID STATE RELAY FOR 50/50

NOTES
1. ALL WIRES, EQUIPMENT AND DEVICES SHALL BE PRESENTED WITH SYSTEM NUMBER UNLESS OTHERWISE SPECIFIED.
2. THIS Dwg. HAS BEEN CREATED TO SHOW EXTERNAL INTERFACING POINTS, BASED ON VENDOR Dwg. # 10601-E-3-14.

REFERENCE DRAWING
BREAKER POWER CONTROL VENDOR Dwg. # 19209074
AND VT CIRCUITS SWC Dwg. # 10601-E-3-14

WIRE NUMBER ALLOCATION

<table>
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<tr>
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<th>BLOCK ALLOCATION</th>
<th>LAST WIRE No. USED</th>
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<tbody>
<tr>
<td>0EB</td>
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<td>525</td>
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SCALE: NONE
DO NOT SCALE THIS DRAWING

THE CONTRACTOR SHALL CHECK AND VERIFY ALL DIMENSIONS AND REPORT ANY ERRORS AND OMISSIONS TO THE ENGINEERS.

THIS DRAWING IS NOT TO BE USED FOR CERTIFIED CONSTRUCTION UNLESS CERTIFIED AND DATED DATE.

TransAlta Energy Corporation
WINDSOR COGENERATION PLANT
4.16KV SWITCHGEAR
MAIN INCOMING BREAKER (0EB-52-1SS) ELEMENTARY WIRING DIAGRAM

STONE & WEBSTER CANADA LIMITED
TORONTO - ONTARIO

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Designed by
Drew by
Chk'd by

DEPT: 53B | C1 - 10601.0000 | TALMA LA | VIEW- | 05/03/96 | 14:28
NOTES:
1. COAX CABLE FOR COMMUNICATION ON DATA
   HWAY SUPPLIED PRECUT C/W CONNECTORS
   BY BAILEY.

EQUIPMENT
CPU  - CENTRAL PROCESSING UNIT
PRNT  - PRINTER
CHM  - COMPUTER
MTD  - MAGNETIC TAPE DRIVE
KBM  - KEYBOARD
CRT  - OPERATOR SCREEN
PL  - PANEL
CWS  - ENGINEERING WORK STATION

INTERFACE BLOCKS:
PLN & WIRING SCHEM1 10601-4DC
1405, LILBY & BODY SHOW
GENERAL BLOCK DIAGRAM

TRANSEALTA ENERGY CORPORATION
WINDSOR COGENERATION PLANT
COMMUNICATIONS LOOP
CABLE BLOCK DIAGRAM

STONE & WEBSTER CANADA LIMITED
TORONTO - ONTARIO

10601-6FF-4AA

Scale: 1:50

1000 5000 10000 15000 20000 25000 30000

Control Room

GAS TURBINE CONTROL PANEL
TRA-PL-6

CONTROL ROOM

CONNET
AS 400

PRODUCTION INTERFACE MODULE

PRODUCTION
MODULE-PL-1

GDCS-PL-1

GDCS-PL-1

NOTE 1

NOTE 1

NOTE 1
APPENDIX-C

TYPICAL CALCULATION SHEET
STONEx WEBSTER CANADA LIMITED

CALCULATION TITLE PAGE

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<td>10601-E-1</td>
<td>Electrical</td>
<td>TOTAL PAGES</td>
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CLIENT

TransAlta Energy Corporation

PROJECT

Windsor Cogeneration Plant

CALCULATION TITLE

Electrical Station Service Load Estimate

CALCULATION OBJECTIVE

To determine the station service load.

CALCULATION METHOD

Tabulation

REFERENCES

1. 600 V Load List - Updated to Mechanical Lost, dated July 8, 1995
2. 4.16 kV Preliminary Load List
3. GE Motors List Type K, NEMA, Design B, 40° C - Performance Data.

DESIGN INPUT/ASSUMPTIONS

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<tr>
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1. Load Factor = 0.85

2. MOTOR POWER FACTOR EFFICIENCY
   4.16 0.92 0.94
   600 V 0.85 0.91

3. Running Load = (Load × Diversity Factor)/(Power Factor × Efficiency)

4. Diversity Factor = 0.8

CONCLUSIONS

See “Calculation” Sheet.

ISSUE NO. | PREPARED BY | DATE | REVIEWED BY | DATE | CONFIRMATION REQUIRED (✓) |
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ELECTRICAL LOAD ESTIMATE - PRESENT PLANT
(1 x GTG + 1 x STG)

1.0 Summary of Load

Station service running load - summer and overfiring HRSG.

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<tr>
<th>kW</th>
<th>KVAR</th>
<th>KVA</th>
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<td>2410</td>
<td>1027</td>
<td>2620</td>
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<tr>
<td>1355</td>
<td>840</td>
<td>1595</td>
</tr>
<tr>
<td>3765</td>
<td>1867</td>
<td>4202</td>
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1.1 4.16 kV Load Estimate

The summer connected load is the largest load due to the chillers. Two HRSG boiler feed pumps operating the overfiring of the HRSG.
The summer connected load is 2664 kW. (not including the 600V load)

Assumptions:
Motor - Power Factor 0.92
- Efficiency 0.94
Load Factor 0.85

Summer running load = 2664 x 0.85 x 1/0.94 = 2410 kW

= 2410 kW/0.92 = 2620 KVA

VAR's = VA √(1-pf) = 2620 √(1-0.92) = 1027 KVAR

In summer the gas pressure is higher and the gas compressor load will be lower. This has not been allowed for.

1.2 600 V Load Estimate

The summer connected load is the load including the chillers. The chillers are operated at ambient air temperatures above 59 °F.
The summer connected load is 1451 kW.

Assumptions:
For ease of calculation, assume all loads are motors.
Average Power Factor: 0.85
Average Motor Efficiency : 0.91
Load Factor: 0.85

Summer running load = 1451 x 0.85 x 1/0.91 = 1355 kW

= 1355 kW/0.85 = 1595 KVA

VAR's = VA √(1-pf) = 1595 √(1-0.85) = 840 KVAR
## 600V LOAD LIST

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<thead>
<tr>
<th>Equipment</th>
<th>Type/Model</th>
<th>Voltage</th>
<th>HP</th>
<th>RPM</th>
<th>HPF</th>
<th>Type</th>
<th>Size of Motor</th>
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<tr>
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<td>600</td>
<td>0.85</td>
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**27–Jul–95**

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**TRANSLATA–WINDSOR**

**SWCL ELECT DEPT39**
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**10601.000**

**600V LOAD LIST**

**27-Jul-95**
| HRIG MOV | 1AB-MOY-5189 | 0.25 | 0.19 | R | 085 | 0.95 | 0.2 | X#12awg | 2 |
| HRIG MOV | 1AB-MOY-5190 | 0.2  | 0.15 | R | 085 | 0.95 | 0.2 | X#12awg | 2 |
| HRIG MOV | 1AB-MOY-5191 | 0.5  | 0.373|R | 085 | 0.95 | 0.2 | X#12awg | 2 |
## Performance Data

**Type K, NEMA Design B, Normal Starting Torque**

Continuous, 40 C Ambient, 60 Hertz

### Dripproof and Weather Protected I and II, Frames 509-511

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<thead>
<tr>
<th>Horse</th>
<th>Full</th>
<th>Full</th>
<th>Efficiency</th>
<th>Power Factor (Ω)</th>
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</thead>
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<td>power</td>
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<td>RPM</td>
<td>Torque</td>
<td>Max. KVAR (Ω)</td>
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<td>Lb.-Ft.</td>
<td>(Ω)</td>
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### 460 Volts

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<td>RPM</td>
<td>Torque</td>
<td>Max. KVAR (Ω)</td>
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<tr>
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<td>Lb.-Ft.</td>
<td>(Ω)</td>
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<td>ST</td>
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<td>load</td>
<td>RPM</td>
<td>Torque</td>
<td>Max. KVAR (Ω)</td>
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<td></td>
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<td>(Ω)</td>
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<tr>
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<td></td>
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<td>Load</td>
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</table>

### Table Footnotes

See page 11 for additional information.
13.8 kV/4.16 kV Station Service Transformer

To determine the size of the transformer.

Tabulation

Electrical Station Service Load Estimate (10601-E-1)

1. Load Factor = 0.85

2. MOTOR  POWER FACTOR  EFFICIENCY
   4.16 kV  0.92        0.94
   600 V    0.85        0.91

3. Running Load = (Load × Diversity Factor)/(Power Factor × Efficiency)

4. Diversity Factor = 0.8

The transformer should be rated 5 MVA ONAN with provision for fans to be added to increase the rating to 6.67 MVA ONAF, if it is required.
<table>
<thead>
<tr>
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<td>3</td>
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CSF 415A.5/1990
13.8/4.16 kV Station Service Transformer Rating

The transformer is to be capable of supplying the load of the present plant (one gas turbine generator and one steam turbine generator) and a future second G.T.G.

The transformer to be capable of supplying the load of the present plant (1 x GTG + 1 x STG) and a future second gas turbine generator (GTG).

1.0 LOAD SUMMARY

The maximum load for the present plant is in summer with the GTG air intake chillers operating and overfiring the HRSG.

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<th>KVAR</th>
<th>KVA</th>
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<tr>
<td>PRESENT PLANT</td>
<td>3765</td>
<td>1867</td>
<td>4202</td>
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<td>FUTURE GTG (without chillers) from 3.0</td>
<td>510</td>
<td>230</td>
<td>559</td>
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<tr>
<td>TOTAL</td>
<td>4275</td>
<td>2097</td>
<td>4762</td>
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2.0 STATION SERVICE TRANSFORMER RATING

A transformer rated 5000 kVA ONAN can supply the present plant estimated load with 19% spare capacity. It can also supply the future load with only 5% spare capacity. If more capacity is required, fans can be added to increase the rating to 5/6.67 MVA ONAN/ONAF.

3.0 FUTURE WITH SECOND GAS TURBINE GENERATOR

Additional Loads:

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<td>4.16 kV Motors</td>
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<tr>
<td>Gas Compressor</td>
<td>1 x 600</td>
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<tr>
<td>HRSG Boiler Feed Pump</td>
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<tr>
<td></td>
<td></td>
<td>448</td>
</tr>
<tr>
<td></td>
<td></td>
<td>405</td>
</tr>
<tr>
<td></td>
<td></td>
<td>173</td>
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<tr>
<td>* Centrifugal Chiller 1 &amp; 2</td>
<td>2 x 660 kW</td>
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600V Loads

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<th>KVAR</th>
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<td>Gas Turbine Motors</td>
<td>149</td>
<td>135</td>
</tr>
<tr>
<td>* Chiller Towers, etc...</td>
<td>120 kW</td>
<td></td>
</tr>
<tr>
<td>* Chillers may not be installed</td>
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<td></td>
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<tr>
<td>Total Load (without chillers)</td>
<td>510</td>
<td>230</td>
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</table>

CLIENT             TransAlta Energy Corporation  PROJECT       Windsor Cogeneration Plant
CALCULATION TITLE  Short Circuit Analysis
CALCULATION OBJECTIVE  To determine available short circuit current level.
CALCULATION METHOD    Computer log using ETAP 7.301.
REFERENCES            One-Line Diagram

DESIGN INPUT/ASSUMPTIONS

1. 13.8 kV/121 kV transformer impedance = 10% and x″ and x/R value as shown on one-line diagram

CONCLUSIONS

Current is less than 63 kA symmetrical interrupting.
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</table>

CSF 415A.5/1990
COMMENTS

With the chosen 13.8/121 KV Transformer impedance of 11.5%, the maximum current to be interrupted by the 13.8 KV generator circuit breakers are:

- Symmetrical RMS: 54.997 kA at an X/R = 53
- Adjusted symmetrical RMS: 65.643 kA with a multiplying factor of 1.194 for the high X/R value

The current is less than the 63 kA symmetrical interrupting current of the 13.8 kV circuit breaker available from General Electric.
Short Circuit Analysis

Electrical Transient Analyzer Program

SHORT CIRCUIT ANALYSIS

3-Phase Fault Currents

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<table>
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<td>15</td>
<td>40</td>
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<table>
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<th>Ind.</th>
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<td>4</td>
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System Frequency: 60.0 Hz

Unit System: English

Date File Name: 10601

Output File Name: SC10601
## Short Circuit Analysis

### Bus Information (Nominal & Base kV)

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<th>Base kV</th>
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<th>Voltage</th>
<th>Generation</th>
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<th>Static Load</th>
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**42 Buses Total**

All voltages reported by ETAP are in % of bus nominal kVs. Base kVs of buses are calculated and used internally by ETAP. Prefault bus voltages as defined by ANSI/IEEE are in % of base, not nominal kVs.
### Short Circuit Analysis

<table>
<thead>
<tr>
<th>Ckt / Branch</th>
<th>Bus No.</th>
<th>Line / Cable (ohms/1000 ft per phase)</th>
<th>Impedance</th>
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<th>kV</th>
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**CIRCUIT BREAKER DATA**

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**Short Circuit Analysis**

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<td>100</td>
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<td>GTG</td>
<td>Syn Gen</td>
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### Rating

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<th>% Impedance (100 MVA Base)</th>
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**Total Connected Generators ( = 2):** 97.700 MVA

**Total Connected Motors ( = 0):** .000 MVA
### Three-Phase Fault Currents

(Prefault Voltage = 100.00 % of the Bus Base Voltages)

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<thead>
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Short Circuit Analysis

Three-Phase Fault Currents: (Prefault Voltage = 100.00 % of the Bus Base Voltages)

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Method: IEEE - X/R is calculated from separate R & X networks.
CALCULATION TITLE

4.16 kV cable sizing and voltage drop calculations

CALCULATION OBJECTIVE

To determine the size and number of power cables required for limiting steady state voltage drop to an acceptable level of 2%.

CALCULATION METHOD

Voltage drop based on load current and cable impedance.

REFERENCES

1. Main one-line diagram (DWG. no. 10601-FE-1A)
2. IEEE/CEA publication No. S-135 (power cable ampacities)
3. Cable manufacturer's data for typical armoured cable.

DESIGN INPUT/ASSUMPTIONS

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</tr>
<tr>
<td>2.</td>
<td>Ambient temperature of 40 °C assumed</td>
</tr>
<tr>
<td>3.</td>
<td>Conductor temperature is 90 °C</td>
</tr>
<tr>
<td>4.</td>
<td>The 4.16 kV motor's power factor of 0.85 assumed.</td>
</tr>
<tr>
<td>5.</td>
<td>The minimum size of cable required for 4.16 kV system to withstand the available short circuit level is 6 AWG.</td>
</tr>
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CONCLUSIONS

The steady state voltage drop of the BOP electrical system load is well within the acceptable level of 2%.

Table No. 1 shows the required cable size for 4.16 kV system.
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<th>PAGE NUMBER</th>
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**ATTACHMENT NO. | TITLE ___________________________**

CSF 415A.5/1990
1.0 PROCEDURE FOR SIZING POWER CABLES FOR VOLTAGE DROP

The following criterion was used to size the power cables.

1.1 The maximum running current for any load is determined from the load list. An additional factor is added as a safety margin so that the maximum current for:

- Motors is 125% of full load current (FLC)
- MCC is running current less than FLC of the largest motor + 125% x FLC of the largest motor
- 600V switchgear is maximum rated secondary FLC of the transformer
- Emergency generator is maximum generator rating

1.2 Steady state voltage drop is calculated as follows:

\[ \Delta v = 1.732 I L [\cos \alpha + x \sin \alpha] \text{ Volts} \]
\[ \Delta v = \text{voltage drop in volts} \]
\[ I = \text{maximum running current (A)} \]
\[ L = \text{length of cable (m)} \]
\[ R = \text{resistance of cable (ohms/km)} \]
\[ X = \text{reactance of cable (ohms/km)} \]
\[ \cos \alpha = 0.85 \text{ (assumed)} \]

1.3 a) In the case of single conductor cables installed in triplex configuration, the value of \( x \) is calculated as follows:

\[ X = 0.17362 \log_{10} \frac{\text{GMD/GMR}}{\text{ohms/km}} \]

\[ \text{GMD} = \text{Geometric mean distance between conductors (mm)} \]
\[ \text{GMR} = \text{Geometric mean radius of conductors (mm)} \]

b) The \( R \) & \( X \) values for three conductor cables are taken from manufacturers data (attached).

1.4 The short circuit withstand capability of the power cables is determined by the general equation:

\[ (UA)^t = 0.0297 \log_{10} \left[ \frac{(T2+234)}{(T1+234)} \right] \]

\[ A = \text{Conductor area in circular mils} \]
\[ I = \text{Short circuit current (A)} \]
\[ t = \text{Duration of short circuits (s)} \]
\[ T_1 = \text{Maximum operating conductor temperature (°C)} \]
\[ T_2 = \text{Maximum short circuit temperature (°C)} \]

The minimum required size for 4.160 V system feeders calculated per above formula is 6 AWG.

2.0 MOTOR START VOLTAGE DROP CALCULATIONS

The following criterion was used:

- Motors 200 Hp (149.2 kW) and above only were considered for calculation.
- Minimum allowable voltage at terminals of starting motor is equal to or greater than 80% for motors 200 Hp and above.
- Motor starting was done with running load on 600 V bus.
- Starting voltage drop was ignored for variable frequency drive and soft start motors as these motors are recommended to be started from minimum voltage setting and gradually ramp up to full speed and voltage.
## CABLE SIZES FOR 575 V MOTORS

<table>
<thead>
<tr>
<th>MOTOR Hp</th>
<th>Motor kW</th>
<th>Full Load Amps (FLA)</th>
<th>Motor Feeder Cable Qty</th>
<th>Size</th>
<th>Max. Feeder Length (m) for 3% Volt Drop at FLA Tray with No Spacing</th>
<th>Tray with Spacing</th>
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<td>-</td>
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**NOTES:**

Full Load Amps (FLA) is from Table 44 if CE Code - C22.1-94
<table>
<thead>
<tr>
<th>Load Description</th>
<th>Fed From</th>
<th>Load (kVA)</th>
<th>Maximum Current (A)</th>
<th>Cable Length (m)</th>
<th>Allowed (%)</th>
<th>Actual (%)</th>
<th>Cable Type and Quantity</th>
<th>Remarks</th>
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</thead>
<tbody>
<tr>
<td>1. Chiller 1</td>
<td>OKH-CHU-1MO</td>
<td>741.2</td>
<td>135.3</td>
<td>29.9</td>
<td>2</td>
<td>0.07</td>
<td>1x3c - 1/0</td>
<td>Efficiency = 0.95 p.f. = 0.85</td>
</tr>
<tr>
<td>2. Chiller 2</td>
<td>OKH-CHU-2MO</td>
<td>741.2</td>
<td>135.3</td>
<td>28.0</td>
<td>2</td>
<td>0.07</td>
<td>1x3c - 1/0</td>
<td>Efficiency = 0.95 p.f. = 0.85</td>
</tr>
<tr>
<td>3. Comp A</td>
<td>ODG-CMP-1MO</td>
<td>527.1</td>
<td>96.36</td>
<td>14.9</td>
<td>2</td>
<td>0.04</td>
<td>1x3c - 1/0</td>
<td>Efficiency = 0.95 p.f. = 0.85</td>
</tr>
<tr>
<td>4. Comp B</td>
<td>ODG-CMP-2MO</td>
<td>527.1</td>
<td>96.3</td>
<td>13.4</td>
<td>2</td>
<td>0.03</td>
<td>1x3c - 1/0</td>
<td>Efficiency = 0.95 p.f. = 0.85</td>
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<td>5. ERSG 1</td>
<td>OSJ-P-1MO</td>
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<td>40.5</td>
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<td>1x3c - 1/0</td>
<td>Efficiency = 0.95 p.f. = 0.85</td>
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<td>6. ERSG 2</td>
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<td>7. XFMTR 1</td>
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4.16 KV CABLE SIZING
### TABLE 2 — AC Resistance ohms/km (at operating temperature)

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<tr>
<th>CONDUCTOR SIZE</th>
<th>SINGLE STRANDED CONDUCTOR*</th>
<th>ALUMINUM (ACM)**</th>
<th>3 CONDUCTOR CABLE***</th>
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<td>ALUMINUM</td>
<td>FACTOR</td>
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<tr>
<td></td>
<td>60°C</td>
<td>70°C</td>
<td>90°C</td>
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<td>9.7550</td>
<td>10.2930</td>
<td>10.7550</td>
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<td>6.1480</td>
<td>6.4860</td>
<td>6.7780</td>
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<td>3.8680</td>
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<td>0.5289</td>
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<td>0.2517</td>
<td>0.2633</td>
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<td>0.1997</td>
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</table>

*Except for the most critical cases these values may be used for 2 or 3 conductors in non-metallic or aluminum conduit.

**Multiply the single conductor values by these Factors to determine the AC Resistance of 3 conductor cable.

Impedance (Z, ohms/km) is obtained using the following formula: \( Z = \sqrt{R^2 + XL^2} \) (neglecting capacitance). \( R = \) AC Resistance ohm/km. \( XL = \) Inductive Reactance ohm/km.

### TABLE 3 — Inductive Reactance ohms/km (at 60 hertz) 600 Volt & 1000 Volt

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<th>CONDUCTOR SIZE</th>
<th>VOLTAGE</th>
<th>3 SINGLE CABLES</th>
<th>3 CONDUCTOR CABLE</th>
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<td>ONE CABLE DIAMETER SPACING</td>
<td>IN ALUMINUM CONDUIT</td>
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<td>B</td>
</tr>
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</tr>
<tr>
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</tr>
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<tr>
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<tr>
<td>3/0</td>
<td>1000</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>4/0</td>
<td>1000</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>5/0</td>
<td>1000</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>6/0</td>
<td>1000</td>
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</tr>
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<tr>
<td>9/0</td>
<td>1000</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Note: Values shown are based on normal cable diameters which are influenced by changes in materials and conductor design. Except for the most critical cases such variations are of little consequence.

Formula XL = 0.17682 * ln(2X) ohms/km. XL = Inductive reactance ohm/km. GMD = Geometric mean distance between conductors.

GMD = Geometric mean radius of conductors.

*For 3 conductors in steel conduit or steel armour multiply table values by 1.55.
### TABLE 4 — Inductive Reactance ohms/km (at 60 hertz)
**5 kV — TECK90 and HVTECK (Aluminum Armoured)**

<table>
<thead>
<tr>
<th>CONDUCTOR SIZE</th>
<th>3 CONDUCTOR*</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TECK90 5 kV UNSHIELDED</th>
<th>HVTECK 5 kV SHIELDED</th>
<th>TECK90 5 kV UNSHIELDED</th>
<th>HVTECK 5 kV SHIELDED</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
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<tr>
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<td>.1400</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>.1205</td>
<td>.1305</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>.1145</td>
<td>.1220</td>
<td></td>
</tr>
<tr>
<td>1/0</td>
<td>.2240</td>
<td>.2330</td>
<td></td>
</tr>
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<td>.2225</td>
<td>.2270</td>
<td></td>
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<tr>
<td>3/0</td>
<td>.2166</td>
<td>.2205</td>
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<tr>
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<td>.2170</td>
<td></td>
</tr>
<tr>
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<td>.2110</td>
<td>.2150</td>
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<td>300</td>
<td>.2075</td>
<td>.2110</td>
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<tr>
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<td>.2040</td>
<td>.2075</td>
<td></td>
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<tr>
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<td>.2015</td>
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<tr>
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<td>.1920</td>
<td>.1975</td>
<td></td>
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<tr>
<td>1000</td>
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</table>

Note: Values shown are based on nominal cable dimensions which are influenced by changes in materials and conductor design. Except for the most critical cases such variations are of little consequence.

Formula XL = 0.1736 log GMD ohms/km. XL = Inductive reactance ohms/km. GMD = Geometric mean distance between conductors.

GMD = Geometric mean radius of conductors.

*For steel armour multiply table values by 1.25.

### TABLE 5 — Inductive Reactance ohms/km (at 60 hertz)
**15 kV, 25 kV & 28 kV — HVTECK (Aluminum Armoured)**

<table>
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<th>CONDUCTOR SIZE</th>
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</thead>
</table>

<table>
<thead>
<tr>
<th>15 kV (100%)</th>
<th>15 kV (133%)</th>
<th>25 kV (100%)</th>
<th>25 kV (133%)</th>
<th>28 kV (100%)</th>
<th>28 kV (133%)</th>
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</thead>
<tbody>
<tr>
<td>2</td>
<td>.1610</td>
<td>.1500</td>
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<td>.1700</td>
<td>.1605</td>
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<td>.1325</td>
<td>.1406</td>
<td>.1580</td>
<td>.1485</td>
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<tr>
<td>2/0</td>
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<td>.1285</td>
<td>.1380</td>
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<td>.1350</td>
<td>.1430</td>
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<td>.1280</td>
<td>.1180</td>
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<td>.1170</td>
<td>.1140</td>
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<td>.1270</td>
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<td>.1195</td>
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<td>500</td>
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<td>.1110</td>
<td>.1190</td>
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<td>.1100</td>
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<td>.1200</td>
<td>.1100</td>
</tr>
</tbody>
</table>

Note: Values shown are based on nominal cable dimensions which are influenced by changes in materials and conductor design. Except for the most critical cases such variations are of little consequence.

Formula XL = 0.1736 log GMD ohms/km. XL = Inductive reactance ohms/km. GMD = Geometric mean distance between conductors.

GMD = Geometric mean radius of conductors.

*For steel armour multiply table values by 1.25.
# Cable Characteristics

## TABLE 1 — Conductor Reference Table — Stranded Bare Copper Conductor and Aluminum (ACM) Conductor

### Stranded Bare Copper Conductor

**Standards**
- Conforms to: ASTM B 3 for Soft Copper
- ASTM B 8 for Class B Concentric and Compressed Stranding
- ASTM B 496 for Compact Stranding
- ASTM B 33 for Tinned Copper

### Stranded Aluminum (ACM) Conductor

**Standards**
- Conforms to: ASTM B 800 for 8000 Series Aluminum Alloy Wire
- ASTM B 801 for Concentric-Lay-Stranding (including Compressed)
- Stranding: #6 AWG — 1000 kcmil : Compressed

### Concentric Stranding

<table>
<thead>
<tr>
<th>Round 100%</th>
<th>Compressed 97%</th>
<th>Compact 90%</th>
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<table>
<thead>
<tr>
<th>CONDUCTOR SIZE</th>
<th>CROSS SECT. AREA</th>
<th>NUMBER OF STRANDS</th>
<th>DIAMETER</th>
<th>STANDARDS</th>
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<tr>
<td></td>
<td>in² (mm²)</td>
<td></td>
<td>in (mm)</td>
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<td>in (mm)</td>
<td></td>
</tr>
<tr>
<td>AWG or kcmil</td>
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<tr>
<td>14</td>
<td>4,110</td>
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</tr>
</tbody>
</table>

(Diameters and Cable Weights listed below are NOMINAL)

**COPPER CONDUCTOR CABLE WEIGHT**
- 16 = 12 lbs
- 29 = 19 lbs
- 47 = 32 lbs
- 74 = 50 lbs
- 118 = 79 lbs
- 187 = 126 lbs
- 237 = 159 lbs
- 296 = 200 lbs
- 360 = 259 lbs
- 476 = 322 lbs
- 604 = 406 lbs
- 761 = 511 lbs
- 953 = 640 lbs
- 1156 = 777 lbs
- 1464 = 996 lbs
- 1834 = 1223 lbs
- 2314 = 1553 lbs
- 2914 = 1993 lbs
- 3464 = 2333 lbs
- 4165 = 2793 lbs
- 4865 = 3253 lbs
- 5565 = 3713 lbs
- 6265 = 4173 lbs
- 6965 = 4633 lbs
- 7665 = 5093 lbs
- 8365 = 5553 lbs
- 9065 = 6013 lbs
- 9765 = 6473 lbs

**ALUMINUM (ACM) CONDUCTOR CABLE WEIGHT**
- 16 = 12 lbs
- 29 = 19 lbs
- 47 = 32 lbs
- 74 = 50 lbs
- 118 = 79 lbs
- 187 = 126 lbs
- 237 = 159 lbs
- 296 = 200 lbs
- 360 = 259 lbs
- 476 = 322 lbs
- 604 = 406 lbs
- 761 = 511 lbs
- 953 = 640 lbs
- 1156 = 777 lbs
- 1464 = 996 lbs
- 1834 = 1223 lbs
- 2314 = 1553 lbs
- 2914 = 1993 lbs
- 3464 = 2333 lbs
- 4165 = 2793 lbs
- 4865 = 3253 lbs
- 5565 = 3713 lbs
- 6265 = 4173 lbs
- 6965 = 4633 lbs
- 7665 = 5093 lbs
- 8365 = 5553 lbs
- 9065 = 6013 lbs
- 9765 = 6473 lbs

*For Compact Conductors 16 Strands

**Compressed Stranding

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CALCULATION TITLE
Main output Transformer 60/80 MVA losses

CALCULATION OBJECTIVE
Determine the 60/80 MVA Transformer Losses Curve

CALCULATION METHOD
Tabulation

REFERENCES
60/80 MVA Transformer 121/13.8kV Load loss and Impedance Test Report

DESIGN INPUT/ASSUMPTIONS

1. Tap 3, 85°C, 121/13.8 kV

2. Conversion from MVA to MW was obtained based on the assumption value 90% power factor and 98% efficiency

CONCLUSIONS

Transformer losses curve shown in page#5 of this calculation sheet shall be used to built a function block in DCS, to obtain the Net Power Export to Ontario Hydro.
<table>
<thead>
<tr>
<th>PAGE DESCRIPTION</th>
<th>PAGE NUMBER</th>
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</thead>
<tbody>
<tr>
<td>TITLE PAGE AND ISSUE STATUS</td>
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<tr>
<td>TABLE OF CONTENTS</td>
<td>2</td>
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<td>SPECIFIC ASSUMPTIONS</td>
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<td>3</td>
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<tr>
<td>ATTACHMENT NO. TITLE</td>
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</table>
1) General assumptions made to the Main output Transformer is as follows:

- Tap at 3, 85°C, 121/13.8 kV
- Power factor 90%
- Efficiency 98%

\[ MW = MVA \times PF \times EFF \]

2) Load loss was calculated for 50MVA based on the Test report which was done for 60 and 80 MVA.

Total Loss of the Transformer = Load Loss + Core Loss

Load Loss of the Transformer = Total DC Loss + The Stray Loss

The Stray loss was assumed to be the best estimated value of 30 kW.

Total DC Loss at 50MVA = Total DC loss at 60MVA * Square of (50MVA / 60MVA)

The following table has been put together based on the Test report and the calculated value to create Transformer loss curve.

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<th>60</th>
<th>80</th>
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<tbody>
<tr>
<td>Total DC Loss(kW)</td>
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<tr>
<td>Stray Loss (kW)</td>
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<td>LOAD Loss (kW)</td>
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<td>39.7</td>
<td>39.7</td>
<td>39.7</td>
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<tr>
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<td>164.18</td>
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### LOAD LOSS AND IMPEDANCE TEST

**Rating 60/80 MVA**  
**Serial No. 6A752**

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<th>Auto Xfmr (Yea/No)</th>
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<td>60,000</td>
<td>60,000</td>
<td>80,000</td>
<td>80,000</td>
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<tr>
<td>RA pos</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>LTC pos</td>
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<td>287.7</td>
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<td>0.9982</td>
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<td>0.19750</td>
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<td>0.00337</td>
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<td>Calculated Losses</td>
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Calculated by: [Signature]

Mar 29 1990

Approved by: [Signature]

Mar 29 1990
Transformer Losses Curve

Voltage Tap at 121.00/13.8kV (Tap 3) Assumed Power Factor 90%
Based on 85deg Celsius Assumed Efficiency 98%
APPENDIX-D

ELECTRICAL EQUIPMENT SPECIFICATIONS (TYPICAL)
## 15 kV Switchgear Specification

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1.0 GENERAL

1.1 Scope of Work

The scope of work covered by this specification includes the design, materials take off, manufacture, shop testing, delivery, and guarantee of 15 kV class switchgear, complete with auxiliary equipment.

The work is to be completed for the purpose intended and includes all auxiliary equipment and accessories.

1.2 Standards, Codes and References

Equipment and material shall comply with the applicable federal, provincial and local codes, laws, ordinances and regulations and shall be approved by the Canadian Standards Association and Ontario Hydro. The Seller shall obtain approval from the appropriate provincial authority, where CSA approval is not available and shall inform the Purchaser and apply an Ontario Hydro approval sticker in lieu of CSA approval. The equipment shall comply with the applicable Codes and Standards and Guides of the following organisations.

EEMAC Electrical and Electronic Manufacturer's Association of Canada
NEMA National Electrical Manufacturer's Association
NFPA National Fire Protection Association
OSHA  Occupational Safety and Health Association
ICEA  Insulated Cable Engineers Association
ASTM  American Society for Testing Materials
CIS   Canadian Institute of Steel Constructors
ANSI  American National Standards Institute
IEEE  Institute of Electrical and Electronic Engineers
CSA   Canadian Standards Association
OHESC Ontario Hydro Electrical Safety Code
UL    Underwriters Laboratories
FM    Factory Mutual Engineering Guidelines

The switchgear shall be supplied in accordance with EEMAC Standard G8-8.2 Metal Clad and Station Type Cubicle Switchgear.

1.3 Workmanship

Workmanship shall be in accordance with utility practices and be adequate to assure reliable operation of the equipment at maximum and at minimum ambient in accordance with the provisions of this Specification.

No patching, plugging, shimming or other such means of overcoming defects, discrepancies or errors, which prevent the proper assembling and fitting of parts shall be resorted to.
1.4 **Materials and Assembly**

All materials used shall be the best and most suitable quality available for this class of equipment and shall be new, unused, free of defects and shall not be end of production line items or equipment.

2.0 **CHARACTERISTICS AND PERFORMANCE**

2.1 **Service Conditions - Electrical**

Power is generated in the plant at 13.8 kV, transformed to 115 kV and transmitted by an overhead line to an adjacent Ontario Hydro transmission station. The plant auxiliary loads are supplied from the 13.8 kV bus and the station service transformer.

The 13.8 kV system is normally a high resistance system and is grounded at the neutrals of the two generators. Occasionally the generators will be out of service and the 13.8 kV bus will be supplied from the 115 kV system and connected to ground through 3 single phase potential transformers with ground fault protection to de-energise the bus.

The 13.8 kV system is allowed a variation of ±5%. The switchgear shall be capable of withstanding the application of 1.30 x 13.8 kV for 6.35 s.
The two circuit breakers are connected to generators and will be used for synchronising. The circuit breakers shall be rated to interrupt the system short circuit currents at the high X/R ratios given.

**Three phase short circuit current**

Momentary duty: (Close and Latch)

- 54.997 kA rms. symmetrical
- 91.64 kA rms. asymmetrical with a multiplying factor of 1.666 at an X/R = 53.0

Interrupting duty:

- 54.997 kA rms. symmetrical
- 65.643 kA rms. asymmetrical with a multiplying factor of 1.194 at an X/R = 53.0

### 2.2 Abbreviations and Definitions of Terms

Certain terms used in this document have been abbreviated as follows:

- **kV**: Kilovolts
- **DCS**: Distributed Control System
- **PLC**: Programmable Logic Controller
- **DISC SW**: Disconnect Switch
- **FU**: Fuse
3.0 **DESIGN AND CONSTRUCTION**

3.1 *General*

The 15 kV class switchgear enclosures shall be EEMAC Type 1 (General Purpose), designed for installation in a clean air electrical room environment that is heated but not air conditioned.

3.2 *Enclosures*

3.2.1 The 15 kV class switchgear assemblies shall be "one high" construction cells, fabricated from sheet steel panels having a minimum gauge of No. 11 USS, joined together to form a rigid, free standing, metal enclosure.

The complete structure shall be free from magnetic vibration, flexing, twist and distortion. Non-magnetic material shall be provided where required. Each vertical section shall comprise:

- Shrouded horizontal and vertical copper buses

- Horizontal draw out circuit breakers each with its own compartment and individual front door provided with a lockable handle
- Draw out potential transformers

- Current transformers

3.2.2 Power cables clamp-on cleats shall be provided to prevent mechanical and/or electrical stresses being transmitted to cell bus work, insulators, etc.

3.3 **15 kV CLASS BREAKERS**

3.3.1 Each circuit breaker shall have three (3) definite and distinctive positions within the circuit breaker cell:

i) Operating (connected) position

ii) Test position

iii) Withdrawn position

3.3.2 Each circuit breaker shall be provided with a breaker position indicator that is mechanically operated by the movement of the breaker from one position to another.

Mechanical interlocks shall be provided to prevent moving the breaker to or from the connected position with the circuit breaker door closed, and/or with the circuit breaker in the closed position.
3.3.3 Each circuit breaker shall be provided with a breaker, open-close and 125 V dc power supply lights as follows:

- green for breaker open
- red for breaker closed and trip circuit healthy

3.3.4 Safety features shall be incorporated to ensure that the charging spring is automatically discharged before the breaker is withdrawn from the cell.

3.3.5 Each circuit breaker shall be provided with a motor operated stored energy operating mechanism with a spring charged indicator.

Anti-pumping features shall be included in the breaker control circuit.

3.3.6 Facilities for the padlocking of the circuit breaker in the racked-out position shall be provided.

3.3.7 The draw-out movement of the circuit breaker shall mechanically operate a system of shutters to cover the live bus fixed power contacts.

3.3.8 Each circuit breaker shall have auxiliary contacts provided.

3.3.9 Vacuum bottle type circuit breakers shall be supplied.
3.3.10 Breakers shall be of proven design for the application with all parts and vacuum bottles readily available in Canada.

3.3.11 Vacuum bottle breakers shall have circuit interrupters of bolt-in-place design, readily accessible.

3.3.12 Each circuit breaker shall be capable of being electrically operated at the breaker when in the test position and be capable of being electrically operated from a remote control system supplied by Others.

3.3.13 Each breaker shall be supplied with a separately fused breaker close and one separately fused breaker trip circuits.

3.3.14 Adequate provisions shall be incorporated in each breaker such that it is not possible under any circumstances, to force the breaker into the racked-in position, i.e., out of alignment, inadequate guides and rails, damaged bus stabs, improper mating of power, control and ground connectors, etc.

3.3.15 On vacuum bottle contactors, arc stability must be controlled to a fraction of an ampere to minimise exposing the generator(s), cable(s), transformer(s), etc. to current chopping, transient voltages, and harmonics.

3.3.16 The Vendor shall state in the tender documents, or attach manufacturer literature and tables that give:
i) number of open-close operations under full load amperes to inspection of vacuum bottle breakers;

ii) number of open-close operations under full load amperes to replacement of vacuum bottles;

3.4 **Bus**

3.4.1 Main and ground bus rating shall be not less than that stipulated on the 1-Line diagram 10601-FE-1A.

3.4.2 Main buses and bus support insulators shall be braced to withstand the electrical and the mechanical stresses based on the maximum rated short circuit values without deformation or damage as stipulated on the breaker nameplate.

3.4.3 Main buses shall be silver or tin plated copper, but shall be silver plated at locations where there are bolted bus connections.

3.4.4 The main bus supports shall be made from high dielectric, anti-hydroscopic, high impact material.

3.4.5 Bolted connections on the main 13.8 kV bus shall be made with not less than four (4) bolts, including lugs provided for the power entry and exit cables.
3.4.6 The Manufacturer shall furnish main bus bolt torque values and shall verify that shop assembly has complied with these values. These values shall be shown on the drawings and in the manuals.

3.4.7 The main bus phasing arrangement shall be red, white, blue, left to right, top to bottom, front to back, when viewed from the front of the line-up.

3.4.8 All main bus joints and bus shall be fully insulated. Bus work shall be insulated with a non-combustible material, with joints covered with removable plastic boots.

Inter-phase arcing at bus stab locations shall be prevented with barriers.

3.4.9 A full assembly width ground bus shall be provided with 4/0 lugs provided at each end to tie into the Plant's grounding system.

3.5 **Current and Potential Transformers**

3.5.1 Current transformers, and potential transformers shall be provided as shown on the drawings.

3.5.2 Current and potential transformer mechanical and thermal ratings shall be co-ordinated to withstand the short circuit and full load ratings to which they may be subjected.
3.5.3 Accuracy class and ratio requirements shall be as indicated on the drawings and be at least equal to ANSI standard requirements for relaying, instrument, and the metering applications.

3.5.4 Unless stated otherwise, all current transformers shall be single-ratio; and wired to outgoing current rated terminal blocks conveniently located for customer outgoing wiring.

Each set of current transformers shall be wired in physically and electrically separate wire ways to the outgoing terminal blocks.

3.5.5 The HV line side of the HRC fuses to potential transformers is considered to be an extension of the bus system and shall be adequately insulated, shrouded and barriered to prevent phase-to-phase, phase-to-ground faults, or danger to personnel.

3.5.6 Secondary (LV) windings of all potential transformers shall be wired to fuses, clearly identified as to which PT they are connected, and to outgoing terminal blocks conveniently located for customer outgoing wiring.

3.6 **Relays, Transducers, and Indicating Instruments**

Auxiliary relays shall be provided and wired as required.

Supplier will provide his standard meters and switches, and devices.
3.7 **Wiring and Terminal Blocks**

3.7.1 All wiring shall be neat, point to point and be terminated at both ends. No splicing, cutting back, or taping back of unused conductors is acceptable. "T" connections are not allowed. Wiring shall be bundled, strapped and run in wire ways.

3.7.2 Each wire connected to the terminals shall have a properly sized ferrule, which shall be attached to the wire by using the appropriate terminal manufacturer's recommended crimping tool.

3.7.3 All power and control wiring shall be fire retardant type.

3.7.4 Current transformer wiring shall be not less than #8 AWG.

3.7.5 All control wiring shall be of an approved type, having a 90°C continuous conductor temperature rating, 250°C under short-circuit conditions. The conductors shall be stranded copper, minimum No. 14 AWG.

3.7.6 All unused wiring access holes are to be covered with sheet steel covers.

3.8 **Grounding**
3.8.1 The two (2) station ground conductor tails provided for the 15 kV Class assembly will be #4/0, seven (7) strands annealed, high conductivity bare copper cable.

3.8.2 Two suitable grounding terminal points with ground lugs shall be provided for connection to these station ground grid tails.

3.9 **Tools and Accessories**

Provide two sets of special tools and/or accessories required for installation, operation, maintenance, calibration, and/or inspection of the equipment.

3.10 **Painting**

Before leaving the factory, all surfaces of each assembly shall be treated, primed and finished.

Interior surfaces of all compartments on which equipment and terminal blocks are installed shall be painted. Unpainted metal parts, such as door hardware, latches, etc. shall be chromate or cadmium plated for resistance to corrosion. Touch-up paint shall be shipped with the equipment.

3.11 **Nameplates**

3.11.1 Breaker rating nameplate with serial number shall be stainless steel and mounted on the inside of the front door.
3.11.2 Screw-on type laminoid nameplates with engraved black figures on white background shall be placed on the outside, front and rear, of the cubicle.

3.11.3 All relays, control switches, etc. shall have engraved nameplates.

3.11.4 Engraving, letter style, and size shall be submitted for review and approved by the Owner and shall be in English.

3.12 **Shipping**

Provide all bus work, bolts, hardware, terminal blocks, and wiring required in the field to complete the installation. This includes wiring, bus work at shipping section.

4.0 **INSPECTION AND TESTING**

4.1 **Factory Testing**

Each completed assembly shall be tested at the factory in complete accordance with relevant specifications, codes and standards. Tests shall include the following:

4.1.1 Mechanical operation of each breaker, draw-out potential transformer and auxiliary devices.
4.1.2 Inter-changeability of breakers.

4.1.3 Standard insulation withstand tests:

- On each 15 kV Class breaker and bus work

- On all control wiring and all equipment rated 250 V or less, at 1500 V, 60 Hz, for 1 minute

- On component parts as covered by the applicable standards.
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1.0 SCOPE OF WORK

1.1 This specification covers the engineering, design, material take-off, manufacture, shop test, delivery and guarantee of three (3) uninterruptible power systems (hereafter referred to as UPS) as detailed below.

1.1.1 Single Phase, 120 Vac, 60 Hz UPS (20 KVA)

Tag No. OEE-UJX-1 Used as back-up protection and distribution to electronic equipment loads, complete with 30 minute battery back-up.

1.1.2 125 V dc, UPS Battery System (Power) (6 Amps Nominal)

Tag No. OEE-UJX-2 Used to power steam turbine emergency lube oil pump motor and solenoid valves.

1.1.3 125 V dc UPS Battery System (Control) (100 Amps Nominal)

Tag No. OEE-UJX-3 Used for control power to switchgear, turbine control, generator control, etc.

1.2 All equipment furnished shall be standard catalogue products of the Manufacturer with add ons where required and have proven field operation.
1.2.4 All materials and components supplied shall be new, of current manufacture and shall not have been in prior service except as required for factory testing.

1.2.5 The systems shall be designed, manufactured, tested and prepared for shipment in accordance with good engineering design and construction practices.

1.3 Where practicable, identical components, sub-assemblies and modules shall be used to allow interchangeability, minimizes spare parts and to simplify servicing and repairs.

1.4 All active electronic devices shall be solid state and should be derated below the Manufacturer's recommended tolerances for maximum reliability.

1.5 The noise generated by the systems under all operating conditions, shall be less than 65 dBA measured 1 metre (3.3 ft.) from the surface of the cabinet.

1.6 Proposals for the furnishing of this equipment shall be in complete accordance with this specification. Any exceptions shall be clearly stated, and referenced to the specific paragraph of this specification and data sheets. In addition, the reasons for the exception and the advantage or disadvantage of the exception to the Purchaser shall be clearly explained. Failure to do so will be interpreted to mean the system fully complies with the requirements of this specification. Statements such as "general exception" or "functionally equivalent" shall not be acceptable.
1.7 Submittals

A proposal with complete descriptive data for the furnishing of the systems shall be provided. The proposal shall also include the following information:

- A complete technical description of all the equipment to be supplied.

- Estimated shipping weights.

- Estimated delivery time in weeks from receipt of an official order to proceed and from receipt of approved drawings, if so required.

2.0 CODES, STANDARDS AND REFERENCES

The equipment shall be designed and manufactured in accordance with the applicable standards of CSA, EEMAC, ANSI and IEEE in effect at the date of enquiry. All equipment must bear CSA approval stamps. In cases where special component equipment or materials are used and which do not hold CSA approval, the Manufacturer is responsible for obtaining inspection and approval of such items from the Ontario Hydro Inspection Department.

Some of the relevant references are:
### CSA Standards

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<td>IEEE Guide for the Selection of Valve Regulated Lead Acid (VRLA) Batteries for Stationary Applications</td>
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2.3 **NEMA Standards**

ICS 1-109, 1977  
Tests and Test Procedures

ICS 6, 1985  
Enclosures for Industrial Controls and Systems

PE-5-1985  
Utility Type Battery Chargers

PE-1  
Uninterruptible Power Systems

3.0 **DESIGN CRITERIA**

3.1 **Single Phase 120 Vac UPS**

3.1.1 The battery back-up for this UPS shall be sized to supply the loads for 30 minutes on loss of utility ac input power. Battery sizing calculations shall be submitted.

3.1.2 The loads predominantly consist of electronic control systems and are considered non-linear.
3.2 125 V dc Battery System (Power)

3.2.1 In normal operation there are no loads on this system. On loss of utility ac power, this battery shall be capable of operating the 3.7 kW emergency lube oil pump motor for 60 minutes.

3.3 125 V dc Battery System (Controls)

This system supplies both constant and intermittent loads. Battery shall be capable of sustaining the loads for 30 minutes, after loss of utility power.

3.3.1 Constant Loads

3.3.1.1 Gas turbine control panel
4,000 W

3.3.1.2 Steam turbine/generator excitation control cubicle
2,000 W

3.3.1.3 Steam turbine generator control panel
1,000 W

3.3.1.4 Indicating lights on 115 kV, 13.8 kV and 4.16 kV systems (assume 15 light at 5 W each)
75 W

3.3.1.5 Assume a 80% diversity on above loads.

3.3.2 Intermittent Loads

3.3.2.1 115 kV Motorized
Disconnect switch

14.4 amps
(estimated)

3.3.2.2 **115 V Breakers**

Spring charging motor rated 14.4 amps
Closing coil rated 450 watts
Trip coil rated 450 watts

3.3.2.3 **13.8 kV Breakers (Three in total)**

Closing coil current 6 amps
Trip coil current 10 amps
Spring charging motor 3.7 amps

3.3.2.4 **4.16 kV Breaker (One)**

Assume same valves as 13.8 kV breakers.

3.3.2.5 Assume operation for all above breakers as "OC15SEC-CO-2HRS-CO-15SEC-C" as a minimum for sizing, while all other loads are on.

3.3.2.6 **Remote Tripping and Communications**

Assume 150 watts.
3.3.2.7  

*Line and Transformer Protection Panel*

Assume 150 watts.

4.0  

**SINGLE PHASE 120 V AC UPS**

4.1  

*System Description*

The basic UPS module shall comprise the following:

- Rectifier/charger
- Battery
- Inverter
- Static transfer switch
- Manual bypass switch
- Microprocessor diagnostic monitor/controller
- 42 circuit distribution panel complete with breakers

The functions and characteristics of each individual module shall meet the following requirements:

4.1.1  

*Rectifier/Charger*

The rectifier/charger converts the ac line to the regulated dc link voltage that powers the inverter and simultaneously charges the battery. The technology employed will be a full wave SCR phase controlled bridge with filtering.
4.1.2 **Inverter**

The inverter converts the dc link power from the rectifier or battery to ac power at the required voltage and frequency. The technology employed shall be a pulse width modulation (PWM) transistorized full bridge inverter with linear control loop. The inverter control logic is to be powered by a redundant, input auxiliary power supply with fault detection.

4.1.3 **Static Transfer Switch**

The transfer switch controls the routing of power to the load from the inverter or alternative line depending upon system conditions. It is to consist of two (2) pairs of reverse parallel connected SCRs, each independently controlled. The control and power circuitry for the inverter and alternative line side transfer switch shall have a totally redundant configuration with independent redundant, input auxiliary power supplies.

4.1.4 **Manual Bypass Switch**

The manual bypass switch shall be made before break and is mainly used for safe service of the UPS or to bypass a failed UPS system. It shall function as follows:

Normal This mode of operation routes power to the load through the static transfer switch
Bypass  In this mode, the load is connected directly to the alternative line source and the static switch is isolated from the alternate line. This position is used to power the load during UPS service or to bypass a failed UPS.

Bypass test  This mode is similar to bypass above, except that power is maintained to the transfer switch in order to facilitate testing of the UPS operation prior to putting it back into service.

4.1.5  Diagnostic Monitor/Controller

The UPS module is to be equipped with a microprocessor based diagnostic monitor/controller. A liquid crystal display shall provide information of the system status and human interface by "soft" keys. A comprehensive mimic panel shall be provided for visual system status. Data is to be collected via analogue and digital inputs. All abnormal conditions must be recorded in memory with time of, and end of occurrence. Set-up data is to be stored in EEPROM and alarm history in SRAM backed up by an on-board rechargeable NI-CAD battery.

Memory allocation shall be provided for up to 200 alarms and when full, the last 100 occurrences are to be overwritten one at a time by the most recent. An RS232 port will be provided for an optional panel mounted printer for a hard copy of all monitored occurrences.
4.2 SYSTEM SPECIFICATIONS

4.2.1 AC Input

See UPS 1-Line diagram 10601-FE-1F.

4.2.2 Battery

See UPS 1-Line diagram 10601-FE-1F.

If valve regulated lead acid batteries are (preferred option) utilized, the following features must be supplied:

- 0.5% ripple current filtering (float condition)
- Voltage temperature compensation (0.22%/°C)
- Battery charge current limit (adjustable 10 to 50%)

4.2.3 Ac Output

See UPS 1-Line diagram 10601-FE-1F.
Voltage regulation (normal mode operation):

<table>
<thead>
<tr>
<th>Static ± 1% for</th>
<th>0 to 100% load</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum to maximum battery voltage</td>
</tr>
<tr>
<td></td>
<td>Rated load power factor</td>
</tr>
<tr>
<td></td>
<td>Loss of ac input</td>
</tr>
<tr>
<td></td>
<td>0 to +50°C ambient temperature</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dynamic ± 5%</th>
<th>100% load step (application or removal)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transient</td>
<td>To ± 3% within 10 milliseconds</td>
</tr>
<tr>
<td>recovery</td>
<td>To ± 1% within 30 milliseconds</td>
</tr>
<tr>
<td>Harmonic</td>
<td>3% maximum, single harmonic</td>
</tr>
<tr>
<td>distortion</td>
<td>5% THD maximum up to crest factor 3</td>
</tr>
<tr>
<td></td>
<td>3% THD maximum for linear loads</td>
</tr>
</tbody>
</table>

4.2.4 Mechanical

<table>
<thead>
<tr>
<th>Cubicle type</th>
<th>EEMAC 1, NEMA 1, CSA 1 or IP20</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction</td>
<td>11 gauge formed steel frame with 14/16 gauge bolt on panels</td>
</tr>
<tr>
<td>Access</td>
<td>Front via hinged doors</td>
</tr>
<tr>
<td>Hinges</td>
<td>Concealed type</td>
</tr>
<tr>
<td>Paint</td>
<td>ASA61 grey</td>
</tr>
<tr>
<td>Wire identification</td>
<td>Permanent wire markers</td>
</tr>
<tr>
<td>Wiring</td>
<td>Stranded copper with black, flame retardant type TEW insulation, (thermoplastic polyvinyl chloride having an oxygen index of 24) rated 105°C, 600 V. Capable of meeting ICEA S-19-81 flame resistance tests, UL VW1 and CSA</td>
</tr>
</tbody>
</table>

125 Vdc and 120 Vac uninterruptible power system 13
<table>
<thead>
<tr>
<th>Component identification</th>
<th>FT-1. Wiring sized as required for its current carrying capacity in accordance with the Canadian Electrical Code, Part 1 (CSA C22.2 No. 1 - M 1986)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable entry</td>
<td>Through top gland plate</td>
</tr>
<tr>
<td>Connections</td>
<td>Compression lugs or studs (capacity dependent) located in lower front</td>
</tr>
<tr>
<td>Grounding</td>
<td>Compression type, chassis ground lug</td>
</tr>
<tr>
<td></td>
<td>Doors, panels and magnetics must be grounded to the chassis with external tooth lock washers</td>
</tr>
<tr>
<td>Handling</td>
<td>Bottom fork lift access</td>
</tr>
</tbody>
</table>
### Environmental

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating temperature</td>
<td>-10° to +40°C (+14° to +104°F)</td>
</tr>
<tr>
<td>Storage temperature</td>
<td>-35°C to +70°C (-31° to +158°F) battery excepted</td>
</tr>
<tr>
<td>Altitude</td>
<td>1000 m (3280 feet)</td>
</tr>
<tr>
<td>Humidity</td>
<td>0 to 95% non-condensing</td>
</tr>
</tbody>
</table>

### General

| Cooling                  | Convection cooling preferred. If fan cooled, indicate number and rating of fans used |

### System Features

#### Monitoring

<table>
<thead>
<tr>
<th>Mimic panel</th>
<th>Must indicate power flow and module operation status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitor/controller</td>
<td>A microprocessor based monitor/controller is to provide liquid crystal display (LCD) information for alarm parameters and control. All abnormal conditions shall be recorded in memory with time of and end of occurrence</td>
</tr>
</tbody>
</table>

### Alarms
The following conditions and alarms must be annunciated. Each alarm condition shall be annunciated by a common fault LED, grouped module fault LEDs and an audible alarm with the specific alarm displayed on the LCD display.

Alarm and annunciation condition on the LCD display shall be:

- Float
- High rate
- Inverter off
- Line static switch on
- Status normal
- Time/date
- Battery operation
- Power supply failure
- Charger fail
- Charger input breaker
- Charger output breaker/fuse
- Charger over temperature
- Mains fail (individual phases monitored)
- Battery over temperature
- Battery sensor open
- Battery overcharge
- Positive ground
- Negative ground
- DC volts high
- DC volts low
- Inverter output high
- Inverter output low
- Alternate line high
- Alternate line low
- Alternate line frequency
- Line static switch temperature
- Inverter static switch temperature
- Inverter over temperature
- Overload
- Sync fail
- Battery breaker/fuse
- Battery low
- Battery fault
- Output fail
- Inverter static switch fuse
- Static switch protection fail

Alarm settings and delays must be field programmable.

4.3.3

*Mimic Panel LEDs*

Shall be provided for:

- Mains on (green)
- Alternate line on (green)
- Float (green)
- High rate (amber)
- Inverter on (green)
- Inverter off (amber)
- Sync (green)
- Manual transfer to alternate (amber)
- Static switch manual return mode (amber)
- Inverter static switch on (green)
- Line static switch on (red)
- Output (green)
- Charger fault (red)
- Inverter fault (red)
- Static switch fault (red)
- Battery operation (red)
- Common fault (red)
- Manual bypass (red)

4.3.4 *Alarm Contacts*

Provide contacts for:

- Battery operation
- Common fault
- Manual bypass

Type: Form "C"

Rating:

- 10A at 120 V ac
- 10A at 125 V dc

Life: 100,000 operations

Isolation: 2,500 V ac
4.3.5 **Metering**

Provide 3.5 in. Analogue 2% accuracy meters for:

- Rectifier/charger dc output amps
- DC bus volt
- Inverter ac output volt
- Inverter output frequency
- AC load amps

4.3.6 **Controls**

As a minimum this front panel mounted controls must be provided with the following items:

- AC input breaker
- Manually initiated timed high rate
- Inverter on/off push button
- Static switch manual mode reset/return push button
- Static switch manual transfer push button
- Manual bypass switch (mounted behind front panel)
- Audible alarm acknowledge
- Diagnostic monitor/controller alarm set up parameters for active/inhibit, delay time, LED flash/steady state, relay latch/non-latch
- Diagnostic monitor/controller set up parameters for charging control, high rate active/inhibit, 28 day equalize active/inhibit, manual high rate active/inhibit, high rate time
1 to 24 hours, manual high rate time 1 to 96 hours and high rate time limit 24 to 96 hours

4.3.7 **Protection**

The following protection shall be provided as a minimum:

- AC input breaker
- Rectifier/charger dc output fuse
- Battery fuse (or breaker)
- Timed high rate
- Rectifier/charger current limit (charger output and battery input)
- Electrical galvanic isolation between ac input to output and input to battery
- Rectifier high dc voltage shutdown
- Inverter dc under/over voltage shutdown
- Inverter automatic start-up
- Inverter current limit
- Inverter short circuit proof
- Output overcurrent sensing and transfer
- Transfer to alternate line on inverter failure
- Static switch inverter pole fuse
- Static switch power circuit failure
- Automatic/manual retransfer to inverter
- Static switch anti-cycling circuit
- Battery temperature compensation

4.3.8 **Magnetics**

125 Vdc and 120 Vac uninterruptible power system 20
Magnetics shall be:

- Designed for a 100°C temperature rise
- Vacuum epoxy impregnated
- Insulation Class 155

4.4 **Module Specifications**

The following minimum requirements for each module shall be provided:

4.4.1 **Rectifier/Charger**

Output regulation: ± 1% for 1 to 100% load, ± 10% line voltage variations, ± 5% frequency and 0 to +40°C

Current limit: 10 to 100% adjustable

Battery current limit: 10 to 50% adjustable

Output ripple: < 2% RMS voltage with battery

Battery recharge: Automatic high rate for fast battery recharge

High rate:

- Manually initiated high rate with automatic termination
- 28 day equalize timer
Slow start: Slow walk in (15 seconds) to full load

Protection:

- Input breaker
- High dc voltage shutdown
- Output fuse
- Surge withstand 20 joules for 10 m/sec
- Battery fuse (or breaker)
- High rate time limit forces rectifier back to float charge after programmable 24 to 96 hours period to prevent battery overcharge

Rating: Sized to recharge the specified battery in 8 to 10 hours

Operational features:

- Short circuit proof
- Inductor filtered output
- Battery ripple filter (0.5% RMS voltage)
- Battery temperature compensation

Galvanic isolation: 2,500 V ac input/output

4.4.2 Inverter

DC input voltage: See 1-Line diagram 10601-FE-1F.
Output voltage regulation: Nominal ±1% at 0 to 100% load, dc input range

Output distortion:
- 3% THD maximum
- 5% THD maximum to kVA limit with 25% linear and 75% non-linear load

Dynamic regulation:
- ±5% maximum for 100% load step
- Recovery to ±1% in 30 m/sec maximum

Overload:
- 125% for 10 minutes
- 150% for 1 minute

Voltage drift: ±1% maximum, 0 to 40°C

Frequency: See data sheet

Frequency stability: ±0.1% maximum (free running)

Synchronization:
- Synched within ±5° maximum
- OF/UF sync disconnect ±1%

125 Vdc and 120 Vac uninterruptible power system 23
Slew rate: 0.1 Hz per second maximum

Galvanic isolation: 2,500 V ac input/output

Reflected battery ripple: < 0.5% RMS voltage

Power conversion: Pulse width modulated transistor power bridge with linear control loop

Protection: Surge 1.2 kV for 50 microseconds as per ANSI/IEEE C62.41-1980

Inverter must have the following features:

- Short circuit proof
- High energy filter for fast fault clearing
- Auto shutdown: For 120 V dc input - outside window of 96 to 150 V dc
- Auto start-up

4.4.3  Transfer Switch

Transfer to alternate:

- On 150% load
- On ± 10% voltage (average sensing)
- On -15% voltage (instantaneous sensing)
- Inverter failure
- Manual initiate

Retransfer to inverter:

- Load within inverter continuous current rating
- Inverter output normal
- Line out of limits ± 10%

Sensing/transfer time: 3.5 ms maximum

Return to inverter: 3 seconds delay on return to normal

Transfer inhibit: Bypass voltage out of limits ± 10%

Retransfer inhibit:

- Manual return mode selected
- Inverter not normal

Overload (minimum):

- 125% for 10 minutes
- 150% for 1 minute
- 1000% for 10 ms

Static switch shall have:

- Auto/manual return selector switch
- System output bus sensing
- Anti-cycling circuit with:
  - 4 retransfer attempts
  - 2 minute time period
  - 30 minute reset

5.0 125 VOLT DC SYSTEMS DESCRIPTION

5.1 Environment

The design of the dc system is to be suitable for operation under the following conditions:

- Location: Indoors, protected from the environment
- Elevation above sea level: Less than 1,000 metres
- Maximum ambient temperature: +40°C
- Minimum ambient temperature: -10°C
- Humidity: 0 to 95% non-condensing

5.2 System Components

5.2.1 Storage Battery

5.2.1.1 The battery shall be valve regulated sealed lead calcium type and be supplied filled, and fully charged, ready for service. Preferred batteries are type Liberty Series 1000 as made by C&D powercom and all battery specification shall be same as Liberty Series 1000 standard.
5.2.1.2 The plate group shall be of proven Design for improved current carrying capacity and long float life, for the service encountered.

5.2.1.3 All intercell Connectors and lugs shall be nickel plated copper.

5.2.1.4 The Manufacturer shall supply a battery filler bottle, A hydrometer, an insulated terminal wrench and all the connectors necessary for a complete installation.

5.2.1.5 Duty cycle: The battery shall have sufficient capacity to perform the duty cycles described in Section 3.0.

5.2.2 Battery Charger

5.2.2.1 A SCR type battery charger shall be provided to operate from a 600 V, 1 phase, 60 Hz supply. The charger shall have sufficient capacity to recharge a fully discharged battery in not more than 10 hours to at least 80% charged while simultaneously feeding the constant load.

The charger shall have the following characteristics:

- Regulation: ± 0.5% voltage from 0 to 100% load and simultaneously:
  - ± 10% input voltage variation
  - ± 5% frequency variation
- Ripple voltage: 2% (RMS)
- AC breaker and dc breaker
- Analogue type dc voltmeter, 2% accuracy, 3 in.
- Analogue type dc ammeter, 2% accuracy, 3 in.
- AC and dc surge suppression
- Reverse battery protection
- Automatic current limiting adjustable from 50 to 110% via a trim pot on the charger control circuit
- Current regulation: ± 2%
- Convection cooled
- Short circuit proof
- Soft start
- LEDs to indicate:
  - AC "ON", (green)
  - HIGH RATE "ON" (amber,)

5.2.2.2 The charger shall normally operate in the float mode and shall have a push button on the control panel to initiate a timed high rate charge. The charger shall automatically return to the float mode at the end of the timed out period.

5.2.2.3 Both the float and high rate voltages shall be adjustable via trim pots on the charger control card.

5.2.2.4 The float voltage shall be adjustable from 110 to 140 volts dc and shall be factory preset in the range of volts per cell, as per battery Manufacturer's recommendations.

5.2.2.5 The high rate voltage shall be adjustable from 120 to 154 volts dc and shall be factory reset at the battery Manufacturer's recommended high rate level, but not to exceed 140 volts dc.
5.2.2.6 Complete input/output isolation shall be provided between the ac input and dc output.

5.2.2.7 A solid state automatic charge control shall be provided. It shall automatically switch the charger from float to high rate charge when the charger has operated in current limit for longer than 36 seconds. After the charger comes out of current limit, a timer will keep the charger in the high rate mode for another 10 hour. The charger shall be returned to the float mode at the end of the 10 hours’ time period.

The charger shall be equipped with the following alarms:

- High dc volts alarm: Adjustable from nominal to +40%, and having a 4 second delay.

- Low dc volts alarm: Adjustable from nominal to -35% and having a 4 second delay.

- AC failure alarm: 4 second delay.

- Charger failure alarm: 15 second delay.

- Positive or negative dc ground detection alarm: 10 mA or 100 ohm/volt and having a 4 second delay.

Each of the alarms mentioned in items 3.2.21 to 3.2.25 shall have a red LED on the charger control panel and shall be of the latching type.
A common LED test/reset switch and one (1) common Form "C" alarm contact shall also be provided.

5.2.3 **System Console**

5.2.3.1 A free standing and self supporting formed metal console shall be supplied to house both the battery and the charger. The charger shall be mounted in the top section and the battery in the bottom section; with a barrier between the two (2) sections. Alternatively the battery may be offered on its own rack.

5.2.3.2 The cabinet shall be a free standing IP20, CSA 1 or EEMAC 1 fully metal enclosed type with dead front construction. Ventilation shall be through slotted plates on the top, bottom, sides or front of the cabinet. The cabinet shall have adequate strength to withstand stresses imposed by shipping, handling, installation and operation.

5.2.3.3 One or more hinged doors shall be provided for each section. Hinges shall be of the piano type. Suitable cam type closures shall be provided to hold the doors securely closed. Key lock handles to be provided.

5.2.3.4 The charger shall be mounted in the upper section with front access to all metering, indications and controls.

5.2.3.5 The equipment shall be designed for front access only.
5.2.3.6 The battery shall be mounted on step type shelves in the lower section (or separately) of the console for visual inspection of all electrolyte levels.

5.2.3.7 Incoming and outgoing connections shall be made through knockouts on the top.

5.2.3.8 The cabinet shall be pressure cleaned with a phosphate solution and finished with one (1) coat of ANSI 61 light grey epoxy enamel applied by an electrostatic process. The instrumentation panel shall be blue.

5.2.3.9 The cabinet shall provision for handling by a fork lift, pallet truck or sling.

5.2.3.10 If the battery charger rating is such that it is impractical to be included in the battery enclosure, separate battery charger and battery cabinet would be acceptable.

6.0 TESTING

Routine factory testing and inspection shall be carried out on each unit. The Purchaser and/or his representative has the option of witnessing these tests. The Supplier's Quality Assurance Department must provide detailed test procedures. All technical assistance and test equipment required to perform these tests must be furnished by the Supplier. All test instruments shall be calibrated.
and traceable to recognized standards. The testing and inspection shall include:

6.1 **120 V ac UPS**

- A quantitative check of all features, alarms and items specified in the purchase order.

- Visual inspection of workmanship and finish.

- Measurement of dimensions.

- Dielectric strength test.

- Operation and sequence test.

- Electrical performance at 0, 50% and 100% rated capacity under:
  
  - Specified minimum ac and dc input voltage
  
  - Specified rated ac and dc input voltage
  
  - Specified maximum ac and dc input voltage

- Sensing and transfer time.

- Dynamic regulation and response.

- Frequency.
- Total harmonic distortion.

- Overload.

- Short circuit.

6.2 Battery Chargers and Batteries

The battery charger test and inspection shall cover the following:

- A quantitative check of all features and items specified in the purchase order.

- Visual inspection of workmanship and finish.

- Measurement of dimensions.

- Dielectric strength test.

- Operational and sequence test.

- A functional test to verify electrical performance.

7.0 PACKAGING

The equipment shall be suitably packaged for domestic shipping by common carrier.
8.0 QUALITY ASSURANCE

The Manufacturer shall have a quality assurance program, implemented to maintain product quality. As a minimum an inspection program that complies to the ISO 9001 level shall be offered.

9.0 WARRANTY

9.1 The completed systems shall carry a part and labour warranty for 18 months from date of shipment or 12 months from date of entry into service whichever occurs first.

9.2 The battery shall be warranted for at least 10 years. The Bidder shall submit copies of his detailed warranty policies with his proposal.
APPENDIX-E

CONTROLS TYPICAL LOGIC DIAGRAMS
Figure 1: Graphic Hierarchy
REFERENCES


22. GEC Measurements, "Protective relays application guide".

23. L. J. Powell, "Coordinating with the utility on industrial co-generation design", Industrial power system magazine, Vol.27, No.4, December 1984.


34. ABB power generation manual


36. Power Engineering magazine.
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Since 1990, he had been working with Stone & Webster Canada Limited, engineering consultancy company at the Senior Engineer level mainly in the Power side of the business. He was an M.A.Sc. candidate from 1994 - 1997 as a part time student at University of Windsor, Windsor, Ontario, Canada, N9B 3P4.