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F CLASS 2X0 SIMPLE CYCLE BLACK START ANALYSIS

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PREPARED FOR

CenterPoint Energy

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BLACK & VEATCH

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Executive Summary

As part of the preliminary design and feasibility studies for the new Simple Cycle Power Plant (SCPP) at A.B. Brown, Black & Veatch examined options for black starting CTG 5 of the new SCPP.

Two possible power sources were considered:

- New diesel gensets
- Existing Unit 3 CTG (dual fuel GE 7EA turbine)

Two scenarios were modelled for this evaluation:

- Starting the largest induction motor with all necessary auxiliary electric loads in operation.
- Static starting Combustion Turbine Generator (CTG) 5 with all necessary auxiliary electric loads in operation.

For analysis and modeling purposes, the aggregate auxiliary electrical load necessary to start a combustion turbine was based on the preliminary conceptual design of the new SCPP. In addition, the excitation system of the new black start generators and the Unit 3 CTG was assumed to be capable of providing the necessary reactive power required by the simulated scenarios while maintaining 100 percent system voltage at a frequency of 60 Hz at the generator terminals.

A review of the loads required for black start indicates that, including design margin, a minimum of 7,186 kW of black start generation would be required to start one combustion turbine of the new SCPP. For the purposes of this analysis, (2) Caterpillar Company C175-20 diesel generators rated at 4MW each have been considered. These gensets are proven equipment specifically designed for standby power and offer a reliable and cost-effective design that would be well suited for the A.B. Brown black start application. It is proposed that the black start generators would tie into the new plant 4.16kV switchgear.

Load flow studies for static starting of the largest motor (Air Compressor) and CTG 5 were conducted. Preliminary analysis shows that either the diesel gensets or the existing CTG 3 are capable of providing the necessary real and reactive power to support starting of both these loads. Given the technical equivalency of these two black starting methods, utilizing the existing CTG 3 for black start is likely the preferred option due to lower capital cost.

1.0 Introduction

This report evaluates two options for system black start of the new SCPP: black start via the existing CTG 3 and black start via new diesel gensets. The report also estimates the required size of new diesel gensets that would be utilized at A.B. Brown to black start the new simple cycle power plant (SCPP).

It is assumed that one combustion turbine would be started utilizing the black start generation, and the second combustion turbine could then be started once the first turbine is generating sufficient power to allow for multi-unit operation. This analysis considers black start of CTG 5 only.

The electrical power system analysis software ETAP was used to model and evaluate each black start scenario and to verify the capability of black starting CTG 5 of the new SCPP. Figure 1-1 provides the one-line diagram for the diesel genset option that was modeled in ETAP. Figure 1-2 provides the one-line diagram for the CTG 3 option that was modeled in ETAP. Two scenarios were considered for each black start option: starting of the largest induction motor with all necessary auxiliary electric loads in operation and static starting of CTG 5 with all necessary auxiliary electric loads in operation.

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2.0 Assumptions

In order to simulate the two black start scenarios, reasonable assumptions were made in order to model and simulate the black start capability. The assumptions are defined as follows.

2.1 LOAD LIST

It is necessary to determine the aggregate auxiliary electrical load to start a combustion turbine of the new SCPP. Appendix A provides the load list of all loads considered to be in operation to support the black start. The aggregate was modeled as a lumped load comprised of 70 percent induction motor load and 30 percent static load. The loads of Appendix A are based on the conceptual design of the new SCPP and are preliminary. The required starting sequence of loads is not yet known and a typical sequence has been assumed for the purpose of this evaluation.

2.2 BLACK START DIESEL GENERATORS

Caterpillar C175-20 diesel engines have proven to be a highly reliable design and are well-matched for this black start application. These are EPA certified for Stationary Emergency Applications (EPA Tier 2 Emission Levels) and can utilize ultra-low sulfur diesel (ULSD). For the purposes of this analysis, (2) C175-20 gensets have been considered. The black start diesel generators are self-started by battery cranking via integral 24VDC starting systems.

Each of the new black start diesel gensets are assumed to connect to the new 4.16kV switchgear, where they can power critical plant loads at 4.16kV and 480V via the new station service transformers. Once the gensets are online, the combustion turbine generator auxiliaries are powered, a cranking start signal is issued to the combustion turbine generator, and the unit is brought to rated voltage and speed. Grid restoration activities can then take place. The black start generator controls will have the capability to parallel with the A.B. Brown combustion turbine(s) once they are started for a seamless make-before-break transition.

2.3 STATIC STARTING

The Load Commutating Inverter (LCI) static starting system duty cycle is unknown at this time but is assumed to not exceed 5,450 kVA during the start of a GE 7F.05 combustion turbine. The static starting and excitation equipment is assumed to interconnect at the new 4.16kV system. Implications of feeding the new static starting from the existing plant 13.8kV system were not considered.

2.4 BLACK START GENERATOR EXCITATION SYSTEM

This study does not include analysis of the excitation model or transfer function for the new diesel generators or the existing Unit 3 Combustion Turbine Generator. Therefore, the excitation system for each possible black start resource is fixed in the ETAP simulation. Additional modeling of the excitation system and transfer function would be necessary in order to more accurately simulate the response to the reactive power demands imposed when black starting one combustion turbine generator of the new SCCP, however, the excitation system is assumed to be capable of providing the necessary reactive power required by the simulated scenarios while maintaining 100 percent system voltage at a frequency of 60 Hz at the generator terminals, as long as the real and reactive demands on the black start generators do not exceed the limits of the reactive capability curve.

2.5 PROTECTION, CONTROL AND SYNCHRONIZATION

No investigation into required modifications to the control system or switchyard protection schemes has been performed in support of this black start capability evaluation.

3.0 Static Motor Starting of Largest Motor

The starting of a large motor can have a brief but significant impact on the auxiliary electrical system. When voltage is applied to the terminals of a motor at rest, the motor will draw locked-rotor current (LRA), which decays toward the steady-state full-load amps (FLA) as the motor approaches running speed. This is the result of the motor torque overcoming the combined inertia of the motor and the connected load. For a low voltage induction motor, a typical value of LRA is approximately 600 percent of FLA.

In the black start scenario motor starting can result in voltage and frequency sags at the generator output, which will have a corresponding impact on the capability of the motor to start and to the operation of existing loads. The ability of the generator to accommodate starting of large motors is dependent upon the generator capacity, the response of the excitation system, the rotating inertia of the generator, and the characteristics of the motor at starting. Should a sag in voltage during motor starting result in the motor's inability to develop the torque necessary to accelerate to full speed, the motor could stall. It is necessary to analyze the worst-case motor starting scenario for the purpose of determining the required sizing and capability of the new black start generation.

As a worst-case scenario, static motor starting of the Air Compressor, the largest expected motor, was analyzed with all other loads necessary for a black start in operation, with the exception of the Unit 5 generator static starting system. Static motor starting models the motor by locked-rotor impedance during acceleration, simulating the worst impact to loads in operation at the time of motor starting. The properties of the modeled Air Compressor are 200 HP, 460V, 400 FLA, 0.91 power factor, 85 percent efficiency and 6.0 pu LRA.

3.1 STATIC MOTOR STARTING- DIESEL GENSETS

Figure 3-1 provides the bus voltage, as a percent of nominal, at each bus during starting of the Air Compressor using diesel generators as the black start generation source. The Watt and VAR demand from the black start generators and the starting motor are also displayed on each figure. The maximum demand from the black start generators during starting of the Air Compressor is 0.9 MW and 1.39 MVAR delivered. This is well within the capability curve of the proposed black start generators, as depicted in Figure 3-2. The worst-case motor terminal voltage during starting of the Air Compressor is estimated to be 90.7 percent of nominal system voltage. It is typical to specify low voltage motors rated to start at 80 percent of nameplate voltage. It is also typical to specify motor nameplate voltage below nominal system voltage. In the case of a nominal 480V system, the corresponding motor nameplate is 460V, consistent with ANSI C84.1. The result of the static motor starting analysis for the Air Compressor indicates that the momentary sag in voltage at the motor terminals is not prohibitive to the starting of the motor. The worst-case bus voltage for the 480V system is estimated to be 93.9 percent during starting of the Air Compressor. It is good practice to keep the minimum bus voltage for non-starting motors to 90 percent during transient events such as motor starting. The bus voltage of SWGR A recovers to 98.7 percent of nominal system voltage once the Air Compressor has accelerated to rated speed.

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P/Q-DIAGRAMM	CAPABILITY CURVE		
	RATING	kVA	5026
	VOLTAGE (+/- 10%)	V	13800
	FREQUENCY	Hz	60
	SPEED	1/min	900
	POWER FACTOR	-	0,80
	WINDING CODE	-	J6
	WINDING PITCH	-	5/6

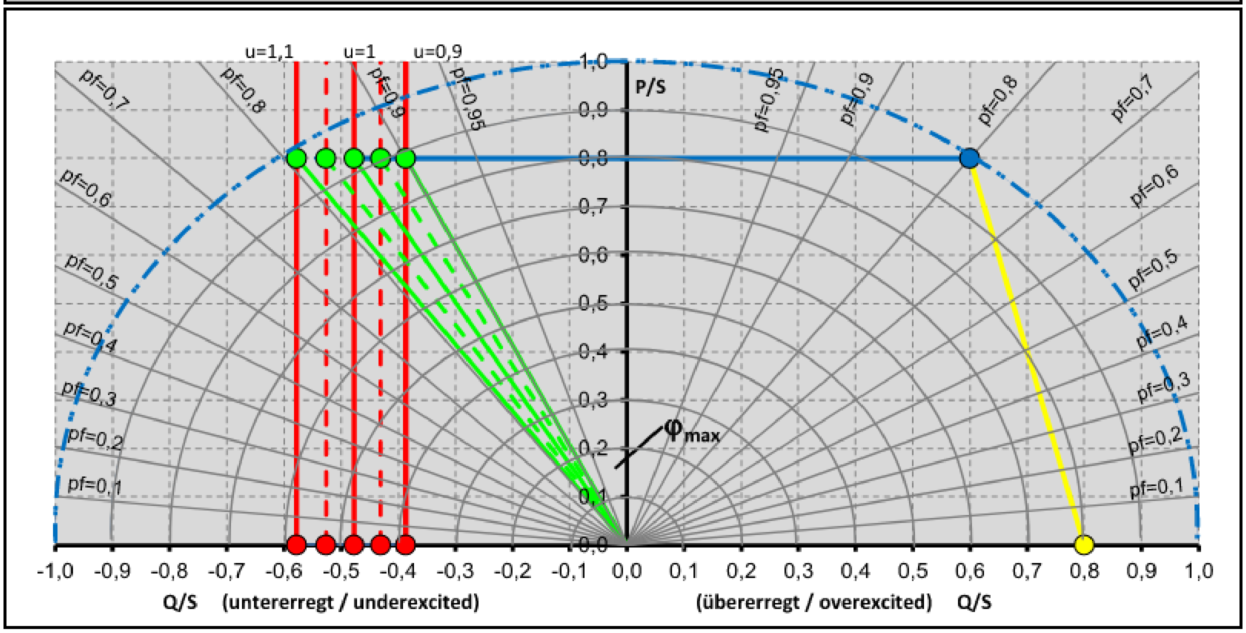

Figure 3-2 CAT C175-20 Reactive Capability Curve (TYPICAL)

3.2 STATIC MOTOR STARTING- CTG 3

Figure 3-3 provides the bus voltage, as a percent of nominal, at each bus during starting of the Air Compressor using CTG 3 as the black start generation source. The Watt and VAR demand from CTG 3 and the starting motor are also displayed on each figure. The maximum demand from CTG 3 during starting of the Air Compressor is 0.92 MW and 1.45 MVAR delivered. This is well within the capability curve of the Unit 3 Generator, as depicted in Figure 3-4. The worst-case motor terminal voltage during starting of the Air Compressor is estimated to be 92.5 percent of nominal system voltage. It is typical to specify low voltage motors rated to start at 80 percent of nameplate voltage. It is also typical to specify motor nameplate voltage below nominal system voltage. In the case of a nominal 480V system, the corresponding motor nameplate is 460V, consistent with ANSI C84.1. The result of the static motor starting analysis for the Air Compressor indicates that the momentary sag in voltage at the motor terminals is not prohibitive to the starting of the motor. The worst-case bus voltage for the 480V system is estimated to be 95.7 percent during starting of the Air Compressor. It is good practice to keep the minimum bus voltage for non-starting motors to 90 percent during transient events such as motor starting. The bus voltage of SWGR A recovers to 98.6 percent of nominal system voltage once the Air Compressor has accelerated to rated speed.

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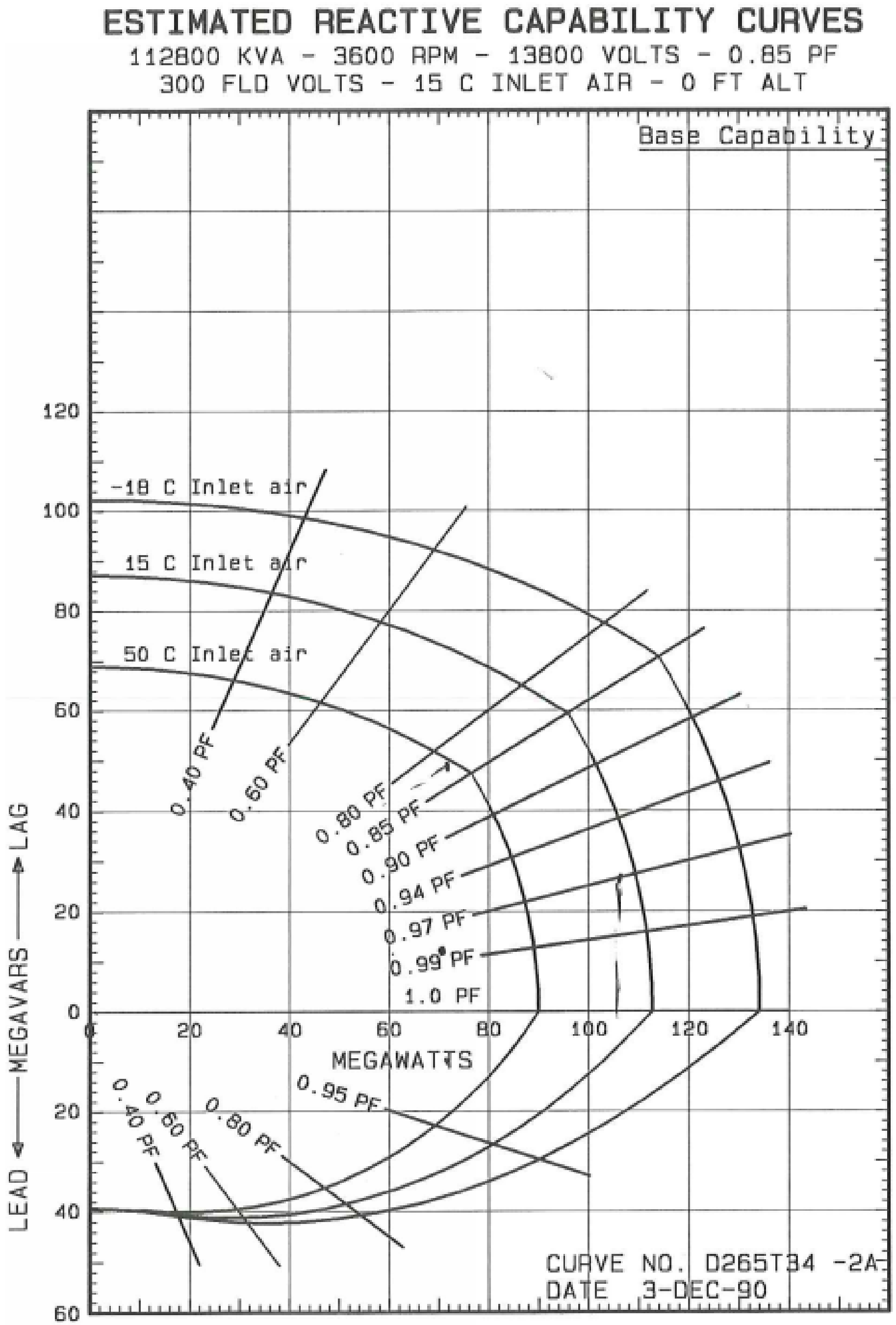

Figure 3-4 CTG 3 Reactive Capability Curve

4.0 CTG 5 Static Starting Load Flow

4.1 STATIC STARTING CTG 5- DIESEL GENERATORS

A load flow model was analyzed during the static starting of the Unit 5 combustion turbine generator using the diesel generators, as show in Figure 4-1. This scenario considered all loads necessary for black start to be in operation at the time the static starting system was energized. The maximum demand from the black start generators during static starting of CTG 5 is estimated to be 5.14 MW and 1.71 MVAR delivered. This is well within the capability curve of the C175-20 generators, as depicted in Figure 3-2.

The worst-case bus voltage during operation of the static starting system is at the 480 V system, which drops to 98.81 percent of nominal system voltage. This is well within the design limits of the system and not considered to have a prohibitive impact to operation during black start. Additionally, the static starting system operates for a short duration until the combustion turbine reaches approximately 90 percent of rated speed, at which point it is self-sustaining and the static starting system is removed from operation and the turbine control system receives control of the turbine. This duration is approximately 30 minutes or less, dependent upon starting conditions with respect to the purging of combustible gases from the hot gas path prior to ignition.

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4.2 STATIC STARTING CTG 5- CTG 3

A load flow model was analyzed during the static starting of the Unit 5 combustion turbine generator using the existing CTG 3, as show in Figure 4-2. This scenario considered all loads necessary for black start to be in operation at the time the static starting system was energized. The maximum demand from the black start generators during static starting of CTG 5 is estimated to be 4.92 MW and 1.66 MVAR delivered. This is well within the capability curve of the Unit 3 combustion turbine generator, as depicted in Figure 3-4.

The worst-case bus voltage during operation of the static starting system is at the 480 V system, which drops to 97.34 percent of nominal system voltage. This is well within the design limits of the system and not considered to have a prohibitive impact to operation during black start. Additionally, the static starting system operates for a short duration until the combustion turbine reaches approximately 90 percent of rated speed, at which point it is self-sustaining and the static starting system is removed from operation and the turbine control system receives control of the turbine. This duration is approximately 30 minutes or less, dependent upon starting conditions with respect to the purging of combustible gases from the hot gas path prior to ignition.

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5.0 Conclusions

In order to support black start capability of CTG 5 at A.B. Brown, approximately 7,186kW of black start generation will be required. With the cases evaluated in this study, (2) CAT 175-20 diesel gensets, rated at 4MW each, appear to be one option that is expected to have sufficient capacity to provide the required real and reactive power necessary to start the largest motor as well as operate the static starting system of the new SCPP. The existing Unit 3 CTG also appears to have sufficient capacity to provide the required real and reactive power necessary to start the largest motor as well as operate the static starting system of the new SCPP. The starting of the Air Compressor was conservatively simulated as a worst-case scenario, with all other loads necessary to support a black start in operation except the static starting system. For both generation options, motor terminal voltage and bus voltages were maintained within reasonable limits for the scenario of a black start. Power requirements to support Air Compressor starting and the static starting system operation were within the capability curve of both the CAT 175-20 generators and the Unit 3 Combustion Turbine Generator. Both analyses assume that the generator excitation system is capable of responding appropriately to meet the reactive power needs, and further analysis with the excitation system modeled is necessary to confirm this response.

Diesel generation of this type is a feasible solution for black starting of CTG 5 at A.B. Brown, as is black start via the existing CTG 3. Given the relatively high capital cost of two (2) CAT 175-20 diesel generators and the technical equivalency of the black starting methods, utilizing the existing CTG 3 is the recommended option for system black start of the new SCPP at A.B. Brown. In addition to the lower capital cost, the greater electrical output of CTG 3 will allow for a simpler black start procedure, as load steps can be larger and less targeted (i.e. non-critical loads can be left switched in as there is adequate excess generation to support them). Provided CenterPoint plans to continue operation of A.B. Brown Unit 3 for proposed black start required lifespan of CTG 5, this option provides the more robust and practical solution for system blackstart.

Appendix A – Preliminary Black Start Load List

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