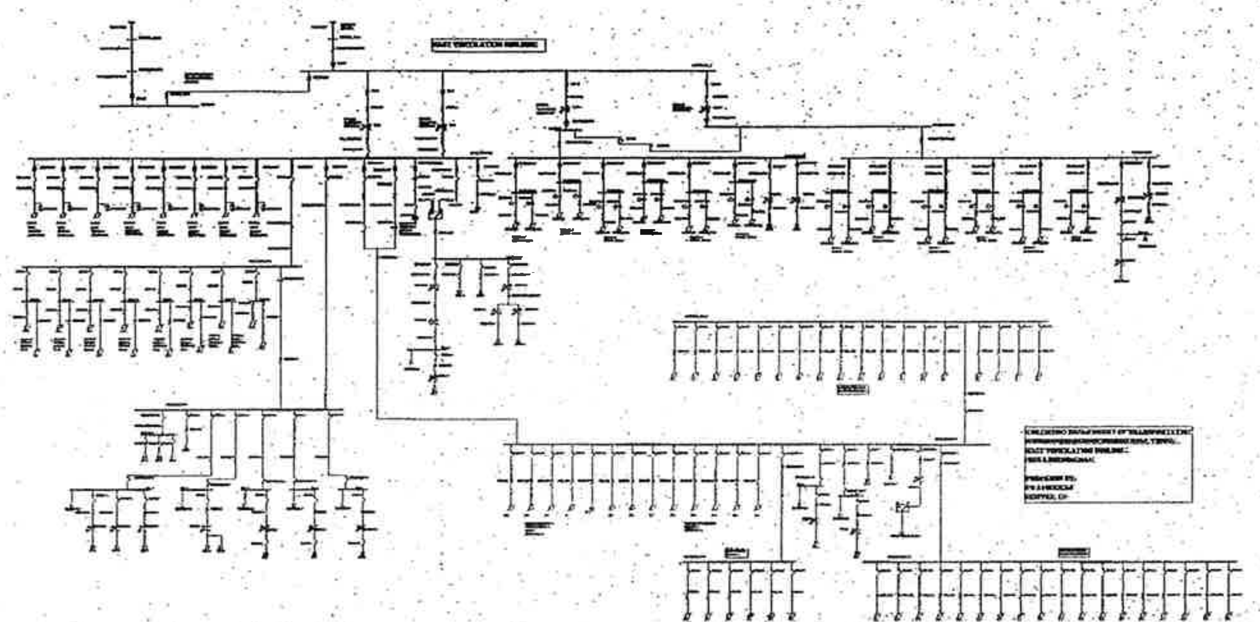
FINAL REPORT

Eisenhower/Johnson Memorial Tunnel Power Study



PB Americas, Inc.

for

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2.0 Methodology

2.1 Construction of Model

A model of the Tunnel distribution system was constructed in the SKM software using relevant electrical equipment data. See Appendices 1 and 2 for the one-line diagrams. Equipment data was obtained utilizing the previous mentioned method for data acquisition. The following is a listing of the major data that was collected:

- Utility data
- Cable length, size and installation type
- Transformer rating information
- Circuit breaker settings, switch, fuse and bus interrupting and continuous rating information.
- Electrical load data, actual or estimated

2.2 Determination of Case Studies

There are an infinite amount of particular case studies that can be evaluated; several likely scenarios were chosen to be analyzed under different operating conditions. The Utility feeders were simulated to be opened one by one to determine how the system operates under the various utility scenarios. In addition to the utility scenarios, it was important to see how the system operated under maximum loading conditions. An explanation of the case studies is described in Section 3.0.

2.3 Modeling Analysis

The data described in Section 1.3 was loaded into the SKM Systems Analysis model. Case studies were then developed to simulate various operating configurations. The case studies are described in Section 3.0. The model was then used to evaluate the different case studies for load flow and short circuit as described in Section 4.0.

2.4 Tabulation of Results

The results for the main equipment are indicated in tabular form in Section 5.0 for ease of accessibility. The complete results of each study are in appendices 3 through 10.

3.0 Case Analysis and Modeling

3.1 Case Studies

Four (4) separate case study possibilities have been examined as part of this study. For each of these cases, runs were made for load flow and short circuit levels, and protective device evaluation studies and device coordination studies were performed.

a) The East Ventilation Building with the tie circuit breaker open and the east utility connection closed.
b) The West Ventilation Building with the tie circuit breaker open and the west utility connection closed.
c) The East Ventilation Building with the tie circuit breaker closed and the east utility connection open.
d) The West Ventilation Building with the tie circuit breaker closed and the west utility connection open.

Analyses were not run for the power system being supplied by the emergency generators because the fault current contributions from the generators is much less than that from the serving utility

3.2 Model

The SKM model One Line Diagrams are in Appendices 1 and 2. It should be noted that the One Line Diagrams, although depicting all elements in the system, may at first appear confusing. This is due to the fact that they are illustrating just one of many possible cases. This is manifested by those elements not involved in the particular case being shown as "open" or "screened". All elements (Switchgear, Transformers, Panelboards, etc.) were named with the designations from their previous construction one line diagrams where the names existed.

4.0 Studies

4.1 Load Flow Study

The load flow study was completed to determine if the various electrical equipment (conductors, motor control centers, panelboards, transformers, etc) are sized accordingly to safely carry the defined continuous demand loads. Each component has been compared to both the listed equipment rating and voltage drop thresholds.

A) Voltage Drop
The load flow study was modeled under various load conditions of ventilation fans running. The results of the load flow studies are in Appendices 3 through 6.
The voltage profile is shown as "Bus Volts in %". The magnitude of the voltage at a bus is expressed as a percentage of the nominal voltage. Thus, a voltage of 97% at a typical 24.9kV bus would be 24.15kV, 2.33kV at a typical 2.4kV bus, or 466 Volts at a 480 Volt bus.

B) Conductor Ampacity
The conductors that connect a power system together are an integral part of the system. Therefore, any complete analysis of a power system must include an analysis of its conductor ampacities. Ampacity is the current in amperes a conductor can carry continuously under the conditions of use without exceeding its temperature rating. The ampacity of a conductor depends on a number of factors. Among these factors are the following:

a) Ambient temperature
b) Thermal characteristics of the surrounding medium
c) Heat generated by the conductor due to its own losses
d) Heat generated by adjacent conductors.

The National Electrical Code takes these factors into account in their tables of conductor ampacities. For the system under consideration here, the conductors were assigned "Allowable Ampacity" figures based on their installation configuration. These values were compared to the values calculated to assure that all cables were operating within their ampacities.

C) Transformer and Bus Loading
The calculation software flags any transformer or bus that is loaded to greater than 90% of its capacity for further investigation. For the power system under consideration in this Report, no transformer or bus was flagged.

4.2 Short Circuit Study

Three-phase and line-to-ground fault studies per ANSI Standard C37 were performed. Each low and medium voltage bus in the system was faulted, in turn, as were the low voltage motor control center buses and panel boards. This study calculates the momentary symmetrical and asymmetrical rms (root-mean-square, which is a means of expressing the effective value of an alternating current), momentary asymmetrical crest, interrupting symmetrical rms, and interrupting adjusted rms short-circuit currents at faulted buses. Generators and motors are modeled by their positive sequence sub transient reactance's, which best represent their contributions in the first few cycles of a fault.

The "Fault Rating" is the interrupting capacity of each electrical equipment item in the study. The "Fault Duty" is the calculated sum total of all sources of short circuit at that particular equipment bus. In order to determine the adequacy of the fault rating of the electrical equipment, a criteria threshold of 90% of fault rating was established. We chose 90% to allow for expansion or other conditions that would increase the fault duty.

The following lists a few such possible conditions:

- Xcel Energy modifies their circuits such that the available short circuit is increased.
- Load is added to the distribution system, particularly motor loads.

Any fault duty exceeding 90% of the fault rating of equipment was considered to be a danger to equipment and personnel.

4.3 Protective Device

It is important that every protective device has a withstand rating greater than the available fault current for any particular scenario. The withstand rating of a device is usually noted on the device and is significantly greater than the normal full load rating. A withstand rating lower than available short circuit current at the device location would subject a protective device to severe damage due to the large amount of energy that a fault current can provide.

4.4 Coordination

Selecting proper protection devices will allow a particular sequence of overload protection to occur. An overload device should open and de-energize the circuit as the circuit exceeds its rated capacity. Ideally, the protective device in the circuit which is located upstream, closest to the incident would be the only one to open. However, several more distantly located upstream protection devices could open and de-energize greater sections of the electrical system if not coordinated. To assure that the electrical system isolates the particular overload, time-current (TC) curves are used. The time-current curves will show the settings of the multiple protection devices on a circuit and allow an analysis to be performed.

5.0 Results

5.1 Load Flow Study

The voltage drops at the various points in the system are tabulated in the Tables contained in Appendices 3 through 6. The voltage drops are all in percent of the nominal voltage rating.

5.2 Short Circuit

The following tables summarize the available fault current at various points in the system. The full fault current results are contained in Appendices 7 through 10. All currents are in amperes. "X/R" is the ratio of the reactive component to the resistive component of the fault current. The X/R ratio determines the extent and duration of the asymmetrical component of the current.

TABLE ONE

******EAST VENTILATION BUILDING FAULT ANALYSIS REPORT SUMMARY******

BUS NAME	VOLTAGE	AVAILABLE FAULT CURRENT				Existing min. kAIC Ratings
	L-L	THREE PHASE	X/R	LINE/GRND	X/R	
2.4kV_MCC_1A	2400	11201.1	3.5	9957.03	4	48.112
2.4kV_MCC_1B	2400	11202.7	3.5	9933.26	4	48.112
480V_MCC_NO4N	480	2475.3	0.3	1444.54	0.3	42
480V_BUS_NO_1	480	54271.2	2.3	57957.52	2.3	42
480V_MCC_NO4S	480	2475.3	0.3	1444.54	0.3	42
480V_MCC_NO_1	480	30838.6	1.6	18723.01	1.2	42
480V_MCC_NO_2	480	39315.3	2	35414.79	1.7	42
480V_MCC_NO_3	480	12614.7	1.5	8613.72	1.3	42
480V_MCC_NO_5	480	7029.4	0.8	4400.52	0.6	42
BUS-24.9kV_EAST	24940	1704.9	1.4	1079.93	1.1	25
BUS-E1	480	29264.7	1.5	17724.75	1.2	* n/a
BUS-E2	480	29264.7	1.5	17724.75	1.2	* n/a
BUS-E3	480	29264.7	1.5	17724.75	1.2	* n/a
BUS-E4	480	29264.7	1.5	17724.75	1.2	* n/a
BUS-EFAN5A	2400	11178.3	3.5	9905.78	4	* n/a
BUS-EFAN5B	2400	11173.4	3.5	9903.23	4	* n/a
BUS-EFAN6A	2400	11178.3	3.5	9905.78	4	* n/a
BUS-EFAN6B	2400	11173.4	3.5	9903.23	4	* n/a
BUS-EFAN7A	2400	11178.3	3.5	9905.78	4	* n/a
BUS-EFAN7B	2400	11173.4	3.5	9903.23	4	* n/a
BUS-REGULATOR	24940	1208.5	1	899.39	1	25
BUS-S1	480	29264.7	1.5	17724.75	1.2	* n/a
BUS-S2	480	29264.7	1.5	17724.75	1.2	* n/a
BUS-S3	480	29264.7	1.5	17724.75	1.2	* n/a
BUS-S4	480	29264.7	1.5	17724.75	1.2	* n/a
BUS-SFAN5A	2400	11179.7	3.5	9882.2	4	* n/a
BUS-SFAN5B	2400	11175	3.5	9879.71	4	* n/a

BUS-SFAN6A	2400	11179.7	3.5	9882.2	4	* n/a
BUS-SFAN6B	2400	11175	3.5	9879.71	4	* n/a
BUS-SFAN7A	2400	11179.7	3.5	9882.2	4	* n/a
BUS-SFAN7B	2400	11175	3.5	9879.71	4	* n/a
BUS-TIE	2400	11282.2	3.5	10104.56	4.2	60.14
BUS-UTILITY_EAST	24940	1710	1.4	1083.41	1.2	25
BUS-UTILTY_WEST	24940	1133	1	820	1	25
BUS_DP_EV	480	9441.6	0.7	6051.1	0.5	65
LGT_BUS	480	22456.5	1.8	17254.96	1.5	65
MCC_1A_1B_TIE	2400	11280.3	3.5	10078.07	4.2	60.14
NCS-1E	480	3583	2.4	3756.02	2.7	14
No_2	480	19116.2	1.2	13782.18	0.9	14
No_3	480	7637.8	0.4	4680.52	0.3	10
No_4	480	14349.8	0.7	9548.78	0.6	14
No_5	480	12585.3	0.6	8175.39	0.5	14
No_6	480	7619.9	0.9	4843.38	0.7	14
No_7	480	5607.3	0.6	3432.3	0.5	10
P1ES	480	19116.2	1.2	13782.18	0.9	25
SEN_1	480	1637.6	2.1	0	2.1	14
WEST_VB	24940	1206.2	1	897.76	1	25

****FAULT ANALYSIS REPORT COMPLETE****

TABLE TWO

****WEST VENTILATION BUILDING FAULT ANALYIS SUMMARY****

BUS NAME	VOLTAGE	AVAILABLE FAULT CURRENT				Existing min. kAIC Rating
	L-L	THREE PHASE	X/R	LINE/GRND	X/R	
2.4KV_MCC_A	2400	11193.2	3.6	9936.2	4.1	48.12
2.4kV_MCC_1A	2400	11191.7	3.6	9959.95	4.1	48.12
2.4kV_MCC_1B	2400	11269.7	3.7	10079.97	4.3	48.12
480V_MCC_NO4N	480	2467.7	0.3	1437.44	0.3	42
480V_BUS-NO_1	480	66766.0	2.2	72829.7	2	42
480V_MCC_NO_1	480	36378.6	1.6	20315.15	1.2	42
480V_MCC_NO_2	480	45312.2	1.8	40177.11	1.5	42
480V_MCC_NO_3	480	13052.4	1.5	8795.74	1.2	42
480V_MCC_NO4S	480	2467.7	0.3	1437.44	0.3	42
480V_MCC_No_5	480	7114.6	0.7	4412.79	0.6	42
BUS-24.9kV_W	24940	1704.7	1.5	990.64	1.2	25
BUS-DP_WV	480	9630.8	0.6	6102.29	0.5	65
BUS-E1	480	34261.5	1.5	19142.92	1.1	* n/a
BUS-E2	480	34261.5	1.5	19142.92	1.1	* n/a
BUS-E3	480	34261.5	1.5	19142.92	1.1	* n/a
BUS-E4	480	34261.5	1.5	19142.92	1.1	* n/a
BUS-EFAN5A	2400	11275.4	3.6	9954.78	4.1	* n/a
BUS-EFAN5B	2400	11270.4	3.6	9952.23	4.1	* n/a
BUS-EFAN6A	2400	11275.4	3.6	9954.78	4.1	* n/a
BUS-EFAN6B	2400	11270.4	3.6	9952.23	4.1	* n/a

BUS-EFAN7A	2400	11275.4	3.6	9954.78	4.1	* n/a
BUS-EFAN7B	2400	11270.4	3.6	9952.23	4.1	* n/a
BUS-REGULATOR	24940	1706.7	1.5	991.97	1.2	25
BUS-S1	480	34584.5	1.5	19175.3	1.1	* n/a
BUS-S2	480	34584.5	1.5	19175.3	1.1	* n/a
BUS-S3	480	34584.5	1.5	19175.3	1.1	* n/a
BUS-S4	480	34584.5	1.5	19175.3	1.1	* n/a
BUS-SFAN5A	2400	11276.7	3.6	9930.91	4.1	* n/a
BUS-SFAN5B	2400	11271.9	3.6	9928.42	4.1	* n/a
BUS-SFAN6A	2400	11276.7	3.6	9930.91	4.1	* n/a
BUS-SFAN6B	2400	11271.9	3.6	9928.42	4.1	* n/a
BUS-SFAN7A	2400	11276.7	3.6	9930.91	4.1	* n/a
BUS-SFAN7B	2400	11271.9	3.6	9928.42	4.1	* n/a
BUS-TIE	2400	11381	3.7	10155.1	4.3	60.14
BUS-UTILITY_EAST	24940	1232.0	1	915	1	25
BUS-UTILITY_WEST	24940	1727.4	1.5	1005.51	1.2	25
EAST_VB	24940	1227.2	1	912.63	1	25
LGT_BUS	480	24200.6	1.7	18228.51	1.4	65
No_2	480	20258.8	1.1	14301.86	0.9	**14
No_3	480	7712.5	0.3	4682.02	0.3	14
No_4	480	14913.4	0.7	9721.4	0.5	14
No_5	480	12971.2	0.6	8277.2	0.5	14
No_7	480	5640.8	0.5	3428.87	0.5	10
No_8	480	5640.8	0.5	3428.87	0.5	14
P1WS	480	20384.2	1.1	14323.26	0.9	25
SCN-1	480	1633	2.1	0	2.1	14
SWN-1	480	1633	2.1	0	2.1	65

****FAULT ANAYSIS REPORT COMPLETE****

* n/a (not applicable) – not rated
** The existing available short circuit fault was calculated to be slightly higher than the equipment rating. However, the calculation software was unable to include the existing current limiting bus duct supplying the feeders to this panelboard via bus 480V_MCC_NO2. Estimating the inclusion of the current limiting bus duct in the circuit would allow the panelboard to be sufficiently rated.

5.3 Protective Device

The ratings of the protective devices throughout the system and the calculated fault duty that they would be subjected to under a fault condition are contained in Tables One and Two, above.

5.4 Coordination

The time-current curves in Appendix 13 show representative coordination curves for the power system.

6.0 Conclusions and Recommendations

6.1 Conclusions

Generally, the power systems at the Eisenhower/Johnson Memorial Tunnels are operating within the parameters of the system.

6.1.1 Load Flow Study

All of the equipment in the electrical systems is operating within their design limits. The cables and equipment are carrying less current than their rated ampacities would allow, and the voltage losses in the system are within acceptable limits.
The conventionally accepted criterion for load flow is to have a voltage drop from incoming power to the load of not more than five percent. The five percent is normally calculated as not more than two percent on the feeder to the distribution switchboard or panel and not more than three percent on the branch circuit to the load. Within this range, most electrical equipment will be operating in its design range.

6.1.2 Short Circuit Study

Except as noted below, the electrical equipment was found to have sufficient interrupting ratings that can safely and adequately survive the worst case conditions of a fault. Although existing data for the 24.9kV switches at the facility were not available, the fault currents available at the 24.9kV switches were well within the ratings of normally encountered equipment of this type.
The one area where the fault current exceeds the rating of the equipment is the main bus of the 480 Volt switchgear in each ventilation building. With the two 24.9kV to 480 Volt transformers operating in parallel, the available fault current exceeds the rating of the switchgear. The likely reason for this is that when the original installation was constructed, it was intended that the 480 Volt switchgear installed for the North Bore would be expanded for the South Bore, and that the final switchgear would operate in a conventional Main-Tie-Main arrangement. In that type of arrangement, the transformers do not operate in parallel. Essentially, one half of the intended final switchgear was installed, including one main circuit breaker and the tie circuit breaker, and the 480 Volt transformers were connected as supplies to the main circuit breaker and the tie circuit breaker, used temporarily as the second main circuit breaker. It was intended that the South Bore construction would install the remaining half of the switchgear including the second main circuit breaker, and the tie circuit breaker would serve its intended function. However, when the South Bore was constructed, the electrical system for the ventilation was installed to operate at 2400 Volts, so the 480 Volt switchgear remained as it had been installed for the North Bore, with effectively two main circuit breakers and no tie circuit breaker. Without a tie circuit breaker, the two transformers operate in parallel, which substantially increases the fault current available.

The new 480 Volt switchgear, for which design is about to commence, will provide a normal Main-Tie-Main arrangement, which will eliminate this situation.
The current-limiting fuses that were installed in the main 480 Volt switchgear reduce the fault current available to downstream equipment to levels that are within the ratings of the equipment. If these fuses had not been installed, the fault currents available at various pieces of equipment would exceed the ratings of the equipment.

6.1.3 Protective Device Study

All of the protective devices in the system are being applied within their ratings.

6.1.4 Coordination Study

The overcurrent devices in the system provide acceptably good coordination. During a fault at any location in the system, only the device closest to the fault will respond to the fault by tripping. This will leave the remaining system operating and minimize the disruption to the electrical power system. Examples of time current curves illustrating this can be found in Appendix 13.

6.2 Recommendations

With the exception of the fault current available at the 480 Volt main switchgear within each ventilation building, which is currently being addressed, the electrical power system at the Eisenhower/Johnson Memorial Tunnels is operating within acceptable parameters, and no other changes to the system are required at this time.

6.3 General

For reference purposes, the input data utilized for this study is included in Appendices 11 and 12.