EWPP Power Failure Analysis

City of Houston

Project No. 153662

February 17, 2023

EXCERPT FROM

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prepared for

City of Houston
Houston, Texas

Project No. 153662

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prepared by

Burns & McDonnell Engineering Company, Inc.
Houston, Texas

LIST OF ABBREVIATIONS

Abbreviation	Term/Phrase/Name
Burns & McDonnell	Burns & McDonnell Engineering Company, Inc.
COH	City of Houston
CT	Current Transformer
EWPP	East Water Purification Plant
GST	Ground Storage Tanks
HS	High Service
HP	Horsepower
kV	Kilovolt
MG	Million Gallons
MGD	Million Gallons per Day
PSI	Pounds per square inch
PT	Potential Transformer
SCADA	Supervisory Control and Data Acquisition
V	Volt

1.0 EAST WATER PURIFICATION PLANT POWER FAILURE EVALUATION

1.1 Introduction and Summary

Burns & McDonnell was requested to assist the City of Houston (COH) with a root cause analysis of the two failure events that occurred at the East Water Purification Plant (EWPP) on November 27, 2022. The two (2) events led to a boil water advisory being issued due to system pressure loss. This report details the specifics of the events and offers insight into the causes behind them.

The report is based on information gathered during visits to the EWPP to walk down the equipment, interviews with COH staff and contractors, COH provided reports, relay settings, event files and waveforms, reference papers on the subject matter, and Burns & McDonnell senior staff experience.

The remainder of this Section 1.1 provides a summary of the details of the events and their causes that are covered in depth in the body of the report. Simplified one-line diagrams showing the sequence of events are in Appendix [A].

The EWPP is normally served by the parallel operation of two (2), [redacted] Main Power Transformers, T1 and T2. On the date of the events, Transformer T1 was not providing power to the facility, as it was out of service for maintenance leaving the facility to be electrically fed via a single source from Transformer T2. Normally open, the [redacted] switchgear bus ties at Plant 1/2 and Plant 3 were closed to allow both plants to be electrically fed from a single source.

The initial event (Event 1) which was the first outage of Plant 1/2 occurred at 10:10 AM and was the result of a three-phase balanced fault detected by relaying for Plant 1/2 Unit 19 which feeds Transformer TR-17. The original Transformer TR-17 was replaced on December 21, 2022, and therefore was not available for inspection. One possible reason for the first fault is a transient over voltage caused turn-to-turn winding failure within Transformer TR-17 which then led to the balanced fault. Dev Paul, Appendix [O], describes transient overvoltage's caused by surge arresters and current chopping as possible causes of turn-to-turn transformer insulation failure which is a common cause for transformers to fail (this is currently conjecture as we have no hard evidence of this at this time without visual inspection and testing of the original transformer).

Three (3) switchgear breakers tripped within milliseconds (ms) of each other because of the detected first fault, two (2) [redacted] feeder breakers, Units 14 and 19 at Plant 1/2 and the [redacted] switchgear breaker Unit 2 located in Plant 3. Since Plant 1/2 and Plant 3 were fed electrically via a single source due to

maintenance at the time of Event 1, the Plant 3 Unit 2 breaker trip resulted in a total loss of all power to Plant 1/2.

The three (3) switchgear breakers tripped within milliseconds of each other due to the current sensed by each respective relay. The settings were coordinated properly, but with greater coordination separation than may be necessary. A full coordination study would be necessary to determine how closely the relays may be coordinated.

The settings for Plant 1/2 Units 14 and 19 were set sensitively and thus, tripped rapidly. The current sensitivity differs between Plant 3 Unit 2 and the Plant 1/2 relays. The current sensing device at Plant 3 Unit 2 had better accuracy of measurement, which caused Plant 3 Unit 2 to interpret the fault signal with better accuracy. Event 1 was caused by largely separated yet properly coordinated relay settings and current sensing accuracy and the solution would be to tighten the coordination between relays or use a more sophisticated relaying system.

During this Event, Plant 3 remained in service. At the time of Event 1, the Plant 1/2 operating pressure dropped from 86 PSI to 0 PSI and the Plant 3 operating pressure dropped from 69 PSI to 55 PSI.

At 10:20 AM, Operations started HS Pump 405 in Plant 3 to help bring pressure up.

At 11:00 AM, EWPP operators attempted to restore power to Plant 1/2 by closing the Plant 3 Unit 2 switchgear breaker which is a main power feed to Plant 1/2. Immediately upon closure of the Plant 3 Unit 2 switchgear breaker, the main [redacted] feeder cables from Plant 3 that feed Plant 1/2 experienced an intermittent ground fault, indicated as Event 2. Of note, an intermittent ground fault occurs when current arcs for a period and then extinguishes. In his paper on the subject, Norman T. Stringer describes how underground cable splice failures tend to fail as intermittent ground faults as was the case in this event. His paper is included in Appendix [M]. The Plant 3 Unit 2 microprocessor based relay sensed the fault but continuously picked up and dropped out, resetting itself due to the intermittent nature of the fault. This resulted in Plant 3 Unit 2 circuit breaker not tripping. At the same time Transformer T2 electromechanical relaying (CO-7) located in the main [redacted] substation control and relaying panels sensed the intermittent ground fault. As electromechanical CO-7 relays are based on an induction disk, they do not reset themselves in the same way the microprocessor based relaying does during intermittent faults. The result was 11 seconds after the Plant 3 Unit 2 breaker was closed at 11:00 AM, the [redacted] ring bus position protection and control panel electromechanical relays (CO-7) tripped substation circuit breakers 130 and 140 taking both Plant 1/2 and Plant 3 off-line. Operating pressure for the EWPP facility then dropped to 0 PSI.

After Event 2, the EWPP operator isolated the Event 2 fault by opening Plant 3 Units 2 and 3 and Plant 1/2 Unit 2. Plant 1/2 Unit 19 remained open as a result of Event 1. Plant 3 Unit 34 was closed restoring power to Bus 1 in the [redacted] switchgear at Plant 3. Then, Plant 1/2 Unit 31 was closed restoring power to the Plant 1/2 [redacted] switchgear. Power was restored to HS Pump C-6 fed from Plant 1/2. These restoration actions were completed by approximately 11:30 AM.

Plant 3 HS Pumps 402 and 407 were restored at approximately 12:40 PM with the clearing of trip flags on the substation electromechanical relays and closing of substation breakers 130 and 140.

By approximately 3:30 PM operating pressure was restored to 75 PSI.

By 6:40 PM HS Pumps 402, 406, 407 in Plant 3, and C-2 in Plant 1/2 were operating.

There were several primary drivers that ultimately led to the total loss of power that resulted in a loss of system pressure and thereafter the regulatory requirement to issue a boil water notice.

- Evidence exists that the three-phase balanced fault detected by relaying in Plant 1/2 Unit 19 was the result of a failure of Transformer TR-17. The cause of the three-phase balanced fault cannot be definitively known without inspection and testing of the original Transformer TR-17. In the EWPP case, the three-phase and ground time over current, calculated residually were engaged. In addition, evidence exists of a blown fuse on surge protection equipment on the TP switchboard downstream of TR-17, Appendix [D]. It is possible that a transient overvoltage caused the initial three-phase balanced fault. The transformer was replaced on December 21, 2022.
- Evidence suggests the three-phase balanced fault detected by relaying in Plant 1/2 Unit 19 initiated the [redacted] cable failure at Transformer TR-17. The age of the cable is over 45 years old and beyond the normal end of life expectancy. It appears to have worn through the insulating jacket over time with exposure to water, ultimately faulting to ground on a cable support rack during the three-phase balanced fault on the primary side of Transformer TR-17, Appendix [N].
- The [redacted] cable failure on the feeder between Plant 3 [redacted] switchgear Unit 2 and Plant 1/2 [redacted] switchgear Unit 2 was the result of a fault at a splice point inside EMH-10 manhole located on the East side of Plant 1/2 [redacted] switchgear building while submerged, Appendix [E]. This cable was originally installed in 1975 and spliced in 2012 when Plant 1/2 [redacted] switchgear was replaced. The cable failed at a vulnerable splice point. Intermittent ground faults are common when medium voltage cables are spliced in underground installations for a long time, Appendix [M].

- There were multiple relay coordination issues as noted below:
  - Event 1:
    - The Plant 1/2 Unit 19 switchgear should have cleared the detected three-phase balanced fault before Plant 3 Unit 2 [redacted] switchgear tripped.
  - Event 2:
    - The Plant 3 Unit 2 [redacted] switchgear should have cleared the intermittent ground fault on the cable between Plant 3 Unit 2 and Plant 1/2 Unit 2 before the ground relaying at the main substation called for trip of the substation breakers.
- Due to maintenance in the high voltage substation feeding EWPP, the system was in a single electrical power source configuration on the date these events occurred.
  - The electrical system is designed to have two (2) separate high voltage [redacted] power transformers, each feeding separate loads isolated from each other so that the loss of one transformer does not result in a total facility outage.

A timeline of the events is provided in Figure 1 below.

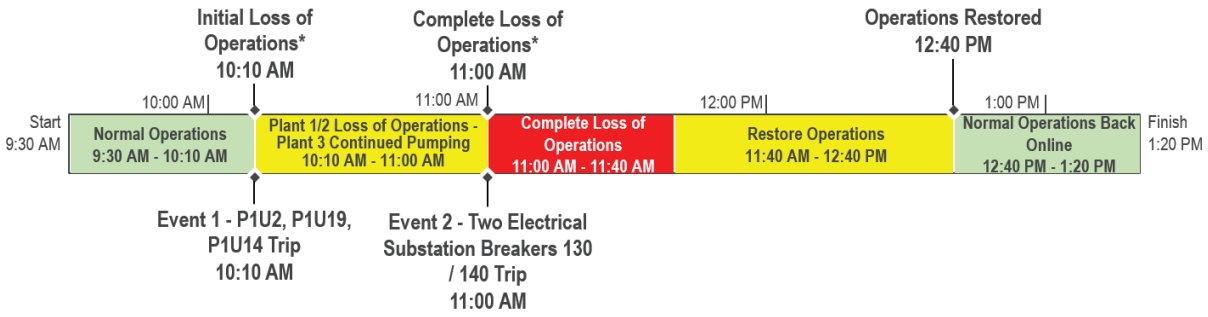

Figure 1: Timeline of events from November 27, 2022

Under an Emergency Purchase Order (PO), Burns & McDonnell was directed to focus solely on the failure diagnosis and not requested to offer recommendations for prevention of future similar occurrences. Therefore, this report is retrospective only and does not attempt to outline solutions. This service can be provided upon request.