Operating Experience Summary

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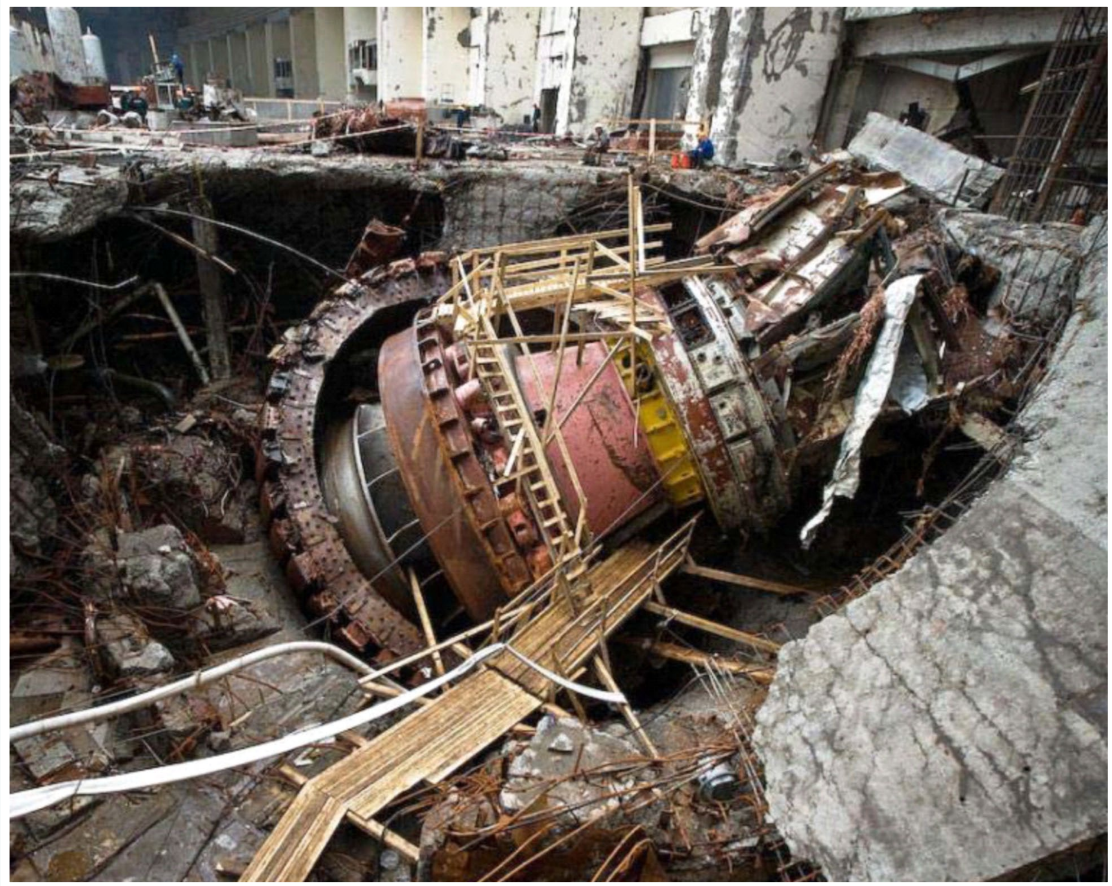

Russian Hydroelectric Plant Accident: Lessons to Be Learned

1

On August 17, 2009, at the Sayano-Shushenskaya Hydroelectric Plant in Khakassia, Russia, a catastrophic "pressure surge" (i.e., water hammer) occurred in Turbine 2 (one of 10 turbines), ejecting the turbine and all its equipment (approximately 900 tons of material); flooding the engine and turbine room; severely damaging four other turbines; and causing a transformer explosion. Figure 1-1 shows some of the destruction to the turbines. The entire plant output (6,400 megawatts) was lost, leading to a widespread power failure in the area. There were 74 fatalities as a result of the accident and one person was listed as missing, but presumed dead. The accident also resulted in an oil spill that released at least 40 tons of transformer oil into the Yenisei River, killing approximately 400 tons of cultivated trout in two riverside fisheries.

At 29 years and 10 months, Turbine 2 was at the end of its expected 30-year life. However, there had been numerous problems with the turbine since the 1980s, when issues with seals, bearings, and turbine vibration were identified. During repairs in 2000, some of these same problems were found. At that time, cavities up to 12-millimeters deep and cracks up to 130-millimeters long on the turbine wheel and defects in turbine bearings were repaired; however, in 2005 similar defects were again evident.

From January to March 2009, Turbine 2 underwent scheduled repairs, including weld repairs of cracks and cavities in turbine blades. However, the turbine wheel was not properly rebalanced after these repairs were completed and the turbine vibration increased. While the vibration did not initially exceed the technical limit, beginning in July 2009, the levels of vibration began to increase quickly until the accident.

Figure 1-1. Turbine hall destruction

When the accident occurred, turbine vibrations were more than five times the specified vibration limit. This high vibration accelerated bolt fatigue, and the functional capacity of the bolts was lost. Nuts on at least 6 of the bolts that held the turbine cover in place were missing and, of 49 bolts that investigators evaluated, 41 had fatigue cracking, with 9 bolts showing fatigue damage that exceeded 90 percent of the total area. Figure 1-2 shows one of the degraded bolts recovered after the accident.

Figure 1-2. Degraded bolt found post-accident

Investigators concluded that a combination of water pressure, which created an enormous uplifting force, and the deficient bolts resulted in the turbine, along with its cover and generator rotor, moving upward, destroying the machinery. Figure 1-3 shows the damaged turbine generator. At the same time, pressurized water flooded the turbine room and continued damaging other areas of the plant, including additional turbines. The flood of water severely damaged the main concrete structure of the powerhouse, which included partial collapse of the roof and walls.

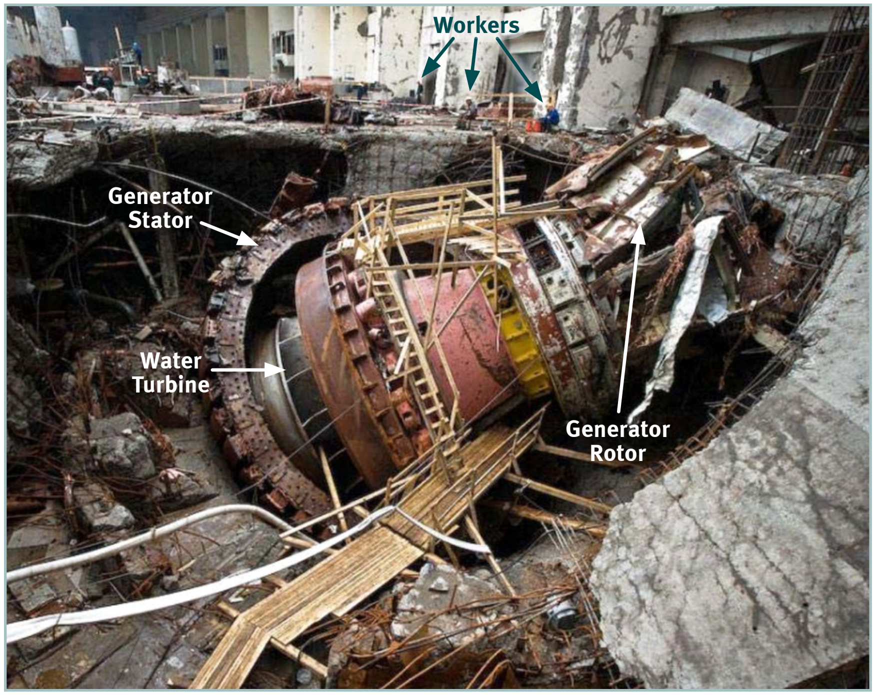

Figure 1-3. Damaged turbine generator
(workers identified for perspective only)

What can be learned from this event?

The Department of Energy External Events Team of the Operating Experience Committee, with significant support from the Waste Isolation Pilot Plant Washington TRU Solutions Lessons Learned Working Group, reviewed independent analysis reports from the U.S. Navy Lessons Learned, Brazilian Engineering, and other analysis documents from Russia, for lessons that would be pertinent to DOE. The result of this review is a multi-slide presentation of the event, with numerous pictures, followed by the lessons to be learned and a number of important questions to be considered by DOE sites.

The lessons learned document on this serious accident is available at http://www.hss.energy.gov/csa/oec/docs/LL_from_Accident_at_Russia's_Hydroelectric_Plant.pdf.

KEYWORDS: Industry, Russia, hydroelectric plant, turbine, vibration, cracks, degraded bolts, water hammer, flooding, fatalities

ISM CORE FUNCTIONS: Analyze the Hazards, Develop and Implement Hazard Controls, Perform Work within Controls, Provide Feedback and Improvement

Incorrect Jumper Cable Connection on Battery Causes Arc Flash and Electrical Burn

2

On November 16, 2009, at the Idaho National Laboratory Advanced Test Reactor (ATR), an electrician (Electrician 1) short-circuited a large battery bank while connecting jumper cables across battery cells, resulting in an arc flash. The electrician was not wearing electrical PPE (e.g., rubber gloves), and sustained first- and second-degree burns to both of his hands. (ORPS Report NE-ID--BEA-RTC-2009-0002; final report issued January 14, 2010)

A work order had been issued to change a 120-cell, 250-volt DC, battery bank into two parallel 60-cell, 120-volt banks, so that a 130-volt charger could be used to charge the batteries. Two electricians were assigned to connect jumper cables to parallel the two, 60-cell battery banks. Figure 2-1a is a diagram showing the correct connections; Figure 2-1b shows how the electricians believed the connections were to be made.

Electrician 1 was going to connect positive to positive and negative to negative on battery cells 1 and 120, while the second electrician (Electrician 2) made the same connections on cells 60 and 61. Although they planned to do the connections simultaneously, Electrician 1 had only connected his cable to the positive terminal of cell 120 when Electrician 2 completed putting his jumpers between cells 60 and 61. Electrician 2 had connected the positive terminal of cell 60 to the positive terminal of cell 61 and then connected the two negative terminals of these cells together (Figure 2-2). This incorrect connection electrically paralleled only cells 60 and 61, which then configured the two battery banks as one battery with 118 cells in series.

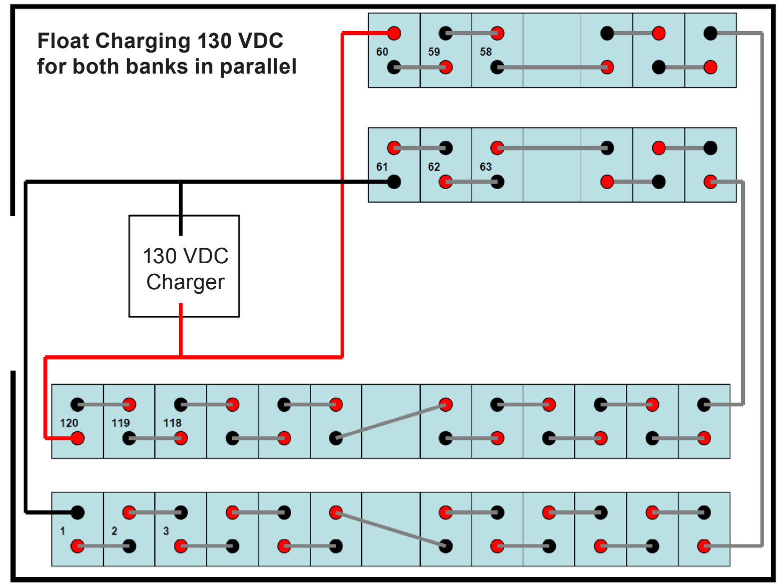

Figure 2-1a. Correct connections

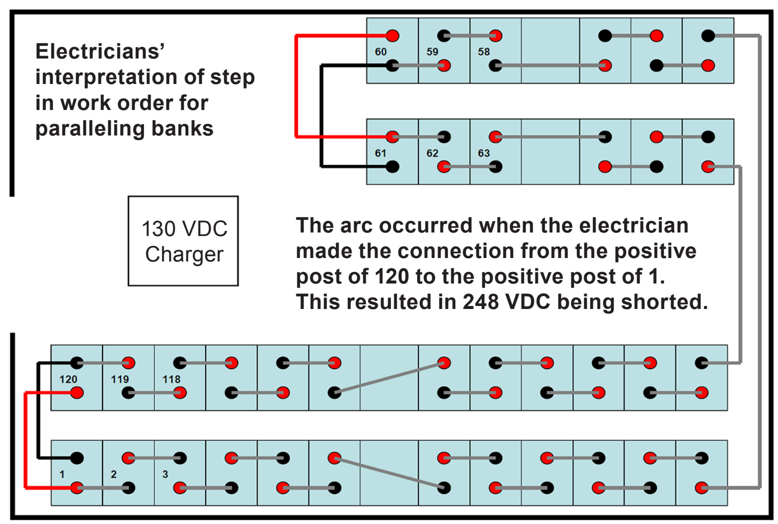

Figure 2-1b. Electricians' interpretation of correct connections

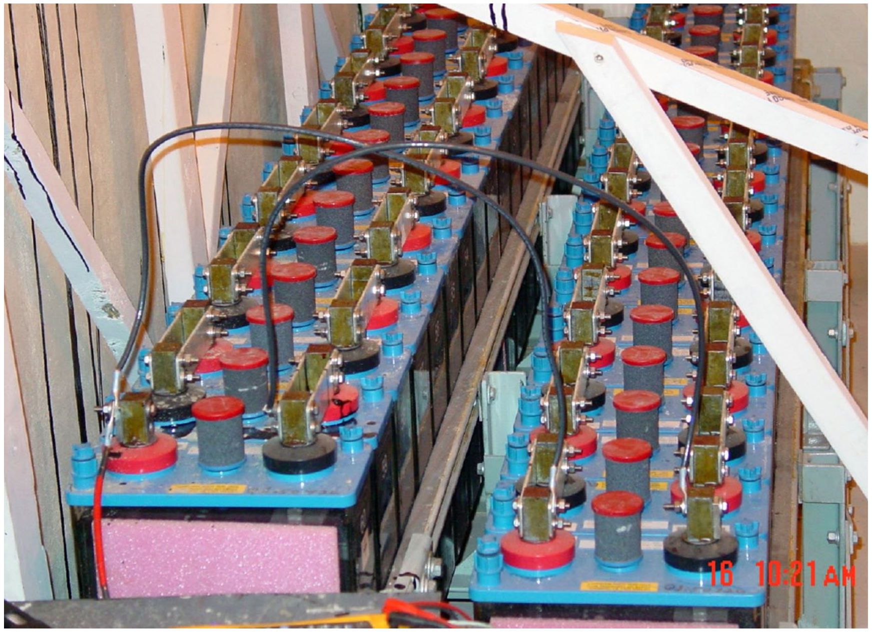

Figure 2-2. Incorrect connection of cells 60 and 61

When Electrician 1 attempted to connect by hand his jumper cable, which was already connected to the positive terminal of cell 120, to the positive terminal on cell 1, the resulting arc flash burned his hands and damaged the battery cell. Figure 2-3 shows the connection made by Electrician 1 and the results of the arc flash.

Although both electricians normally performed battery maintenance, neither had the knowledge or experience to properly connect the two battery banks in parallel. They did not use a meter to test the voltage at the terminals to determine the electrical potential from terminal to terminal and to ground before they made the electrical connections. Although neither electrician realized that they had incorrectly changed the configuration of the battery banks such that 248 volts DC existed at the terminals, a check with a volt meter would have identified the hazard. The electricians also connected the jumpers to the wrong terminals, those terminals with intercell connectors attached, as shown in Figure 2-3. Instead, they should have connected the jumpers to the load terminals on the batteries, which do not have intercell connectors.

Figure 2-3. Connection of cells 1 and 120 and aftermath of arc flash

Investigators determined that because Electrician 2 had incorrectly connected the two cells in parallel, Electrician 1 short-circuited the battery banks when he connected the jumper cable. Investigators concluded that, in addition to the lack of experience, work planning and control issues contributed to this event.

During planning, the task was identified as routine work instead of a reconfiguration of the battery banks, which constituted a temporary modification. This allowed a walkdown of the job to be performed without an evaluation by an electrician and allowed the task to be performed without adequate supervision. This was particularly problematic with two electricians who were inexperienced with this type of work. In addition, there was no discussion of potential hazards or hazard controls in the pre-job briefing and the work package for the "low risk" task lacked the necessary detail to indicate the correct way to connect in parallel the battery banks and did not include a drawing or diagram that showed the proper connection. Since all battery banks at the ATR Complex are in a series or series-parallel configuration, electricians have had infrequent or no experience in connecting battery banks in a parallel configuration.

Investigators identified the following issues that contributed to this event.

- All involved "assumed" this was routine work, because they looked at the task at the generic level "battery work," not at the specific task level (i.e., disconnecting and connecting a large number of battery cells in a new configuration).
- The work control process was not correctly followed; therefore, hazards were not properly identified and controlled, and the pre-job walkdown by the planner did not include an electrician.
- The work order was missing detailed information necessary to ensure safe performance of the task, such as a drawing or sketch to ensure that the terminals and cells were properly connected for a parallel configuration.

Corrective actions for this event included (1) evaluating the engineering, work control, and conduct of operations interfaces for temporary modifications to clarify management expectations and (2) developing specific training focused on battery disconnection/connection. In addition, the need to include specific directions or wiring diagrams in work orders will be discussed with job planners, and electricians will be reminded about the need to wear appropriate electrical PPE.

Although a primary contributor to this event was assigning a work task to two electricians who lacked the experience to perform the specific task, careful work planning and control are necessary to ensure that workers understand the scope of work and that all hazards have been identified and mitigated.

OE Summary 2004-10 discussed events that resulted when work planning and controls were lacking and provided examples of instances when good planning and appropriate work controls averted a potential accident.

This event demonstrates the importance of careful planning before performing work and the necessity for ensuring that workers thoroughly understand the job task to which they are assigned. Incorrectly identifying work as "routine" may circumvent procedures put in place to ensure that all hazards are identified and that controls are in place to mitigate them. The level of detail included in the work package needs to be commensurate with the complexity of the task and associated risks to ensure that workers can safely and correctly perform the work task.

KEYWORDS: Battery bank, jumper cable, short circuit, arc flash, burn injury, PPE, work planning and control

ISM CORE FUNCTIONS: Define the Scope of Work, Analyze the Hazards, Develop and Implement Hazard Controls, Perform Work within Controls

The Office of Health, Safety and Security (HSS), Office of Analysis publishes the *Operating Experience Summary* to promote safety throughout the Department of Energy (DOE) complex by encouraging the exchange of lessons-learned information among DOE facilities.

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Commonly Used Acronyms and Initialisms

Agencies/Organizations	
ACGIH	American Conference of Governmental Industrial Hygienists
ANSI	American National Standards Institute
CPSC	Consumer Product Safety Commission
DOE	Department of Energy
DOT	Department of Transportation
EPA	Environmental Protection Agency
INPO	Institute for Nuclear Power Operations
NIOSH	National Institute for Occupational Safety and Health
NNSA	National Nuclear Security Administration
NRC	Nuclear Regulatory Commission
OSHA	Occupational Safety and Health Administration

Units of Measure	
AC	alternating current
DC	direct current
mg	milligram (1/1000th of a gram)
kg	kilogram (1000 grams)
psi (a)(d)(g)	pounds per square inch (absolute) (differential) (gauge)
RAD	Radiation Absorbed Dose
REM	Roentgen Equivalent Man
TWA	Time Weighted Average
v/kv	volt/kilovolt

Job Titles/Positions	
RCT	Radiological Control Technician

Authorization Basis/Documents	
JHA	Job Hazards Analysis
JSA	Job Safety Analysis
NOV	Notice of Violation
SAR	Safety Analysis Report
TSR	Technical Safety Requirement
USQ	Unreviewed Safety Question

Regulations/Acts	
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
D&D	Decontamination and Decommissioning
DD&D	Decontamination, Decommissioning, and Dismantlement
RCRA	Resource Conservation and Recovery Act
TSCA	Toxic Substances Control Act

Miscellaneous	
ALARA	As low as reasonably achievable
HEPA	High Efficiency Particulate Air
HVAC	Heating, Ventilation, and Air Conditioning
ISM	Integrated Safety Management
MSDS	Material Safety Data Sheet
ORPS	Occurrence Reporting and Processing System
PPE	Personal Protective Equipment
QA/QC	Quality Assurance/Quality Control
SME	Subject Matter Expert