해외 대규모 사고사례를 통한
Accident at Russia’s Sayano-Shushenskaya-2009
수력발전소 안전성 향상 방안

2013.11

권 창섭
발표순서

1. 러시아수력 개요
2. 사고내용
3. 원인분석 및 교훈
개요

- 러시아는 세계 5위의 수력발전국가이며 설비 총 용량 220GW의 약 20%인 45GW를 운영 중

- 예니세이 강에 위치한 Sayano-Shushenskaya 발전소는 설비용량 6,400MW로 러시아 최대 발전소이며, 연간 발전량 기준으로 세계에서 6번째로 큰 발전소

- 연간 235억kWh를 발전, 생산된 전력의 70% 이상을 시베리아 철광산업에 송전
참고

■ 국내 발전원별 현황

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<th>기 타 (신재생 등)</th>
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<tr>
<td>설비용량(MW)</td>
<td>6,450</td>
<td>24,534</td>
<td>5,149</td>
<td>25,123</td>
<td>20,716</td>
</tr>
<tr>
<td>구 성 비(%)</td>
<td>7.5</td>
<td>28.5</td>
<td>6.0</td>
<td>29.1</td>
<td>24.1</td>
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■ 세계 발전원별 현황

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<tr>
<td>설비용량(GW) (비중, %)</td>
<td>1,649 (32)</td>
<td>1,351 (26)</td>
<td>1,033 (20)</td>
<td>394 (8)</td>
<td>435 (8)</td>
<td>321 (6)</td>
<td>5,183 (100)</td>
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<tr>
<td>발전량( TWh) (비중, %)</td>
<td>8,687 (41)</td>
<td>4,760 (22)</td>
<td>3,431 (16)</td>
<td>2,756 (13)</td>
<td>1,000 (5)</td>
<td>774 (4)</td>
<td>21,408 (100)</td>
</tr>
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Sayano-Shushenskaya 发電所 主要 組成

- Number of Units: 10
- Turbine Type: Francis
- Rated Power: 650 MW each
- Rated Discharge per Unit: 358.5 m³/s
- Nominal Speed: 142.86 rpm
- Net Head: 194 m
- Operation Date: 1978
- Runner Weight: 156 ton
- Runner Diameter: 6.77 m
- Total Employee: 375명
The Accident – 2009 Aug 17
The accident

At 08:13 local time on 17 August 2009, the station suffered a catastrophic "pressure surge" in turbine known as a water hammer. The sudden water pressure surge resulted in the ejection of turbine 2 with all equipment, a total weight some 900 tons, from its seat.

Turbines 7 and 9 also suffered from severe damage, while the turbine room roof fell on and damaged turbines 3, 4 and 5. Turbine 6, which was in scheduled repair at the time of accident, received only minor damage as it was the only one of the station's 10 turbines that did not receive electrical damage due to shorting of transformers, and it will be restarted as soon as possible.

Water immediately flooded the engine and turbine rooms and caused a transformer explosion.

On 23 August 2009, authorities said 69 people were found dead while 6 people are still listed as missing. Efforts to pump flood water from the engine room and complete a search for the missing workmen are expected to take 3 to 8 days.

http://en.wikipedia.org/wiki/2009_Sayano%E2%80%93Shushenskaya_hydroelectric_power_station_accident
Before the Accident

- Crane
- Power Units
- Air-Oil Tanks
- Sump Tank
- Governor Pumps
- Generators floor
After the Accident

- Air-Oil Tanks
- Sump Tank
- Collector Ring
- Unit 2
- Crosshead – Unit 2
- Unit 1
- Generator floor
Before the Accident

Generator Rotor – Unit 5

The accident started here

Generator Runner
Sump Tank (turned)

Air-Oil Tank

Crosshead
Water + Oil
Consequences

76 people dead

- It will cost at least $310 million.
- A long time to repair the damages.
- The production of more than 500,000 tons of aluminum will be lost.
- Oil slick is travelling down the river.
Consequences

• It is not clear how many people were potentially affected by the accident.

• The plant satisfied 10% of Siberia’s energy needs.
• Aluminum smelters consumed over 70% of the energy generated by the power plant.
1 - Causes

Our main hypotheses about the sequence of the disaster:

(Attention: Preliminary hypotheses based only on the pictures)

- Sudden closing of the Unit 2 wicket gates.
- Heavy waterhammer in the spiral case and penstock, causing their collapse.
- Upward force, resulted from the waterhammer, destroying the civil structure over the spiral case and penstock.
- Pressure of the upstream water causing elevation of structures and peaces.
- Heavy reverse waterhammer (draft tube) causing elevation of the turbine cover, shaft, etc.
- Rapid flooding of the Powerhouse.
- Units 7 and 9, without closing, in runaway speed with the generators inside the flood water.
2 - Causes

Our main hypotheses about the cause of the sudden closing:

- A large piece entered in the turbine runner and stuck in it (could not pass the exit of the blades, which is of smaller dimensions).
- This piece turned with the runner and hit all the wicket gates, causing their sudden closing, at a fraction of a second.
- This piece could be: a log (passed by an opening in the trashrack), stay vane or wicket gate broke.

Or (less probably):

- Rupture of the governor oil pipe in the closing side of the distributor servomotors (in this case, the orifice that controls the oil flow should be in the pipe and not in the body of the servomotors).
- Rupture in sequence of the wicket gates links; closing by hydraulic tendency.
Seeking the victims

Preliminary works
Some Next Steps

- Continuing the seeking of victims.

and

- Finishing the cleaning of the debris.
- Completing the drainage of the water.
- Constructing a temporary roof (one week) and then a better one (two months or less) to protect against the winter (this will prevent new photos…).
- Recover the columns and beams supporting the rails of the Powerhouse Crane, to allow its use.
최종 원인분석

- 2005~2011년까지 노후설비 개대체 추진 중(제어설비는 교체완료)

- 사고 당시 제6호기를 제외한 9개 호기 모두 운전 중

- STEP1 : 2호기 Turbine Cover Bolt 파손
- STEP2 : 수차발전기가 수압에 의해 위로 솟구치며 전도
- STEP3 : 변압기 파열되고 전체 발전소 연쇄 파손
* Cover BOLT 49개 중
- 41개 : Crack 결함
- 6개 : NUT 미체결

* 진동감시장치 미작동
사고의 3박자가 결합, 대형사고로 연결

- 외주 정비업체의 정비불량
- 설비관리 및 정비감독 소홀
- 사고 전 수 차례 진동과다 발생되었으나, 운전근무자가 이를 간과

국내 수력발전소는 저낙차 소유량 설비이며, 관련법에 의해 주기적인 안전점검과 자체 정비를 잘 하고 있어 안정성이 확보되어 있음

교훈

- 노후설비 점검 개ㆍ대체 및 감시제도설비 보강ㆍ관리 철저
- 안전교육 강화, 운전수칙 준수 및 예방정비 철저
- 재해ㆍ재난 또는 대형사고 발생시 대처 시나리오 확보
- 사고발생 취약설비 주기점검 및 관리감독 강화