Use of a Nitrogen/Water Mist (Hybrid) Fire Extinguishing System in a Hydroelectric Generator in New Zealand

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Abstract:

Traditionally, carbon dioxide (CO_2) gaseous fire extinguishing systems have been used in the original construction for the protection of older hydroelectric generators in New Zealand power stations. Replacement of the aged CO_2 systems has been necessary for safety, maintenance and service reasons.

This paper discusses the feasibility of why a nitrogen/water mist (hybrid) system was selected instead of new CO_2 or fully inert gas-type gaseous fire extinguishing systems.

The discussion includes the acceptance processes of electrical safety and recovery after discharge in the context of older paper-insulated windings.

A case study of a completed hybrid system installation at a hydroelectric generator enclosure is discussed, including the challenges of dealing with a high volume air flow from the open cycle cooling, leaky enclosure and resolving the acceptance criteria for the lowered oxygen level. The commissioning results of measured oxygen levels in the generator are included.

The paper discusses the effect of the hybrid system discharge on the windings, including the drying process and electrical criteria required for generator restart.

1. INTRODUCTION

Many of the hydro generators in New Zealand were installed with CO_2 gaseous fire extinguishing systems as standard features. These systems are essentially a CO_2 bottle store, with related discharge valving and nozzles.

CO_2 is considered one of the most efficient extinguishing mediums because of its efficacy as an extinguishment, being electrically non-conductive, having high expansion volume on discharge, a cooling effect on a fire and a lack of clean up after discharge. It is still routinely used on gas turbine generator plants as the preferred extinguishment method.

Figure 1 illustrates typical installations with generators.

Figure 1: Typical existing CO_2 generator gaseous fire extinguishing systems.

These systems are aged and maintenance is problematic owing to: a lack of confidence in the systems' controls and isolation reliability for service, pipework condition, (particularly the use of low pressure fittings with a high pressure discharge requirement), deterioration of rubber connectors and how to replace components safely.

Another factor of concern is that the generators into which CO_2 is discharged are inherently leaky and link to areas that are 'below grade'. There is an inherent distrust and a risk of CO_2 leakage (being heavier than air) to occupied areas and the obvious lethal life safety risk.

The Genesis Energy Tuai Power Station generators were the most urgent to be investigated, as no suppression system existed at this particular site. The generators were considered at significant risk, given their age, winding type – being a mix of rice paper epoxy-mica and bitumen-mica. Genesis Energy required new and replacement systems with modernising extinguishing systems across its other hydro-generation facilities. Holmes Fire reported on the range of options that would be most suitable, with input from Genesis Energy.

Generally in New Zealand common solutions have been to install gaseous fire extinguishing systems for generators, using inert gas solutions, such as IG-541 (Inergen) or IG-55 (Argonite and Proinert). These options are the most popular in the generation and transmission industries in New Zealand. In other countries a range of solutions have been implemented, including water mist, water spray, as well as CO_2.

Technology, such as hybrid fire extinguishing systems, have recently entered the market. Genesis Energy has required an analysis of this new technology, compared with CO_2 systems and the industry norm of gaseous fire extinguishing systems, to enable a consistent policy of replacement across the hydro-generation facilities and other essential equipment rooms.

There are currently two manufacturers of similar hybrid systems: Victaulic with the Vortex and Tyco with the Aquamist-branded system.

A hybrid system is a total flooding system that incorporates the beneficial features of an NFPA 750 Water Mist Fire Protection Systems [1] and an NFPA 2001 Clean Agent fire Extinguishing Systems [2]. The hybrid system suppresses the fire by dispersing a nitrogen/water mist mixture. The nitrogen gas acts as an inerting agent, which reduces the percentage of oxygen in the air to a level that does not support combustion but is safe for humans. The water also cools the fire, which reduces heat transfer and produces steam, which in turn displaces oxygen at the base of a fire. It offers stability to the gas in terms of leakage from the enclosure area.

The water and nitrogen supplies are stored in tanks and discharged via piping, tubing and emitters. The agent is released automatically from a fire detection system, typically high-sensitive aspirating smoke, the same as from a clean agent inert gas system. Manual electronic and non-electronic release is provided as well.

This study's challenge

The challenge of this study was the lack of information on installation of hybrid systems in generators specifically and how suitable a hybrid system would in fact be. The Salt River Project [3], (United States based) was the only hydro-generator known to have hybrid-type systems at that time. There was little experiential information available from the supplier or the Salt River Project because of confidentiality agreements. No NFPA specific hybrid system standard exists, although the NFPA 770 Hybrid Extinguishing Standard is currently being drafted and due for release in the first quarter of 2018.

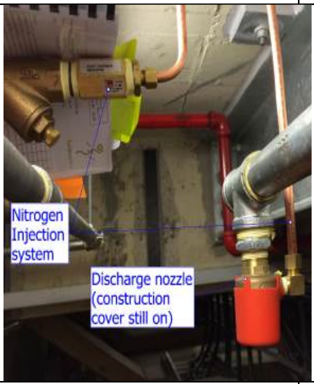
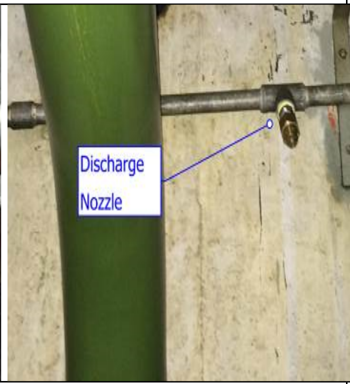
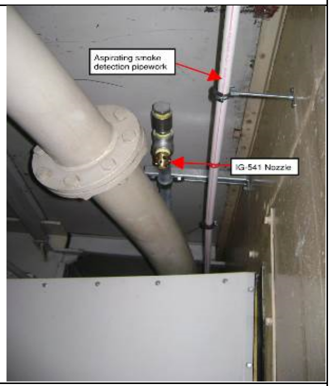
Background information

Further background information included: a study on the success of a Vortex system in an aero-derivative gas turbine [4], the Putman Power Plant combustion turbines [5], Victaulic White Paper on Vortex [6] and FM Global Data Sheet 4-2 Water Mist Systems [7].

2. SUMMARY OF COMPARATIVE STUDY OF SYSTEMS FEATURES

Table 1 provides a summary of the principle features of the systems proposed in this comparative study.

	Hybrid systems	**Carbon Dioxide (No trade name)**	**Inergen, IG–541 or Argonite IG – 55**
Chemical composition	$N_2 + H_2O$	CO_2	N_2+A+CO_2 IG-541 Inert Gas N_2 + A IG-55 Inert Gas

	Hybrid systems	**Carbon Dioxide (No trade name)**	**Inergen, IG–541 or Argonite IG – 55**
Typical system discharge nozzles (actual installs)			
Typical Installation Standards	NFPA 750 water mist system and an NFPA 2001 clean agent system.	AS 6183 Fire Protection equipment, – carbon dioxide extinguishing systems – design and installation (ISO 6183 2009, MOD).	AS ISO 14520-1 Gaseous fire-extinguishing systems – physical properties and system design.
Fire suppression medium	Nitrogen gas acts as an inerting agent, the water also cools the fire, which reduces heat transfer and produces steam, which in turn displaces oxygen at the base of a fire. (http://static.victaulic.com/assets/uploads/literature/WP-08.pdf).	Oxygen depletion and cooling effect.	Oxygen depletion using an inert gas.
Reinstatement timeframes if no reserve bank	Typical nitrogen bottle refill times can be 1-2 days but at peak times this may extend up to 2 weeks.	Typical refill times are 2-5 days, excluding transport time, this is variable based on quantity of containers to be refilled as limited quantities of extinguishant may be held on refill sites.	Depending on the number of bottles to be refilled owing to independent refilling agents having a minimum refill quantity of 12-16 bottles., However, some suppliers do offer an exchange system, subject to availability, with an expected turnaround of 2 days, excluding transport.
Suitable for use in normally occupied spaces	Yes	No	Yes
Suitable for use in normally unoccupied spaces	Yes	Yes; lockout devices must be installed.	Yes
NOAEL % v/v[1]	43.0% [2]	All practical functional equivalents of extinguishing concentrations exceed the NOAEL.	43.0% [2]
Global warming potential	0	Global warming gas but considered favourable because gas is CO_2 contained in the bottles and is removed from the atmosphere.	0
Bottle storage area based on a 150 m^3 enclosure	0.3 m^2 cylinder storage + 0.5 m^2 water storage.	0.6 m^2	0.5 m^2
Room sealing / pressure relief	Does not require total room integrity and can be discharged effectively for fire suppression even when openings are present.	Room must be sealed and dampers fitted to close off the room. Pressure relief is not typically required.	Specific venting must be provided owing to a larger volume of gas released and the pressures generated. In leaky generators venting is not typically required. In sealed rooms, eg, control and computer rooms, venting is required.
Discharge time	Approximately 3 minutes.	1-2 minutes.	1 to 2 minutes.
Hold time	45 minutes can typically be achieved in a reasonably sealed environment. 15 minutes based on supplier	Until the generator has stopped (AS 6186-2011) FM Datasheet 13-2 recommends a minimum of 20 minutes.	Minimum of 10 minutes (AS ISO 14520.1:2006, MOD)

	Hybrid systems	Carbon Dioxide (No trade name)	Inergen, IG–541 or Argonite IG – 55
	recommendations is typical with 3 minutes actually accepted as Tuai		
Extinguishment efficacy	Considered more efficient than an inert gas system owing to the cooling effect of the vapour when combined with the oxygen reduction function of the hybrid extinguishment.	Generally temperature drop caused by $C0_2$ is considered a major benefit in generator fires but does not appear to be quantified. Evidence appears to be experientially based. Empirically a very successful extinguishing agent.	Extinguishment may not be achieved for smouldering fires where pyrolozates continue to be produced, even for a 10-minute soak density. Inert gases have only generally been verification tested on wood crib fires and have not been tested on electrical or deep-seated fires. Needless to say the efficacy cannot be argued on the grounds of oxygen depletion.
Maintenance	Inert gas systems tend to have a slightly higher maintenance cost owing to the manifolding and number of bottles. Manifolding is required where a number of rooms share the same bottle bank and are physically piped together. Control valves are required when the rooms are different sizes to ensure the gas dump volume is appropriate for each room. $C0_2$ maintenance costs are similar to inert gas, as regular testing regimes are similar. As inert gas and $C0_2$ systems age, bottle testing can add cost and inconvenience, as well as eventual bottle replacement. $C0_2$ bottle testing is recommended 5-yearly by the Environmental Protection Agency (NZ) Technical Guide 2013, the recommendation for bottle testing for inert gases and nitrogen is 10 years. Inert gas cannot be reclaimed and reused at bottle retesting.		
Clean up after fire discharge[3]	No clean up required that can be directly contributed to the discharge of the extinguishant, only debris generated by the initial fire would be expected. For Hybrid systems a “dryout” period of 12-24 hours is required before restart.		
Equipment cost	CO_2 systems have much less valving than the inert gas and hybrid systems because the number of gas bottles used is about 1/4. Therefore the hardware cost of inert gas systems is much higher. This is related to the significantly larger number of bottles and manifolding required.		
Budget capital costings	Cost comparisons between systems are becoming less predominant as competition from suppliers and similar generic products become available. Costs also depend on how systems are manifolded and the bottle redundancy requirements.		

Table 1: Summary of gas comparisons

[1] NOAEL is the no-observed effect level; this information is extracted from AS ISO 14520.1 [8] and manufacturers’ information. It is the highest concentration at which no adverse toxicological or physiological effect has been observed.
[2] Based on physiological effects on people in hypoxic atmospheres. These values are the functional equivalents of NOAEL and correspond to a 12% minimum oxygen level at the NOAEL.
[3] It should be noted that the products of a fire will release toxic gases that would be of significance when entering a room after a fire.

3. SELECTED SYSTEM

The drivers for the final selection of a hybrid nitrogen/water mist system included the following key considerations:

1. The beneficial feature of discharge sealing requirements being less onerous and the generator’s enclosure being very leaky and, in some cases, having through (open cycle) air cooling systems compared with inert gases.
2. The supplementary extinguishing capability offered by the mist-based system, cooling and lowered oxygen level.
3. Costs were the same order of magnitude as for gaseous fire extinguishing systems.
4. CO_2 systems were considered unfavourable, even with appropriate safety controls, because the perception of risk could never be eliminated.

5. Consideration that recovery after discharge of generator electrical components windings was viable, see Section 4.

4. HYBRID ELECTRICAL IMPLICATIONS OF GENERATORS

The Vortex White Paper 'The Victaulic Vortex Fire Suppression System' discusses the issues of water permeability with Vortex operation. This indicates a maximum humidity at time of discharge of 73%. [6] Two considerations were raised with respect to the hydro-generator environment:

1. The condensation potential onto cooling coils and therefore some moisture circulation into the windings.
2. The recovery after the hybrid system discharge.

Genesis Energy has proven recovery procedures for a significant water discharge for generators. These relate to drying and testing the stator windings,

The following lists the questions asked on electrical issues raised by Genesis and the responses prepared in the options report prepared by Holmes Fire:

1. Concern that the introduction of very fine water droplets into a hot machine will accelerate core corrosion. Some generators have rice paper-insulated core laminations. This paper is hydroscopic and provides no corrosion protection. Surface corrosion of the laminations, combined with vibration and clamping force damages the paper, shorting the laminations together. This causes localised heating, efficiency loss and eventually core failure. It is also of note that the varnished core laminations are not immune to this failure mode. As the cores age, thermal cycling and vibration cause the varnish to unbound or be worn away, exposing the same surface corrosion failure mode.

   Some Genesis Energy generators have bitumen mica-insulated stator windings. These are also susceptible to water resulting in accelerated turn to turn and ground wall failures.

   All stator winding systems are vulnerable to surface tracking and surface voltage stress caused by moisture combining with contamination (usually carbon dust from slip rings).

   Response: The mist injection is very fine and test results on electrical equipment indicate that water ingress is extremely unlikely.

2. The generator fans circulate large flow rates of high velocity air through the generator. This is a tortured path by design, please comment.

   Response: If anything the high air velocity assists in mixing into convoluted spaces and the generators are generally partially sealed, therefore expected concentrations for fire extinguishment should be met.

3. What is the relative humidity rise?

   Response: The humidity is predicted to rise to 73%, which is well below saturation level. [6]

4. What is the impact of the tortured path on suspension?

   Response: There should be little effect and the system remain effective, as the injected nitrogen water mist is highly effective (being primarily a gas) and the extremely fine size, less than 10 microns, means the injection extinguishing medium is highly effective in its permeability into convoluted spaces.

5. CASE STUDY: TUAI POWER STATION

In 2016 Genesis Energy completed a hybrid extinguishing system at Tuai Power Station on the Lake Waikaremoana scheme to the existing three 20MW horizontal shaft-driven Francis turbine units. Of all Genesis Energy's generators Tuai has the most onerous design parameters, with horizontal shaft generators. Unique challenges include:

1. The configuration of the generator: it has the enclosing air housing as its external shell. Removable sections of the housing allow for routine maintenance but reduce possible locations for pipework, sample points and discharge nozzles for both detection and extinguishing systems. Creating new openings in the existing plate risks the generator casing.
2. The open cycle cooling method utilised by the units on site, with air flow of between $28.33m^3/s$ and $37.53m^3/s$, relating to enclosure sealing and increased volume requiring protection.
3. The run down time of the units being in the vicinity of 20-30 minutes due owing to the turbine being un-braked upon shut down and the effect this has on extending discharge times and the concentrations being achieved.

Figure 2: Tuai generators with hybrid system installed.

The figures below illustrate the features of the installation.

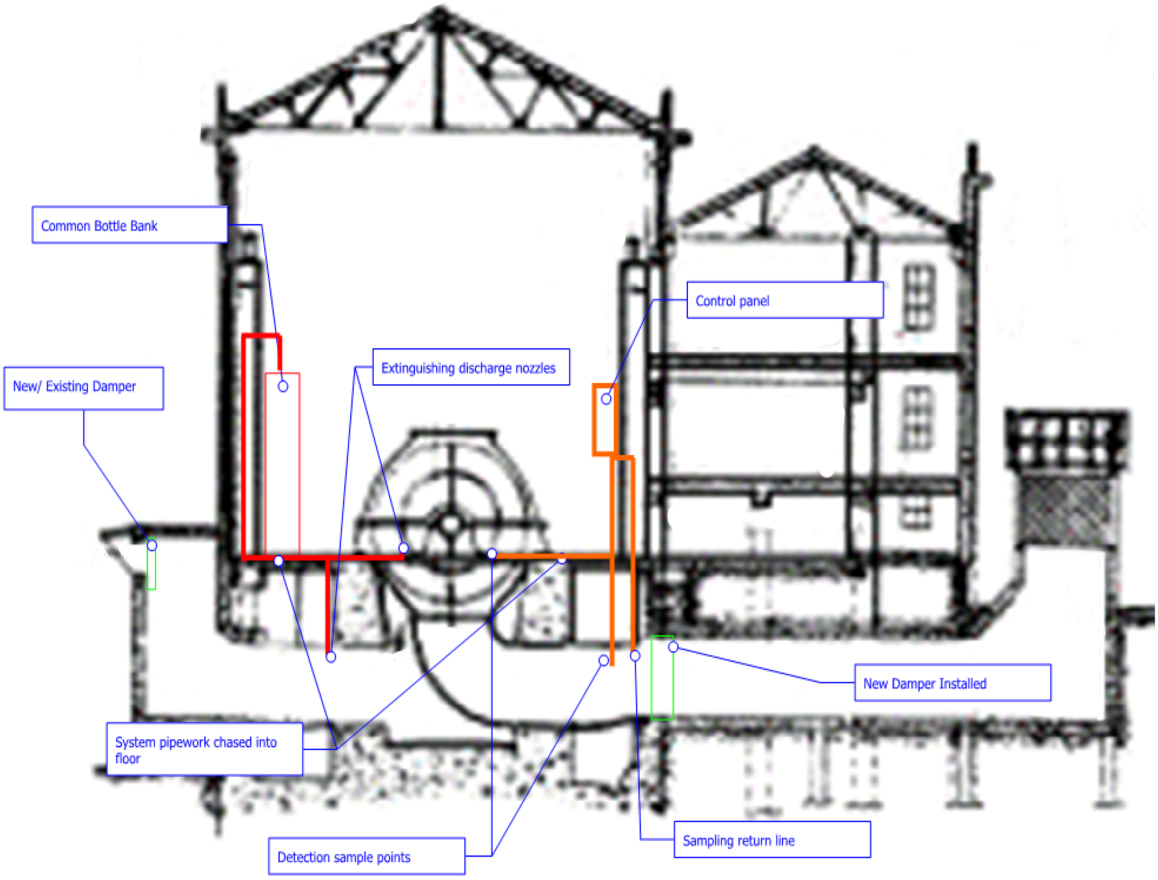


Figure 3: Proposed design of hybrid system Tuai Power Station.

Figure 4: Nitrogen and mist discharge piping and entry.

Figure 5: Controls and signage, discharge panel and modular bottle bank.

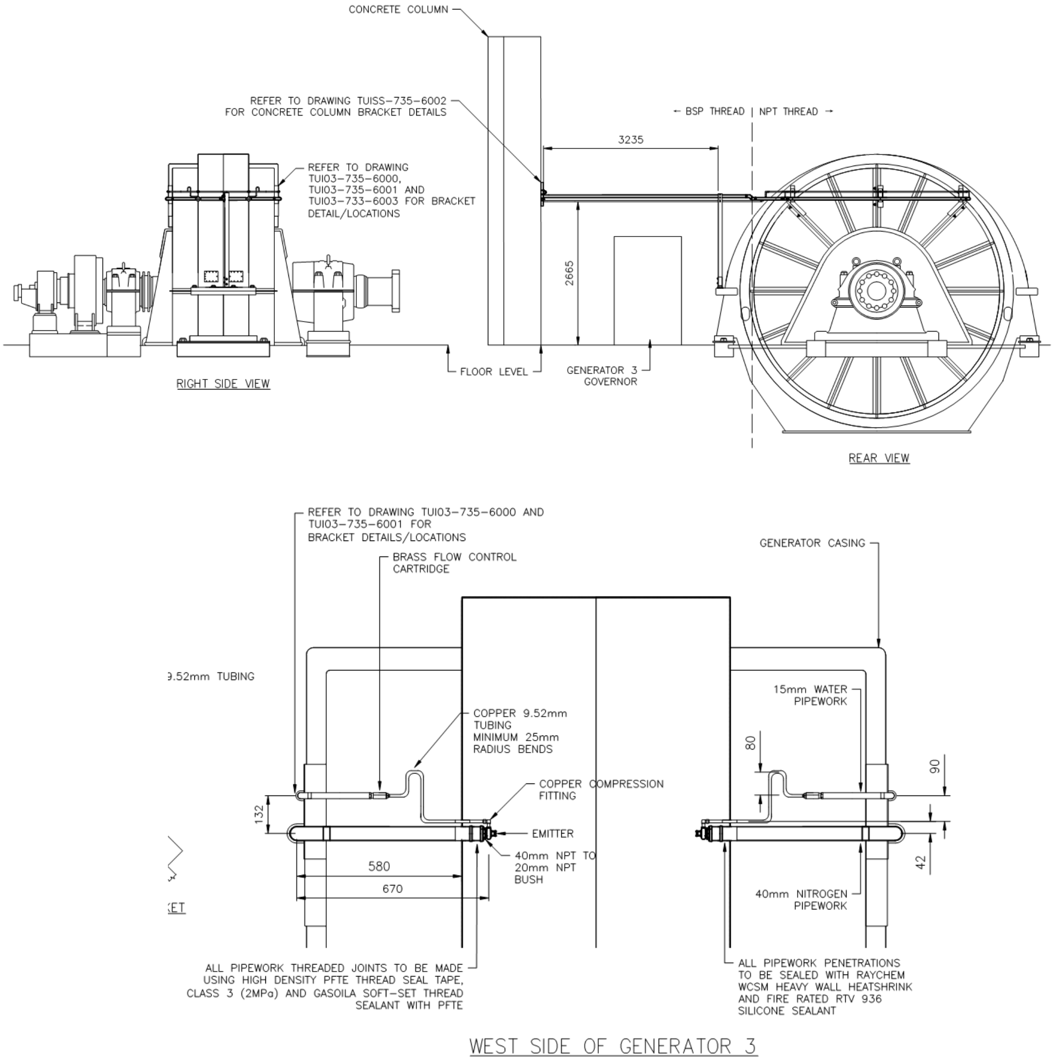


Figure 6: Typical installation details

The actual installation and commissioning was eventually successfully implemented. However, the initial commissioning live discharge test revealed insufficient gas concentrations for extinguishment. Reworking of the installation to achieve a gas concentration providing a generator fire extinguishment was then required. The target oxygen maximum levels were 15% for 20 minutes for system extinguishing, within a discharge time of five minutes.

The key issues included:

1. Implementing testing of gas locations as the critical part of the generator winding locations and as far as practicable applying the guidance of the AS ISO 2009 Annex ZC Discharge Test [8] so that the test locations represented where the gas concentrations were required, as gas concentrations were not initially measured at the top of the generators where the prime extinguishment was being discharged.
2. It was generally agreed that the initial design underestimated the required gas discharge volume and period of discharge, taking full account of the generator wind down time, the significant airflow through the generator and the leakage through the generator casing, cover plates and existing shut off damper.

Resolution included:

1. Modification of the test procedure more in line with AS ISO 2009 Annex ZC, which was reasonably critical to the result.
2. An improved sealing of the very crude existing inlet shutoff damper.
3. The addition of a further nitrogen bottle to the discharge bank.

A further discharge test was undertaken and the maximum oxygen concentration level achieved was 15% for three minutes at the recommended test locations.

The Victaulic designers confirmed that a two-minute duration of 15% maximum oxygen concentration was satisfactory for extinguishment.

Genesis Energy recognised that whilst the target original design concentration duration was not achieved, the revised system acceptance value was tolerable. This is also in the context that the Tuai generators are to undergo a full refurbishment in several years' time. This will result in the cooling system changing to a closed circuit type and the leakage substantially eliminated. The refurbished hybrid system should more than adequately meet the 15-minute duration criteria for achieving a longer extinguishing concentration duration.

6. CONCLUSIONS

1. A successful hybrid extinguishing system has been installed in the generators at Genesis Energy's Tuai power station, despite being challenging because of its open cycle ventilation system and lack of generator enclosure space for the installation of discharge piping and nozzles.
2. The key issue of recovery of the generator after a hybrid discharge test with fog/mist on rice paper windings has been successfully executed, with no apparent detrimental effects.

3. Lessons learnt for the design and installation of hybrid extinguishing systems include a full understanding of the generator ventilation characteristics, the generator wind down time and leakage.
4. Genesis Energy is now proceeding with its next hybrid installation at Tekapo B Power Station.

7. REFERENCES

[1] NFPA® 750 Standard on Water Mist Fire Protection Systems 2015 Edition. National Fire Protection Association, Quincy, MA, USA.

[2] NFPA® 2001 Standard on Clean Agent Fire Extinguishing System 2015 Edition. National Fire Protection Association, Quincy, MA, USA.

[3] PS-PWR.10 Vortex SRP hydro power station information.

[4]http://www.victaulic.com/en/news-events/news/evaluating-hybrid-fire-suppression-systems-for-the-protection-of-aeroderiva/#

[5] Barstow, F. *Reliable Fire Protection for Turbine Rooms.* (02/01/2014). http//www.powermag.com/reliable-fire-protection-for-turbine-rooms/?pagenum=1

[6] Puzio, M. *The Victaulic Vortex TM Fire Suppression System Fire Suppression for Electrical and Electronic Applications*. (Updated April, 2011). White Paper. Senior Project Engineer Fluid Control Technology, Victaulic.

[7] FM Global Property Loss Prevention Datasheets 4-2 Water mist systems.

[8] AS ISO 14520.1, 2009, Gaseous fire-extinguishing systems – Physical Properties and system design, Part 1: General requirements (ISO 14520-1:2006, MOD), Standards Australia, Sydney, Australia.