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Cable Propelled Gondola System Operation in Icing Conditions

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ABSTRACT

The scope of this study comprehends problems associated with modern urban vehicles known as cable propelled gondolas system operations in icing conditions. The aspects under consideration are problems related to the operations, safety, and maintenance of cable car systems in harsh climate conditions. The geographical location of the gondola cars makes them vulnerable to severe weather conditions especially in cold climates of the northern hemisphere, where icing on its components is an operational, maintenance, and safety concern. The harsh climate conditions can cause unadorned malfunctions posing a threat to the integrity the of system as well as a high risk to human safety. The study basis on the identification of these problems in operational, maintenance and safety domain including implications the industry faces in the form of severe accidents costing precious lives and lost capital. Furthermore, it incorporates the ice detection, anti/de-icing approaches as well as the safety strategies in use nowadays. The massive increase in operations and dynamic climate conditions gondola cars require serious attention. This study unsheathes serious underlying problems that severely affect the gondola operations, makes them prone to major maintenance shutdowns and poses high risk to structural and human safety. The identified problems in this study and severity of risks draw attention to need for practicable solutions incorporating de-icing and ice removal techniques for safe operation of gondolas in cold climates saving time, effort, inconvenience, and prodigious lost capital.

1. INTRODUCTION

The urban vehicles also known as cable cars have become a particular transport method having an infrastructure based on land. The small distance cars carrying people aerially prove to be effective when it comes to terrains and mountainous regions [1]. This system caught the attention worldwide and has become an integral component of ski resorts. According to the press release in 2013 published by Patrick Throne [2] mentioned that almost 100 countries across the globe have snow throughout the year that are reliable for outdoor skiing or have artificially developed slopes. Among these, 68 countries have at least one ski zone with cable cars. Furthermore, based on statistical data approximately 400 million skiers visit the resorts worldwide amongst which Alps grab the maximum share of 43% skier visit while North America stands at the second place with a share of 21%. Tourists as well as ski enthusiast globally use gondola cars to visit as well as enjoy skiing at high altitudes. Northern hemisphere is considered as one of the most attractive spots for snow sports with skiing and tourism being the most protuberant and adored [3]. Since millions of skiers and tourists visit ski resorts throughout the year, it is important to consider their mode of transportation on the ski mountains. The urban cable cars also known as gondola, draw attention to an exciting experience to witness ski events, facilitating skiers to reach the top of mountains and relish skiing to the fullest. It is a matter of significant importance to ensure the operational safety of these cars with the ability to efficiently maintain their smooth operation. The high frequency of use put these cars under extensive test, especially when it comes to transporting millions of people in a year. It is certainly a highly demanding and critical task in the presence of extreme climate conditions. Environmental factors such as ice and wind prove to be enormously important parameters that can drastically affect the operation with great potential to put safety of people at risk with massive consequences.

Ice jacking is a phenomenon in which the water trickles or creeps into structures and freezes due to rapidly changing climate [4]. It is usually observed on gondola towers. Due to sudden ice buildup the structures become susceptible to extreme loads which can lead to cracks creeping and ultimately causing failure if the accumulated ice is not removed soon. The ski resort in British Columbia in 2008 faced a partial failure due to ice jacking on towers leaving onboard visitors stranded for hours. Some of the cable cars dropped due to sagging cables and caused minor injuries [5]. An incident that could have resulted into a catastrophic failure was fortunately not worse.

Furthermore, in cable cars safety switch and monitors are of prime importance, although these are designed for harsh climate conditions, however they are prone to malfunctions in snowstorms and windy conditions. An error in these systems can cause the gondola to stop immediately, leaving the passengers at the disposal of emergency staff to be rescued. An incident occurred in 2022 at Sandia peak cable car in New Mexico at the height of approximately 3140m left twenty people stranded for twelve hours in an extremely low temperature around -20℃ [6]. Fortunately, there was no causality reported, however such incidents prove to be time sensitive which can be worse if the weather doesn't allow a quick rescue.

In the presence of moist air and a seafaring climate, there are high chances of ice accumulation on the towers, haul ropes as well as gondolas putting the system under extensive loads and possible ice shedding problems. A resort in New Zealand Mt Ruapehu [7] is considered to face one of the biggest ice concerns which can pose a huge risk to the integrity of structure as well as skiers skiing through the slopes [8-10].

Similarly, strong winds can also cause the derailment of cable cars which could be catastrophic when it comes to cable propelled gondola cars. At Sugarloaf Mountain ski resort in US, the wind speed of 13.5 m/s to 23 m/s caused the cable cars to isolate from cable while passing through a support tower causing injury to eight passengers and leaving hundred and fifty stranded [11]. The disruption caused to the operation of cable cars along with the grave risk posed to the safety of people by the harsh weather conditions specifically due to icing and strong winds signifies a need to analyze this domain further and ascertain the requirements for safe urban vehicles to ensure a smooth and safe operation.

2. SYSTEM SCHEMATICS

In cable propelled gondola system the cable circulates on a bull wheel powered by a motor and speed reducing gearing system. The motor transfers the power mechanically to the gearing system which is further connected to the bull wheel. The drive bull wheel is responsible for the movement of cable. Furthermore, an emergency diesel engine is integrated into the system as a backup. The cars are fixed on the cable with a grip and move along with the cable. The cable is supported with several pillars along the way which act as an orientation guide for the cable car system as well with pulleys and suspension mounted at the top. A simplistic schematic of this system can be seen in Figure 1.

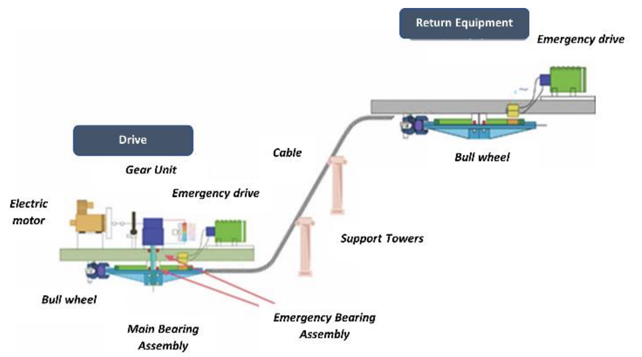

Figure 1. Schematics for Gondola cable car system [12]

3. CLASSIFICATION

There are numerous problems associated with the cable car or Gondola system that may arise due to operating conditions, maintenance regimes and significantly lack of attention to safety of the system as well as of people. Hence, we can classify these problems into following three main domains:

i. Operational domain
ii. Health and safety
iii. Maintenance

3.1 Operational domain

3.1.1 Accumulation of ice

Atmospheric icing in one of the major concerns for a cable car system due to ice accumulation on cables and towers as shown in Figure 2. It can severely affect the performance, lifecycle, useability as well as maintenance. The process of water getting frozen in the atmosphere, sticks to an object or freezes when encounters the objects is known as atmospheric Icing. It can be result of altitudes as well as troposphere and the process can also be termed as ice accretion [13]. Ice accretion has a significant impact on cable cars with respect to operational ability, lifecycle, performance, and safety etc. According to ISO 12494 the term has been classified into four types based on physical properties of ice shown in Table 1 [14, 15].

Table 1. Ice accretion classification

Classification	Attributes
Glaze	Transparent, smooth, dense, highly cohesive and adhesive, converts to icicles
Wet Snow	White, less density, not very cohesive and adhesive
Hard Rime	Cloudy or less transparent, rough, low/ medium density, highly cohesive and adhesive
Soft Rime	White, rough, low/ medium density, low/medium cohesive and adhesive

The accretion takes the mentioned characteristics depending on various parameters such as temperature gradient, geometry, material properties, exposure time, relative humidity, wind speed and direction. Cable cars being used in harsh climate regions such as northern hemisphere undergo massive challenges due to icing. It affects the operational performance, efficiency, reliability, and safety of the gondola system. Afore mentioned lasses could further be distinguished into hoar frost, cloud icing and icing due to precipitation [13]. All these forms of icing occur under different environmental circumstances. For structural design purposes, the effects of atmospheric icing on structures such as increased vertical and horizontal loads due to strong wind, dynamic effects and damage caused by falling ice must be considered ISO 12494, 2017 [14].

Figure 2. Ice on Gondola support tower, Mt Ruapehu [14]

3.1.2 Structural loads

The icing condition known as ice jacking [4] adds vertical as well as horizontal dynamic loads to the haul cable exerting tons of load over the towers and cable. Additionally, when it comes to aerodynamics, added layer of ice being non uniform, rough, and dense in some conditions can add drag force under the influence of winds flowing past the haul rope. The ice accretion [13] on haul rope in such state also significantly varies the cross-section throughout the length. Being exposed to varying wind speed and direction can cause unstable movement or vibration in the haul rope which can severely affect the cable car grip mounted on the haul rope as well as it can snap the haul cable and damage support towers [5].

3.1.3 Galloping

Wind can cause dynamic and static effects such as flutter, galloping and suction induced vibration [16]. The gondola cable cars usually gain elevation from ground station to the resorts, the dynamics change abruptly in the form of sudden temperature variation and increased winds speeds result into a low frequency high amplitude vibration. The haul rope in a gondola system extends from the low to high altitude carrying cable cars. The icing on haul rope has the potential to vary cross-section thus temporarily developing unsymmetrical section [17] along the length, strong winds can result into large amplitude galloping which can severely damage the structure as well as the haul rope. Furthermore, in case of cable driven gondola cars, the operation depends on idle run to remove ice from haul rope avoiding transportation of people due to high amplitude vibrations. Similar kind of vortex induced vibrations can be observed in suspension bridges resulting into an aeroelastic instability in the presence of rain and strong wind [18].

3.1.4 Gear system

It is power transmission mechanism that transmits torque between driver and the driven components in a system similar to most other mechanical systems it has to operate between allowable limits for temperature, noise and vibration [19]. Gondola cable cars can have different configurations of gear systems depending on single, double, or tri-cable system of haul ropes. The system generally comprises of gear reduction at the base station responsible rotation of haul rope. It is a major component of a cable car system as it not only provides the speed required to run the cable via bull wheel but also prevents the system from rollback in case of any malfunction.

Ice accumulation on gearing system can severely affect the efficiency of power transmission while posing a great risk to the integrity of subcomponents. Temperature difference between the atmosphere and gearbox can result into sudden liquification of accumulated ice, which seriously can cause seal damage and result into water seeping through the moving parts. The external dirt particles entering a moving hub can cause wear and tear inside the gearbox leaving behind indents or irregularities in the form of pitting resulting into increased friction [20]. Additionally, in extremely low temperatures the gear components are prone to become brittle and with the passage of time this brittle nature of components under fatigue, chips of the material which certainly hinders mechanical movement of gears results into further wear and tear and the torn particles become part of the lubricant. In such cases the lubricant becomes carrier for particles and reduces the gear life.

Furthermore, temperature gradients induced can greatly affect the efficiency of the gearing system. In extreme cold temperatures the viscosity of lubricant can vary to a great extent, which means that the mass flowrate of the lubricant due to change in viscosity may get affected, certainly increasing temperature inside the gear housing. A thermal gradient in repeated use of mechanical system can result into thermal expansion or contraction thus affecting the geometrical tolerances, thermal discrepancy inside the gear material structure and ultimately uneven thermal distribution can result into broken gears [21].

3.1.5 Eccentricity

The gear system under mechanical wear might also undergo uneven geometrical loads. This uneven distribution of loads during rotation can result into vibration or chattering of gear tooth. Due to abrasive wear non uniform mass distribution might convert to a gear's misalignment. Gear system is considered as the primary drive for a gondola cable cars. In case the power transmission collapses, reverse runover of haul rope might occur leaving the cable car at the dispense of emergency power.

3.1.6 Connecting shaft

The electric motor and gear assembly are coupled by a shaft responsible for transmission of power. It is considered of significant importance as it is a part of the primary driver. Icing like many mechanical components can adversely affect the rotating shaft as well as it's subcomponents such as bearings. The extreme cold temperature can cause jamming of bearing due to increase in viscosity of the lubricant which can hinder the rotational capability of shaft and result into wear inside bearings. This could be catered by using the climate suitable bearing and proper insulation of mechanical components. Furthermore, the shafts are subjected to torsional, bending, and axial loads. Icing on the rotating shaft can induce eccentricity due to unsymmetrical profile and deflection. With even a minor deflection if the shaft rotates at a high rpm the vibration could be severely damaging and might result into shaft failure. Also, the thermal stresses induced by the rotating bearings, frictional heat and ice accumulation on the outside can result into thermal stresses.

3.1.7 Frequency of use

There is a limitation to number of people that can board cable cars at once however another factor that is of prime importance is the frequency of use. The repeated operation of cable car system can also cause fatigue to the drive assembly. As expected, the gondolas might have to be used by thousands of people during the championship which means a non-stop operation would be required to meet the needs of tourists. This can eventually put the system excessive under fatigue.

3.1.8 Inaccurate forecasting

To make the cable car operations sustainable in regions where climate plays the key role the weather forecasting and its accurate communication can have a massive impact. As the cable cars in northern hemisphere operate seasonally it is important to correctly forecast the weather conditions or issuing probable storm and avalanche warnings.

The dynamic nature of climatological changes requires a robust and real-time sensing along-with effective communication. This can prove to be a critical information as it can prevent skiers, tourists as well as tourists from encountering severe storms or avalanches thus reducing the likelihood. Therefore, the risk of an incident could be reduced.

3.1.9 Haul rope or cable

Haul rope in a cable driven system also plays a key role in mobilization of gondola system. A haul rope being used in Gondola system is a steel cable with multiple strands of steel wires braided together. The issue of weight being cable is often overlooked. Considering its criticality, it is important to note that this rope is a primary driver on which the cable cars are gripped by a mechanical device. The haul rope continuously runs over the bull wheel, sheave train and tower pulleys. The rope is intentionally kept under tension to avoid any flexibility during operation of cable cars. Under these circumstances the contact area between rope and components along the way is always maintained.

This contact in repeated operation results into buildup of minute notches resulting into unsymmetrical shape of the rope. These notches or microscopic cracks can propagate as under extremely cold weather conditions as the ropes do not have any protective coating, they tend to become brittle. This might result into a catastrophic rope failure, a severe threat to the lives of people and can damage the equipment severely. The consequences can be devastating economically, legally and from safety point of view [22].

3.1.10 Gondola support assembly

The support towers play a vital role in terms of support to the carriers against wind and structural loads as well as the deropement or cable overhanging. These towers are placed between base station as well as at mountain station.

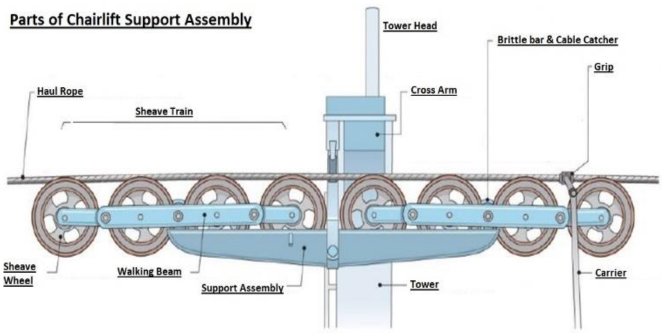

Figure 3. Gondola pillar support mechanism [23]

Towers support shown in Figure 3 carries weight of haul rope, provide a guided movement to it as well as prevent it from being suspended or getting loose. If it fails the cable cars can crash into ground, possible derailment of cable from bull wheel, and uncontrolled acceleration can injure the passengers. Usually, this can happen in the presence of ice on cable surface. The cable loses traction on the sheave wheels and gets derailed. To understand the deropement and its risks, it is necessary to comprehend components involved in mechanism. Some basic components of support pillars are as follows:

Sheave train. Multiple of sheave wheels on the uphill and downside of pillar to support loads and provide guided movement in both directions.

Sheave wheel. These are pulleys that move clockwise as well as anticlockwise. These are interconnected by the passing haul rope which drives them. The groove on surface acts as a guide for the rope.

Beam links. These are horizontal links that provide flexibility to sheave wheels during rope operation. In case of increased weight due to passengers or cross winds, these automatically adjust with lateral movement. These are axially constrained to prevent wobbling movement which can result into derailment of cable.

Breakover assembly. The breakover assembly provides support to the sheave wheels and carry the load of cable at each tower.

Cable Catcher/Safety Pin. This is a preventive safety mechanism installed to stop the cable while engaging a safety pin in case of unstable movement. This can greatly reduce the vulnerability of cable cars crashing the ground however these can only act as a secondary support system as the operation of cable might get affected numerous times resulting into control systems malfunction, cable car grip failure, bull wheel misalignment and financial setbacks.

3.2 Health and safety

3.2.1 Ice shedding

Another important factor associated with the safety of people in gondola system is ice shedding from the haul ropes which are primary movers in the gondola network [13]. In the case of ice accretions with high reflectivity, the energy is absorbed by the surface of the cable in the areas not covered by snow. In combination with ambient air temperature even below 0◦C, a layer of ice at the cable-ice interface melts and weakens the adhesive bond between the ice and the cable. Once the gravity and wind forces overcome this bond, the accreted ice slips, and sheds off the cable in various sizes. Although the gondolas are usually operated vacant before operation however, the cable when run through sheaves and towers, or even if encounter strong winds the ice shedding can occur. The shredded ice can be injurious to people trekking towards the resort or down to station, operators of snow movers, people riding snow bikes or skiing even in normal working days.

3.2.2 Avalanche

Avalanches are usually huge chunks of ice, snow or rocks falling down a mountain mostly during the winters [24]. The frequency as well as nature of these can depend upon steepness of slope, the amount and nature of snow as well as under influence of external force. These can be triggered by precipitation, temperature difference, steepness of slope, storms or even by a human being walking or skiing over such terrain. In this phenomenon the ice or snow slab at top of soft snow or weak layer of snow can cause it to break or move. As soon as the base layer moves the weight distribution becomes unbalanced which can transform into an avalanche. These can be severely hazardous and must be considered during ski events. In-case of an emergency, such as a malfunction, speed control failure, cable failure etc. It is quite difficult for rescuers to respond to such situations immediately due to a difficulty in access to site, bad weather and especially if the cable car stops mid-air suspended from the cable. These are limitations to urban vehicles, although there are methods which could be used to reach out to be affected by rope slider equipment, helicopters etc. However these are still not very efficient if emergency need immediate medical attention [25, 26].

3.3 Maintenance

3.3.1 Routine inspection and system integrity

The gondola system usually should have a routine inspection procedure in place which includes running cables idly without passengers for de-icing and smooth operation of the cable car system. It should be under the constant supervision of the operators both at the base and the resort station. They also should have a periodic maintenance schedule for the entire system at least every two years. The responsible contractors must carry out the inspection and are responsible for replacing malfunctioned or faulty equipment.

3.3.2 Cable car grip

At the gondola system, one of the major problems faced by the administration is grip system that holds the cable cars on the haul rope. This is a mechanical assembly that not only holds the cable car at the haul rope but also is excessively used for slowing down the cable cars at base stations for smooth boarding and off boarding. Although, there could be several cable cars available as a backup to keep the system running however this can cause unnecessary delays in operation if malfunction occurs during operation.

3.3.3 Logistics

The mountain ski resorts are usually at heights ranging from few hundreds to thousands of meters above sea level [27]. In case of major breakdown or even the logistics supply there seems to be no other mode of transport except the cable car system itself. So, supply of equipment in case of major maintenance or repair might pose many limitations.

4. CABLE CAR INCIDENTS

Although Cable cars have evolved over the period and nowadays are integrated with advanced safety mechanisms to make it safe for use. However some external factors such as human error, harsh and dynamic climate conditions can cause disruptions in operation as well as there is a possibility of breach of duty of care in the form of safety failure. Some of the reported incidents occurred over the period are mentioned below [28, 29]:

December 04, 2008 [4, 30] In British Columbia Whistler Blackcomb Canada, due to ice jacking the gondola cable car support tower under extreme ice accumulation got overloaded structurally and ruptured after bearing tons of load due to ice. The tower was split into two cutting two cable cars apart which hit the ground. Although there were no serious injuries reported however 53 passengers had to be rescued from stuck cable cars. Similar ice jacking incident was reported in December 2006 at this resort.

December 27, 2010 [11] In the US state of Maine, the Spillway East double chairlift on Sugarloaf Mountain during operation jumped off the haul rope, injuring 6 to 8 passengers on board. The derailment occurred due to strong winds causing 5 cable cars to fall on ground.

August 12, 2011 [31] In Schwangau, Bavaria, a paraglider hit the cable causing the cable car to stop leaving behind 30 people stranded at a height of 100m. In the presence of strong winds rescue operation had to be delayed for a day after rescuing 11 stranded passengers. The rest were brough down by a helicopter the following day.

December 7, 2014 [32, 33] At the start of operations on the Stubai Glacier in Tyrol, an empty gondola of the EUB Gamsgarten II got detached from the haul rope due to a malfunction in the locking rail/grip, throwing the cable car off the mountain station towards ground, fortunately no one was injured. Investigations also revealed that the fault warning was also neglected by staff.

January 4, 2015 [34] From the uphill cabin of the Schlossalmbahn II near Bad Hofgastein in Austria, strong winds derailed the haul rope, cable cars got overturned leaving behind 80 people stranded. No injuries were reported.

September 8, 2016 [35] In Vallée Blanche in France, a strong gust of wind caused the hauling rope to overturn over the carrying rope. 110 people had to be rescued, partly by helicopter, partly by abseiling. 33 of them could not be saved until the next morning. There were no injuries.

February 01, 2018 [36] In Chamonix France, one of the most famous Mont Blanc gondola cable had to close the operation due to ice accumulation resulting into failure of haul rope. The ice accumulated over the weekend exerting excessive load on cable car due to which the haul rope snapped, and multiple cable cars hit the ground. The gondola was not operating during the time which prevented serious consequences.

March 16, 2018 [37] In Gudauri in Georgia resort located at about 3279m elevation, the resort rarely opens due to avalanche warnings, a sadzele chairlift built by the Vorarlberg company Doppelmayr had an emergency brake malfunction along with unusual voltage fluctuation, got out of control due and reversed at unusually high speed. The passengers tried to jump of the cars which resulted into 11 people with mild injuries.

October 30, 2018 [38] In Frümsen to Rhine Valley, Switzerland located at an altitude of 1800m one of the two cable cars derailed off the cable, falling down approximately 12 meters to the ground. Fortunately, the cars were empty resulting into no injury however 8 passengers were rescued from the overhanging cable car.

December 9, 2018 [39] In the event of a heavy storm, a Wimbach Express gondola gets stuck on support 6 in the Hochfügen-Hochzillertal ski area. Before the cable car comes to a standstill, four more cabins collide with the first and become wedged. Passenger operations on the railway had already been stopped due to the wind alarm, and the empty gondolas were already on their way to the garage. No injuries were reported.

February 6, 2020 [40] In Stoos- Fronalpstock SZ chairlift after closing time during a special operation for tourists four seater car collided with a tensioned winch rope falling down almost 10m from the haul rope. Two passengers sustained serious injuries while two had a life-threatening injury. The rest of six passengers were rescued by a helicopter.

5. ICE DETECTION METHODS

Ice monitoring and detection can help to identify the critical areas where ice can be damaging for equipment. Some of the methods used for ice detection are as follows [13, 41].

5.1 Ultrasonic

An ultrasonic damping technique uses sound waves to identify the presence of Ice. The acoustic equipment is installed at the start and end point of the area that needs to be monitored. It can prove to be a very useful method as the temperature has almost negligible effect, however it is limited in terms of its applicability practically.

5.2 Piezoelectric

The piezo-electric sensors could be placed on the surface where ice needs to be detected. These sensors communicate in the form of wavelength pocket energy signals. As the thickness of ice increases the value of the energy signal decreases.

5.3 Resonant frequencies

The structure in operation runs at a certain frequency, using resonance technique the vibration probe is vibrated at the same frequency as that of the structure, in case of icing the increase in mass locally could easily be identified by comparison. Although it is effective on smaller scale, however there are chances of errors in this detection technique.

5.4 Temperature variation

This is a simple and effective ice detection technique that uses temperature sensors to detect presence of ice. It is based on a comparative method where two temperature sensors are heat treated, one of the sensors is fixed on the structure while the other one is placed in ambient condition. If the temperature of sensor on structure doesn't drops suddenly, it indicates the presence of ice.

5.5 Internal reflection

This is a technique based on properties of light. It is a known fact that light reflects internally while moving through high refractive index to low refractive index media. However, in the presence of ice the light passes through ice thus indicating it's presence.

5.6 Noise detection

The noise levels can help identify the presence of ice. Using this technique, the cable cars could be assessed in ice free form. The values obtained could be benchmarked or referenced to identify the changed noise levels in the presence of ice. This statistical analysis is useful for small scale experiments however dynamic winds in case of a cable car system can induce errors and can result into false indication on presence of ice.

6. DE-ICING METHODS

Cable cars systems is exposed to harsh climate conditions, therefore ice accumulation on its components can be seriously hazardous, damaging to structure and can induce inefficiencies to the system. Usually this is quite common with transmission lines with several techniques developed to get rid of accumulated ice. In most cases these techniques are applicable for cable car systems to be used for deicing. Some examples of these are [42-52]:

6.1 A.C voltage

It is a technique invented by Victor F. Petrenko and Charles R. Sullivan patented in US patents under high-frequency de-icing of cableways [53]. In this method AC voltage of high frequency ranging between 60-100Hz is supplied to the conductor across the cableway, by a source at 3 to 15kV. This voltage with high frequency generates alternating current field. The capacitive field associated with AC field flows through the conductor generating enough dielectric loss heat to melt the ice as shown in Figure 4. This technique could be used for gondolas, aerial tramways, and ropeways [53, 54].

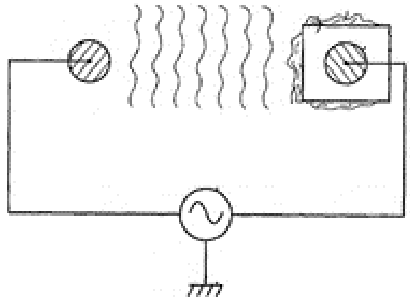

Figure 4. High frequency de-icing circuit schematics [55]

6.2 Mechanical de-icing

This method involves use of external mechanical forces to de-ice or break the ice on lines. By using a pry or a rod, the ice is being knocked off the haul ropes or cables manually, using special devices such as impeller deicers or by using an autonomous robot [55].

6.2.1 Impeller de-icer

A mechanical deicing device proposed by Rohrer and Emil, Germany 2005 [56] shown in Figure 5 work mechanically such that the grip presses impeller against rope resulting into friction, while at the same time heating the cables by using a self-contained burner, laser or microwaves. the system could be used in cable run gondola systems by fixing these devices close to support towers. The cable continuously running could easily be deiced as soon as it passes through the impellers. The heating and continuous operation can significantly deice as well as prevent further accumulation [56].

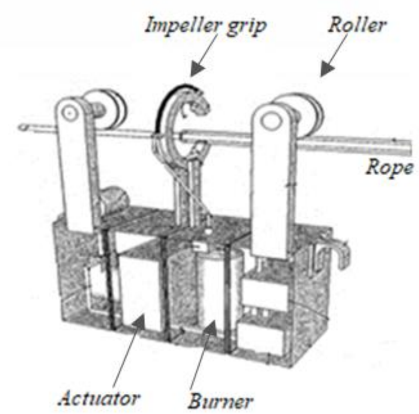

Figure 5. Powered impeller deicing device [42]

6.2.2 Remotely operated vehicle

In this method a mechanical robot operated remotely clamps the haul rope up to an extent that there is low clearance between the rope and inner diameter of the clamp. This method allows slow de-icing of conductors, without creating sudden stress on structures. An illustration of ROVs [57] is shown in Figure 6.

Additionally, these devices have high traction force which are robust, lightweight, and compact. This allows them to perform the task better. This method is effective for removing ice from haul ropes. However, these methods usually cause wear in the system with mechanical interference.

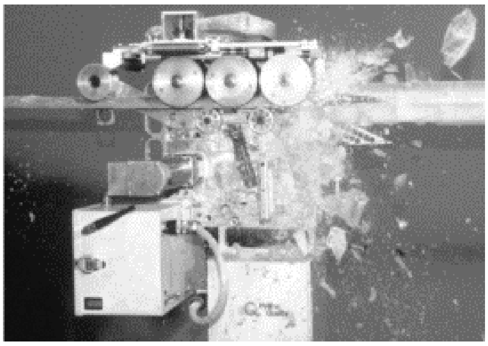

Figure 6. ROV de-icer prototype [57]

6.2.3 Pulse electro thermal de-icer

In conventional deicers, the heater is thermally connected to the ice, the structure, or through the outside environment. A pulse electro-thermal deicer (PETD) uses a short heating pulse – approximately 1s to 5s long – to heat a minimal layer of interfacial ice. This short heating time limits the heat penetration depth into both the ice and the structure [58, 59]. A PETD [60] pulse heats the ice-structure interface just above the melting point causing the ice to slide off on the resulting thin water film. This method could be used for many applications such as cable cars, tramways, transmission lines and bridge structures.

There are many other methods of de-icing cables however, to be implementable to a cable car system this needs a thorough study of cable car mechanisms in place, operating conditions, frequency of use, operating time, climate affects and numerical simulations to identify the most suitable method. Some more types of de-icing used nowadays are mentioned in Table 2 [61, 62].

Table 2. Other anti-icing & de-icing methods

Other Methods	
Method	**Description**
Coatings	Viscous fluids, Icephobic, chemically reactive, polymer coating, Ice electrolysis, chemically reactive coating etc.
Mechancial methods	Rollers or scraping, shock waves, cartridge based de icer, ROVs.
Passive devices	Snow rings and Teflon tapes, Aeolian shedding
Pneumatic devices	Pneumatic hammer
Impusive method	Electro Impulse method (EIDI)
Vibration	Ice shredder device, induced vibrations
Heat source methods	Infrared waves, radiation, ultrasonic removal of ice, anti-icing fluids

The economic comparison in Table 3 of anti/de-icing methods is based on economic indicators that influence the usability of each method for gondola cable cars. The cable cars are installed at high altitudes and require special attention for installation, repair, maintenance as well as troubleshooting. Based on the comparison, coatings and vibrational method can be viable solutions. However the cost of vibrational setup, installation and maintenance requirements makes coating more feasible option. Furthermore, coating is a preventive method that offers less weight on system, ease of application, requires almost no maintenance and offers smooth yet slip free surface for gondola rollers to operate [63].

Table 3. Economic comparison of methods for gondola

Method	Economical comparison			
	Cost	Practicability	Sustainability	Durability
Coatings	L	H	H	H
Mechancial methods	H	L	M	L
Passive devices	L	M	M	M
Pneumatic devices	H	L	M	M
Impusive method	H	L	L	L
Vibration	H	M	M	H
Heat source methods	H	M	L	L

* Note: Low= L, Medium= M, High = H

7. SAFETY STRATEGIES

Gondola cable cars specifically in northern hemisphere as well as in harsh weather conditions across the globe need additional consideration in terms of safe operation. Considering the accidents and near misses in cable cars due to icing, strong wind, corrosion, component failure and sensor malfunctions it is important to develop standard operating procedures focused on safety strategies [64-66].

7.1 Idle operation

Cable cars in northern hemisphere usually operate in the presence of ice. Being favorable conditions for ice accumulation overnight the cable cars are run idly for duration of at least one hour to get rid of icing on the haul rope, sheave wheels as well as gondola cars. The idle operation helps the operators ensure that cars are empty when the risk of an accident is highly likely while get rid of ice at the same time.

7.2 Routine inspection

Before the cable cars are operated a thorough routine inspection is usually conducted. Trained professionals keep a check on control room where parameters such as emergency stops, haul rope tension, safety pins, operating temperatures, wind speeds are analyzed. An analysis of this sort assists the operators in making decisions related to operation.

7.3 Gondola speed control

In terrains of dynamic wind speeds, it is important to constantly analyze and adjust the speed of gondola cars. As the winds speeds significantly increase along with elevation the speed control ensures that the operating speed of gondola cars is varied accordingly and to stop them if necessary. A controlled speed helps reduce the risk of high amplitude vibration on gondola cars.

7.4 Safety device

In icy conditions the haul ropes can develop ice on the surface, which can result into deropement from sheave wheels. Safety pins being part of support towers is engaged to ensure that gondola cars stop automatically and prevent any hazardous event as well as further damage. The pin is triggered in circumstances when gondolas oscillate uncontrollably, haul rope slips or when gondola car grip malfunctions.

7.5 Cable car parking

In winter season during non-operational hours the cable cars are usually parked in a sheltered area to prevent accumulation of ice on the cars, this preventive strategy saves time that would have been consumed on ice removal as well as ensures that no excessive loads would add up to the system due to cars.

8. CONCLUSION

Icing conditions in the form of glaze, hard and soft rime severely affect the operation, safety, and maintenance of cable propelled gondola systems. The presence of ice results into probable derailment, structural weakening of components as well as excessive loads. Specially, in Northern hemisphere where temperatures drop as low as -69°C. The harsh climate puts their structure & system components at unacceptable risk of failure or malfunction. Such incidents at heights in an extremely rough terrain covered in snow prove to be injurious and fatal for the safety of passengers, skiers as well as tourists. Utilizing ice prevention, de-icing and ice detection techniques in cable propelled gondola systems will significantly reduce likelihood of incidents therefore minimizing the overall risk to moderate or even acceptable level. There are numerous icing prevention or removal techniques being utilized in transmission lines and bridges however it is essential to further test these techniques followed by implementation on gondola systems to ensure increased safety and uninterrupted operation in harsh climates.

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