



**Washington State
Department of Transportation**



WSDOT

WASHINGTON STATE FERRIES

Investigation into the Loss of

Propulsion on the

M/V TACOMA

on July 29, 2014

Board of Inquiry Report

March 27, 2015

**WSDOT/Washington State Ferries Investigation
into the Loss of Propulsion on the
M/V TACOMA on July 29, 2014
Board of Inquiry Report**

Submitted:

Darnell Baldinelli
Safety Systems Manager/DP
Washington State Ferries



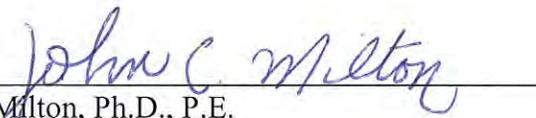
3-12-15

Mark Nitchman
Staff Chief Engineer
Washington State Ferries



3/12/15

Cotty Fay, P.E.
Chief Naval Architect
Washington State Ferries



John Milton, Ph.D., P.E.
Director, Enterprise Risk Management
Washington State Department of Transportation

Approved:



3/18/15

Lynne Griffith
WSDOT/Ferries Division Assistant Secretary

Table of Contents

Title Page:	i
Signature Page:	ii
Table of Contents:	iii
List of Attachments:	iv
Executive Summary:	2
Investigative Methodology:	4
Findings of Fact:	6
Apparent, Fault Tree and Root Cause Analysis and Findings:	25
Conclusions:	35
Recommendations:	36
Attachments:	1 thru 10

Table of Contents

Title Page:	i
Signature Page:	ii
Table of Contents:	iii
List of Attachments:	iv
Executive Summary:	2
Investigative Methodology:	4
Findings of Fact:	6
Apparent, Fault Tree and Root Cause Analysis and Findings:	25
Conclusions:	35
Recommendations:	36
Attachments:	1 thru 10

WSDOT/Washington State Ferries Investigation Into the Loss of Propulsion on the

M/V *TACOMA* on July 29, 2014

Board of Inquiry Report

List of Attachments

- ATTACHMENT 1.....Electrical Propulsion System Photos
- ATTACHMENT 2.....WSF letter, Emergency Contract, M.V. Tacoma dated September 8, 2014
- ATTACHMENT 3.....Director’s Work Order Authorization Request of October 10, 2014
- ATTACHMENT 4.....Siemens Commissioning & Field Services Report of WSF “Tacoma” Investigation of “July 29th” Incident by Fritz Schuckert of August 11, 2014
- ATTACHMENT 5.....Siemens Commissioning & Field Services Report of WSF “Tacoma” Investigation of “July 29th” Incident by Loren Bailey Jr of August 5 to 8, 2014
- ATTACHMENT 6.....Siemens Commissioning & Field Services Report of WSF “Tacoma” 3AF Circuit Breaker Initial Examination of August 5 to 8, 2014
- ATTACHMENT 7.....Siemens Root Cause Analysis and Recommendations Investigation of July 29th Incident on Washington State Ferry – Tacoma of October 24, 2014
- ATTACHMENT 8.....DEI Electrical Consultants, Inc. *MV Tacoma* “Root Cause Analysis” letter of October 21, 2014
- ATTACHMENT 9.....Medium Voltage Vacuum Circuit Breaker Test Reports: 11 Reports of September 30, 2014
- ATTACHMENT 10....ABS Marine Root Cause Analysis Map

Executive Summary:

At approximately 12:44 Pacific Standard Time on July 29, 2014, while entering the approach to Eagle Harbor the M/V TACOMA experienced a complete loss of electrical power which caused the crew to implement emergency actions to keep the vessel from running aground near Tyee Shoal east of Bainbridge Island. In accordance with Washington State Ferries' Safety Management System policy, SMSM SAFE 0100, a Board of Inquiry was appointed on August 7, 2014. The Board of Inquiry was made up of senior level managers and a senior Staff Chief Engineer. The Board of Inquiry was appointed to conduct an investigation into the circumstances of the incident, to identify the causes and contributing factors, recommend corrective actions, and capture the lessons learned from this incident.

The Board of Inquiry has determined that the root cause of this incident was a design oversight feature of the electrical system that allowed the #4 alternator circuit breaker to close when it should not have been allowed to close. The electrical propulsion system had been designed by Siemens to meet all the regulatory requirements at the time of construction and the design was approved by the U.S. Coast Guard and the American Bureau of Shipping and accepted by WSF. The Board of Inquiry concluded that had the propulsion switchboard been fitted with redundant protective devices such as a synchronizer (SPM-A) with voltage comparator or digital voltage regulators with phase loss sensing, this incident would not have occurred.

The Board of Inquiry found that the engineering crew did not recognize an alarm associated with the number four alternator when arriving in Seattle. Additional training on the vessel's control, alarm and monitoring systems may have averted the cascade of events which led to the loss of propulsion. Additionally, the Board concluded that engineering officers could benefit from increased hands-on experience and training.

The Board of Inquiry has developed four recommendations which directly address the finding of this Board. Finally, it is the opinion of the Board that although training is needed, the crew was not responsible for the incident.

Investigative Methodology:

In accordance with Washington State Ferries' (WSF's) Safety Management System (SMS) policy SMSM SAFE 0100, a Board of Inquiry was chartered on August 7, 2014. The Board of Inquiry was a cross-departmental team of senior managers and vessel engineers. The members were:

Board of Inquiry Chairperson
Darnell C. Baldinelli
Safety Systems Manager/Designated Person Ashore
Washington State Ferries

Board of Inquiry Member
Mark Nitchman
Staff Chief Engineer
Washington State Ferries

Board of Inquiry Member
Endicott Fay
Chief Naval Architect
Washington State Ferries

Board of Inquiry Member
John Milton, PhD, PE
Director Enterprise Risk and Safety Management
Washington State Department of Transportation

The Board of Inquiry used the American Bureau of Shipping (ABS) Marine Root Cause Analysis Technique (MaRCAT) investigation methodology as a guide in the Board's deliberations. The ABS MaRCAT approach to incident investigations was particularly helpful because the methodology is designed specifically to address many of the unique aspects of the marine industry, including human element, machinery and engineering, and structural elements.

The MaRCAT methodology uses tools such as causal factor charting, fault tree analysis and the "5 whys" technique to identify the casual factors of an incident. The Board used a combination of these techniques in its analysis and found them helpful in identifying the

questions that needed to be answered to understand the incident and its causes. The Board used a three step process of analysis.

1. The Board conducted an Apparent Cause Analysis, in which key events from the event were extracted and the apparent causes of these events were identified.
2. The Board then used the apparent causes and subjected them to an additional examination through a Fault Tree Analysis. The Fault Tree Analysis frames the events by presenting a series of “and” and “or” declarations.
3. The findings from the Fault Tree Analysis were used as the starting point in the Root Cause Analysis Map. A Root Cause Analysis was performed and the findings were then described in plain language.

A complete explanation of the MaRCAT methodology and the ABS Marine Root Cause Analysis Map can be found in the Guidance Notes on The Investigation of Marine Incidents, June 2005, at

http://www.eagle.org/eagleExternalPortalWEB/ShowProperty/BEA%20Repository/Rules&Guides/Current/142_InvestigationofMarineIncidents/Pub142_InvestMarineIncidentsGuide

In its deliberations the Board reviewed a wide array of data and information, much of which are included as enclosures to this investigation. As a deliberative body, the Board of Inquiry spent in excess of 40 hours meeting to examine evidence and develop causal factors and root causes.

The purpose of this report is to provide a formal record of the investigation process and as a means of documenting what was learned. The primary objective of this report is to describe the events which lead to damage of the #3 and #4 alternator circuit breaker cubicles and the resulting loss of power. The events that occurred following the loss of power will be addressed briefly but they were not the primary focus of the Board’s deliberations.

Findings of Fact:

The M/V TACOMA is a Jumbo Mark II Class ferry operated by WSF. The vessel was launched in 1997; it was the first in its class. The vessel is inspected and certificated by the U.S. Coast Guard to carry 2,500 passengers and 202 vehicles on a “lakes, bays and sounds” route. It has a crew of crew of fifteen personnel, eleven Deck Department and four (4) Engine Department. On duty that day were:

- Master Taylor Anderson
- Chief Mate Scott Freiboth
- Second Mate Kornstein
- Able Seaman Mark Henry
- Able Seaman Peter Hart
- Able Seaman John Lohrey
- Able Seaman Ryan Brazeau
- Ordinary Seaman Robert Parker
- Ordinary Seaman Janelle Eller
- Ordinary Seaman Douglas Lorig, Jr.
- Ordinary Seaman Whitten Volentine
- Chief Engineer Andrzej Sienicki
- Assistant Engineer David Shaw
- Oiler Brandon Lee
- Oiler Breing Sienicki

At the time of the incident the M/V TACOMA engineering department was supervised by Chief Engineer Andrzej Sienicki. Mr. Sienicki is the permanently assigned Assistant

Engineer of the watch but was temporarily promoted to Chief Engineer due to a daily vacancy. Mr. Sienicki holds a USCG Chief Engineer's license and has been qualified to serve on the M/V TACOMA as Chief Engineer since October 23, 2012. He has worked for WSF since 1999 and was assigned to the M/V TACOMA as Assistant Engineer in 2011.

Replacing Mr. Sienicki as the M/V TACOMA's Assistant Engineer was Vacation Relief Assistant Engineer David Shaw. Mr. Shaw was not permanently assigned to the M/V TACOMA but can be dispatched to any vessel where a temporary vacancy occurs. Mr. Shaw is qualified to serve as Assistant Engineer on 15 WSF vessels. He has served on the Jumbo Mark II Class (similar to the M/V TACOMA) six days in the last year prior to this event.

In addition to the two engineering officers, there were two unlicensed engine room crew members on the M/V TACOMA. The #1 Oiler was Mr. Brandon Lee who was assigned to the M/V TACOMA in January of 2014 and has been employed with WSF since May of 2011. The #2 Oiler, Mr. Bering Sienicki, has worked on the M/V TACOMA since September of 2013 and he has been employed by WSF since May of 2011.

Timeline/Description of Incident:

The following time line is constructed primarily from the M/V TACOMA's Alarm and Monitoring System Log, Automatic Identification System (AIS) data, the Watch Supervisor Log, and statements made by the crew.

The events that took place on the M/V TACOMA are well documented in the ship's data recorders. There are gaps where data points are captured in the alarm and monitoring system or where reliance on human memory is necessitated.

There are two times represented in the following timeline. The first time signature was the actual time and the second time signature appearing in red is from the vessel's alarm and

monitoring systems. The alarm and monitoring system on the M/V TACOMA was not set to the correct Pacific Standard Time (PST). There is no Global Positioning System or ship's clock input to the alarm and monitoring system so often the events depicted in the alarm log do not correlate with the actual clock time of external events. In this case, an accurate clock time is established by reconciling common events between AIS data and the corresponding alarm and monitoring event.

The external clock time recorded on the time line is in black and constructed backwards from the landing in Seattle where the vessel stopped and the #4 propulsion alternator was shut off at approximately the same time. The alternator breaker was opened at 11:51:58. The PST is therefore approximately 13 minutes and 17 seconds later than the alarm and monitoring time stamp.

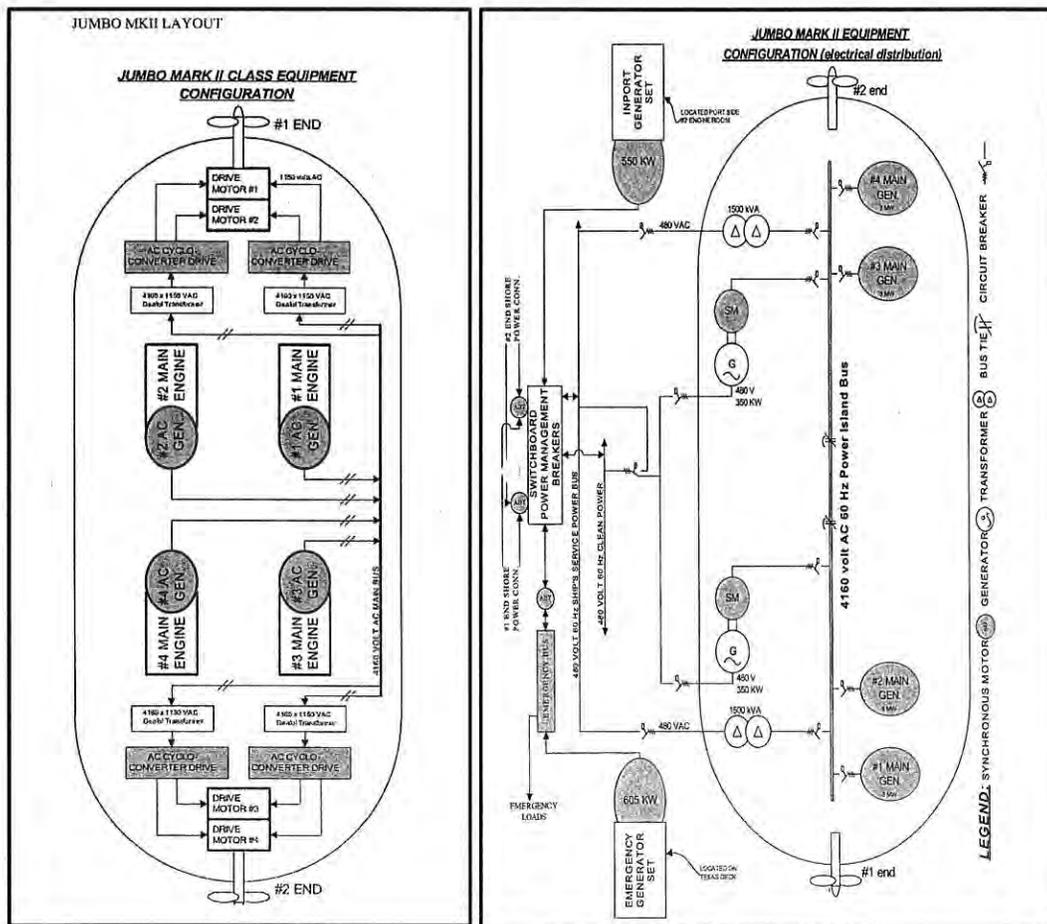
The reconciliation of times appears to be very consistent with the AIS track.

Within the timeline certain key events are prefaced with a subheading in bold text. These subtitles are provided to orient the reader along the critical path of the incident.

04:00 to 11:58 PST:

The M/V TACOMA was started and begins routine operations for the day. The vessel was using #1 and #3 propulsion alternators for propulsion under normal conditions. The #4 propulsion alternator was being used as the "landing engine" meaning it was being used to provide additional power for all landings. After each landing it was shut down in accordance with procedures described in SMS policy DECK 0030. The #2 propulsion alternator was also available for service but was not being used on this date due to warranty work being performed by a vendor after a recent overhaul.

The M/V TACOMA has five electrical switchboards. There are the two 4.16 kilovolt (kV) main propulsion switchboards and three 480 volt (V) switchboards; ships service, clean power and the emergency switchboard. The ship's service switchboard was being powered by the main propulsion switchboards through the #2 ship's service transformer. The clean power switchboard was being energized by the main propulsion switchboard through the #1 motor-generator set. Both clean power and ship's service switchboards were feeding power to various sections of the emergency switchboard.



In emergencies the 480 V switchboards may also be powered by an emergency generator or by an in-port generator. These are arranged for automatic starting and operation in the event of 480 V power failure. The ship was arranged so that either the emergency or the in-port

generator could provide power to all 480 V services in the event there is a loss of power sourced from the 4.16 kV propulsion system.

The in-port generator was set-up as the “blackout power source,” meaning it would automatically start and energize the ship’s service and clean power switchboards during a power failure. All conditions within the plant appeared normal throughout the morning.

11:59:04 PST (11:45:47 alarm and monitoring)

The #4 propulsion alternator was started in preparation for the Seattle landing. Adding the third propulsion alternator for landings is a routine procedure designed to improve the ship’s maneuverability and reduce the risk of a machinery casualty during the final approach to the dock that could result in a collision with the dock. The alternator is then shut down after the landing for fuel conservation purposes.

Paralleling the incoming propulsion alternator to the switchboard is a partially automated process on the M/V TACOMA. The diesel is first started and placed in low idle, about 400 revolutions per minute (rpm) until the Master directs that it be placed into service. The diesel is then sped up to high idle (900 rpm); the engineer places the diesel control into the “run” position. This enables the engines to be synchronized.

The engineer then turns the circuit breaker control to “close” and holds it in that position until the circuit breaker closes. While in the “close” position, the synchronizer controls the incoming alternator speed so that the frequency and phase relationships of the incoming alternator are within acceptable parameters. Then the synchronizer issues a permissive signal to the circuit breaker causing it to close.

12:05:15 PST (11:51:58)

Upon completion of the landing, the engineers began to remove the #4 propulsion alternator from service using approximately the same process as above but in reverse order. The #4 propulsion alternator circuit breaker was opened by the Assistant Engineer. At approximately the same time a high voltage condition or “surge” occurred in the #4 alternator circuit breaker cubicle. This voltage surge caused alarm A404 to annunciate for .920 seconds.

The cause of the voltage surge cannot be definitively determined from the body of evidence currently available. Third party electrical engineers examining this issue for WSF have associated the surge with the opening of the #4 propulsion alternator breaker. (According to IEEE.C62.48 [2], short duration over-voltage conditions can occur at breaker opening). WSF is still considering other possible causes of the voltage surge, such as the #4 propulsion alternator voltage regulator.

Failure of fuses F1 and F3

The voltage surge is suspected to have blown two fuses that protect critical control, protection and monitoring equipment for the #4 propulsion alternator. Post casualty tests revealed that fuses F1 and F3, which protect transformers –T7 and –T9, were open. These transformers are critical to the safe operation of the alternator because they supply (along with fuse F2 and transformer –T8) low voltage feedback to the control system that is representative of the actual voltage being produced in the alternator. Without these two phases of voltage output, the alternator cannot be controlled.

The Board could find no documentation or anecdotal evidence of any previous F1, F2 or F3 fuse failure in Jumbo Mark II Class history. Evidence that fuses F1 and F3 failed at this time is circumstantial.

Alarm A404 annunciation

The alarm A404 annunciated when the #4 alternator output voltage exceeded 4.784 kV. This voltage represents a highly unusual deviation from the normal operating voltage of 4.16 kV and is not associated with any routine operations on the vessel. The engineering crew does not see a description of what causes alarm A404 or the level of high voltage that sets it off.

The Assistant Engineer cleared the alarm from the screen 1 minute and 26 seconds later when all of the routine alarms associated with shutting down the #4 propulsion alternator diesel engine were reset. All evidence suggests the crew thought the shut-down in Seattle was uneventful. They did not investigate the brief A404 high voltage alarm. The Chief Engineer reported that he was not in the control room when the circuit breaker was opened and not aware the alarm had occurred.

The Board has determined that it is very rare for the alternator voltage alarm A404 to annunciate during normal operations. However, it is an alarm that is very similar to another alternator voltage alarm that does occur occasionally at the time of breaker opening. This is alarm A403 which is set at 4.25 kV.

The difference in how these two alarms are generated and levels at which they annunciate is significant and critical for operators to understand. Problematically, the description used in the alarm and monitoring system to annunciate these alarms can lead to confusion between them:

A404 "ALT4 V HIGH"

A403 "ALT4 VOLTAGE"

Phase Loss Relay

The voltage signals (phases) from the three transformers are critical to the safe operation and control of the alternator. To ensure the alternator is protected from damage caused by phase loss, the M/V TACOMA's controls are fitted with a protective device called the "phase loss relay." The phase loss relay monitors each of the three voltage phases from the low voltage side of the three transformers. The phase loss relay prevents an alternator circuit breaker from closing if a phase loss is detected. It will also open the circuit breaker if the phase loss occurs when the breaker is already closed. The phase loss relay (F14) is a Siemens Type 7TU9914 relay.

When the two fuses blew on the M/V TACOMA, the phase loss relay for the #4 alternator should have functioned to prevent that circuit breaker from closing. The phase loss relay failed to function. If the phase loss relay had functioned as intended there would have been no significant damage to the vessel. The ship would not have lost power and would not have experienced an interruption in service.

In post-casualty testing of the phase loss relay, it has been conclusively demonstrated that the phase loss relay will only function correctly when one phase or three phases are lost. It will not function when two phases are lost as it is installed. The M/V TACOMA lost two phases in the control circuit when fuses F1 and F3 were blown. The Jumbo Mark II Class circuit design can be modified in the field to ensure the relay will function when two phases are lost.

The phase loss relay has no periodic safety testing protocol which would demonstrate functionality with two phases missing.

12:05:16 PST (11:51:59)

The “end time” of alarm A404 was annunciated at the time the #4 alternator circuit breaker was opened.

12:05 to 12:43 PST (1152 to 1230)

The M/V TACOMA was unloaded and loaded in Seattle. It then made the scheduled 12:20 departure for Bainbridge Island on time. There were no unusual conditions or alarms in the M/V TACOMA power plant during this period.

12:43 to 12:44 PST (12:30 to 12:31)

Voltage Regulator

During the transit, the #4 propulsion alternator was started by the Assistant Engineer and was coming up to normal operating speed. As the alternator’s speed approached 900 rpm, the voltage it generated is believed to have risen to values far in excess of 4.16 kV. This is thought to have occurred because the voltage regulator lost two phase inputs when the potential transformer fuses were blown. The voltage regulator responded to this condition by increasing #4 alternator excitation until alternator output voltage rose to excessive levels. The actual voltage being produced by the alternator at this time cannot be verified by the data record.

SPM-A synchronizing device

When the alternator speed reached 900 rpm, the Assistant Engineer turned the diesel engine speed switch from “high idle” to “run” on the Engineering Operation Station (EOS) console. This action enabled the Woodward SPM-A synchronizing device to bias the incoming alternator speed to match the frequency and phase with that of the propulsion bus. When these

are matched for a pre-defined period of time, the synchronizer issues a permissive signal that allows the circuit breaker to close.

The SPM-A synchronizer was also affected by the phase loss condition. The phase loss impairs the ability of the SPM-A to accurately determine when the proper time to close the circuit breaker occurs. In this condition the synchronizer can issue a breaker close signal when the alternators are not properly synchronized.

12:44:17 PST (12:31:00)

Arc fault occurs

The vessel was under power and proceeding at a speed of 18.2 knots in route to the Bainbridge Island terminal. The #4 propulsion alternator circuit breaker was closed by the Assistant Engineer. The circuit breaker closed even though the alternator voltage was severely mismatched with the switchboard and out of phase with it. This condition resulted in an arc event within the #3 and #4 alternator potential transformer cubicles in the #2 switchboard room.

An arc fault is a thermal energy release that can attain temperatures as high as 20,000 degrees Celsius. In an enclosed cubicle, this heating causes rapid expansion of air and gasses within the enclosure and can cause catastrophic structural failure if this pressure is not carefully released.

On the M/V TACOMA the heat of the arc event melted copper bus work and damaged electrical conductors. All of the surge arrestors in two alternator cabinets were destroyed by high energy levels that deformed the structure of the steel supports. The rear (steel) covers of the switchboard were pushed outward due to the high pressure within the cubicles. The gaps created by these covers issued smoke from the transformer cubicles into the atmosphere of the engine room.

This arc event drove down the bus voltage being produced in the other propulsion alternators briefly. The 4.16 kV bus voltage dropped so low as to cause the low voltage protection in most of the circuit breakers to open, breaking the electrical circuit.

Ship propulsion lost

All ship's service electrical power and emergency electrical power was lost when the low voltage protection for the circuit breakers was activated. The propulsion system breakers and contactors that energize the propulsion drive motors opened. There was a complete loss of all AC power on the ship. For 13 seconds the only power available was the DC power provided by the ship's various battery supplied installations. The only lighting available was provided by the battery powered Temporary Emergency Lighting system which operated properly.

12:44:21-25 PST (12:31:00-04)

During the first four seconds after closing the #4 alternator circuit breaker, 110 individual visual and audible alarms were annunciated on the ship's alarm and monitoring system. Each of these alarms described a system experiencing loss of power or reporting anomalous conditions caused by the loss of power. Virtually every system on the ship was reporting that it was in a state of failure.

12:44:23 PST (12:31:02)

Diesel engine shutdown

Both #3 and #4 alternator breakers tripped and their diesel engines were shut down automatically by the differential protection relay (Siemens Type 7UT512). Neither the #3 nor the #4 alternator was available for further service after the arc event because of the damage done to their alternator cubicles.

The ship was left with #1 propulsion alternator running but providing no power to any systems on the vessel. The #1 propulsion alternator and the 4.16 kV switchboard tie breakers remained closed. All other 4.16 kV breakers were opened. The ship's speed began to drop.

12:44:26-31 PST (12:31:05-10)

Emergency generators start power to ship's service switchboard

The in-port and emergency generators started automatically three to eight seconds after the loss of switchboard power. The in-port generator was set to provide power to the ship's service switchboard.

There were no operational ventilation fans left in the engineering spaces and all fire dampers closed automatically. This eventually allowed an accumulation of smoke from the arc event to hang in the #2 engine room, causing the engineering crew investigate the possibility that an active fire existed in the engine room or switchboard.

12:44:35 PST (12:31:13)

Emergency switchboard re-energized

The emergency switchboard was re-energized automatically by the emergency generator. The ship's service switchboard was re-energized by the in-port generator.

The ship's power management system closed breaker P401 to connect the clean power switchboard to the ship's service switchboard. Power for the steering system was restored and emergency and all normal lighting were restored throughout the ship.

12:44:42 PST (12:31:20)

Repeated opening and closing of breakers

Circuit breaker P401, which fed power from the ship's service switchboard to the clean power switchboard, opened due to low voltage from the ship's service switchboard. This de-energized the clean power switchboard. Two seconds later the power management system reclosed the breaker. Over the next four minutes, this breaker automatically opened and closed 35 times. Later, it was determined that this condition was caused by a problem with the in-port generator voltage regulator.

The continuous opening and closing of P401 in the control room during the first four minutes of the casualty sounded like a loud banging back and forth as the breaker operated. It presented a distracting and confusing element to the engineers responding to the power loss casualty. Simultaneously, all of the lighting and other power services supplied through the clean power switchboard were turning on and off with each cycle of the breaker.

12:45 PST

The Master logged the loss of power in vicinity of Tyee Shoals in the Pilothouse Log Book.

12:46:42 PST

Vessel speed dropped to 12.1 knots. The Master turned north to avoid grounding. Power for the steering gear was provided by the emergency generator.

12:48:20-33 PST (12:35:03 to 16)

The engineering crew began an attempt to restart the power plant using remaining 4.16 kV power from the #1 propulsion alternator.

12:48:34 PST (12:35:17)

Switchboard loses 480 V supply

The #2 motor generator was energized from the 4.16 kV bus and placed into service supplying power to the clean power switchboard. This eliminated the problem with the P401 breaker; it stopped cycling open and closed. The #1 main engine took over the clean power switchboard electrical loads (through the motor generator set) from the in-port generator.

At the same time the motor generator was restored to service, the ship's service switchboard lost the 480 V supply from the in-port generator. This is a critical development because it does not appear that the crew realized they lost power to the ship's service switchboard. If they had been able to identify this situation there were multiple sources of power available to restore it. The cause of the switchboard power loss is unknown, but being coincidental in time suggests the two events are related. The in-port generator remained running but was no longer providing power to any switchboards.

Without power to the ship's service switchboard, the propulsion system could not be restarted. The cooling water pumps necessary to cool the diesel engines for the in-port generator and the #1 propulsion alternator were not functioning and caused the diesel engines to overheat in minutes.

12:51 PST

Ship drops anchor

Via Channel 16 VHF, the WSF Operation Center Watch Stander received M/V TACOMA Master's report of loss of propulsion. The Master reported that he had ordered the dropping of the anchor to stop the vessel from drifting to the beach. The WSF Operation Center

Watch Stander immediately began making notifications to WSF management and the Federal Joint Harbor Operations Center (JHOC).

12:51:31-55 PST (12:38:14-38)

The #1 propulsion alternator diesel engine began to overheat and high jacket water temperature (208°F) alarms sounded. Cooling for the engine could not be restored until the ship's service switchboard was restored to service. This overheating condition became an immediate priority for the engineers to address.

12:53:53 PST (12:40:36)

#1 diesel engine begins to overheat

The #1 propulsion alternator diesel oil temperature alarm sounded (223°F).

12:56:05 PST (12:42:48)

In port generator begins to overheat

The in-port generator also began to overheat due to the failure of the secondary cooling water pumps (heat recovery and sea water cooling).

12:56:17 PST (12:43:00)

The crew made one more attempt to restore propulsion but was unsuccessful due to the loss of 480 V power in the ship's service switchboard. Propulsion breakers opened with twenty-six related alarms in the next four seconds.

Excessive temperatures threaten damage to the #1 propulsion alternator diesel if it is not secured quickly.

12:58 PST:

M/V TACOMA's Master logged in Pilothouse Log Book that the vessel's anchor was released.

12:58:56 PST (12:45:29)

The 4.16 kV propulsion bus was shut down, the #1 diesel had been secured. There was no clean power or ship's service power. Power availability was limited to the emergency generator switchboard services and the DC systems.

12:59 PST:

Rescue boat launched

M/V TACOMA's Master logged in Pilothouse Log Book that the #1 rescue boat was launched. The rescue boat was launched to take an emergency tow line to the M/V SEALTH which was on its way to assist the M/V TACOMA.

13:02 PST:

M/V TACOMA's Master logged in Pilothouse Log Book that the M/V SEALTH was on scene to assist and that the emergency towing bridle was sent via the #1 rescue boat and attached to the M/V SEALTH.

13:03 PST:

The U.S. Coast Guard was updated via the JHOC and confirmed the Eagle Harbor channel was blocked.

13:07 PST

M/V TACOMA's Master confirmed that the anchor was down and reported that he was concerned about the stern drifting to the beach. He requested information on the tug. The Watch Stander reported they were working on getting the tug LINDSEY FOSS and that the current estimated time of arrival was one hour, but they were still working on getting a tug sooner.

13:07:27 PST (12:54:10)

In-port generator is shut down

The in-port generator was shut down due to lack of secondary cooling water supply. The emergency generator remained in service and continued to provide power to the emergency switchboard.

13:10 PST:

WSF's Emergency Operation Center (EOC) was activated. All primary EOC positions were staffed. Vessel status: Fuel on board 77,000 gallons; anchor dropped, not drifting; position 47°36'41.2"N 122°29'10.7"W; next tide – Low 17:54; heading: 309° NWxW 304.

13:13:07 PST (12:59:50)

In-port generator restarted

The in-port generator was restarted and power was restored.

13:13:32 PST (12:00:15)

In-port generator was providing power to the ship's service switchboard. Emergency generator loads were transferred to the in-port generator.

13:13 PST (13:02)

The main engine heat recovery pumps (#1 and #2) were reset and started.

13:15 PST

M/V TACOMA's Master logged in Pilothouse Log Book that the emergency tow bridle was switched from the M/V SEALTH to the towing vessel LINDSEY FOSS.

13:21:17 PST (13:08)

The engineering crew prepared the #2 propulsion alternator diesel for operation.

13:25 PST

M/V TACOMA's Master logged in Pilothouse Log Book that the M/V SEALTH was released to normal service.

13:35 PST

M/V TACOMA's Master logged in Pilothouse Log Book that the towing vessel PACIFIC KNIGHT was on site to assist the LINDSEY FOSS in towing the M/V TACOMA to the Bainbridge Island terminal.

13:48:51 PST (13:35:34)

#2 propulsion alternator diesel started

The engineering crew started #2 propulsion alternator diesel.

13:49 PST (13:36)

The #2 propulsion alternator was placed on the 4.16 kV bus and re-energized the propulsion switchboard.

13:49:37 PST (13:36:20)

#1 propulsion alternator diesel started

The #1 propulsion alternator diesel was started.

14:11:42 PST (13:58:25)

In-port generator secured

In-port generator was secured, all electrical loads were being provided from the propulsion bus through the ship's service transformer and motor-generator set.

14:19 PST

M/V TACOMA's Master reported that the vessel was under tow with the LINDSEY FOSS and PACIFIC KNIGHT, and headed to Bainbridge Island terminal slip 2. The M/V TACOMA was moored at the terminal and offloaded vehicles and passengers.

Timeline ends

Apparent, Fault Tree and Root Cause Analyses and Findings:

The following table summarizes the findings from the three levels of analysis used in the Board of Inquiry’s investigation. First, the Board conducted an Apparent Cause Analysis. Second, the Board used the Apparent Cause Analysis to conduct an additional examination through a Fault Tree Analysis. The Fault Tree Analysis frames the problem statements by presenting a series of “and” and “or” declarations. Third, the Board used these problem statements as the starting point in the “ABS Guidance Notes on the Investigation of Marine Incidents” Marine Root Cause Analysis Map. Finally, the Board’s findings from the Marine Root Cause Analysis Map are described in plain language in the last column of this table.

Key Event	Apparent Cause Analysis Findings	Fault Tree Analysis Findings	Root Cause Analysis Map Path	Root Cause Findings and Description
1.	11:59: Initial field testing of the #4 alternator circuit breaker indicates it may have a defective vacuum bottle after only 8000 cycles. The breaker is rated for 30,000 cycles between major maintenance intervals.	<ul style="list-style-type: none"> • And a voltage surge occurred. • And created excessive current that blew two fuses protecting the #4 “potential transformers”. • And the blown fuses in the potential transformers circuit caused a voltage phase loss condition at the phase loss relay, synchronizer and voltage regulator. • And the failure of the phase loss relay to function allowed the breaker to close when it should not have been allowed to. 	2. Machinery/ Equipment 6. Design Problem 31. Design Verification 33. Review Verification Issue 266. Industry Standard Issue 268. Standard Confusing, Contradictory, or Incomplete	<i>The phase loss circuit could not detect two phases and the testing and verification process did not identify the feature.</i>

2	11:59: It appears that the crew did not reduce electrical loads on the #4 alternator before opening the circuit breaker.	<ul style="list-style-type: none"> • Or because the crew did not shed the electrical load to the #4 alternator circuit breaker before it was opened, if there was a defective vacuum bottle, this procedure may have resulted in a voltage surge that caused the fuses in the potential transformer to fail. 	5. External Factors 18. External Events	<i>If the crew had shed the load it may have reduced the risk a surge would occur in the event there was a compromised vacuum bottle. However, since the cause of the surge is still unknown and requires a compromised vacuum bottle to have occurred, this may have not been a root cause</i>
3	12:05: Two of the three fuses in the #4 potential transformers blew	<ul style="list-style-type: none"> • And caused the loss of phase voltage. • And with the loss of the phase voltage signal the phase loss relay should have prevented the #4 alternator circuit breaker from closing • And led to an arc event 	2. Machinery/ Equipment 6. Design Problem 31. Design Verification 33. Review Verification Issue 266. Industry Standard Issue 268. Standard Confusing, Contradictory, or Incomplete	<i>The design allowed the phase loss relay to function if one fuse or if three fuses are lost, but it was not designed to protect against the loss of two fuses.</i>
4	12:05: The alarm and monitoring system does not monitor the condition of these fuses, or the phase loss relay	<ul style="list-style-type: none"> • And if the monitoring system had been designed to alarm on fuse failure, the crew would have been alerted that the #4 alternator could not be used. • Or if the monitoring system had been designed to monitor the 	5. External Factors 19. Other	<i>Because the phase loss relay did not function as designed had the alarm and monitoring system functions been available it may have alerted the crew to the problem with the #4</i>

		voltage of the #4 alternator circuit before the circuit breaker is closed then arc event would not have occurred		<i>Alternator.</i>
5	12:05: Alarm P404 sounded but no action was taken to investigate the cause of it.	<ul style="list-style-type: none"> • And because the #4 alternator circuit breaker was opened in Seattle the alarm monitoring system show that the fault had ended in 9/10th of a second • And because the alarm quickly ended, the crew believed that there was no ongoing problem with the system • And the Relief Assistant Engineer who was monitoring the alarms concluded that no further action was required (*Note: at the time of the P404 alarm sounded and the Relief Assistant Engineer cleared the alarm the Chief Engineer was not present.) 	4. Human 11. New Assigned/ Contract/ Temporary Officer/ Crew 72. Management Systems 89. Problem Identification 91. Problem Analysis Issue 256. Company Standards, Policies, or Administrative Controls Issues	<i>The Alarm P404 is not easily distinguishable from Alarm P403, and the function of P404 was not understood by the crew.</i>
6	12:05: The alternator phase loss relay did not function as designed (field test post incident revealed that with one fuse loss it worked as intended but when tested with two	<ul style="list-style-type: none"> • And as a result of the failure of the phase loss relay the #4 alternator circuit breaker was able to be closed in an over voltage and out of phase condition (*Note: This is a 	2. Machinery/ Equipment 6. Design Problem 31. Design Verification 33. Review Verification Issue 266. Industry Standard Issue 268. Standard	<i>The phase loss circuit could not detect two phases and the testing and verification process did not identify the feature.</i>

	fuses opened the relay failed to function	<p>single point of failure and there was no protection for phase loss elsewhere in the circuit, and there are no test procedures to validate the design or the function of the phase loss relay.)</p> <ul style="list-style-type: none"> • And this led to the arc event 	Confusing, Contradictory, or Incomplete	
7	12:05: After the breaker is opened, alarm and monitoring system logic blocks the A403 alarm from sounding	<ul style="list-style-type: none"> • And since monitoring system blocked the alarm the crew did not realize that there was an ongoing fault in the system • And after the Relief Assistant Engineer acknowledged the alarm it was removed from the monitoring system's screen and it did not reoccur. Which indicated that the fault no longer existed when in fact the fault was ongoing • And if the crew had realized that there was an ongoing fault with the #4 alternator circuit breaker they would have used the #2 alternator as a backup. • 	<p>4. Human 11. New Assigned/ Contract/ Temporary Officer/ Crew 72. Management Systems 89. Problem Identification 91. Problem Analysis Issue 256. Company Standards, Policies, or Administrative Controls Issues</p>	<i>The Alarm P404 is not easily distinguishable from Alarm P403, and the function of P404 was not understood by the crew.</i>

8	1243: The loss of two voltage signals to the #4 alternator voltage regulator cause it to respond by raising alternator voltage to extremely high levels.	<ul style="list-style-type: none"> • And that caused a significant voltage imbalance between the incoming alternator and the switchboard voltage. • And this voltage difference caused high levels of current flow while the #4 alternator circuit breaker was closed. • And had the voltage regulator been a digital model that recognized phase signal loss it would have stopped exciting the alternator and would shut down the prime mover. • And this led to the arc event. 	5. External Factor 18. Other	<i>One of the consequences of the phase loss was for the control system to increase voltage to the #4 alternator prior to the closing of the #4 circuit breaker. The alarms P403 and P404 were blocked because the #4 alternator circuit breaker was open.</i>
9	1243: The Relief Assistant Engineer may have not checked or may not understood the V meter readings when raising engine speed to high idle (900 rpm).	<ul style="list-style-type: none"> • And if the Relief Assistant Engineer had checked and recognized the V meter reading was unusually high or anomalous • And the Relief Assistant Engineer may have decided not to close the #4 alternator circuit breaker • Or if the phase loss relay had been functioning properly the Relief Assistant Engineer would have not 	Path 1 4. Human 11. New Assigned/ Contract/ Temporary Officer/ Crew 143. Human Factors 150. Situation Awareness 157. Knowledge Based Decision Required 256. Company Standards, Policies, or Administrative Controls Issues 257. Not Addressed Path 2 4. Human	<i>WSF's training programs do not provide training for alarm and monitoring or propulsion control systems.</i>

		<p>been able to close the #4 alternator circuit breaker (*Note: An administrative control has been put in place to ensure that voltage is verified before any alternator circuit breaker is closed.)</p>	<p>11. New Assigned/ Contract/ Temporary Officer/ Crew 178. Training/ Personnel Qualifications 179. No Training 183. Training Need Not Identified 256. Company Standards, Policies, or Administrative Controls Issues 257. Not Addressed</p>	
10	<p>1243: The Relief Assistant Engineer had only six days on Jumbo Mark II vessels during the previous 12 months.</p>	<ul style="list-style-type: none"> • And his relative lack of familiarity with the complex Jumbo Mark II engineering systems may have inhibited the Relief Assistant Engineer's ability to recognize the situation leading up to the arc event. 	<p>4. Human 11. New Assigned/ Contract/ Temporary Officer/ Crew 178. Training/ Personnel Qualifications 192. Continuing Training Issue 256. Company Standards, Policies, or Administrative Controls Issues 257. Not Addressed</p>	<p><i>WSF has a policy that limits Relief Chief Engineers to serving on no more than three classes of vessels. WSF's current assignment policies do not limit Relief Assistant Engineers to the number of vessel classes they can be assigned.</i></p>

11	1243: SPMA does not compare voltage differences, it only compares phases.	<ul style="list-style-type: none"> • And had the SPMA had a voltage comparator it would have recognized that the voltage coming from the #4 alternator was too high and would have prevented the closure of the #4 alternator circuit breaker • And this would have prevented the arc event 	5. External Factors 19. Other	<i>Had the SPMA designed to monitor voltage levels it would not have allowed the closing of the #4 alternator circuit.</i>
12	12:44:17: Relief Assistant Engineer closes the #4 alternator circuit breaker. There was an arc event in the potential transformers drawers for alternators 3 and 4 destroying the surge arrestors and causing bus bars to vaporize and over pressurize the electrical cabinet. The arc event causes results in a large drop in the propulsion switchboard voltage. This triggered low voltage protection devices tripping propulsion, ship service and clean power. The high current imbalance caused by the arc event activates differential relays	<ul style="list-style-type: none"> • And this allowed excessive out of sync voltage from the #4 alternator to drive extremely high currents to the main switch board bus. • And the extremely high currents caused the arc event • And the arc event caused the bus voltage to drop • And the voltage drop caused the protective devices in energized circuit breakers to trip off line • And this resulted in the complete loss of propulsion and vital systems. 	2. Machinery/ Equipment 7. Reliability Program Problem 72. Management Systems 84. Safety/ Hazard/ Risk/ Security Review Issue 87. Risk Acceptance Criteria Issue 261. Company Standards, Policies, or Administrative Controls Not Used 262. Tolerable Risk	<i>Because of the low voltage condition during the arc event all energized AC circuits in the vessel opened causing the vessel to lose all power.</i>

	causing #3 and #4 alternators to trip and their diesels to shut down.			
13	12:44:42: Vessel's "in port" generator has excessive voltage droop which cause the breaker to cycle open and close for 4 minutes. The crew transferred clean power loads to the main generator set. At the same time, the ship service switchboard is de-energized.	<ul style="list-style-type: none"> • And this caused the crew to spend time trying to diagnose a problem that was not directly related to put the main propulsion alternators back on line • And this prevented the crew from restarting the auxiliary systems necessary to restore propulsion 	Path 1 4. Human 11. New Assigned/ Contract/ Temporary Officer/ Crew 143. Human Factors 150. Situation Awareness 157. Knowledge Based Decision Required 256. Company Standards, Policies, or Administrative Controls Issues 257. Not Addressed Path 2 4. Human 11. New Assigned/ Contract/ Temporary Officer/ Crew 178. Training/ Personnel Qualifications 179. No Training 183. Training Need Not Identified 256. Company Standards, Policies, or Administrative Controls Issues 257. Not Addressed	<i>WSF's training programs do not provide formal training for dealing with the consequence of the total loss of vessel power.</i>

14	<p>12:51:31: The #1 propulsion alternator began to overheat because there was no cooling water</p>	<ul style="list-style-type: none"> And this created a new set of problems for the engineers to respond to and eventually forced them to shut down #1 main engine. This interrupted lighting and made it impossible to restore the propulsion system. 	<p>Path 1 4. Human 11. New Assigned/ Contract/ Temporary Officer/ Crew 143. Human Factors 150. Situation Awareness 157. Knowledge Based Decision Required 256. Company Standards, Policies, or Administrative Controls Issues 257. Not Addressed</p> <p>Path 2 4. Human 11. New Assigned/ Contract/ Temporary Officer/ Crew 178. Training/ Personnel Qualifications 179. No Training 183. Training Need Not Identified 256. Company Standards, Policies, or Administrative Controls Issues 257. Not Addressed</p>	<p><i>WSF's training programs do not provide formal training for dealing with the consequence of the total loss of vessel power.</i></p>
15	<p>12:56:05: <ul style="list-style-type: none"> Vessel's "in port" generator over heats because cooling water pump was de-energized on loss of ships service switchboard. </p>	<ul style="list-style-type: none"> And this had no actual impact on the availability of power to restore the ship's various systems because the in port was not powering the ships service switchboard and because the Emergency Generator was 	<p>Path 1 4. Human 11. New Assigned/ Contract/ Temporary Officer/ Crew 143. Human Factors 150. Situation Awareness 157. Knowledge Based Decision Required</p>	<p><i>WSF's training programs do not provide formal training for dealing with the consequence of the total loss of vessel power.</i></p>

		<p>available to restore the switchboard and did not rely on electric pumps for cooling.</p>	<p>256. Company Standards, Policies, or Administrative Controls Issues 257. Not Addressed</p> <p>Path 2 4. Human 11. New Assigned/ Contract/ Temporary Officer/ Crew 178. Training/ Personnel Qualifications 179. No Training 183. Training Need Not Identified 256. Company Standards, Policies, or Administrative Controls Issues 257. Not Addressed</p>	
--	--	---	--	--

Conclusions:

The Board of Inquiry concluded that the root cause of this incident was a feature of the propulsion control system, namely the phase loss relay (F14), which allowed the #4 alternator circuit breaker to connect or close when it should not have been allowed to energize the circuit causing the loss of propulsion.

The Board of Inquiry concluded that the electrical propulsion system had been designed by Siemens to meet all the regulatory requirements at the time of construction and the design was approved by the U.S. Coast Guard and the American Bureau of Shipping and accepted by the Washington State Ferries. The Board of Inquiry concluded this incident would not have occurred had the propulsion switchboard been fitted with redundant protective devices such as a synchronizer (SPM-A) with voltage comparator or digital voltage regulators with phase loss sensing.

The Board of Inquiry concluded that the engineering crew did not recognize an alarm associated with the number four alternator when arriving in Seattle. Additional training on the vessel's control, alarm and monitoring systems may have averted the cascade of events which led to the loss of propulsion.

The Board of Inquiry concluded that regular and relief engineering officers need more hands-on experience and training on the Jumbo Mark II vessels.

Recommendations:

1. Conduct a complete design review of the vessel's phase loss relays and other protective devices. At minimum this design review will accomplish the following tasks:
 - a. Modify the circuit design of the phase loss relay (F14) so that it will activate when 2 phases are lost.
 - b. Develop periodic test protocol to verify phase loss relay function.
 - c. Upgrade existing SPM-A synchronizers with models that also compare voltage.
 - d. Replace analog voltage regulators with digital regulators that sense phase loss.
 - e. Impose administrative controls that prescribe paralleling procedures.
 - f. Evaluate existing flash over protection for personnel safety and equipment.

2. Complete an internal review of vital electrical systems to identify improvements and further redundancies of protective devices. At minimum the following additional protective device enhancements will be accomplished:
 - a. Incorporate Siemens recommendations for surge suppressor design.
 - b. Increase the vacuum bottle testing frequency of medium voltage circuit breakers.
 - c. Evaluate and modify alarm and monitoring system "blocking" logic and condition descriptions.
 - d. Provide alarm and monitoring reference guide to alarmed conditions.
 - e. Expand the use of power management to the ship's service switchboard.
 - f. Increase data points monitored by the "black box" data recorders and alarm and monitoring system to improve plant diagnostic and analysis capabilities.

3. In consultation with the Jumbo Mark II Class Staff Chief Engineers initiate a dedicated program of Jumbo Mark II Class engineer training that addresses the following areas of competency:
 - a. Propulsion Controls
 - b. Alarm and Monitoring System
 - c. Main 4160 V switchboard
 - d. Emergency power systems
 - e. Blackout and casualty recovery strategies and training

4. In consultation with the class Staff Chief Engineers, evaluate existing policies and procedures related to break-in, familiarization and qualifications for Jumbo Mark II engineering personnel.