No. 95-203

Wave-Piercing Catamaran *Condor 10*

Queen Charlotte Sound

16 April 1995

Abstract

On 16 April 1995 at 1425 hours the Wave-Piercing Catamaran *Condor 10*, inbound on approaches to Picton Harbour, suffered a total blackout of main power and ran aground on "The Snout". No injuries were sustained by passengers or crew and damage to the vessel was slight. Causal factors included mechanical failure, fault analysis procedures, and faults in setting up and testing the vessel's electrical systems. Recommendations included design changes, better management of maintenance, and more stringent testing procedures on a more regular basis.

Figure 1

Transport Accident Investigation Commission

Marine Accident No. 95-203

Vessel particulars:

Name:	*Condor 10*
Registered:	Singapore
Official number:	385519
Type:	Passenger/car Wave-Piercing Catamaran Ferry
Classification:	Det Norske Veritas +1A1 HSLC R1 Car Ferry A EO
Naut B	
NZ Operating Class:	NZ Coastal Passenger Ship Class II
Built:	1992 by Incat Australia Pty. Ltd, Hobart
Main engine units:	4 x 4050 kW Turbocharged V16 Ruston diesels
Propulsion units:	4 x Riva Calzoni steerable Water Jets each displacing 11 cubic metres of water per second
Power plant:	4 Caterpillar diesel engines each driving 1 Stamford AC 155 kVA generator type UCM274 (124 kW)
Speed:	42 knots (Maximum light ship) 37 knots (service)
Length over-all:	74.16 m
Breadth:	26 m
Loaded draft:	3.2 m
Gross tonnage:	3241 tonnes
Vessel joint owners:	Holyman Ltd and Condor Ltd, under Enterprise Trading Pte Ltd, of Singapore
Charterer/Operator:	New Zealand Rail Ltd
Location:	Queen Charlotte Sound, The Snout, 41° 15.15'S 174° 02.8'E
Date and time:	16 April 1995 1425 hours *
Persons on board:	Crew: 24 Passengers: 352 + 3 infants Supernumerary: 2
Injuries:	Nil
Nature of damage:	Minor damage to Forward T-foil Strut Box on port hull
Information sources:	Transport Accident Investigation Commission field investigation Connell Wagner (electronics engineering consultants)
Investigator in Charge:	T M Burfoot

* All times in NZST (UTC + 12 hours)

1. Factual Information

1.1 History of the voyage

1.1.1 The Operators, New Zealand Rail Ltd (NZRL), chartered *Condor 10* (see figure 1) to expand their existing conventional passenger/rail/car link and offer a fast ferry service over the summer period between the ports of Wellington and Picton. *Condor 10* completed three return voyages per day (weather permitting), each voyage taking about 105 minutes with an approximate turn-around time of 45 minutes. The first return voyage of each day departed Wellington at 0800 hours, the last arriving at Wellington at 2255 hours. This left approximately nine hours each day for over-night maintenance.

1.1.2 On Sunday, 16 April 1995 *Condor 10* had completed the first round voyage without incident and had departed Wellington on her second voyage on schedule at 1259 hours bound for Picton. The trip across the open waters of Cook Strait was uneventful and *Condor 10* entered Tory Channel at 1403 hours at a speed of about 36 knots.

1.1.3 The electro-hydraulic ride control system was in operation but would not have been drawing a significantly high electrical load, due to the vessel being in the relatively smooth waters of Tory Channel and Queen Charlotte Sound. The electricity supply was from Generator No's one, two and four (G1, G2 and G4) which were operating on-line in parallel. G3 was in stand-by mode.

1.1.4 On the bridge were the Master who was steering the vessel manually from the centre console, the Chief Engineer who was monitoring all machinery from his console, and the Duty Watchman. The First Mate had, with the Master's permission, left the bridge. He went down onto the car deck to check the motorbikes prior to arrival at Picton as he had experienced problems with salt water leaking from the fire sprinkler system in that area in the past.

1.1.5 At 1425 hours in approximate position "The Snout Light Beacon" bearing 236 ° (T) x 8.1 cables (see figure 2) the Master had initiated a gentle turn to port using about 10 ° bucket deflection when *Condor 10* experienced a total loss of main electric power. As designed to do in this event, the four propulsion engines automatically reduced to idle speed. The resulting loss of power to the hydraulic bucket and steering actuators meant the four waterjet units remained at ahead thrust and 10° port deflection. This resulted in *Condor 10* continuing her gentle turn to port at a reduced speed of about eight knots. At 1427 hours the Master called Wellington Radio on VHF radio Channel 16 and informed them of the situation.

1.1.6 The First Mate was on the car deck at the time of the blackout and proceeded to the bridge where, on his arrival, he observed Allports Island to be about four points on the Starboard bow. He observed the Master trying to get some response from the engine controls. At the Master's request the First Mate left the bridge with the Duty Watchman to prepare the vessel's anchor for letting go.

1.1.7 The First Mate and Duty Watchman experienced difficulty in preparing the anchor as the windlass was housed in a confined space which had no emergency lighting.

1.1.8 When the sea lashings were removed from the anchor it was discovered that it had been left in gear after the last time used and with no power available for the hydraulic winch the First Mate was unable to disengage the gear to let go the anchor. As he was reporting this fact to the bridge by portable radio he was advised by the Master to brace for imminent grounding.

1.1.9 Full bridge instrumentation was available to the Master throughout the blackout period including visible and audible alarms, navigation, communication and monitoring equipment which were all continuously supplied by the emergency 24 V DC power supply.

1.1.10 The Chief Engineer had the use of the main group visual and audio alarm panel but, as the alarm monitor was not connected to the emergency power supply, he was faced with a blank screen. Video cameras, at strategic positions around the vessel including the engine room, were usually monitored from the bridge but the bridge monitor for the cameras was not supplied with emergency power. This meant that the Chief Engineer could not monitor the engine room machinery nor could he visually check the machinery spaces from his console. The Chief Engineer did not activate the Bus-tie circuit breaker. (See 1.5.13)

1.1.11 At the time of the main power failure the First Engineer was working in the starboard Jet Room. He noted the lights dimming and returning to near full brilliance for about three seconds before blacking out totally. Aided by the 24 V emergency lighting he made his way to the starboard main switch board (MSB) room and made contact with the Chief Engineer using the intercom.

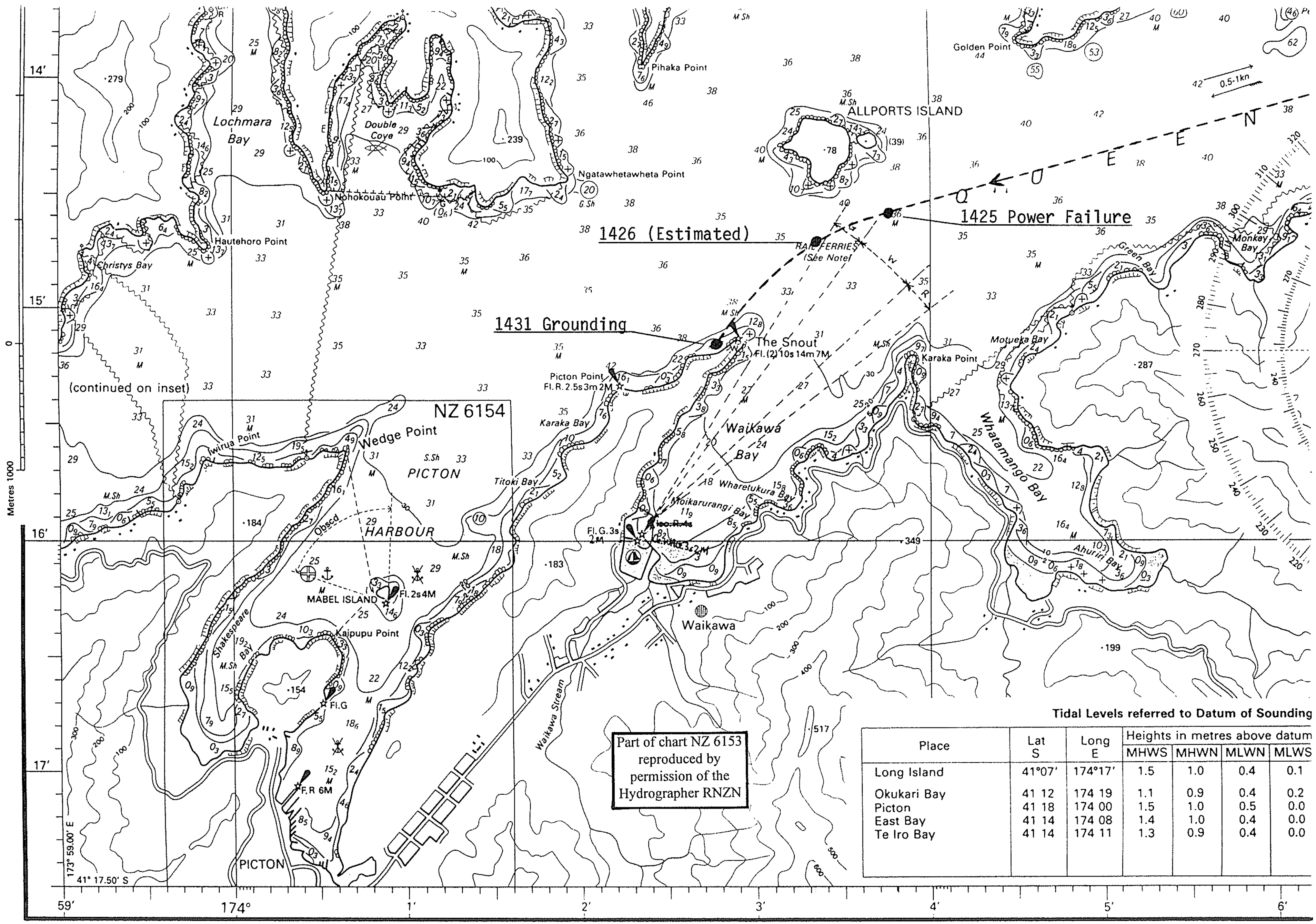
1.1.12 The Chief Engineer, not being able to obtain any information from his monitor, left the bridge with the Master's permission and proceeded to the port MSB room where he had arranged to meet the First Engineer to try to identify the cause of the blackout and re-establish power to the vessel.

1.1.13 The Chief Engineer arrived in the port MSB room and found G1 and G2 stopped, having tripped out on under-voltage. He sent the First Engineer into the port machinery room to visually check the generators for any obvious problems while he attempted to restart G1. On restarting he noticed that G1 was not producing any voltage so he shut it down and attempted to restart G2. G2 was producing the correct voltage and frequency but kept tripping off on overload when he attempted to connect it manually to the Bus.

1.1.14 The First Engineer, having checked the port machinery room, reported to the Chief Engineer that there were no obvious abnormalities and proceeded across to the starboard machinery room where he found G3 and G4 also stopped. He went back to the port MSB room and reported this to the Chief Engineer. At this time, approximately five minutes after the loss of power, the Chief Engineer instructed the First Engineer to call the Master on the bridge and inform him that it was unlikely main power would be restored immediately. On hearing this the Master ordered that all propulsion engines be stopped using the fuel shut-off levers. This was done immediately. The vessel grounded shortly after on the north-west side of "The Snout" (see figure 2).

1.1.15 Approximately 1 minute before *Condor 10* grounded an announcement was made on the public address system requesting all passengers to be seated as the vessel was about to run aground. The speed at the time of grounding was estimated to be slightly under eight knots. The nature of the sea bed where *Condor 10* grounded was steeply rising rock and shingle. Approximately four metres of the port hull as far back as the supporting structure for the forward T-foil took the ground. The impact was mild and no injuries to crew or passengers were sustained.

1.1.16 Inspection of the void spaces confirmed that the watertight integrity of the vessel was intact. The Master informed Picton Radio of the grounding and requested a diver to carry out an underwater inspection to help assess the situation.



Tidal Levels referred to Datum of Sounding

Place	Lat S	Long E	Heights in metres above datum MHWS	MHWN	MLWN	MLWS
Long Island	41°07′	174°17′	1.5	1.0	0.4	0.1
Okukari Bay	41 12	174 19	1.1	0.9	0.4	0.2
Picton	41 18	174 00	1.5	1.0	0.5	0.0
East Bay	41 14	174 08	1.4	1.0	0.4	0.0
Te Iro Bay	41 14	174 11	1.3	0.9	0.4	0.0

Figure 2

1.1.17 The Chief Engineer meanwhile had gone to the Starboard MSB room and, after having to manually trip circuit breakers for non essential loads, was able to restore power at 1435 hours, firstly with G3 and G4 and later with G2, G3 and G4 working in parallel. G1 remained out of service due to its failure to produce any voltage as detailed in 1.1.13.

1.1.18 Shortly after the grounding the Master ordered that the cars on the car deck be moved aft to trim the vessel by the stern and take some weight off the grounded hull. At 1453 the two inner engines were started to give the Master control in case the vessel should slide off the steeply rising bank on which it was resting. As power had been restored and the vessel, passengers and crew were in no immediate danger the Master decided not to disembark the passengers on to the flotilla of rescue craft that had arrived on the scene.

1.1.19 The diving team arrived at 1615 hours and made an underwater inspection. Their report revealed that the forward port T-foil structure was buried into the shingle bank to a depth of one metre. There was no apparent damage. Later inspections revealed slight elongation of the structure surrounding the T-foil in way of the actuating cylinder spherical bearing mounting. It is probable that the hull striking the bank caused an underwater rock slide to bury the structure.

1.1.20 At 1707 hours it was decided to attempt to refloat the vessel and the Master requested that all passengers move to the rear of the vessel to trim her further by the stern. All four jet units were put in the astern thrust position and the inner engines were increased to 350 rpm. Aided by the rising tide *Condor 10* was refloated at 1713 hours. Some manoeuvring control tests were carried out before the voyage to Picton was resumed at slow speed. On arrival Picton at 1743 hours the passengers and their vehicles were unloaded and another underwater survey was made by divers to confirm that no other damage had been sustained.

1.1.21 That evening, on MSA's orders, *Condor 10* returned to Wellington with no passengers to undergo analysis and repairs. This was MSA's pre-requisite to allowing the vessel to return to full service.

1.1.22 The weather at the time of grounding was partly cloudy with very good visibility. The wind was blowing south-by-west about 10 knots. The grounding occurred in sheltered waters.

1.2 Vessel information

1.2.1 *Condor 10* is a Wave-piercing Catamaran constructed mainly in aluminium and designed to ferry passengers and cars at high speed for short coastal voyages. The twin hulls are shaped to produce lift at speed and ride up on a semi-plane when driven at or near full power. The fine entry profile of the hulls is designed to cut through significant waves up to about 3.5 metres in height rather than ride over them as with conventional vessels. When all motive power is stopped or reduced the vessel very quickly comes off the plane, with an associated rapid drop in speed.

1.2.2 *Condor 10* is powered by four turbocharged diesel engines giving a combined power output of 16,200 kW. Each diesel is coupled to a steerable waterjet unit displacing a total of 44 cubic metres of water per second giving a normal loaded service speed of 37 knots.

1.2.3 Directional control is achieved by use of hydraulics to swivel the jet units in the horizontal plane. Speed control and reverse thrust is initially controlled by a hydraulic driven deflector plate located inside the buckets which are mounted behind each jet unit. The bucket diverts water aft for forward thrust, forward for reverse thrust and equally forward and aft for neutral. The bucket can be set at any number of other positions within these three extremes. Once the bucket has been fully opened in any one direction further increase in thrust is achieved by increasing engine revolutions. In the event of a power failure to the hydraulic pumps that control the buckets and jet units, a back-up is provided where each bucket and unit can be operated manually, firstly by adjusting a series of hydraulic valves, and then working a hand hydraulic pump to alter their position. This back-up control system is located on top of the hydraulic reservoir tanks which are located in the jet rooms.

1.2.4 Stabilising is achieved by two trim tabs aft and two T-foils forward mounted on the centre line under each hull. The aft trim tabs were fitted as standard equipment at the time of building and the forward T-foils were fitted by the owners just prior to commissioning. When in operation the trim tabs and T-foils are constantly adjusted by electro-hydraulic actuators controlled by a common computer to operate as a single "ride control system".

1.3 Personnel information

1.3.1 The Master of *Condor 10* had a total of 17 years' sea going experience, the last 18 months of which had been operating Fast Ferries such as *Condor 10*. He had gained his first command on board *Condor 10* about six months prior to the grounding.

1.3.2 The Chief Engineer had about 24 years in the industry, the majority of which had been served on a variety of conventional and more recently fast ferries. He had been sailing on *Condor 10* for about nine months, initially as First Assistant Engineer and soon after as Chief Engineer.

1.3.3 The First Mate and the First Engineer both had approximately 15 years' sea going experience. This was their first fast ferry experience, the First Mate having joined *Condor 10* six months before, and the First Engineer two months before the grounding.

1.3.4 Both the Master and Chief Engineer were employees of Condor Ferries and came to NZRL as part of the charter to man the vessel and assist in training NZRL's own staff in fast ferry operation.

1.4 History of the vessel

1.4.1 *Condor 10* was built in Hobart, Tasmania, by Incat Australia Pty Ltd in 1992 for joint owners Holyman Ltd and Condor Ferries Ltd of Guernsey. When launched *Condor 10* was registered in Singapore and has remained so to date.

1.4.2 *Condor 10* was built to comply with the Code of Safety for Dynamically Supported Craft (DSC code) which was current at the time of building. The DSC code is an International Maritime Organisation (IMO) document which was adopted on 14 November 1977 to form a code of safety for the design, construction and operation of dynamically supported craft such as hydrofoil boats and air-cushion vehicles which were increasingly being introduced as a popular method of transporting passengers internationally.

1.4.3 The owners chose to have *Condor 10* classed with Det Norske Veritas (DNV) Classification Society as **+1A1 HSLC R1 Car Ferry A EO Naut B**. This meant that the vessel also had to comply with the DNV Rules For Classification of High Speed And Light Craft. These rules were based on the DSC code but were more detailed and more stringent in their requirements in certain areas.

1.4.4 Building plans for *Condor 10* were submitted to DNV for approval prior to and during construction. A DNV representative was present in Hobart during the construction, outfitting and testing stages to ensure that the finished product would meet the requirements of the DSC code and DNV rules.

1.4.5 Some of the building plans and design approval for *Condor 10* were undertaken by the United Kingdom Marine Safety Agency (UKMSA) which also had a surveyor present in Hobart during the building and commissioning of the vessel. Their interest was that of port state control for *Condor 10.*

1.4.6 After the launching of *Condor 10* and prior to delivery, sea trials were held to carry out design and performance tests. The vessel made her delivery voyage from Tasmania to United Kingdom where she underwent further outfitting, which included installing the forward T-foil ride control system.

1.4.7 Prior to *Condor* 10's commissioning into service in 1993, a United Kingdom DNV representative surveyed *Condor 10* and issued her with a SOLAS Passenger Ship Safety Certificate, together with a SOLAS Exemption Certificate. The latter was issued because *Condor 10* was classed as a high speed craft under DNV rules and was therefore exempt from certain requirements made of ocean-going passenger vessels. This SOLAS exemption certificate was issued on the basis that *Condor 10* would be operating only within the limits imposed by the DSC Permit to Operate (English Channel).

1.4.8 Also, prior to commissioning into service, UKMSA, at the request of the Singapore Marine Department, carried out a survey and issued *Condor 10* with a DSC Permit to Operate, on their behalf. The issuing of the DSC Permit to Operate and the relevant SOLAS certificates are the responsibility of the Flag State (State or country of Registry).

1.4.9 The UKMSA survey was made to ensure that *Condor 10* complied with the required operating procedures, and with the DSC code.

1.4.10 In November of 1994 *Condor 10* was dry-docked in preparation for her charter to NZRL. The delivery voyage from United Kingdom to New Zealand meant the vessel would venture outside the operational limits imposed on her by the DSC Permit to Operate, and the DNV SOLAS Exemption Certificate. To allow for this some temporary modifications were made to the vessel and DNV issued the appropriate Cargo Ship Safety Certificate to allow the voyage to be made without passengers.

1.4.11 IMO was aware of the continuing development, in speed and size, of different types of high speed craft, some of which were not necessarily dynamically supported, carrying larger numbers of passengers over greater distances from places of refuge. IMO recognised that improvements in maritime safety standards since the adoption of the DSC code needed to be reflected in the provisions for the design, construction, equipment and operation of such high speed craft in order to maintain certification and safety equivalence with conventional ships. This prompted the IMO to write a new "International Code of Safety for High Speed Craft" (HSC code) which was adopted on 20 May 1994. This code is expected to be brought into force by amending the 1974 SOLAS Convention to take effect from 1 January 1996.

1.4.12 IMO has recommended to contracting Governments that they apply the HSC code on a voluntarily basis to craft being constructed between the date of adoption and 1 January 1996.

1.4.13 Although *Condor 10* had been commissioned before the HSC code was adopted by IMO, the Maritime Safety Authority of New Zealand (MSA) requested NZRL to comply with Chapter 18 of the new HSC code with regard to operational procedures. NZRL agreed to do this.

1.4.14 When *Condor 10* arrived in New Zealand she underwent Port State Control inspection and was surveyed as "New Zealand Coastal Passenger Ship Class II." The Singapore Marine Department requested MSA to survey and issue *Condor 10* with a DSC Permit to Operate, SOLAS Passenger Ship Safety Certificate, and SOLAS exemption Certificate on their behalf.

The SOLAS Exemption Certificate was issued on the basis that the vessel would be operating only within the limits outlined under the new DSC Permit to Operate (Cook Strait)

1.4.15 The DSC Permit to Operate in Cook Strait was issued on the assumption that *Condor 10* already complied with the DSC code with regard to design and construction. This assumption was made by MSA because the vessel had been commissioned and operating for approximately 18 months before arriving in New Zealand.

1.4.16 *Condor 10* commenced operation in New Zealand in December 1994.

1.5 The electrical system

1.5.1 *Condor 10* is fitted with 4 x 124 kW (at 0.8 power factor) diesel driven AC generators, which are arranged for parallel operation. Electrical power for normal operation is provided by any (3) generators running with the fourth generator acting as stand-by. The power output is at 415V AC, 50 Hz, 3 phase.

1.5.2 The alternators use a permanent magnet generator (PMG) to generate excitation power for the automatic voltage regulator (AVR). The AVR regulates the alternator rotor current via the exciter field, to maintain the alternator output at the nominal value. (see figure 3)

Block schematic diagram showing principle of operation (Stamford UCM274 alternator)

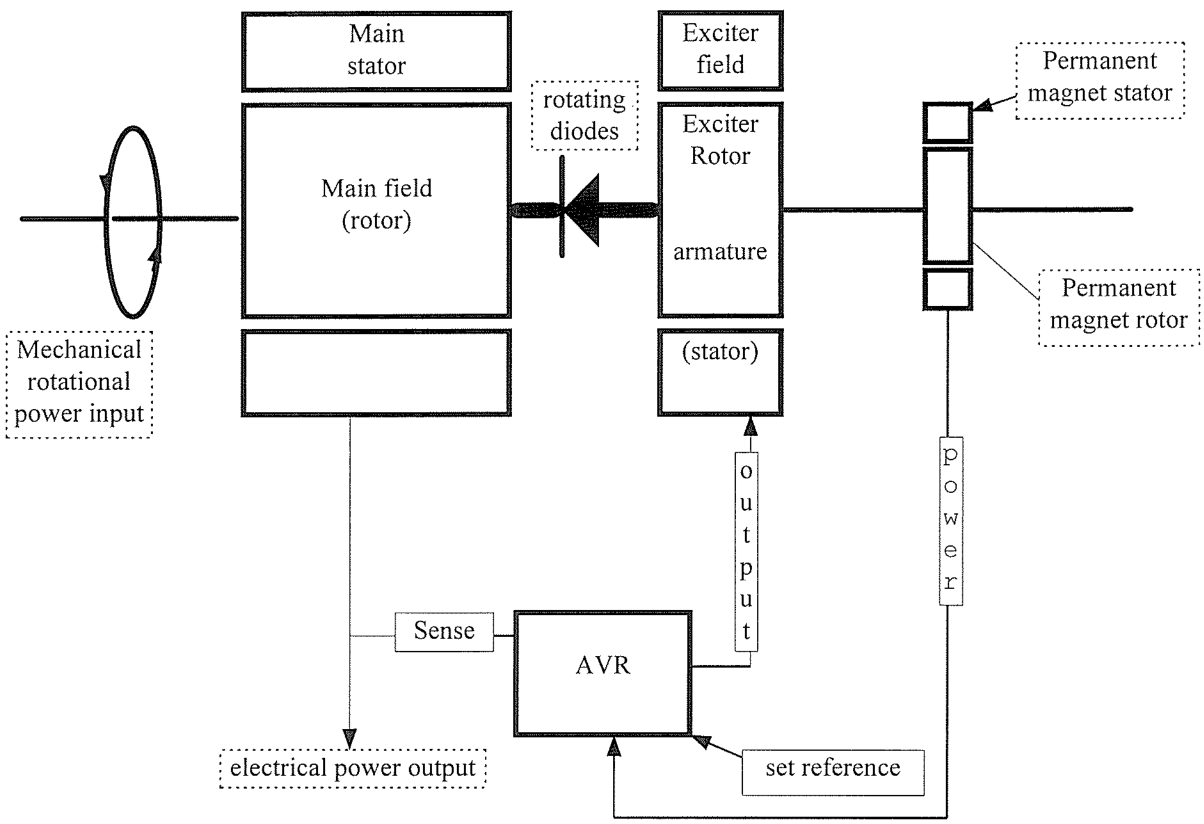


Figure 3

1.5.3 Being of catamaran design, *Condor 10*'s electric generation and distribution is split with half of the system located in each hull. The halves, each consisting of 2 generators and a main switchboard (MSB), can operate independently, or be tied together in parallel by a Bus-tie. Numbers one and two generators are housed in the port hull and numbers three and four in the starboard hull. The vessel's four main propulsion engines are similarly placed in the port and starboard hulls. The propulsion jet units are housed at the rear of each hull in separate compartments called Jet Rooms.

1.5.4 Each generator is controlled by an Omron Sequencer programmable logic controller (PLC) and an Omron C200 PLC controls each MSB.

1.5.5 An auxiliary continuous 24 volt DC battery power supply provides power to the PLC's and emergency services.

1.5.6 When the Port and Starboard MSB's are connected via the Bus-tie, one of the C200 PLC's becomes the master and the other the slave. They communicate via a data link.

1.5.7 The major electrical loads on board *Condor 10* are:

- electric motors driving the hydraulic pumps for the steering and buckets
- electric motors driving the hydraulic pumps for the forward and aft ride-control system
- engine room ventilation supply fans
- vehicle deck exhaust air fans
- air-conditioning system
- kitchen and bar
- emergency power
- general power and lighting

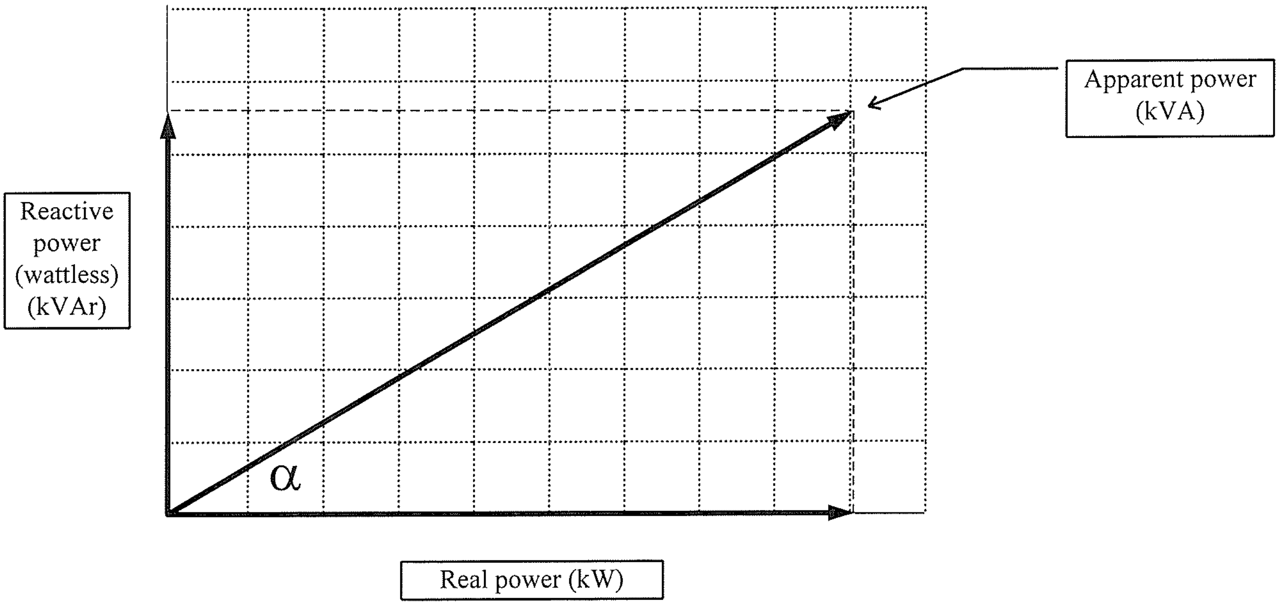
Most of these loads have a reactive load component.

1.5.8 The generation control system on *Condor 10* detects only the true power transferred to the loads. With inductive loads such as the electric motors on *Condor 10*, there is a substantial component of reactive power (sometimes referred to as "wattless" power), as well as real power required for the load. The generators still have to supply the reactive power but it is returned to the system during the second half of each supply voltage cycle. In other words reactive power circulates between the load and the generators rather than being permanently transferred to the load as work. (See figure 4)

1.5.9 The greater the reactive component of power compared to the real power component, the lower the power factor. Power factor values can range from 0.0 (no real power) to 1.0 (all power is transferred to the load as work).

1.5.10 Each generator on *Condor 10* has a reverse power trip protection device whereby the generator will be shut down and disconnected from the Bus if it draws significant reverse power from the Bus. This protects against diesel engine failure or loss of fuel affecting the alternator output. There is no detection or protection of the power supply on *Condor 10* if an alternator fails.

Power Vector Diagram



Power factor = Cos α = $^{kW}/_{kVA}$

Figure 4

1.5.11 *Condor 10* does not have power factor indication or monitoring installed. The total current of the ship's electrical load was measured (approximately 225 A) during tests conducted after the grounding and compared against the indicated kilowatt reading (approximately 100 kW). This equated to a power factor of approximately 0.6. This is considered to be a poor power factor but is consistent with the number and type of inductive loads installed on *Condor 10*. Later models of Incat fast ferries with electrical systems similar to *Condor 10* have been provided with power factor indicators which indicate similar readings.

1.5.12 *Condor 10* does not have a designated emergency generator as such with its own switchboard that would connect to the essential loads in the event of a black out, as is the case with most conventional vessels. It was intended that with three out of the four generators on-line, the system would be able to cope with the maximum load at any one time, leaving the fourth generator as a standby or emergency generator. If a problem was encountered with one of the on-line generators then the PLC would automatically disconnect the faulty generator and call up the standby generator and connect it on-line to compensate. Under the DNV rules, this system was allowed for on catamaran type vessels, such as *Condor 10*, on the basis that a failure in one machinery space could not affect the machinery in the other space.

1.5.13 A Bus-tie trip was installed which, when activated, disconnected the two sides so that they could operate independently. The Bus-tie trip had to be manually activated from any one of three positions, one of which was fitted on the Chief Engineer's control panel on the bridge and one in each MSB room. The Bus-tie trip was intended, by the system designers, to be used in an emergency such as fire, collision or fault affecting machinery spaces on only one side of the vessel. This was supposed to prevent a failure in one on-line generator affecting on-line generator/s in the other machinery space when the two systems were being operated normally, in parallel. A secondary effect of activating the Bus-tie trip was that all non-essential loads were automatically disconnected from the Bus allowing a single generator to connect on-line without tripping out on overload. With the Bus-tie trip open a generator would only be able to supply power to services on its side of the vessel.

1.5.14 Under normal operating conditions the port and starboard generation systems should be connected in parallel via the Bus-tie with one of the C200 PLC's acting as a slave to the other. This is stated in the operating manual on board *Condor 10*.

1.5.15 On the main switch boards there are priority switches for each generator. Each generator is assigned a priority status ranging from 0 to 4. The status relating to each priority ranking is as follows:

- Priority 0 — The generator is taken off automatic selection and can only be started manually.
- Priority 1 — The generator will start up and connect on-line and try to remain there regardless of the load on the Bus.
- Priority 2 — First standby generator (usually called on-line when the load reached 90% of the capacity of the current on-line generator/s)
- Priority 3 — 2nd standby generator
- Priority 4 — 3rd standby generator

During normal sea-going operation, two generators would be selected priority 1, one generator selected priority 2 and the remaining generator on priority 3. This was the case at the time of the power failure.

1.5.16 Stand-by generators are called up by the PLC when the load reaches pre-set levels, depending on the number of on-line generators and the priority selected for the remaining stand-by sets. If the pre-set load levels were surpassed and the stand-by generators were not available either due to a fault, or not being selected for automatic operation, then the PLC "Load Shedding" system would be initiated.

1.5.17 Incorporated in the PLC load sharing and monitoring system is a "Load Shedding" feature. If the loading of an on-line generator were to rise above 130 kW, the "Load Shed Imminent" alarm would be raised to alert the vessel's staff that the capacity of the generator/s was about to be exceeded and thus give them the opportunity to manually shed some non-essential load. If no action was taken and the load was to rise above 136 kW for more than 15 seconds, "Load Shed Imminent" was replaced by a "Load Shed" alarm. At this point a signal would be sent to the vessel's air conditioning board to shed that load. This signal would be removed when the load dropped below 124 kW, allowing the load to stage back in (the air conditioning would automatically restart).

1.5.18 However if the load had not dropped below 124 kW after a further 5 seconds, then a second stage signal would be sent for the pantry and forward and aft trim tabs, to drop out. If at any time the load subsequently dropped below 124 kW then all such signals were removed and the loads would be allowed to automatically switch back in progressively.

1.5.19 If two generators were on-line together and the system load had risen above the full capacity of one generator (i.e. 124 kW), and one generator was lost due to a detected fault, then "instantaneous Load Shedding" would occur. This feature was incorporated into the PLC to prevent the resultant excessive load from stalling the remaining generator. In this situation all load shed signals are sent without delay. The load shed set points increased accordingly when multiple sets were on-line.

1.5.20 The Generator Operation, Service and Maintenance Manual, 8th Edition, contains the following warning:

> **! Loss of excitation** to the generator can result in large current oscillations with consequent damage to generator windings. Excitation loss detection equipment should be fitted to trip the main circuit breaker.

The 7th Edition of this manual, which had been placed on board *Condor* 10, did not contain this warning.

1.5.21 The Manufacturer's Operation, Service and Maintenance manual, 8th Edition, for the generators makes the following selected statements;

- Alignment of single bearing generators is critical and vibration can occur due to the flexing of the flanges between the engine and the generator.
- Torsional vibrations occur in all engine-driven shaft systems and may be of a magnitude to cause damage at certain critical speeds. It is therefore necessary to consider the torsional vibration effect on the generator shaft and couplings.
- All bearings are sealed for maintenance free operation. During major overhaul however, it is recommended that the seals are checked for wear or loss of grease. Bearings showing excessive loss of grease should be replaced.
- Periodic checks for overheating or noise during the life of the bearing are recommended.

These selected statements are also contained in the 7th Edition of the manual.

1.5.22 The bearing life expectancy is quoted as being in excess of 40,000 running hours in an ambient temperature of 40° Celsius. The bearings on *Condor 10's* generators had been in service for approximately 10,000 hours.

1.6 Maintenance programme

1.6.1 In November 1994 *Condor 10* was dry docked prior to her delivery voyage to New Zealand. Major work was carried out on the four main propulsion engines. Routine work was carried out on the vessel's electrical plant as required by the planned maintenance system.

1.6.2 Each generator was load tested during the dry dock period to the satisfaction of NZRL. DNV rules did not require this test to be made for a further 3 years. The load sharing and monitoring system was not tested, nor was it required to be under DNV rules.

1.6.3 Records of major overhauls and maintenance were kept in the owner's office in Guernsey. Such information was placed on board *Condor 10* as required. The owners of *Condor 10* supplied the Masters and Chief Engineers to operate the vessel and to train NZRL staff over the first summer of operation in New Zealand.

1.6.4 The Chief Engineers were responsible for the running of the planned maintenance system and for the requisitioning of any necessary repairs. Routine maintenance and minor repairs were carried out by a night maintenance team employed by NZRL. Such work was carried out each night, after the vessel's arrival in Wellington at 2300 hours, under instruction from the Chief Engineer before he departed the vessel. Unless contacted earlier, the Chief Engineer would return to the vessel 90 minutes before the first sailing to complete checks on any overnight work that had been carried out, and to prepare the vessel for the trip.

1.6.5 Normally, if an item was in need of repair, the Chief Engineer would complete a "requisition for engineering repairs" form that was forwarded to the Technical Superintendent for NZRL. If the work was approved the Superintendent would issue a "work order" to an approved shore based contractor. A copy of this was sent on board to the Chief Engineer. If the work was of a sensitive nature it was overseen by NZRL technical staff and/or manufacturers representative, otherwise the contractor would work with the night maintenance team. The contractor would eventually forward a service report to the Superintendent. On occasions, instructions and reports between the contractor and the Chief Engineer were relayed in writing using a maintenance instruction book.

1.6.6 A diary was kept by the Chief Engineers separate from the engine room log book. This diary was used as a hand-over between the Chief Engineers as they were rostered on and off the vessel. It also acted as a work record and log of unusual events or technical problems encountered, some of which should have been entered in the vessel's engine room logbook.

1.6.7 The diary did not follow the same format as a log book and was not signed by the persons making the entries. It was inspected by NZRL management on a regular basis, as it was required to be. The diary contained notes and comments on problems encountered, some of which were not relayed to the NZRL technical management.

1.6.8 Prior to the power failure and subsequent grounding the following faults were known by NZRL staff: to exist.

- G3 had been tripping out due to the AVR shutting down.
- G3 had been intermittently failing to synchronise with other generators.
- Various generators on opposite sides of the vessel would intermittently trip on reverse power when first synchronised.

These faults had been recognised by the crew at least one month before the grounding and efforts had been made to resolve the problems.

1.7 Classification requirements

1.7.1 *Condor 10* was designed and constructed under the DNV classification rules for High Speed and Light Craft prevailing at the time of her construction. These rules incorporated the provisions contained in the DSC Code.

1.7.2 As part of the investigation the DNV rules relating to electrical installations and their remote control automation and instrumentation were examined. The following requirements were noted:

1.7.3 **Part 4 Chapter 3 Section 3 Clause B Main Source of Electrical Power**

Clause B102(e) states:

> The main power sources are to be designed so that no failure or malfunction of any power source can create a hazard or impair the ability of remaining sources to supply all essential loads.

Clause B105 identifies the essential loads that must be powered if a generator fails. These included the services necessary for the propulsion, steering, draining, firefighting, internal communications and signalling, and safe navigation of the craft.

1.7.4 **Part 4 Chapter 3 Section 5 Clause A700**

This states the general overload capability of electrical machines.

AC generators should be able to withstand an overload of 150% full load current for 2 minutes at 0.6 power factor, with the voltage and frequency being maintained as near as possible to the nominal values.

1.7.5 Part 4 Chapter 3 Section 5 Clause B400

The clause defines the operational characteristics of generators in response to load changes and load sharing. It includes the following paragraphs:

> The voltage regulation is to be automatic and such that the voltage is kept within 97.5-102.5% of the voltage under all steady load conditions between no-load and full-load current and at all power factors which can occur in normal use.
>
> . . . . .
>
> When the largest load on board which can normally be switched on/off is suddenly applied or thrown off, the instantaneous voltage drop/rise is not to be more than 15-20% of the rated voltage. In general, the voltage is to be restored to the normal value within 0.5 seconds.

1.7.6 Part 4 Chapter 3 Section 9 Clause D testing

This defines tests on the generators which should be carried out before a completed installation is first put into service. There is no requirement to carry out these tests on a regular basis during the vessel's life.

1.7.7 Part 4 Chapter 4 Section 2 Clause B100

This states that the surveillance system (plant monitoring) shall be continued during an emergency. The clause also defines alarms that must be monitored.

1.7.8 Part 4 Chapter 4 Section 2 Clause L Programmable Electronic Systems

This paragraph outlines the requirements for Programmable Electronic Systems (PES) such as the PLC's controlling the generators and the plant monitoring system on *Condor 10.*

Paragraph L403 requires:

> Access to the PES operating system is to be highly restricted, and major modification of application programs which may affect system function are subject to approval prior to modification.

Paragraph L501 requires:

> Software development, coding, modification, integration and testing are to be subject to documented quality assurance procedures which ensure that the PES is designed, assembled, installed and tested in compliance with the relevant Rules of the Society.

2. Analysis

2.1 Tests and research after the grounding

2.1.1 Subsequent inspection and tests carried out on *Condor 10*'s generating plant revealed that G1 had suffered a circumferential fracture where the permanent magnet exciter rotor drive plate was welded to the main drive shaft extension causing the laminated iron core to separate from the shaft. This caused the permanent magnet rotor to come in contact with its stator, pulling the stator off its mountings and parting the electrical cables carrying the power supply from it. (See figure 5)

2.1.2 The failure of the permanent magnet generator (PMG) on G1 caused the excitation field to collapse causing a complete and virtually instantaneous loss of generating power output on that generator.

2.1.3 The Generators installed on *Condor 10* were of the single bearing type. Inspection of the shaft bearing on G1 indicated that the bearing was worn and the outer race of the bearing had been fretting inside its housing. The wear in the bearing and its housing had been allowing the shaft to rotate off axis causing the PMG to scuff the inside of its stator (poling). The high speed uneven rotation of the PMG and associated vibration, together with the poling, is thought to have caused the PMG to fail in the manner that it did.

2.1.4 In spite of conducting the manufacturer's recommended periodic checks for bearing overheating or noise, wear in the bearing and its housing on G1 indicated that noise in the bearing assembly may have gone undetected for some time. The bearing and assembly on G3 was found in similar condition.

2.1.5 The cause of G3 tripping out on AVR shut-down was found to be an insulation breakdown in the exciter rotor caused by the poling of the PMG, the same condition that was noted in G1. The breakdown in insulation caused excessive excitation voltage when G3 was under heavy load. The AVR was switching off the excitation to avoid damage to the alternator windings thus shutting down the output voltage from the generator.

2.1.6 The cause of G3 intermittently failing to synchronise with other generators was traced to a faulty synchroniser.

2.1.7 The fault whereby various generators on opposite sides of the vessel would intermittently trip on reverse power when first synchronised is believed to have been caused by an earth fault on the 24 volt DC system. Although the fault was never traced, during subsequent testing a deliberately induced DC earth fault had the same effect. A temporary solution was found and, pending further discussions with the manufacturers of the system and *Condor 10*'s owners, will probably be made permanent.

2.1.8 During testing none of the four generators on board would reach their Load Shed set points of 136 kW. G4 was the best performer, just managing to reach its Load Shed Imminent set point of 130 kW and G3 was the poorest , reaching only 110 kW. This deterioration of performance was due to a combination of the normal, minor drop off in engine performance, and problems with the electrical governing. In view of its importance the governing system warranted closer monitoring and analysis.

2.1.9 During testing the load Shedding system was found to be cycling, i.e. when the load shedding set point was reached the selected equipment would drop off, resulting in a load reduction to a point where the system assumed it was safe to allow the equipment to be switched back in, thereby raising the load again to a point where the system would shed it. This resulted in equipment being continually switched in and out when the total electrical load on the system was close to the load shed set point.

Photo Showing Failed Permanent Magnet Exciter From G1

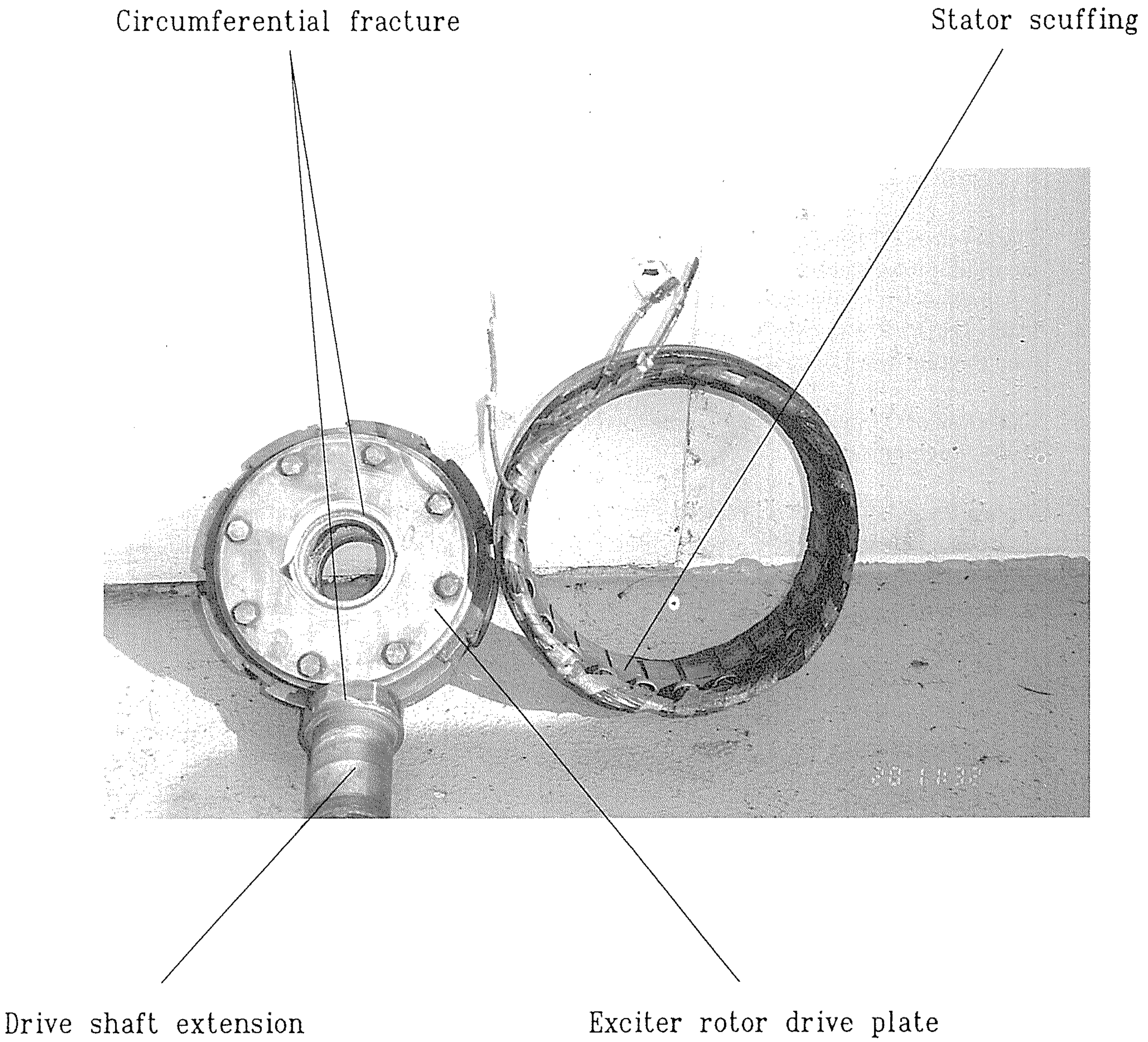


Figure 5

2.2 Sequence of events causing the power failure

2.2.1 G1, G2 and G4 were running in parallel with an estimated total load of 150 kW at the time of the power failure. G3 was the selected stand-by (emergency) generator, because it was considered by the vessel's crew to be unreliable in operation.

2.2.2 As no accurate timing of events could be determined from the printout of engine room alarms, all timing information has been estimated based upon general equipment characteristics.

2.2.3 The following is the probable sequence of events against estimated time that caused the power failure:

Approximate time from fault	**Event**
0 seconds	G1 PMG failed resulting in the loss of excitation voltage and generator output. This fault was not detected and G1 remained connected to the Bus. G1 rotor field collapsed and G1 shed its load to G2 and G4. G2 and G4 supplied Bus voltage fell on account of the reactive load current shed by G1 and the increasing inductive load presented by G1 as its field collapsed. Based upon a load of 150 kW with an assumed power factor of 0.5, a maximum reactive load of 155 kVAr from G1, and reactance values from a UC274F alternator data sheet, it was calculated that the Bus voltage could have momentarily dropped to 85% of nominal. The "undervoltage input" to the PLC was either not activated by this voltage drop or the signal was delayed by the PLC and the voltage returned to normal before the PLC took action. The fluorescent lights were observed by the ship's crew to dim momentarily, then return to normal for about 3 seconds, then go out completely.
+ 0.3 seconds	The AVR's on G2 and G4 would have then detected the low Bus voltage and increased the excitation current to compensate to the extent allowed by the Quadrature droop load sharing control characteristic. It was calculated that this may have risen to approximately 93% of the nominal output voltage. The Bus voltage returning to near normal was indicated by the ship's lights seeming to return to full brilliance. The parallel generator load sharing signal (based upon real power output) increased the fuel flow signal to G1 and decreased the signal to G2 and G4 in order to attempt to rebalance the load amongst three generators. The diesels would not respond immediately due to inertia and control loop response delays.
+ 1.0 seconds	G2 and G4 slowed slightly due to the effect of the parallel generator load sharing signal. The Bus frequency would have remained slightly under the nominal frequency due to the effect of G1 upon the load sharing signal. G1 was still connected to the Bus but was not supplying real power. Alternators 2 and 4 were then overloaded (possibly about 207 kVAr load each or 220% of nominal kVAr rating) and the AVR's would have cut back the excitation after a few seconds to protect the generator excitation systems from permanent damage. (Note that an overload of this order would have exceeded the DNV recommended minimum rating

Approximate time from fault	Event
	of 150% full load for 2 minutes at 0.6 power factor.)
+ 5.0 seconds	The Bus voltage would then have dropped by approximately 20% of nominal output to 184V AC, as the AVR's reduced the excitation current. The undervoltage relay for G2 (assumed to be G2) would have detected a voltage drop of this proportion and sent a signal to the PLC which, according to the PLC flow diagram, tripped that generator off the Bus. The Bus voltage dropped even further as G4 became grossly overloaded, ensuring that the same undervoltage relays on G1 and G4 operated and the PLC tripped those generators off the Bus also. The generator Bus would have been dead from that point.

2.2.4 As the PLC was monitoring only real power it probably would not detect that the Bus was overloaded until only one generator was connected, then starting G3 to compensate. By the time G3 had started from rest, and was ready to come on-line, the Bus would have been dead for about 12 seconds.

Analysis of the events

2.2.5 The PLC software did not detect the real extent of the overload due to a combination of the following factors:

2.2.5.1 The PLC software incremented the generator capacity setpoint for load shedding by a set amount for each generator connected to the Bus. Records showed that with 3 generators on line, the PLC would need to detect a load of 248 kW and the failure of 1 generator before it would load shed with the "Load Shed Instant On" action (taken from Condor Ltd documented test procedures of the generator sequencer PLC operational setpoints).

2.2.5.2 The load shedding software only sensed the real power loads connected to each Main Switchboard, which had been estimated to total 150 kW for the ship. This is well below the load shedding setpoint for 3 generators at 410 kW. The reactive power load component presented to the Bus by the faulty G1 was not able to be detected by the PLC. Therefore the software would have had no reason to shed load.

2.2.5.3 The G1 PLC had not detected a fault with G1 (no "loss of excitation" detection such as reverse kVAr detection), so would not have signalled this to the load shedding software. This would have given the false impression to the PLC that 3 generators were normal and on line.

2.2.5.4 The usual load shedding setpoint had an inbuilt 15 second delay before load shedding occurred. The load would not have exceeded 410 kW for 15 seconds.

Under these conditions the PLC would not have detected any requirement to shed a portion of the load.

2.2.6 As no loads had been shed, G3 circuit breaker would have tripped immediately when the circuit breaker closed onto the dead Bus. (4 bucket pumps, 4 steering pumps, 6 engine room fans and various other smaller loads would have tried to start immediately when the reserve set came on line)

2.2.7 If the Bus-tie trip had been activated immediately by the ship's crew, all non-essential loads would automatically have been shed and G3 should have been able to connect on-line automatically. While this would not have prevented the black out, power could have been restored to essential services within about 10 seconds and the grounding may have been prevented.

2.2.8 Some confusion existed between the parties involved in the design and construction of *Condor 10* as to the function of the Bus-tie. The designers of the electrical system (with DNV approval) intended the Bus-tie to be tripped in the event of any problem, electrical or mechanical, and had set the system up where the Bus tie had to be operated to shed all non-essential loads from the Bus in an emergency, thus allowing the stand-by (emergency) generator to connect to the Bus without tripping off on overload. The builders, in considering the electrical system failure mode effect analysis, intended the Bus-tie to be activated in event of incapacitation of the machinery in one hull due to fire or collision. As neither of these events had occurred, and the Chief Engineer was unaware of the inherent flaw in the control system, it is considered he acted appropriately in the given situation.

2.2.9 Although post-grounding tests carried out on generators and comments written in the Chief Engineer's diary revealed that G3 was not in good repair, these faults would not have affected its capacity to accept the base load on the dead Bus if non essential loads had been disconnected.

2.2.10 If excitation loss detection equipment had been fitted in accordance with the manufacturer's recommendation, such equipment would have tripped the main circuit breaker for G1 when the PMG failed. G1 would not then have presented itself as a large inductive load on the Bus and G2 and G4 would have been able to carry the total load. This would have prevented the black out.

2.3 Compliance with the DNV rules

2.3.1 Part 4 Chapter 3 Section 3 Clause B102(e)

2.3.1.1 *Condor 10* did not comply with this rule. The fourth standby generator was considered by DNV to be the back-up source of power; however, in this incident, that source was affected by the failure of G1. This left *Condor 10* with no power to the services essential for her manoeuvring.

2.3.1.2 If the Bus-tie trip had been activated, as intended by DNV to comply with their rules, then it is probable that power to essential services would have been restored by G3; however this relied on manual input by the vessel's crew. Such an action, when considered to be vital to the safe running of the vessel, and directly affecting the vessel's generation system, should have been automatically controlled and should have operated independent of any human input, without compromising the safety of the vessel in any other way.

2.3.2 Part 4 Chapter 3 Section 5 Clause A700

Although this clause appears to be a recommendation only, the capacity of the generators to handle similar overloads could be tested after each refit or major overhaul. This would establish an effective historical database of the generator performance. Had this been done on *Condor 10* the maintenance deficiencies that were identified in tests carried out after the grounding may have been highlighted and rectified earlier.

2.3.3 **Part 4 Chapter 3 Section 5 Clause B400**

Governor response tests were conducted on all four generators at the time of installation and all four generators were found to comply with the DNV rules. The state of the generators found when post-grounding tests were made in Wellington indicate that *Condor 10* may not have complied at that time. If the governor response had been checked regularly, possibly to coincide with the annual survey, some of the highlighted deficiencies should have been revealed.

2.3.4 **Part 4 Chapter 3 Section 9 Clause D Testing**

2.3.4.1 This defines tests on the generators which should be carried out before a completed installation is first put into service. There is a requirement to carry out these tests every five years.

2.3.4.2 Conditions change as equipment is operated and additional equipment is installed so, after several years of operation, the generator system should be rechecked against these rules. If an annual test against the generator specifications of the initial survey had been required it may have revealed that:

(a) The initial tests were not made or were not stringent enough, or;

(b) Unauthorised changes had been made to the load shedding set points and load shed cycling feature in the PLC.

2.3.5 **Part 4 Chapter 4 Section 2 Clause B100**

2.3.5.1 This states that the surveillance system (plant monitoring) shall be continued during an emergency.

2.3.5.2 The bridge monitor and associated printer for the plant monitoring system lost power when the ship lost power, therefore *Condor 10* failed to comply with this rule.

2.3.5.3 The clause also defines alarms that must be monitored. There appears to be no requirement to monitor the status of the electrical systems. *Condor 10*'s generation and propulsion plant is designed to be operated from the bridge, therefore the electrical systems, which are critical to the safety of a ship of this nature, should be fully monitored from the bridge.

2.3.6 **Part 4 Chapter 4 Section 2 Clause L**

2.3.6.1 This clause outlines the requirements for Programmable Electronic Systems (PES) such as the PLC's controlling the generators and the plant monitoring system on *Condor 10.*

2.3.6.2 Sufficient information was not provided to comment upon the applicability of these clauses but it remains questionable whether paragraphs L403 and/or L501 have been complied with, or were fully enforced by DNV. It appears that the DNV rules in these areas were not stringent enough or were not adequately followed up, for the critical and sophisticated functions that the generator PLC control software is designed to handle.

2.3.6.3 Paragraph L403 requires:

> Access to the PES operating system is to be highly restricted, and major modification of application programs which may affect system function are subject to approval prior to modification.

2.3.6.4 At the time *Condor 10* was built, the software was installed in an EEPROM chip and commissioned by the manufacturer's representative. The software was not issued to the owner so, in the manufacturer's view, "major modifications would be extremely difficult to perform by others". The evidence shows that the software for load shedding was not working correctly at the time of the grounding, despite the requirements of the DNV rules, because the load was found to be cycling off and on and non-essential loads were not automatically disconnected from the Bus in a dead-Bus situation. It is not known whether this condition was present during the initial survey or was introduced in later unauthorised software modifications.

2.3.6.5 Paragraph L501 requires:

> Software development, coding, modification, integration and testing are to be subject to documented quality assurance procedures which ensure that the PES is designed, assembled, installed and tested in compliance with the relevant Rules of the Society.

2.3.6.6 According to the manufacturer, a DNV surveyor witnessed and approved the "factory acceptance test" at their premises to ascertain the equipment's integrity and function complied with the Society rules. This test was duplicated by a second DNV surveyor at the ship yard prior to installing.

2.3.6.7 The cycling of the load shedding system and the failure of the PLC to automatically disconnect non-essential loads from the Bus in a "dead Bus" situation meant the stand-by (emergency) generator could not perform as designed. Either this condition was present at the time of commissioning and was not detected by effective failure mode effect analysis or the software had been modified during a subsequent unauthorised alteration of the PLC software. In either event, one or both of paragraphs L403 and L501 had not been complied with.

2.3.6.8 Ironically, however, the quality assurance programme did prevent information about the PLC software being released to the Transport Accident Investigation Commission for the purpose of this investigation.

2.3.7 It should be noted that although it appears that the general requirement for post-commission testing of the generation and monitoring equipment by DNV was largely inadequate, this does not exonerate *Condor 10*'s owners and crew from their responsibilities.

2.4 Other observations

2.4.1 As part of sea trials before commissioning an inertia test was conducted where from a speed of 39 knots the engines were stopped dead and the distance and time taken for the vessel to be stopped in the water was measured. *Condor 10* took 58 seconds and 0.25 nautical miles to be stopped in the water with no reverse thrust applied (no significant wind factor). During the time taken to stop *Condor 10* remained directionally stable, deviating only 14 degrees from her original heading.

2.4.2 From the time of the black out *Condor 10* travelled a distance of about one nautical mile over a period of approximately 5 minutes before running aground. Ignoring the negligible wind factor and allowing for the added inertia due to being fully loaded, if the engines had been stopped dead soon after total loss of power occurred it is probable that she would not have grounded before power was restored. The Master was not aware at the time of the power failure that the jet buckets would remain in their set position in the event of total power failure.

2.4.3 A power failure on any vessel will always be a possibility and is one of many emergencies for which there should be a documented emergency procedure checklist. The crew should be familiar with and practise these during the normal course of the day to day operation of the vessel. This was a requirement under Chapter 18 of the IMO International Code of Safety for High Speed Craft, with which *Condor 10* was supposed to be complying.

2.4.4 A fast ferry spends little (if any) of its working life at anchor. Although it is recognised that the anchoring arrangements on fast ferries are generally designed for emergency use only, had the engines been stopped at an earlier stage and had the anchor been stowed ready for use and used accordingly after the vessel was almost stopped in the water, it is likely that the grounding could have been avoided.

2.4.5 During the course of the investigation some difficulty was experienced in trying to reconstruct the voyage of *Condor 10*, and the events as they occurred from the data made available. No equipment had been installed for recording the track or course of the vessel or the engine power selected. Information recorded in the engine room log books was sparse and not in keeping with good watchkeeping practices. The alarm monitor and printer lost their power source as a result of the black out. Therefore when power was restored the alarms were printed out in random fashion making it difficult to establish with any certainty the sequence of events as they occurred.

2.4.6 Course recorder and engine loggers (providing a record of course and selected power setting against time) were not required under the DSC code, nor are they required under the new HSC code. Officers navigating high speed vessels in confined waters such as the Marlborough Sounds will experience great difficulty in manually plotting the vessel's position. To perform this duty satisfactorily would be a full time task, time that may be better spent monitoring the vessel's progress visually and/or by radar. To manually record the changes in engine power setting would also be a labour intensive task, and become impossible when the vessel is being manoeuvred using the "LIPPS" system (an automatic ship manoeuvring system used when berthing and unberthing).

2.4.7 The navigating officers on board *Condor 10* noted times of passing prominent points of land, with an occasional distance off selected points, in the vessel's log book. The vessel's track was automatically plotted on a GPS referenced electronic chart monitor. This track could not be stored or printed and was erased at the turn of each trip. In the event of an accident, there was therefore no recorded data as to the vessel's position, and actions taken by the crew immediately before, during, or after the event.

2.4.8 Planned maintenance programmes on board vessels are usually based on the manufacturer's instructions and recommendations. With time and experience, changes are often made to optimise the programme to suit each particular vessel and the trade on which it is engaged. Some changes may be made based on the results of previous inspections and surveys. *Condor 10* had been commissioned and in service for approximately 18 months. The planned maintenance programme had been adjusted to suit the vessel's trade accordingly. Most of the major overhauls and surveys were scheduled for the annual refit period when the vessel dry docked in between charters.

3. Findings

3.1 At the time of the grounding *Condor 10* was manned and certified as required for vessels of her class.

3.2 *Condor 10* was operating under a DSC Permit to Operate in Cook Strait area.

3.3 A condition suggested by MSA, and agreed to by NZRL, for *Condor 10* to operate in New Zealand waters was that the vessel operations should comply with Chapter 18 of the HSC code.

3.4 The parallel connection of generators as used on *Condor 10* can be a reliable method of electrical supply when set up and adjusted correctly.

3.5 G1 failed due to a mechanical failure of the PMG which resulted in an unforeseen set of events.

3.6 The failure of the PMG on G1 caused the excitation field to collapse causing a complete and instantaneous loss of alternator power output on that generator.

3.7 The generation control system did not detect the fault in G1 because there was no "loss of excitation" detection (such as reverse kVAr detection) fitted, so it did not take corrective action.

3.8 If "loss of excitation" equipment had been fitted the generation control system would have detected the fault in G1.

3.9 G2 and G4 would have been able to carry the total electrical load of the vessel after the failure of G1 had the system been designed and adjusted correctly.

3.10 The Generator output voltage monitoring was interpreted by the control system as if it were a stand alone generator voltage, despite being paralleled onto a common Bus.

3.11 When the Bus became overloaded and the voltage dropped, the control system accentuated the problem by reducing generator capacity instead of shedding load.

3.12 The generation control system supplied power to a load that was largely inductive due to the high proportion of electric motors.

3.13 All load detection and display systems worked on true power (kW) and ignored the large reactive component (kVAr).

3.14 The generation control system did not detect that the reactive power load had exceeded the available generator capacity.

3.15 When there was only one generator about to connect onto the Bus, the generation control system did not automatically disconnect sufficient load to remain below the maximum available capacity of one generator.

3.16 The generator failure symptoms were not detected by the manufacturer's preventive maintenance programme for the generation system on board *Condor 10.*

3.17 The generators were not able to perform to their maximum output at the time of the incident due to the limits imposed by the generation control system.

3.18 The generation control system was not able to handle the low power factor load conditions, apparent on *Condor 10.*

3.19 An inherent flaw in the generation control system actually shut the vessel's generation system down when G1 failed, instead of disconnecting the fault. This action by the generation control system caused the total power failure onboard *Condor 10.*

3.20 The DNV classification rules applicable to this type of vessel required post commissioning functional tests of the electrical systems or software production after five years.

3.21 *Condor 10* did not comply with some of the DNV and DSC rules applicable to vessels of her class at the time of build (see section 2.3).

3.22 Post-grounding tests conducted on *Condor 10*'s generation control system revealed a number of deficiencies that required replacement equipment, software modification, and readjustments.

3.23 Some of the faults revealed by the post-grounding tests had remained undetected during the approved commissioning, handover trials, regular testing and maintenance program.

3.24 Post-grounding tests conducted on *Condor 10*'s generators revealed several faults and areas of reduced performance. Continuing efforts to correct these throughout the normal use, programmed maintenance work, tests and annual surveys of the vessel had not resulted in the appropriate rectification.

4. Factors Contributing To The Grounding

4.1 Paragraph 18.3 (Training and Qualifications) of the HSC code was not complied with entirely. The crew were not familiar with all the failure modes of control, steering, propulsion and electrical systems on board *Condor 10*.

4.2 The Master was not aware that in the event of a power failure the jet buckets would remain in their set position.

4.3 As a result of the power failure the Master was unable to control the direction of the vessel from the bridge.

4.4 As a result of the power failure the Master was unable to control the buckets from the bridge and they remained in the full ahead position.

4.5 The position and operation of the hydraulic back-up directional control for the vessel make it too time consuming and impracticable for such an emergency when the vessel is operating at high speed in confined waters.

4.6 The Master elected to keep the four propulsion engines running, powering the vessel ahead at idle speed (approximately 8 knots) despite having no control over the vessel. He chose this option on the assumption that power would be restored to the vessel before running aground.

4.7 *Condor 10*'s anchor was not stowed ready for use when operating within confined waters and consequently could not be used when the power failure occurred.

4.8 Routine maintenance and surveys failed to detect noise and vibration in the main shaft of G1.

4.9 The quality assurance system encompassing the vessel and its operators for identifying, recording, solving, and following up on problems, did not result in appropriate rectification of some equipment.

5. Safety Actions

5.1 After the grounding *Condor 10* was not allowed by MSA to operate with passengers on board until it was demonstrated that the cause of the blackout had been identified and put right.

5.2 The vessel underwent extensive tests on her generation system where several deficiencies were identified.

5.3 To reduce the risk of a generator becoming overloaded the PLC set points for load shedding were lowered as follows:

	1 gen. set	2 gen. sets	3 gen. sets	4 gen. sets
"Load shed imminent" on	130 (100)	260 (200)	390 (300)	
"Load shed imminent" off	124 (100)	253 (200)	372 (300)	
"Load shed" on	136 (106)	272 (212)	410 (318)	
"Load shed" off	124 (100)	253 (200)	372 (300)	
"Load shed instant" on		125 (106)	248 (212)	
"Load demand call-up" on	108 (95)	218 (190)	327 (285)	
"Load demand call-up" off	80 (75)	160 (150)	240 (225)	

New settings in brackets
Settings in kW

5.4 These changes in set points were considered to be a temporary partial fix to the overall problem; they were made due to time constraints on the vessel's schedule.

5.5 The PLC was reprogrammed so that once a load was shed it would remain off until manually reconnected (the load shedding would no longer cycle).

5.6 The PLC was reprogrammed so that in the event of a dead Bus situation, all non-essential loads will be automatically shed. This will ensure that the base load will be less than the maximum capacity of the smallest generator i.e. the first generator connected onto the Bus will be able to support the base load. The system no longer relies on the operation of the Bus-tie to effect this. This modification is currently being made to all other vessels using the same plant.

5.7 The control linkage arrangement on the governor for G3 was adjusted with significant increase in generator performance.

5.8 A new synchroniser was ordered for G3. One was not available in New Zealand so the vessel was allowed to continue passenger operations for the remaining 2 days of scheduled service for that charter with an engineer standing by the switchboard to manually synchronise G3 onto the Bus if required.

5.9 The intermittent fault with reverse power trips between generators on opposite sides of the vessel was temporarily solved by tying the DC negatives in the port and starboard MSB rooms together and moving the current transformer safety earth in each generator cubicle to DC negative. This was done to prove their effectiveness and pending approval, may be adopted permanently at the discretion of the owner.

5.10 Preventive maintenance, inspection and repairs were carried out on all four generators.

5.11 *Condor 10* was due to be repositioned shortly after the grounding to commence her next charter in Europe. Because it was suspected at the time that a similar generator failure would still result in loss of power to the vessel and her control systems, a letter was sent by the MSA to the relevant authorities at *Condor 10*'s destination, warning them of such a possibility.

5.12 In all operational matters, MSA will require all high speed craft operators to comply with chapter 18 of the HSC code.

5.13 Condor Ltd has reviewed all the operation and procedures manuals on board *Condor 10* and made changes to them where required to comply with the HSC code.

5.14 NZRL has reviewed the Route Operations Manual and made changes where required to comply with the HSC code, which included procedures relating to anchor management. This will be placed on board *Condor 10* on her return to New Zealand.

5.15 Several of NZRL's Masters and Chief Engineers have been employed on board *Condor 10* while it has been operating in Europe, to become familiarised and type-rated in fast ferry operation.

5.16 Condor Ltd provided an owner's representative to assist in training NZRL's staff for the next charter period. One of his responsibilities will be to continue reviewing the Operation Manuals on board.

5.17 NZRL will continue safety training for its crews to familiarise them with all aspects of safety on-board fast and conventional passenger ferries.

5.18 Condor Ltd will set standards of training for officers to become type-rated on *Condor 10* and on the route over which she will be operating.

5.19 DNV have proposed new rules for the certification, documentation and testing of software for programmable electronic systems. The proposed rule changes are extensive and cover all aspects of design, failure mode effect analysis, installing, testing and protecting the programmes. It is hoped to make the new rules effective from January 1996.

5.20 *Condor 10's* owners have modified the vessel in that shaft driven hydraulic pumps have been fitted to the outboard main engine drive shafts. These are activated automatically on mains power failure and supply hydraulic power to the outboard jet units, thus maintaining directional control. The system was tested in the presence of surveyors from MSA and DNV prior to *Condor 10* going on hire to NZRL (renamed Tranz Rail). This modification was made so *Condor 10* would comply with DNV rule B102(e) (power supply to essential services).

6. Safety Recommendations

6.1 It was recommended to the Operations and Technical Director for Condor Ltd that he liaise with the Manufacturing Electrical Manager for Industrial and Marine Electrics Pty Ltd to implement the following:

6.1.1 Install reverse reactive power (kVAr) detection on each generator on *Condor 10* to prevent the reoccurrence of an undetected alternator failure so that if an alternator draws significant reactive power from the Bus, except for transient conditions, that generator would then be tripped off the Bus. (053/95)

6.1.2 Install a test key switch in the alternators on *Condor 10* that would reduce excitation to the stability limit and cause the alternator to draw reverse reactive power. (054/95)

This switch would be able to simulate the symptoms of this incident and be operated at regular intervals to coincide with other generator tests to test the reverse kVAr detection. This switch may also be used to create a dummy reactive load for generator load tests.

6.1.3 Change the PLC software on *Condor 10* so that undervoltage detection only functions to back up the undervoltage release on the circuit breaker before the generator is connected to the Bus. Undervoltage measurement of the individual generator output serves no useful purpose once the generator is connected to the Bus in parallel with other generators. (055/95)

6.1.4 Supplement the MSB load monitoring on *Condor 10* with an analogue value for reactive power (kVAr load). Load shedding could then be controlled using both the real and reactive power components. A partial fix has already been achieved by reducing the real power setpoints. At the very least, these setpoints should be reassessed after likely power factor ranges are determined by measurement. (056/95)

6.1.5 Fit the MSB's on *Condor 10* with a reactive power (kVAr) meter to supplement the real power (kW) meters (A multifunctional meter that replaces several meters may be more economical). This would enable the gathering of historical trends and greatly assist in generator load sharing and shedding control adjustments. This data could be automatically logged by the plant monitoring system. (057/95)

NB Each of the above safety recommendations should be considered for existing and future vessels using this type of electrical plant.

6.2 It was recommended to the Operations and Technical Director for Condor Ltd that he Liaise with Det Norske Veritas to implement the following:

6.2.1 Introduce six monthly testing, calibration and adjustment of the generator load sharing and output until satisfactory results of these tests allow the period to be extended. (060/95)

6.2.2 Upgrade the plant monitoring system's power supply to be continuous and unaffected by power failures, by providing a UPS or inverter powered from the 24V DC ships power supply.(061/95)

6.2.3 Upgrade the present alarm print out system if it cannot provide an accurate sequential record of alarm events. The information presented on the plant monitoring printout was confusing due to the sequence of events being printed out in random order. Such equipment, if fitted, should provide a sequential record of alarm events. (062/95)

6.2.4 Introduce regular visual inspections of the PMGs and the shaft bearings into the maintenance programme. (063/95)

6.2.5 Arrange for the manufacturers to examine the damaged PMG and be requested to consider any necessary design changes that may prevent a future occurrence. (079/95)

6.2.6 Test the load shedding system, thoroughly, immediately after each "generator maintenance and testing" has been completed. Upon satisfactory test results this test could be extended to a longer period. (064/95)

6.3 It was recommended to the Operations and Technical Director for Condor Ltd that he liaise with the Manufacturing Electrical Manager for Industrial and Marine Electrics Pty Ltd and Det Norske Veritas to implement the following:

6.3.1 Assess the present system on *Condor 10* critically and upgrade as necessary to ensure that essential electrical conditions are monitored and recorded. (059/95)

6.4 It was recommended to the Operations and Technical Director for Condor Ltd that he implement the following:

6.4.1 Fit an engine logger device on *Condor 10* for recording the selected power settings against time for the propulsion units. (076/95)

6.4.2 Upgrade the video cameras and bridge monitor power supply to be continuous and unaffected by power failures, by providing a UPS or inverter powered by the ships 24V DC power supply. (077/95)

6.4.3 Fit a course recording device on *Condor 10*. At present there is a chart monitor on the bridge that shows the vessel's position based on a GPS input. Some means of either storing or printing out this information at the completion of each crossing would suffice. (078/95)

NB The above recommendations should be considered for other vessels owned or being built for Condor Ltd.

6.5 The Fleet Superintendent for Condor Ltd responded as follows:

6.5.1 053/95 - *reverse reactive power (kVAr) detection, and* 056/95 - *load monitoring with an analogue value for reactive power. As suggested, these two recommendations could be best covered by the recommendation in* 057/95 - *multifunctional meter. Condor is in discussion with IME as to the best means of satisfying all three recommendations.*

6.5.2 054/95 - *test key switch. At present this is still under discussion as IME, Condor and DNV are not satisfied that this is necessarily a good idea. There exists the possibility that even though a key switch, it could be inadvertently used. The idea has not been dismissed, rather than waiting more thought and research.*

6.5.3 055/95 - *undervoltage detection and change of PLC software, again in discussion with IME and DNV.*

6.5.4 059/95 - *critical assessment of Condor 10's electrical system, has been and will continue to be done with IME and DNV.*

6.5.5 060/95 - *six monthly testing. Since the incident, testing on Condor 10 has been carried out more frequently than six monthly intervals. Condor, IME and DNV will monitor the situation closely until consistent satisfactory results allow the period to be extended.*

6.5.6 061/95 - *Upgrade of plant monitoring system, and* 062/95 - *alarm print out system, power supplies to be continuous in event of mains power failure. At the time of the incident, only the display screen and printer were powered by 240 volts, all the other equipment had 24 volt DC battery back up. A UPS was fitted in the recent dry-dock and refit and tested successfully.*

6.5.7 063/95 - *Regular visual inspection of the PMGs and shaft bearings. This is now being done on a six monthly basis and discussions are taking place with the generator manufacturer. Vibration analysis has been carried out and will continue to be carried out at regular intervals.*

6.5.8 079/95 - *examination of failed parts, will be done by an independent authority and also possibly the manufacturer.*

6.5.9 064/95 - *test of load shedding system, has been done at frequent intervals since the incident.*

6.5.10 076/95 - *engine logger, not felt to be entirely essential, but will be considered.*

6.5.11 077/95 - *video cameras and monitors to have UPS, under consideration, will no doubt fit as soon as possible.*

6.5.12 078/95 - *course recording device, again as stated above with* 076/95, *not considered essential, but will be considered.*

6.5.13 *As recommended, Condor will consider all the above for existing vessels owned and new buildings.*

6.5.14 *In addition to the above, instruments have been fitted to the bridge console to monitor the kW loading and current on each generator, along with system volts and frequency.*

6.5.15 *Condor believes that following the incident, it has acted responsibly in resolving the situation and to ensure that a repeat will not occur. DNV and IME likewise have also acted responsibly for the same reasons.*

6.6 It was recommended to the Manufacturing Electrical Manager for Industrial and Marine Electrics Pty Ltd that he liaise with the Operations and Technical Director for Condor Ltd to implement the following:

6.6.1 Install reverse reactive power (kVAr) detection on each generator on *Condor 10* to prevent the reoccurrence of an undetected alternator failure so that if an alternator draws significant reactive power from the Bus, except for transient conditions, that generator would then be tripped off the Bus. (046/95)

6.6.2 Install a test key switch in the alternators on *Condor 10* that would reduce excitation to the stability limit and cause the alternator to draw reverse reactive power. (047/95)

This switch would be able to simulate the symptoms of this incident and be operated at regular intervals to coincide with other generator tests to test the reverse kVAr detection. This switch may also be used to create a dummy reactive load for generator load tests.

6.6.3 Change the PLC software on *Condor 10* so that undervoltage detection only functions to back up the undervoltage release on the circuit breaker before the generator is connected to the Bus. Undervoltage measurement of the individual generator output serves no useful purpose once the generator is connected to the Bus in parallel with other generators. (048/95)

6.6.4 Supplement the MSB load monitoring on *Condor 10* with an analogue value for reactive power (kVAr load). Load shedding could then be controlled using both the real and reactive power components. A partial fix has already been achieved by reducing the real power setpoints. At the very least, these setpoints should be reassessed after likely power factor ranges are determined by measurement. (049/95)

6.6.5 Fit the MSB's on *Condor 10* with a reactive power (kVAr) meter to supplement the real power (kW) meters (A multifunctional meter that replaces several meters may be more economical). This would enable the gathering of historical trends and greatly assist in generator load sharing and shedding control adjustments. This data could be automatically logged by the plant monitoring system. (050/95)

NB Each of the above safety recommendations should be considered for existing and future vessels using this type of electrical plant.

6.7 It was recommended to the Manufacturing Electrical Manager for Industrial and Marine Electrics Pty Ltd that he liaise with the Operations and Technical Director for Condor Ltd and Det Norske Veritas to implement the following:

6.7.1 Assess the present system on *Condor 10* critically and upgrade as necessary to ensure that essential electrical conditions are monitored and recorded. (052/95)

6.8 It was recommended that Det Norske Veritas Liaise with the Operations and Technical Director for Condor Ltd to implement the following:

6.8.1 Introduce six monthly testing, calibration and adjustment of the generator load sharing and output until satisfactory results of these tests allow the period to be extended. (065/95)

6.8.2 Upgrade the plant monitoring system's power supply to be continuous and unaffected by power failures, by providing a UPS or inverter powered from the 24V DC ships power supply.(066/95)

6.8.3 Upgrade the present alarm print out system if it cannot provide an accurate sequential record of alarm events. The information presented on the plant monitoring printout was confusing due to the sequence of events being printed out in random order. Such equipment, if fitted, should provide a sequential record of alarm events. (067/95)

6.8.4 Introduce regular visual inspections of the PMGs and the shaft bearings into the maintenance programme. (068/95)

6.8.5 Arrange for the manufacturers to examine the damaged PMG and be requested to consider any necessary design changes that may prevent a future occurrence. (080/95)

6.8.6 Test the load shedding system, thoroughly, immediately after each "generator maintenance and testing" has been completed. Upon satisfactory test results this test could be extended to a longer period. (069/95)

6.9 It was recommended that Det Norske Veritas Liaise with the Operations and Technical Director for Condor Ltd and the Manufacturing Electrical Manager for Industrial and Marine Electrics Pty Ltd to implement the following:

6.9.1 Assess the present system on *Condor 10* critically and upgrade as necessary to ensure that essential electrical conditions are monitored and recorded. (075/95)

6.10 It was recommended to the District Manager for Det Norske Veritas that the following be required and, if necessary, incorporated in the DNV classification rules for High Speed and Light Craft.

6.10.1 Test the capacity of generators to handle general overloads (110% of rated output) after each refit or major overhaul. (070/95)

6.10.2 Check the operational characteristics of generators in response to load changes and load sharing regularly e.g. to coincide with the annual survey. (071/95)

6.10.3 The electrical systems are able to be monitored from the bridge, as they are critical to the safety of a vessel of this nature. (073/95)

13 December 1995

M F Dunphy
Chief Commissioner

Glossary Of Marine Terms

AC	Alternating current
Aft	Rear of the vessel
AVR	Automatic voltage regulator
Beam	Width of a vessel
Beam on	When a side of the vessel is exposed to the weather
Bilge	Space for the collection of surplice liquid
Bulkhead	Nautical term for wall
Bus	An arrangement of copper conductors (Bus bars) within a switchboard, from which the circuits are supplied
CO_2	Carbon Dioxide
Cable	0.1 of a nautical mile
Charge	In control of the vessel
Chart datum	Zero height referred to on a marine chart
Command	Take over-all responsibility for the vessel
Conning	Another term for "in charge" or "in control"
DC	Direct current
Deckhead	Nautical term for roof
DNV	Det Norske Veritas Classification Society
Draft	Depth of the vessel in the water
DSC code	Code to which dynamically supported craft were built before June 1994
EPIRB	Emergency Position Indicating Radio Beacon
EEPROM	Electronically Erasable Programmable Read Only Memory Chip
Freeboard	Distance from the waterline to the deck edge
G1 2,3 & 4	Generator 1, 2, 3 & 4
GM	Metacentric height (measure of a vessel's statical stability)
GPS	Global Positioning System

Hove-to	When a vessel is slowed or stopped and lying at an angle to the sea which affords the safest and most comfortable ride
HSC code	Code under which high speed craft are recommended to be built to from June 1994, and will be made mandatory in January 1996
Hz	Hertz (cycles)
IMO	International Maritime Organisation
kHz	Kilohertz
kVA	Kilo Volt Amperes
kVAr	Kilo Volt Amperes (reactive)
kW	Kilowatt
m	Metres
MSA	Maritime Safety Authority
MSB	Main switch board
PES	Programmable electronic system
PLC	Programmable logic controller
PMG	Permanent magnet generator
"set"	Act of laying out the fishing gear
SOLAS	Safety Of Life At Sea convention
Sounding	Measure of the depth of a liquid
SSB	Single side band radio
Statical stability	Measure of a vessel's stability in still water
Supernumerary	Non-fare-paying passenger
Telegraph	Device used to relay engine commands from bridge to engine room
T-foil	An articulated strut, in the form of an inverted "T", having an aerofoil section and a flap on the trailing edge.
UKMSA	United Kingdom Maritime Safety Agency

V	Volts
VHF	Very high frequency radio
Windlass	Winch used to raise a vessels anchor