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Summary

The New Zealand registered roll on/roll off, gas turbine/electric ship Union Rotorua was about 27 miles south of Sydney Heads, en route for Melbourne, when a fire broke out in the gas turbine house.

It was established that the seat of the fire was in one of the cubicles of the 6.6 kilovolt switchboard, which distributed power from the gas turbine generator to the propulsion motors and auxiliary electrical systems.

Initial attempts to fight the fire with extinguishers proved to be ineffective and a decision was made to utilise the fixed fire fighting medium and flood the space with CO_2.

This was effective in extinguishing the fire. With the high voltage switchboard out of commission, the vessel was towed to Sydney, where it remained for three months undergoing repairs.

The incident was investigated by the Marine Incident Investigation Unit under the provisions of the Navigation (Marine Casualty) Regulations.

Sources of information

The Master and officers of Union Rotorua
Union Shipping N.Z. Ltd.
CEGELEC Ltd.
Westinghouse Pty.Ltd.

Acknowledgements

Photograph page 11 courtesy of
Westinghouse Pty.Ltd.

Union Rotorua

Union Rotorua is a New Zealand flag ro-ro vessel of 22,357 gross tonnes, with an overall length of 203.21m and a beam of 26.25m. The ship was built in Whyalla, South Australia, in 1976 for its current owners, Union Shipping, New Zealand, and operates a regular service between the ports of Auckland, Tauranga, Napier, Wellington, Nelson, Brisbane, Sydney and Melbourne. The gas turbine/electric main machinery, which is operated in the unmanned machinery space (UMS) mode, gives it a speed of 20 knots

The original manning consisted of 42 officers and crew. In 1987, the manning was reduced to its present complement of 19. This reduction included the removal of one of the two electricians. The remaining electrician is expected to take a turn in the duty roster with the other engineers.

Main machinery

The vessel's main gas turbine/electric propulsion machinery consists of an A.C. generator driven, through a reduction gearbox, by a single marine gas turbine operating on a regenerative cycle. The gas turbine is a Thomassen/ General Electric type MM5262RB designed to give a total maximum continuous rating for the propulsion system of 18822kW at a motor/ propeller speed, for the twin screws, of 200 rpm. The speed of the gas turbine is controlled by a solid state electronic control and safety system, integrated with the propulsion controls to provide, under normal operating conditions, single lever control from the bridge.

The A.C. generator (producing 6.6 kV, 3-phase, at 50Hz with a rated output of 20MVA) is directly coupled to the reduction gearbox which reduces the turbine speed, of 4670 rpm, to the generator speed of 1500 rpm.

The vessel's two diesel generators, which generate 415 Volts, 3-phase, 50 Hz, are arranged such that they can be run in parallel with the two ship's service step-down transformers (6.6 kV to 415 V) supplied by the main A.C. generator. They are, however, usually used only for short change-over periods.

The main A.C. generator supplies power, via a 6.6 kV (high voltage) switchboard, to the four closed air circuit water-cooled synchronous A.C. propulsion motors, each rated at 4775 kW. These motors are arranged as two, forward and aft, on each shaft.

The high voltage switchboard, situated at the starboard side, forward end, of the turbine machinery house, consisted of nine cubicles designed such that, in the event of an internal fault condition arising, any damage should have been confined to that cubicle in which the fault arose, with the bus-bars in the adjacent cubicles energised.

Electrically operated circuit breakers, with provision for manual control, were situated in the relevant cubicles. Interlocking, protection and control devices were included for the propulsion motor feeder circuits, the two ship's service transformer feeder circuits and the bow thruster motor.

Remote control facilities for the propulsion motors and the sequence start selector switch are situated at the machinery control room (M.C.R.) console. In addition, fitted in the M.C.R., is a Londex alarm system with a display at the M.C.R. control console and also on the ship's bridge where the alarm display is duplicated. The alarm system provides both visual and audible alarm warning.

During normal running, the pitch levers in the M.C.R. or on the bridge set the pitch of the propellers. The propulsion control system regulates the turbine power at the same time as it modifies the pitch of the propellers.

Provision is made for operating the system at 45 Hz, 5940 Volts nominal and 40 Hz, 5280 Volts nominal, corresponding to generator speeds of 1350 and 1200 rpm respectively at appropriate values of propeller pitch.

The high voltage (6.6 kV) switchboard

The nine cubicles which made up the high voltage switchboard were arranged as follows, No.1 being at the aft end:

Cubicle 1
Automatic Voltage Regulators and auxiliary controls

Cubicle 2 1-ACCB
Main Generator circuit breaker

Cubicle 3 6-ACCB
No.1 Ship's Service Transformer circuit breaker

Cubicle 4 4-ACCB
Starboard Aft Propulsion Motor circuit breaker

Cubicle 5 2-ACCB
Port Aft Propulsion Motor circuit breaker

Cubicle 6 5-ACCB
Starboard Forward Propulsion Motor circuit breaker

Cubicle 7 3-ACCB
Port Forward Propulsion Motor circuit breaker

Cubicle 8 8-ACCB
Bow Thruster Motor vacuum contactor

Cubicle 9 7-ACCB
No.2 Ship's Service Transformer circuit breaker

A "local/remote" selector switch on cubicle no.1 enabled control of the circuit breakers (except the bow thruster) from either the H.V. switchboard or the machinery control room.

Circuit breakers

The breakers themselves were "DIARC" series medium voltage air circuit breakers manufactured by SACE S.p.A. of Bergamo, Italy, the main generator circuit breaker being designed to carry 2000 amps and all others.1250 amps.

Each circuit breaker was connected to copper pins on the bus-bars by six "tulips" carried on the ends of copper connecting posts. In the case of the main generator breaker, each of the three phases had an incoming connection from the generator and an outgoing connection to the main bus-bars. In the case of all the other breakers, the incoming connection was from the bus-bars and the outgoing connection to the relevant equipment. Each "tulip" consisted of a number of silver-plated "fingers" which, upon racking the circuit breaker into the cubicle, would close around the end of the post on the bus-bars. The "fingers" were spring-loaded to provide the necessary contact pressure.

(See photograph page 17)

Surrounding each bus-bar pin was a tube of insulating material and, similarly, each post on the circuit-breaker was encased in insulation up to the point where the "tulips" were mounted on the end of the post.

Each circuit breaker was fitted with the usual protection equipment (in the form of circuit breaker trips) to safeguard the systems against electrical faults. Additional interlocks were fitted so that, when the main generator was operating in the reduced frequency mode at 45Hz (or less), the circuit breakers for the two ship's service transformers could not be closed.

Narrative - 29 December 1993

Union Rotorua, carrying mixed general cargo, sailed from Darling Harbour, Sydney at 1506 on 29 December 1993 bound for Melbourne.

At 1600, after the harbour pilot had disembarked, the Master rang "full away on passage". A course of 180 degrees was set with the vessel on reduced power to meet its scheduled arrival time in Melbourne. The sky was partly cloudy, the visibility clear and the sea slight with a short to moderate swell.

At 1630, the 2nd Engineer, who was the duty engineer for the day, left the machinery control room, switching to unmanned machinery space (UMS) operation.

At approximately 1730, the UMS alarm sounded in the duty engineer's cabin and in other spaces in the engineers' accommodation. The duty engineer immediately went to the engine control room and the Chief Engineer went to the bridge to look at the alarm panel. Both the duty engineer in the control room and the Chief Engineer on the bridge saw the warning light "Main Generator Differential Protection" flashing. The Chief Engineer started for the machinery control room. On his way there, at about 1733, the main fire alarm sounded.

The ship's position at this time was 34 degrees 17 minutes South, 151 degrees 15 minutes East, 17 miles south of Cape Banks at the entrance to Botany Bay.

In accordance with established emergency procedures, the engineers went to the machinery control room and the crew mustered at the fire station outside the accommodation.

When the Chief Engineer arrived in the control room he saw smoke in the turbine house up to the height of the control room platform. The main motors had tripped but the gas turbine was still running. The duty engineer reported that the engine room fans were stopped and called for breathing apparatus back up.

At this time, the smoke in the turbine house was still such that the Chief Engineer was able to leave the control room and, by descending the ladder within the turbine house, to reach the fire station at the shore power room on the port side of the main deck. By this time the crew had been directed to emergency stations and the Chief Engineer joined the response team. There an integrated rating (IR) had donned a fire suit and was putting on breathing apparatus. The electrician, who was familiar with the space, also put on breathing apparatus. The Second Engineer, meanwhile, had left the control room via the forward access door and the escape ladders, directly to the upper deck.

The Third Mate checked the pressures on the breathing apparatus and, when the two men entered, began timing them. The rest of the emergency party were deployed as necessary for boundary cooling and as back up to the men in breathing apparatus. The Mate had shut the engine room fire flaps and boundary cooling was started with one hose running slowly on the deck above the space.

The Electrician led the IR across the deck of the turbine house. The smoke was thick and their vision was restricted to less than a metre. When they reached the high voltage switch board, on the starboard side of the turbine house, they could detect flames coming from the base of one of the cabinets toward the after end of the switch board and also saw that the door of a cabinet was hanging off. They discharged a CO_2 extinguisher into the area of the flames and the fire died down but flared up again almost immediately. The pair withdrew from the space.

At 1752, the gas turbine main generator was stopped.

A further attempt was made to tackle the fire with dry powder, but this was also unsuccessful and the decision was made to flood the space with CO_2 from the fixed fire extinguishing system. Attempts to fight the fire directly were abandoned at about 1803, when the turbine house diesel generator was shut down and the engineers left the engine control room. Electrical power was then being supplied by the diesel generator in the motor room. All personnel were accounted for and the turbine house was sealed. Boundary cooling was still in progress on the funnel deck.

At 1807, the space was flooded with CO_2. When the flooding was started, it was seen that gas was leaking from a number of the cylinder fittings on the CO_2 system and so the CO_2 room was evacuated. Thereafter, a watch was kept on the exterior of the turbine house, first by the fire party and later by the engineers who commenced a watchkeeping roster.

The shore authorities were alerted and the tug Woona dispatched to the ship, arriving at 2226. Woona then towed Union Rotorua to Sydney Harbour, arriving at the pilot at 0500 and berthing in White Bay at about 0800 on 30 December. Acting on advice received by radio from the Sydney Fire Brigade, the ship's crew had made no attempt to open up the turbine house.

The Sydney Fire Brigade boarded the ship on arrival. Two firemen in breathing apparatus and equipped with CO_2 detectors and heat sensors entered the turbine house at 0826. After discharging a further 7 portable CO_2 extinguishers into the switchboard cabinets to lower the temperature, they established that the fire was extinguished.

The fire flaps were opened and the ventilation fans started.

Once it had been confirmed that all fire had been extinguished and the atmosphere within the turbine house was safe, an examination was made of the high voltage switchboard. (The atmosphere in the CO_2 room, however, was found unbreathable and the space required purging by the CO_2 room fan.)

The aftermost six of the nine cubicles were found to have been damaged by the fire, the forward three suffered some smoke and heat damage. Cubicles nos.2 and 3 (main generator and no.1 ship's service transformer respectively) were the most severely affected. The circuit breakers in both these cubicles were completely destroyed. The door on the cubicle containing the main generator circuit breaker was found open and hanging partly off its hinges, indicating that there had probably been explosive combustion of gases in that cubicle at some point during the incident.

The temperature of the fire within the circuit breakers was sufficiently high to reduce their high voltage insulation to fine powder, allowing the metal components to separate and collapse. Alloy components, such as the spring retaining rings and collars mounting the "fingers" of the "tulip" connectors, had all burned away completely. (See photographs, page 17)

No.1 cubicle, containing the automatic voltage regulators and associated control equipment, was also badly burned with nearly all wiring insulation and equipment casings destroyed.

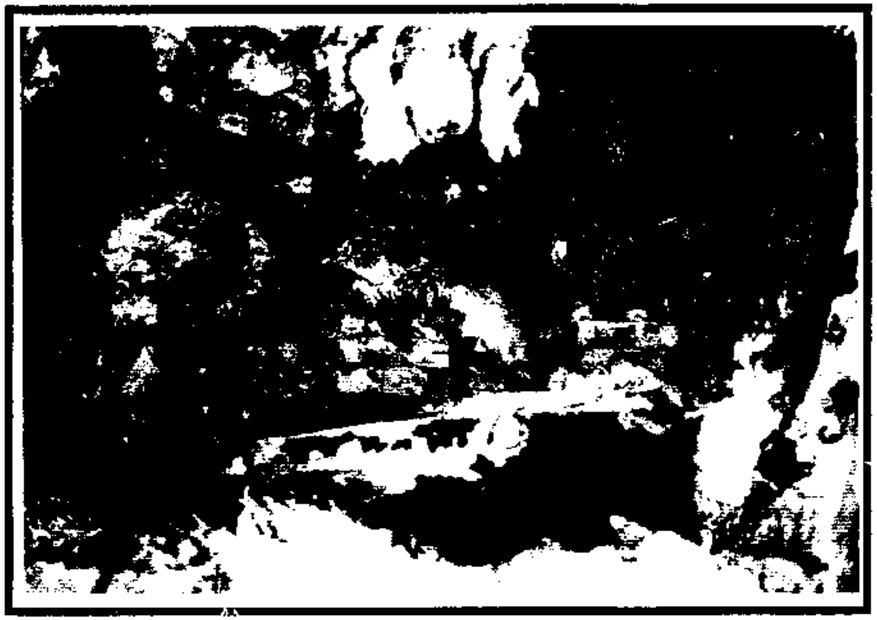
The dividing panels between cubicles 1 and 2 and between cubicles 2 and 3 were slightly distorted, although otherwise intact.

The significant finding during the examination of the remains of the circuit breakers was in the main generator cubicle, where the incoming yellow phase from the generator connected to the circuit breaker. At this point, 25mm of the end of the circuit breaker connecting post, which carried the "tulip", was burned away. The bus-bar pin, onto which the "tulip" connected, was burned away for its whole length, i.e. back to its rectangular mounting flange. (See photograph page 11) The post was made of solid copper, approximately 50mm in diameter, the pin to which it connected also being of solid copper, approximately 30mm in diameter.

The ship remained at White Bay for three months undergoing repairs, during which a complete new high voltage switchboard was fitted by CEGELEC Ltd.. The vessel sailed from Sydney on 27 March 1994.

Main generator circuit breaker posts, yellow phase
(note burned away end of right hand post)

Similar type of circuit breaker failing on test



Main generator busbar connecting pins
(note burned away pin just below centre of photo)

Comment

Planned Maintenance

The ship's planned maintenance system was originally set up when there was a total complement of 42 on board, including 2 electricians. This system had not been modified to reflect either the reduced manning or the age of the vessel and thus the ship's staff could not, and did not, adhere strictly to the original schedule but had carried out planned maintenance on an "ad hoc" basis.

The circuit breakers in the high voltage switchboard were 17 years old and, from the vessel's records, underwent regular inspections. Circuit breakers not damaged by the fire were examined during the investigation and, from a visual inspection, appeared to have been satisfactorily maintained. High and medium voltage circuit breakers do, however, deteriorate with age. This is especially true of their springs and insulation.

Evidence

During an examination of the debris, the only evidence found which pointed to the cause of the fire, was the missing end of the input connector post on the yellow phase of the main generator circuit breaker and the burned-away pin onto which its "tulip" connected. There was also some electrical erosion noted at the lower corners of the main generator feeder bus bar on which this pin had been mounted, indicating that, at some stage during the incident, there had been some arcing to earth.

It was not possible to establish, with certainty, the exact cause of the fire, however its origin was probably at this "tulip" connector. The most likely cause would have been one or more of the following:

1. Reduced contact pressure, due to ageing of the springs, between the "fingers" of the "tulip" and the bus bar pin.

2. Oxidation of the contact surfaces of either the pin or the "fingers".

3. Cracking, due to vibration and work-hardening, of the copper post at the point where there is an abrupt change in cross sectional area.

4. Loosening or fracture, due to vibration, of the socket-head cap screw holding the aluminium-alloy collar, upon which the "fingers" are mounted, onto the end of the post.

Any of these could have caused a slow build-up of heat due to increasing electrical resistance, to the point where the components of the "tulip", particularly the aluminium alloy parts, would have melted and the "tulip" disintegrated. This would have been followed by arcing, which would account for the burned-away end of the post and the pin, and the rapid destruction of the circuit breaker, together with initiation of a fire.

The remains of the post and the base of the pin were submitted by CEGELEC Ltd. for metallurgical examination, but beyond the fact that they had been burned away by arcing, the examination was inconclusive.

On 15 June 1991, an entry was made in the Electrician's work book stating:

"All H.T. breakers removed for inspection. Found to be in good condition. However, main H.T. breaker "tulips" require re-silvering of contacts. Very good for 15 years use."

There was no record or indication that these contacts had been either renewed or re-plated during the intervening $2^1/_2$ years.

Another factor which may have a bearing on this incident is that, for several weeks prior to the fire, the vessel had been running on the starboard propeller alone, the port being out of service due to problems with the hydraulic pitch-control mechanism. As a consequence of this, considerable vibration was imparted to the ship, over and above the normal propeller-induced vibration experienced on most vessels.

At the time that the fire occurred, the main generator circuit breaker (cubicle 2) had been closed, connecting power from the gas turbine main generator to the bus bars for vessel propulsion. The circuit breaker in the adjacent cubicle (cubicle 3), for no.1 ship's service transformer, had been open at that time as the ship's services were being fed by the diesel generator in the turbine house. The main generator was operating in the 45Hz mode and, in this condition, system interlocks would have prevented the closing of the circuit breakers for the ship's service transformers. There was no evidence to indicate that they had failed to do this or that the circuit breakers had been closed.

The fire damage sustained by both the circuit breakers in cubicles 2 and 3 was virtually identical, the breakers being destroyed by intense heat within the circuit breakers themselves. This is despite the fact that one was on line and the other was open. (See photographs page 17)

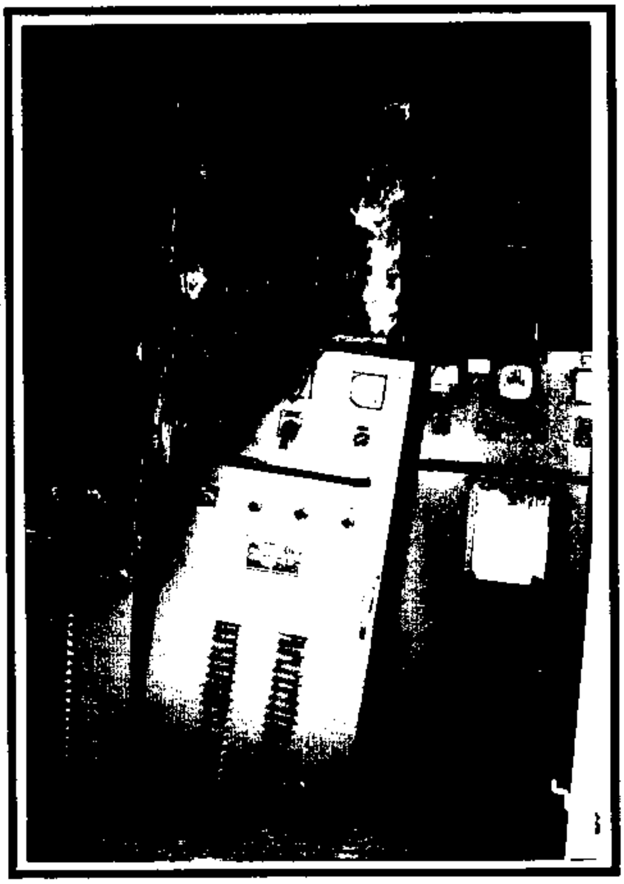
If the fire was initiated in the main generator circuit breaker as outlined above, the breaker having failed and thus been unable to clear the fault, then it is possible that ionised gases rapidly filled the adjoining cubicle, (no.3) and caused flash-over to occur across the open contacts of the no.1 ship's service transformer circuit breaker or to earth. A potential of 6.6 kV would have existed across the contacts of this breaker and to earth. This would then, in turn, have led to a rapid destruction of that breaker also, with accompanying fire.

The fire alarm sounded and the fire was discovered a few minutes after the alarm for "Main generator differential protection" had been activated. The combination of these two events should have indicated to the Engineer Officers the need for the immediate shut-down of the gas turbine generator and the removal of all power from the high voltage switchboard. In the event, the gas turbine generator continued running for nearly twenty minutes after the start of the incident. The Inspector considers that this delay was excessive. The Inspector acknowledges, however, that significant damage would in all probability have occurred before any action could have been taken by ship's staff and that, on account of the position of the fault, this damage could not have been entirely prevented by any form of protection equipment.

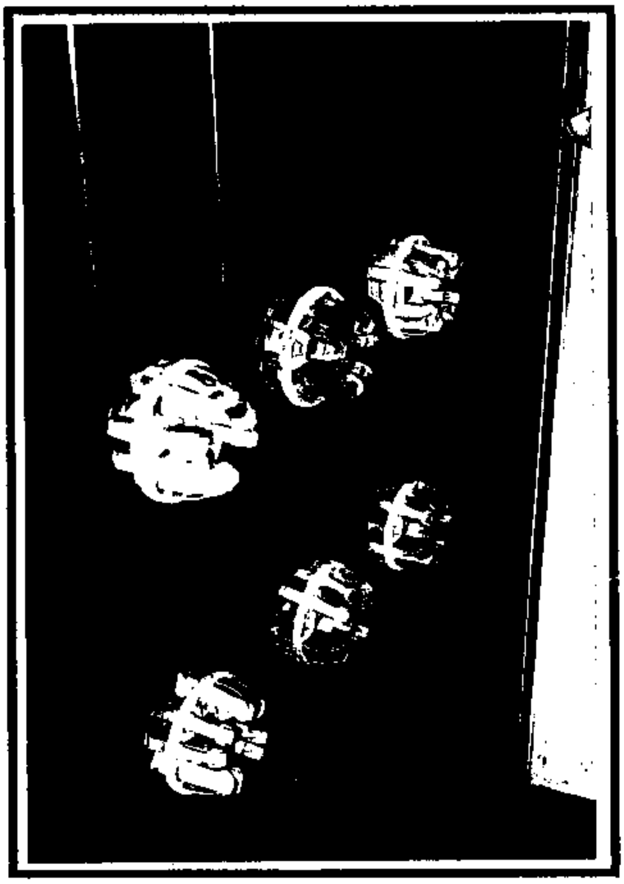
The almost explosive nature in which a circuit breaker will fail is seen in the photograph (page 11) of a similar type of breaker failing under test. The breaker pictured was designed to carry 43 kilo amps, but the failure occurred at a current of only 32 kilo amps and the breaker was destroyed in a period measured in milliseconds.

Remains of main generator circuit breaker (cubical No.2 from aft)

Remains of No.1 transformer circuit breaker (cubical No.3 from aft)



Front view of switchboard cubicals



View of circuit breaker "tulips" on the ends of connecting posts.

Conclusions

1. It was not possible to establish the exact cause of the fire, although evidence indicates that it probably started in the yellow phase of the main generator circuit breaker at the lower "tulip", connecting the generator input to the circuit breaker.

2. Initiation of the fire at the "tulip" connector may have been due to high electrical resistance caused by one or more of the following:

Loss of spring pressure (due to age or other causes) behind the connecting "fingers" of the "tulip".

Oxidation of the contact surfaces due to loss of silver plating on the contacts.

Mechanical fracture, due to vibration, of the end of the circuit breaker's connecting post at the point of change of cross-sectional area.

Loosening or fracture (due to vibration) of the socket-head cap screw securing the aluminium alloy collar mounting the connecting "fingers", to the end of the copper post.

3. Although the Electrician's workbook noted, in June 1991, that the contacts on the "Main HT breaker" needed re-silvering, there was no indication that this was ever carried out.

4. The fire spread to the adjoining cubicle containing the circuit breaker for the no.1 ship's service transformer. This may have been due to ionisation of the atmosphere by products of combustion from the fire in the main generator circuit breaker cubicle.

5. The Inspector considers that the delay in shutting down the gas turbine generator, after the fire was discovered, was excessive, but that the actions of the ship's officers and crew in tackling the fire were prompt and correct in all other respects.

6. The emergency response was effective and demonstrated planning and procedures of a high standard.

Annex 1

<u>The requirements of a circuit breaker</u> are such that it should be able:-

A. In the open condition

1. To withstand applied system voltage and impulse voltage

   - between phases
   - between each phase and earth
   - across the open contacts

2. If required, to successfully close onto a fault up to a maximum peak value of 2.5 X RMS fault current.

B. In the closed condition

1. To withstand applied system voltage and impulse voltage
   - between phases
   - between each phase and earth

2. To withstand short time current for one or three seconds, depending on the relevant standard.

3. If required, to successfully interrupt any current up to a maximum fault current and to withstand any restrike. Subsequently to be capable of the following sequence :-
   - break as above
   - 3 minute make, break
   - 3 minute make, break

<u>Circuit breaker failure</u>

If the breaker is unable to successfully cope with any of the above conditions it is said to have failed.

Possible causes of failure are:

Electrical

Flashover due to:

- ageing and deterioration of insulating materials
- accumulation of dust, moisture or other conducting material on solid insulators

- presence of foreign material between conductors
- ionisation of the surrounding atmosphere

Overheating, due to:

- high resistance joint (loose connection)
- high resistance contact caused by misalignment or reduced spring pressure

Mechanical

- wear and/or seizure of pivots, bearings, etc.
- deterioration of throw-off springs due to ageing
- mechanical failure of links, push rods, etc.
- misalignment of contacts, arc chutes etc.

Development of faults and consequential damage

Relatively minor faults occurring within a switchboard usually develop very rapidly into full-scale 3-phase faults. The immediate effect is to impose extremely high mechanical forces tending to bring conductors together and imposing high bending stresses on support insulators etc. Mechanical failure can ensue under these conditions.

Unless the fault can be cleared within a few cycles, the heating effect of the fault current will rapidly lead to charring and eventual igniting of insulating materials, and the melting of copper and other metals.

The effects of mechanical stress and heating can spread into other parts of the switchboard and to cables and connected apparatus not directly affected by the original fault.