Statens haverikommission
Swedish Accident Investigation Authority

ISSN 1400-5719

Final report RL 2012:20e

Serious incident involving the aircraft EI-DAD at Skavsta Airport, Södermanland county, on 25 April 2011

Case L-30/11

2012-11-14

The report is also available on our website: www.havkom.se

Postal address	*Visitors*	*Phone*	*Facsimile*	*E-mail*
P.O. Box 12538 SE-102 29 Stockholm	Sveavägen 151 Stockholm	+46 8 508 862 00	+46 8 508 862 90	info@havkom.se

Statens haverikommission
Swedish Accident Investigation Authority

1. The Swedish Transport Agency
Civil Aviation Department
601 73 NORRKÖPING
2. FAA
3. EASA

Final report RL 2012:20e

The Swedish Accident Investigation Authority (Statens haverikommission, SHK) has investigated a serious incident that occurred on 25 April 2011 at Skavsta Airport, Södermanland county, involving one aircraft with the registration EI-DAD.

The Authority hereby submits under the Regulation (EU) No 996/2010 on the investigation and prevention of accidents and incidents in civil aviation, a report on the investigation.

The Authority will be grateful to receive, by February 16 at the latest, particulars of how the recommendations included in this report are being followed up.

This document is a translation of the original Swedish report.

Jonas Bäckstrand Stefan Christensen

Postal address	Visitors	Phone	Facsimile	E-mail
P.O. Box 12538 SE-102 29 Stockholm	Sveavägen 151 Stockholm	+46 8 508 862 00	+46 8 508 862 90	info@havkom.se

APPENDIX

1 FOI MEMO E28246:
Simulation and analysis of electric power distribution. (Swedish only)

Postal address	Visitors	Phone	Facsimile	E-mail
P.O. Box 12538 SE-102 29 Stockholm	Sveavägen 151 Stockholm	+46 8 508 862 00	+46 8 508 862 90	info@havkom.se

General points of departure and limitations

The Swedish Accident Investigation Board (Statens haverikommission – SHK) is a state authority with the task of investigating accidents and incidents with the aim of improving safety. SHK accident investigations are intended so far as possible to determine both the sequence of events and the cause of the events, along with the damage and effects in general. An investigation shall provide the basis for decisions which are aimed at preventing similar events from happening again, or to limit the effects of such an event. At the same time the investigation provides a basis for an assessment of the operations performed by the public emergency services in respect of the event and, if there is a need for them, improvements to the emergency services.

SHK accident investigations try to come to conclusions in respect of three questions: *What happened? Why did it happen? How can a similar event be avoided in future?*

SHK does not have any inspection remit, nor is it any part of its task to apportion blame or liability concerning damages. This means that issues concerning liability are neither investigated nor described in association with its investigations. Issues concerning blame, responsibility and damages are dealt with by the judicial system or, for example, by insurance companies.

The task of SHK does not either include as a side issue of the investigation that concerns emergency actions an investigation into how people transported to hospital have been treated there. Nor are included public actions in the form of social care or crisis management after the event.

The investigation of aviation incidents is regulated in the main by the Regulation (EU) No 996/2010 on the investigation and prevention of accidents and incidents in civil aviation. The investigation is carried out in accordance with the Chicago Convention Annex 13.

The investigation

SHK was notified on 29 April 2011 that an incident involving a Boeing 737 with the registration EI-DAD had occurred at Skavsta Airport, Södermanland county on 25 April 2011 at 07.50 hrs.

The incident has been investigated by SHK represented by Mr. Göran Rosvall, Chairperson until 26 January 2012, Mr. Jonas Bäckstrand, Chairperson from 6 February 2012, Mr. Stefan Christensen, Investigator in Charge, Ms Ulrika Svensson, Operational Investigator and Mr. Kristoffer Danèl, Technical Investigator (aviation).

The investigation was followed by Mr. Bo Eriksson, Swedish Transport Agency.

Final report RL 2012:20e

Aircraft; registration and model	EI-DAD; B737-800
Class, Airworthiness	Normal, Certificate of Airworthiness and valid Airworthiness Review Certificate (ARC)
Owner/Operator	Ryanair Ltd
Time of occurrence	25-04-2011, 07.50 hrs in daylight Note: All times are given in Swedish daylight saving time (UTC + 2 hrs)
Place	Skavsta Airport, Södermanland county, (pos. 5847N 01654E; 45 m above sea level)
Type of flight	Commercial air transport
Weather	According to SMHI's analysis: west-north-westerly wind, 5 kts, visibility >10 km, no clouds below 5000 feet, temp/dewpoint 8/5 °C, QNH 1024 hPa
Persons on board; Crew members	
Passengers	6
	173
Injuries to persons	None
Damage to aircraft	None
Other damage	None
Commander	
Age, licence	35, ATPL
Total flying time	7011 hours, of which 6200 hours on type
Flying hours previous 90 days	168 hours, all on type
Number of landings previous 90 days	86
Co-pilot	
Age, licence	38, CPL
Total flying time	7400 hours, of which 6100 hours on type
Flying hours previous 90 days	137 hours, all on type
Number of landings previous 90 days	60
Cabin crew members	4 persons

Summary

On 25 April 2011, shortly after take-off, a Ryanair Boeing 737-800 received an indication that one of the aircraft's two electrical systems had lost electrical power. This had been preceded by one of the two generators that supply electrical power to the aircraft being disconnected, upon which redistribution took place so that the other generator supplied power to both electrical systems. An electronic monitoring and control unit automatically ensured that this took place.

The pilots followed the checklist and attempted to reconnect the generator. They also attempted to connect the generator from the Auxiliary Power Unit (APU). Either during the attempt to reconnect the disconnected generator or the connection of the auxiliary power unit's generator, the connection between the two systems was broken, with the consequence that one of the systems lost electrical power.

The pilots made a further attempt to reconnect a power source but were unsuccessful. The decision was therefore made to return and land at Skavsta Airport. Flying with one of the electrical systems not having power meant among other things losing the display of flight instruments on the affected side. Flap indication and pitot heating were among the systems which lost their power supply and stopped working during the incident.

The electronic monitoring and control units are intended to ensure that both electrical systems are always supplied with power as long as there is at least one power source available. They are also intended to prevent electrical interconnection of the electrical systems when each subsystem is supplied by its own power source. The control units' commands are based on status signals from relays, among other things.

The incident was caused by the system logic for the Generator Control Unit (GCU) and the Bus Power Control Unit (BPCU) enabling erroneous status signals from the breaker (Generator Control Breaker, GCB) to lead to a transfer bus losing power.

Recommendations

The FAA/EASA are recommended to:

- Ensure that Boeing introduces measures so that the logic in the electrical system prevents an X-bus from losing power as a result of an erroneous status signal from GCB. (RL 2012:20 R1)

- Ensure that Boeing investigates whether a revision of the procedure in QRH for reconnecting IDG can rectify erroneous status signals from GCB. (RL 2012:20 R2)

1. FACTUAL INFORMATION

1.1 History of the flight

The description of the incident is largely based on interviews with the pilots. There are some differences between the pilots' descriptions.

An aircraft of type Boeing 737-800 with registration EI-DAD (Figure 1.) was to conduct a regular flight between Stockholm Skavsta and Paris Beauvais on 25 April 2011. There were 173 passengers and 6 crew members on board. The flight had the call sign RYR 9503.

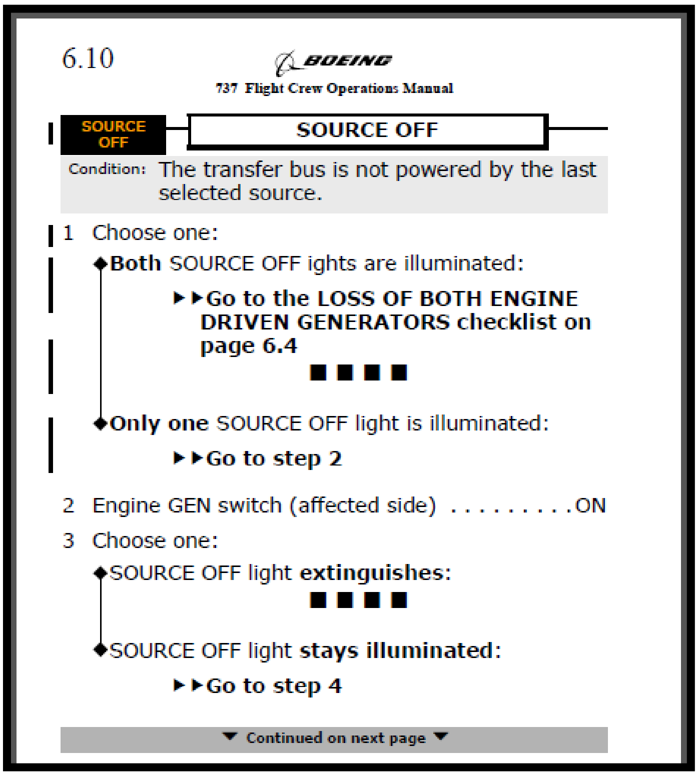
Fig. 1. EI-DAD

During the take-off sequence, at a speed of around 110 kts, a warning light illuminated. PM[1] extinguished the light and the commander – who was PF[2] – completed the take-off. At an altitude of 400 feet, the pilots began investigating what had triggered the alarm and discovered that the light for the right-side Source Off and Master Caution had illuminated. Source Off means that a power source which should normally be connected to one of the main transfer buses has been disconnected in the system. The pilots established that there were no Memory Items[3] for the fault in question and continued to climb to 1000 feet where, according to the operator's procedures, they continued with the normal checklist used in connection with take-off.

Once the normal checklist was completed, PF asked for the Quick Reference Handbook for Source Off. PM brought out QRH[4] and began handling the problem. Where only one power source is missing, which was the case in this incident, the generator in question should in accordance with QRH be selected to ON – see Figure 2.

---

[1] PM: Pilot Monitoring (Pilot who assists PF)
[2] PF: Pilot Flying (Pilot who manoeuvres the aircraft)
[3] Memory Items: Points which the pilots check without the help of checklists.
[4] QRH: Quick Reference Handbook


6.10 BOEING
737 Flight Crew Operations Manual

SOURCE OFF

SOURCE OFF

Condition: The transfer bus is not powered by the last selected source.

1 Choose one:

◆**Both** SOURCE OFF ights are illuminated:

►►**Go to the LOSS OF BOTH ENGINE DRIVEN GENERATORS checklist on page 6.4**

■ ■ ■ ■

◆**Only one** SOURCE OFF light is illuminated:

►►**Go to step 2**

2 Engine GEN switch (affected side) . . . . ON

3 Choose one:

◆SOURCE OFF light **extinguishes:**

■ ■ ■ ■

◆SOURCE OFF light **stays illuminated:**

►►**Go to step 4**

▼ Continued on next page ▼

Fig. 2. QRH for Source Off (page 1 of 2)

When the pilots selected Engine GEN on the affected side to ON, a consequential fault arose which resulted in a new warning signal illuminating. This signalled Transfer Bus Off, which meant that Transfer Bus 2, hereafter referred to as X-Bus2, was not receiving power from any of the generators.

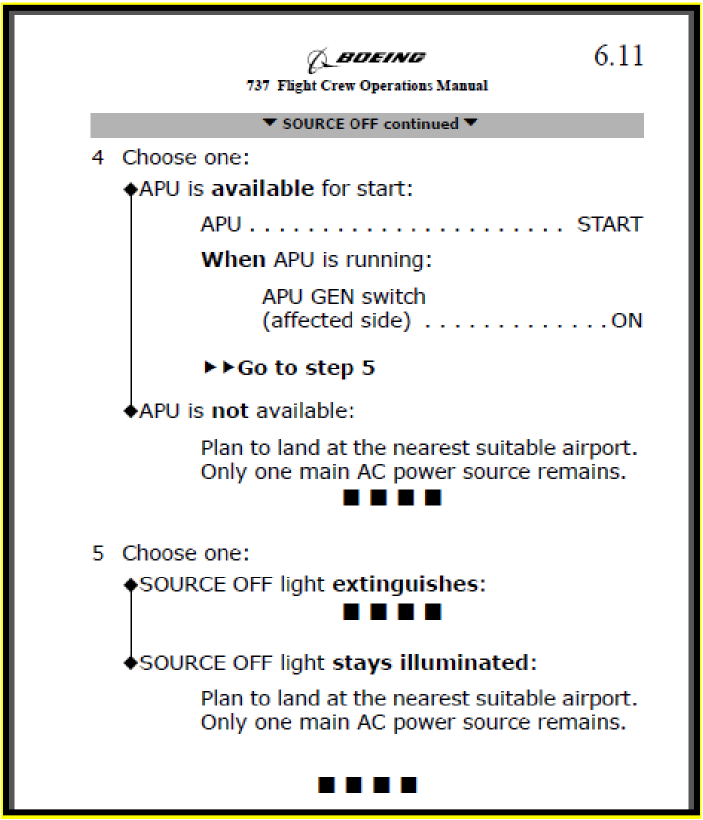
The difference in the pilots' accounts of the incident comes in when the following occurred:

“A number of warning lights illuminated, all displays on the first officer's side went out and the autopilot disengaged. Altitude reporting on the transponder disappeared, which meant that air traffic control could no longer see the aircraft's altitude.”

The described event above may therefore have occurred when the pilots selected Engine GEN on the affected side to ON, or it may have occurred when the pilots continued with the checklist to page 2 for Source Off and started up the aircraft's APU[5].

When the APU had started and its generator became available, APU Gen was selected to ON. APU was however not automatically connected to X-bus2.

5 APU: Auxiliary Power Unit



BOEING 6.11

737 Flight Crew Operations Manual

▼ SOURCE OFF continued ▼

4 Choose one:

◆APU is **available** for start:

APU . . . . START

When APU is running:

APU GEN switch
(affected side) . . . . ON

►►**Go to step 5**

◆APU is **not** available:

Plan to land at the nearest suitable airport.
Only one main AC power source remains.

■ ■ ■ ■

5 Choose one:

◆SOURCE OFF light **extinguishes**:

■ ■ ■ ■

◆SOURCE OFF light **stays illuminated**:

Plan to land at the nearest suitable airport.
Only one main AC power source remains.

■ ■ ■ ■

Fig. 3. QRH for Source Off (page 2 of 2)

One of the warning lights which illuminated was the Battery Discharge Light, which is normally interpreted to mean that the battery is supplying power to the system instead of being charged. If battery power is used to supply power during flight, this is normally in an emergency situation. According to the pilots' description, the Battery Discharge Light stayed illuminated for between “a few” and 25 minutes.

According to the pilots' incident report, the following systems went offline:

- Autopilot A+B as a result of automatic pitch trim ceasing to function
- Electrical trim
- PFD[6]+ND[7] on the first officer's side
- The transponders’ altitude reporting (both transponders 1 and 2)
- Nose wheel pedal steering
- Indicator for trailing edge flap

According to the same report, the following warning lights illuminated:

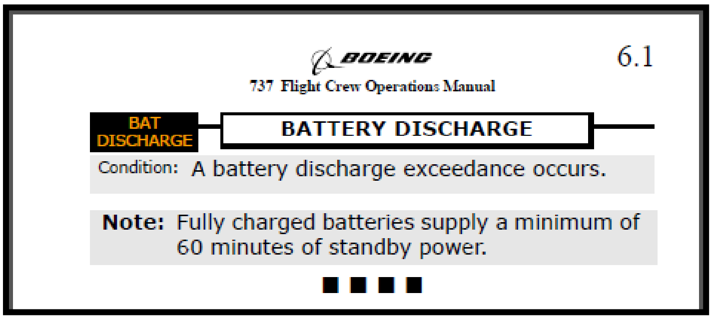
- Battery discharge
- Master caution
- (RH) Source off
- (RH) Transfer Bus Off
- Mach Trim Fail
- Auto Slat Fail
- Fuel Pump 2 Fwd
- Fuel Pump 1 Aft
- A Elec Pump 2 Hydr
- Probe Heat B (4 lights)
- Eng EEC Altn (Both)
- Zone Temp (3 lights)

---

[6] PFD – Primary Flight Display (Screen for flight status information)
[7] ND – Navigation Display (Screen for navigation system)

Battery discharge is described as follows:

Illuminated (amber) – with BAT switch ON, excessive battery discharge detected.


BOEING 6.1

737 Flight Crew Operations Manual

BAT DISCHARGE

BATTERY DISCHARGE

Condition: A battery discharge exceedance occurs.

Note: Fully charged batteries supply a minimum of 60 minutes of standby power.

Fig. 4. QRH for Battery discharge

Air traffic control contacted the aircraft when altitude reporting disappeared. The pilots tried to switch to another transponder, but the fault with the altitude reporting persisted.

The pilots also read the emergency checklist for Transfer Bus Off, but as the measures were the same as for Source Off, which had caused the main fault, they chose not to take any further measures and to instead return to Skavsta.

From the time the autopilot disengaged automatically and could not be reconnected due to the auto trim no longer functioning, the commander flew the aircraft manually.

As there was some uncertainty concerning the status of the instruments, and as much of the commander's concentration was devoted to flying and trimming the aircraft manually, the commander requested radar vectoring from air traffic control back to Skavsta. Initially, clearance was given to the NDB[8] PEO, for which reason the pilots had to repeat their request for vectoring to the air traffic controller and explain that they had problems with the instruments on board.

On a later occasion during the approach, the pilots added PAN-PAN x 3 to their call signal in order to indicate that they wished to have priority but that it was not an immediate emergency situation.

The aircraft was vectored for an ILS[9] approach to runway 26 at Skavsta. During the first approach, the commander chose to abort the approach as the pilots were still carrying on discussions via the radio with Priority Air Maintenance, the maintenance organization contracted by Ryanair at Skavsta. The commander also wanted the first officer to perform a visual inspection from the cabin in order to verify that the trailing edge flaps had indeed been extended.

Thereafter, the aircraft was vectored onto an ILS for runway 26 and the landing was executed with no problems. After the landing, the pilots pulled the circuit breaker to the CVR in accordance with the operator's procedures. The entire crew was relieved from service for the rest of the day.

[8] NDB – Non-Directional Beacon.
[9] ILS – Instrument Landing System – Approach aid which provides both horizontal and vertical positioning.

1.2 Injuries to persons

	Crew members	Passengers	Total	Others
Fatal	–	–	–	–
Serious	–	–	–	–
Minor	–	–	–	–
None	6	173	179	–
Total	6	173	179	–

1.3 Damage to the aircraft

None.

1.4 Other damage

None.

1.5 Personnel information

1.5.1 Commander

The Commander was 35 years old at the time and had a valid ATPL[10]. At the time of the incident, the Commander was PF.

Flying hours				
Latest	24 hours	7 days	90 days	Total
All types	4.4	18	168	7011
This type	4.4	18	168	6200

Number of landings this class/type previous 90 days: 86.
Type rating was performed on 2 June 2003.
Latest PC (Proficiency Check) performed on 10 December 2010 on B737.

1.5.2 Co-pilot

The Co-pilot was 38 years old at the time and had a valid CPL[11]. At the time of the incident the Co-pilot was PM.

Flying hours				
Latest	24 hours	7 days	90 days	Total
All types	1.1	6	137	7400
This type	1.1	6	137	6100

Number of landings this type previous 90 days: 60.
Type rating was performed on 24 June 2002.
Last PC performed on 7 April 2011 on B737.

1.5.3 Cabin crew members

Four persons.

1.5.4 The pilots' duty schedule

Not applicable.

[10] ATPL - Airline Transport Pilot Licence, with authorization to act as commander
[11] CPL - Commercial Pilot Licence

1.6 Aircraft information

1.6.1 *Airworthiness and maintenance*

Aircraft	
TC-holder	The Boeing Company
Model	737-800
Serial number	33544
Year of manufacture	2002
Gross mass	Max authorized start/landing mass 74990 kg, actual 64835 kg
Total flying time	28847 hours
Flying time since latest inspection	0 hours (50-cycle inspection carried out the same morning/night as the incident)
Number of cycles	18833
Fuel loaded before event	Jet A1
Defered items	
MEL	None
HIL	None

The aircraft had a Certificate of Airworthiness and a valid ARC[12].

1.6.2 *Boeing 737-800 Electrical system - general*

The purpose of the electrical system is to produce and distribute electrical power. The system also checks that the distributed current is within specified limit values. The electrical system consists of an alternating current section and a direct current section. The alternating current has three phases, a voltage of 115 V and a frequency of 400 Hz. The alternating current section in turn consists of two subsystems; no. 1 left and no. 2 right.

The direct current section maintains 28 V and is also divided into a number of subsystems. The alternating current system, hereafter referred to as the AC system, has four main power sources with a capacity of 90 kVA each: left IDG[13]1, right IDG2, APU[14] and external power. From each power source run three feeder lines, one for each phase, to one of the two PDPs[15], where breakers connect the selected power source and distribute the current to the rest of the AC system – see Figure 5.

---

[12] ARC - Airworthiness Review Certificate
[13] IDG - Integrated Drive Generator, a unit which can maintain a constant rpm. It is mounted on the aircraft's engine and consists of a hydromechanical gearbox and generator.
[14] APU – Auxiliary Power Unit.
[15] PDP – Power Distribution Panel, containing breakers and branch breakers.

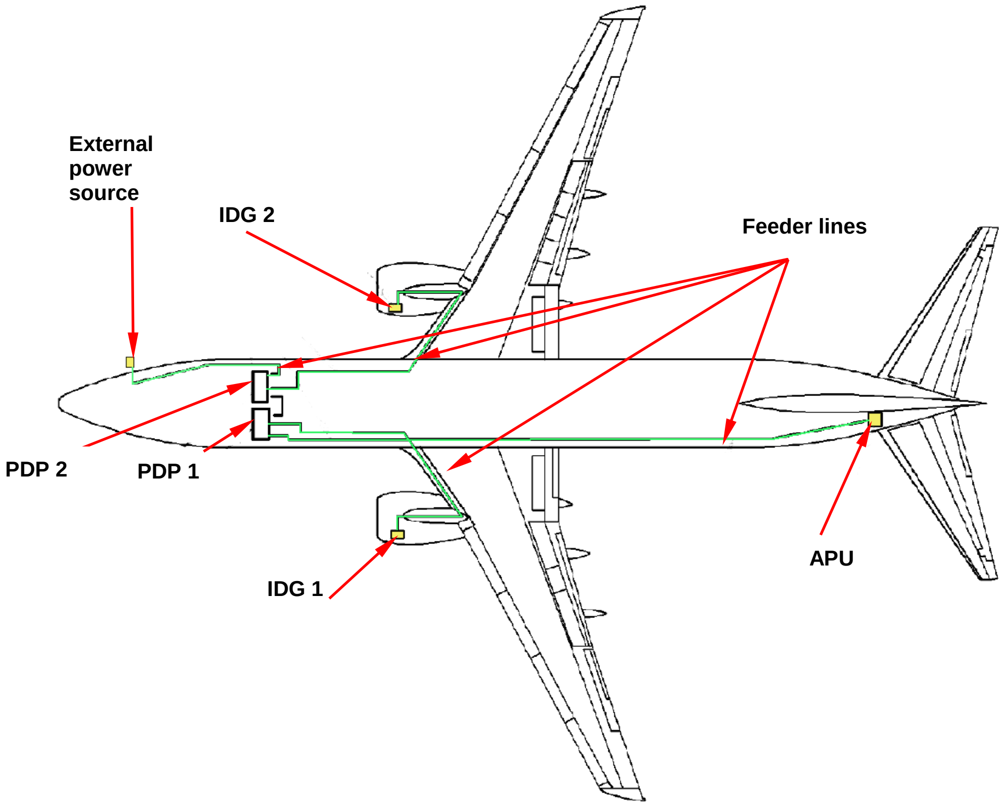


Fig. 5. Power sources and feeder lines.

The AC system is designed so as to prevent two power sources from supplying current to the same subsystem. On the other hand, one power source can supply current to two subsystems. When there is no AC power source supplying current, a limited number of users can receive alternating current from the “AC standby” bus via a convertor from the direct current system.

The direct current system, hereafter referred to as the DC system, receives power from the AC system via a transformer rectifier, TRU[16], and battery.

1.6.3. *The AC system's monitoring and checks*

The distribution and quality of the power is checked and controlled by a number of control units. The control units GCU[17]1 and GCU2 monitor and check the current supplied from their respective IDG, thus constituting a protection for the system and its IDG. Current supplied from APU is monitored and checked by similar control units – AGCU[18] and SCU[19]. Current supplied by an externally connected power source is monitored and checked by the control unit BPCU[20].

The different power sources can be connected manually from a panel in the cockpit. The control units contain a diagnostic function known as BITE[21]. This function can perform self-tests and diagnostics and can show faults in the control unit and the system.

---

16 TRU – Transformer Rectifier Unit.
17 GCU - Generator Control Unit, control unit for current coming from IDG.
18 AGCU - APU Generator Control Unit, control unit for current coming from APU.
19 SCU – Starter Control Unit, control unit for current coming from APU and controlling the activation of APU.
20 BPCU – Bus Power Control Unit, control unit for current coming from an external power source and interconnection of the two AC subsystems.
21 BITE – Built In Test Equipment

The current is distributed to users via transfer buses. The distribution is controlled by the control units, which check various breakers. The breakers GCB[22]1 and GCB2 connect the respective IDG to the rest of the system, APB[23] connects APU, and EPC[24] connects the external power source to the rest of the AC system. A schematic of the electrical system is shown in Figure 6.

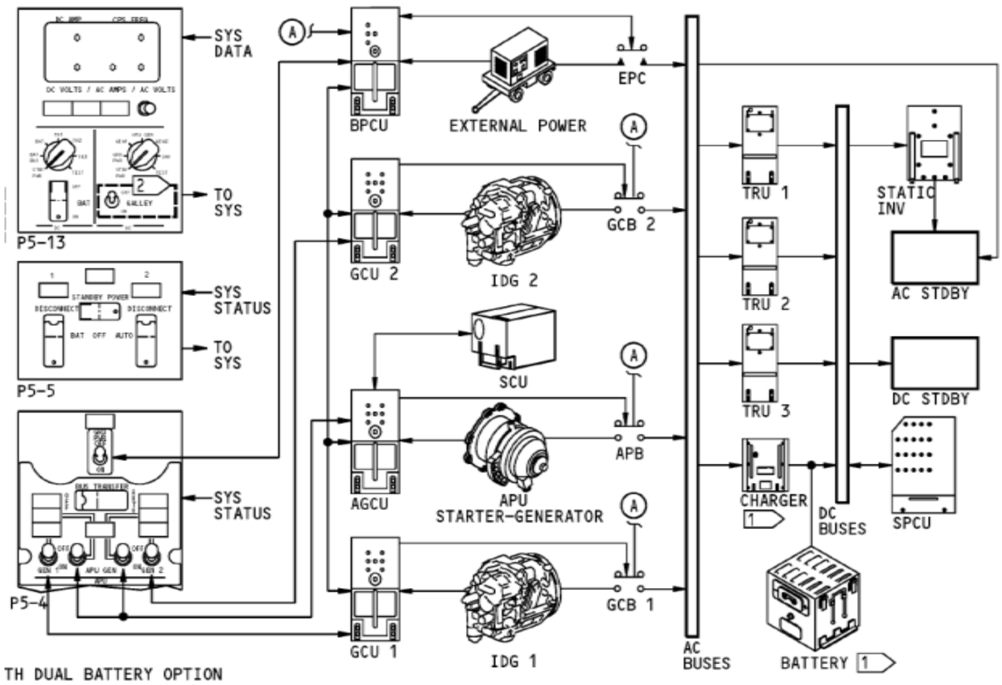


Fig. 6. Schematic of the electrical system.

During flight, power is normally supplied by the IDG's. IDG1 supplies the user on system 1 via the bus "Transfer Bus 1", hereafter referred to as X-bus1, and IDG2 supplies the user on system 2 via X-bus2 – see Figure 7.

[22] GCB – Generator Control Breaker.
[23] APB – Auxiliary Power Breaker
[24] EPC – External Power Contactor

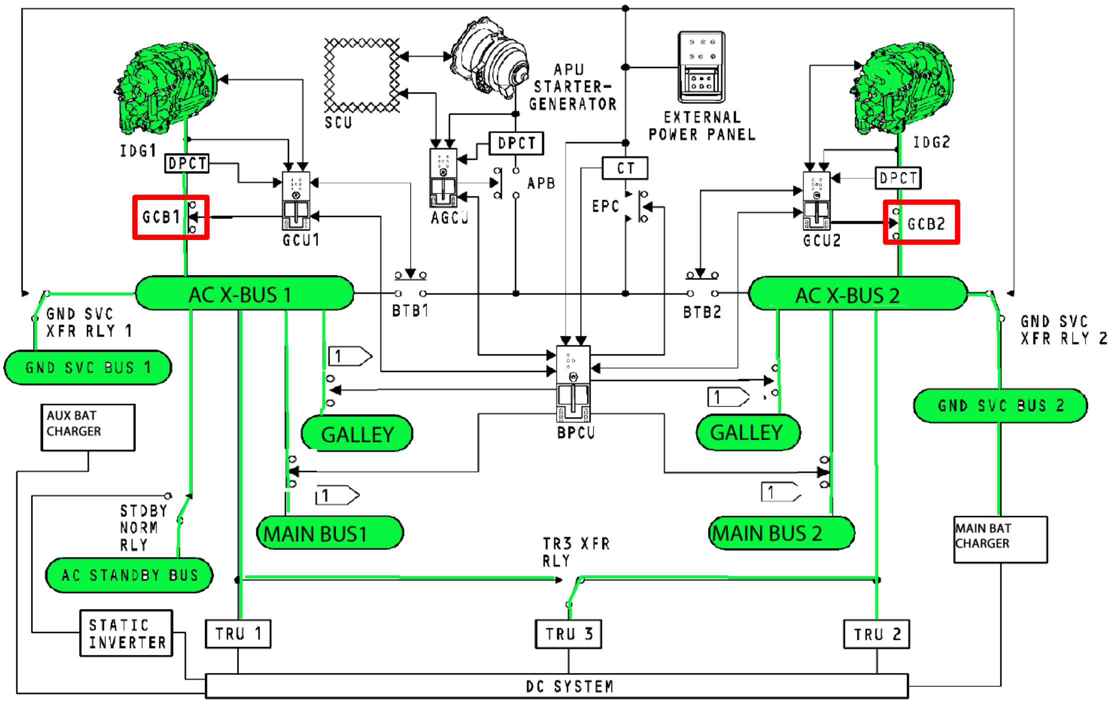


Fig. 7. Green indicates AC current which fulfills quality criteria. Current is led via GCB1 and GCB2 out to the X-buses and on to the users.

When only one power source is available, X-bus1 and X-bus2 are interconnected by the breakers BTB[25]1 and BTB2.

Each GCU (GCU1, GCU2 and AGCU) monitors and checks, among other things, frequency, voltage, current, phase sequence, difference in current originating from IDG and received by GCB. This difference indicates either an interruption or leakage current, and should under normal circumstances be 0 Amperes. GCU sends control signals to IDG in order to maintain the correct current quality. It also monitors the status of the GCB and BTB breakers and sends control signals to them.

Status and control signals operate on a 28 V direct current. When the quality of the current is for whatever reason not within the limits, GCU sends a signal to GCB to tell it to open and thus disconnect IDG from its respective X-bus. This was the situation shortly after take-off, shown in Figure 8.

[25] BTB – Bus Tie Breaker

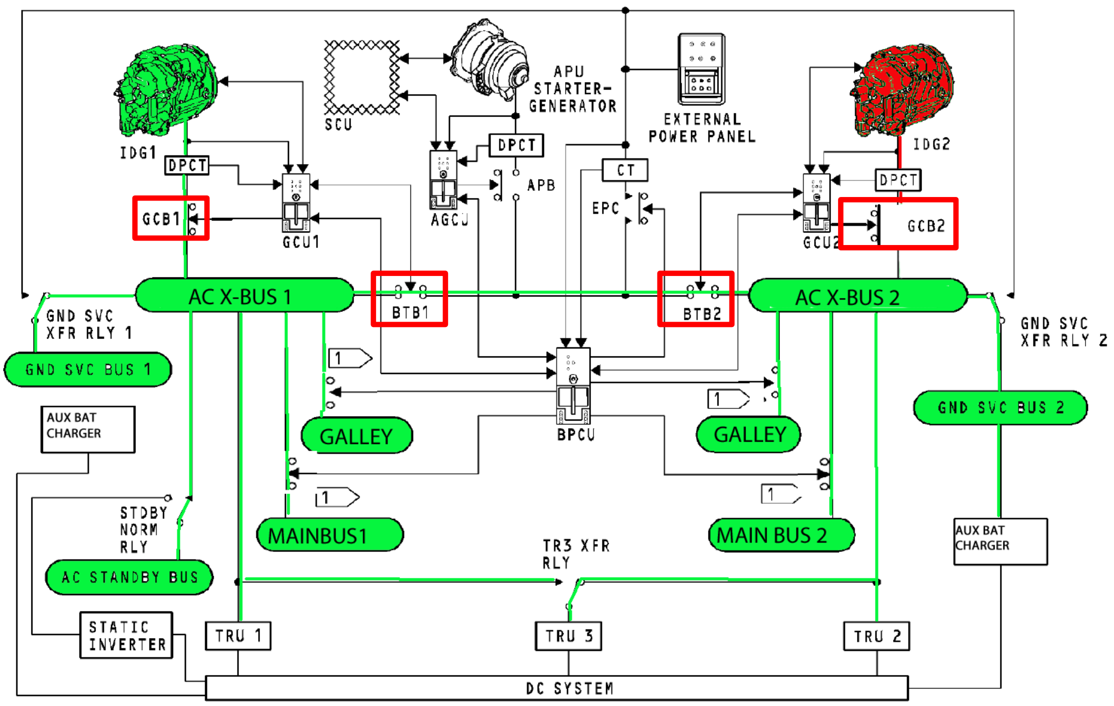


Fig. 8 The AC system is supplied by one power source, IDG2 disconnected. The two BTB breakers are connected.

BPCU monitors the power quality from the external power source and the power consumption. When the consumption is too high, BPCU sends control signals to the breakers which, according to a predetermined schedule, disconnect users such as the "galley". BPCU also ensures that the two X-buses are interconnected, in the event that an X-bus loses its normal power source. When BPCU receives a signal that GCB is open, it sends a signal to each GCU to close their respective BTB. When both BTBs are closed, X-bus1 and X-bus2 are interconnected and a joint power source can supply current to the users. The bus that goes between the two BTB breakers is called a "Tie Bus".

Connection and selection of power source for current to the respective X-bus is done via panel P5-4, located on the cockpit ceiling. This panel also shows status and warnings from the electrical system – see Figure 9.

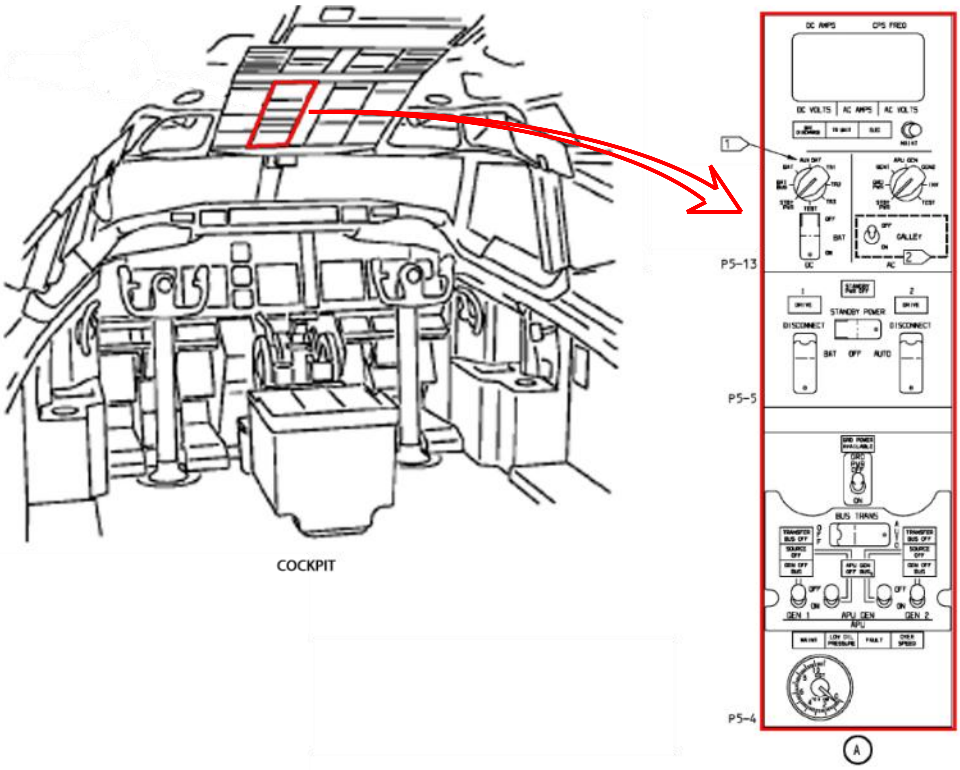
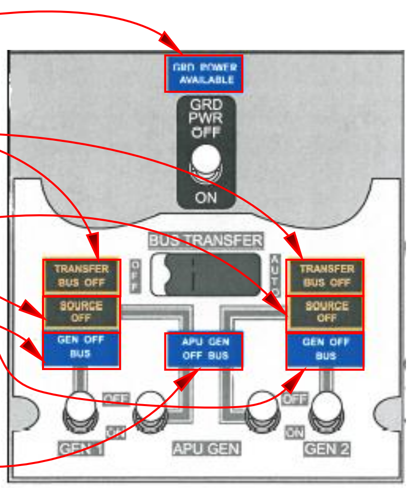


Fig. 9. Cockpit, panel P5 and its subpanels.

Panel P5-4 houses switches for connecting and disconnecting the various power sources. These are three-position switches and are non-locking, i.e., they return to the neutral position in the middle. A 28 V direct current signal is passed from the GCU to the switch for IDG. When the switch is placed in the ON or OFF position, this signal is returned to GCU on the corresponding input terminals. Provided that necessary conditions are met, a signal is thereafter sent from GCU to the requisite breakers to tell them to either open or close. The panel also features status lights. Below is a description of these and what is signified when they are illuminated and extinguished respectively.

- Indicator light - “Ground Power Available” – Illuminates in blue when external power source is connected and the quality of its current is within the limit values.

- Indicator light - “Transfer Bus Off”– Illuminates in amber when the respective X-bus is without current.
- Indicator light - “Source Off”- Illuminates in amber when the respective X-bus is not receiving current from the selected power source.
- Indicator light - “Gen Off Bus” - Illuminates in blue when the respective GCB is open.
- Indicator light - “APU Gen Off Bus” - Illuminates in blue when APU is running but not connected so as to supply current. The light is extinguished when APU is switched off or connected and supplying current.



The panel also features a two-position switch. The protected mode “Auto” allows the system to automatically connect the X-buses together. In the “Off” position, the X-buses are prevented from interconnecting.

1.6.4. *Description of the breakers GCB, BTB, APB and EPC*

The breakers GCB, BTB, APB and EPC are manufactured by HONEYWELL ASCA INC. They are all identical and all have the same part number: 1151968-1. The purpose of these breakers is to break the three phases of the alternating current or conduct them into the rest of the AC system. Inside the breaker, there are three primary contacts; one for each phase A, B and C. These conduct the main current. In addition, there are a number of auxiliary contacts, which conduct the breaker's control current and provide an indication of the breaker's state. The auxiliary contact system operates on 28 V direct current. The breakers are located in PDP1 and PDP2. Figure 10 shows the location of BTB2, GCB2 and EPC in PDP2.

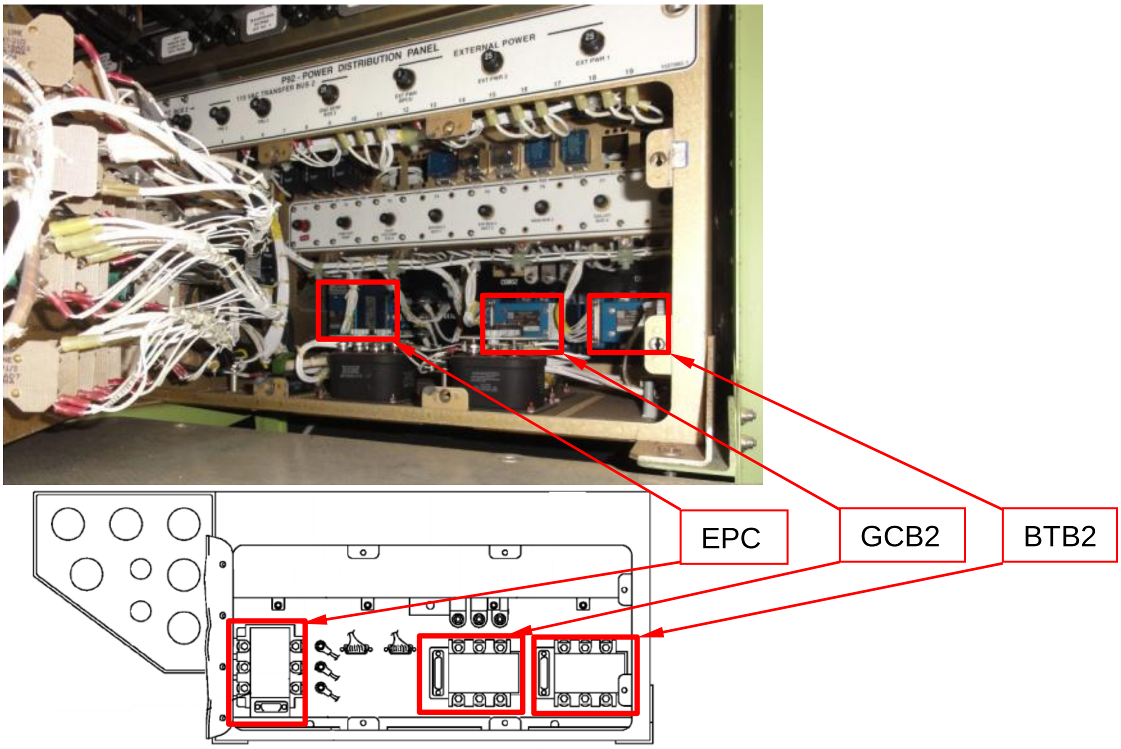


Fig. 10. Image and diagram of PDP2, showing the location of the breakers.

Each breaker mechanism has two electromagnetic coils; one to close and one to open the breaker. The coils are located at each end of a piston which moves the primary and auxiliary contacts between open and closed positions. When a current passes through the spools, a magnetic field is formed which moves the piston in an axial direction. A permanent magnet holds the piston in its respective closing position. The auxiliary contacts give an indication of the breaker's state to the control units and to the indicator lights on panel P5-4. The auxiliary contacts conduct or break the supply of current to the spools. Depending on what function the breaker has; GCB, BTB, APB or EPC, different connections on the auxiliary contacts will be used. Figure 11 shows GCB2 and its terminals.

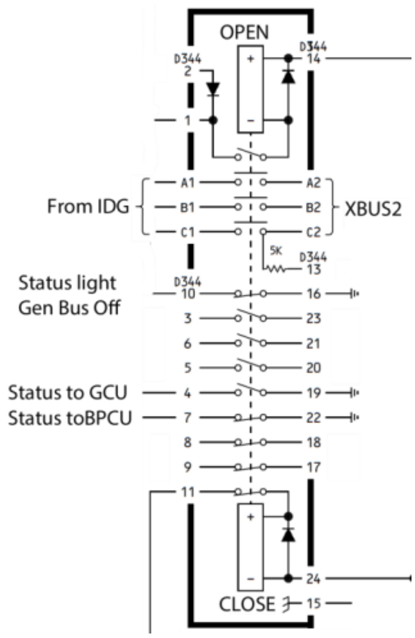


Fig. 11. The breakers GCB2. Connections 1 and 11 are control current to the electromagnets.

The Boeing 737-800 is certified in accordance with the FAR Part 25 and JAR -25. These documents contain the standards and the requirements that should be met for the different systems and its components. They also contain among other things, a guide to assess the severity of a system or component failure.

The certification criteria for the breakers are that they can manage 50,000 cycles, where the voltage drop over the primary contacts must be below 0.150 V with 290 A in rated current. The breakers have no inspection interval; instead, they run "On Condition", which means that units are replaced when required. Information received late in the investigation, shows that these units are within the certification criteria. During 3 158 000 cycles 42 units were replaced. 21 of these units were verified having a fault.

1.6.5. *Description of the control units GCU and BPCU*

The GCUs monitor and check the quality of the current from IDG and APU. They send control signals to the breakers GCB and BTB, monitor their position, convey GCB's position status to BPCU and have a diagnostic function known as BITE.

GCU, AGCU and BPCU operate on 28 V direct current and together check the aircraft's AC system. GCU is supplied with current in the first instance by its respective IDGs through separate cables and secondarily by the DC system. AGCU is supplied with current from the DC system's bus "Switched hot battery bus" or alternatively DC bus 2. BPCU can be supplied by an external power source and by the DC system.

GCU monitors, among other things, voltage, frequency, power consumption, sequence of the phases, difference in current originating from IDG and received by GCB. The internal logic of GCU determines which measures shall be carried out in order for the respective X-bus to receive current of a good quality. Input signals to the GCU include:

- Generator switch position.
- Position status from GCB.
- Position status from EPC.
- Position status from APB.
- Position status from BTB.

- Position status from GCB
- BTB control signal from BPCU.

Output signals to the GCU include:

- Control signals to GCB.
- Control signals to BTB.

The control signals sent by the GCU are based on internal logic and can be represented by “gates”. The value of the input and output signals represent logical variables which can have the value 1 or 0, corresponding to 28 V DC or 0 V DC. In order to gain a perception of the number of inputs and outputs and the structure of the logic, the inputs and outputs are shown in Figure 12 and parts of the internal logic in the GCU in Figure 13.

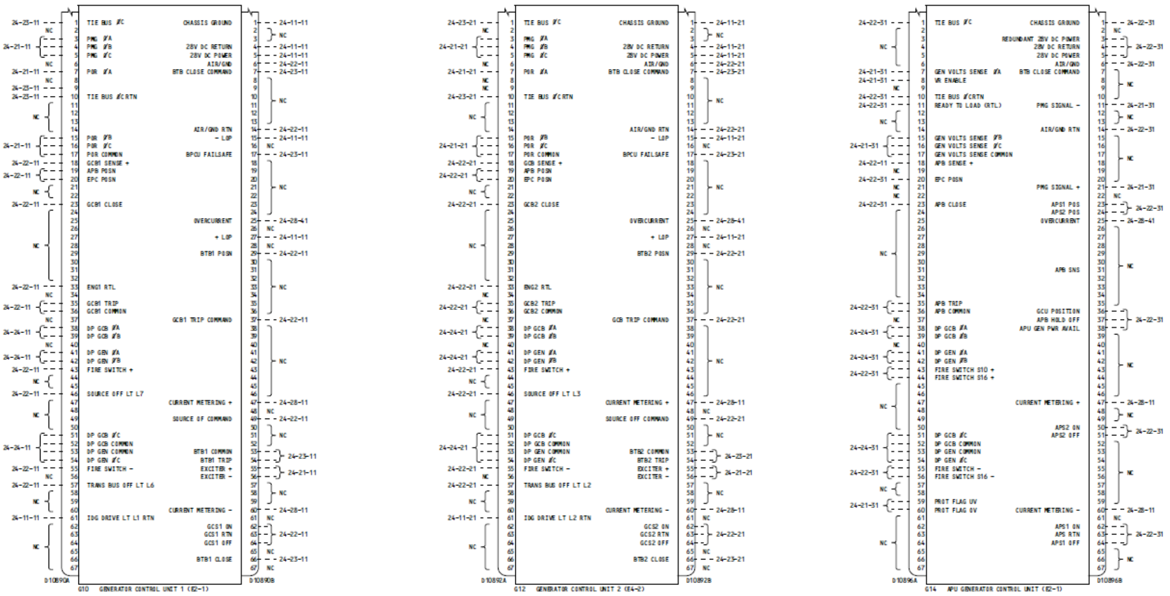


Fig. 12. Connections to the various GCUs.

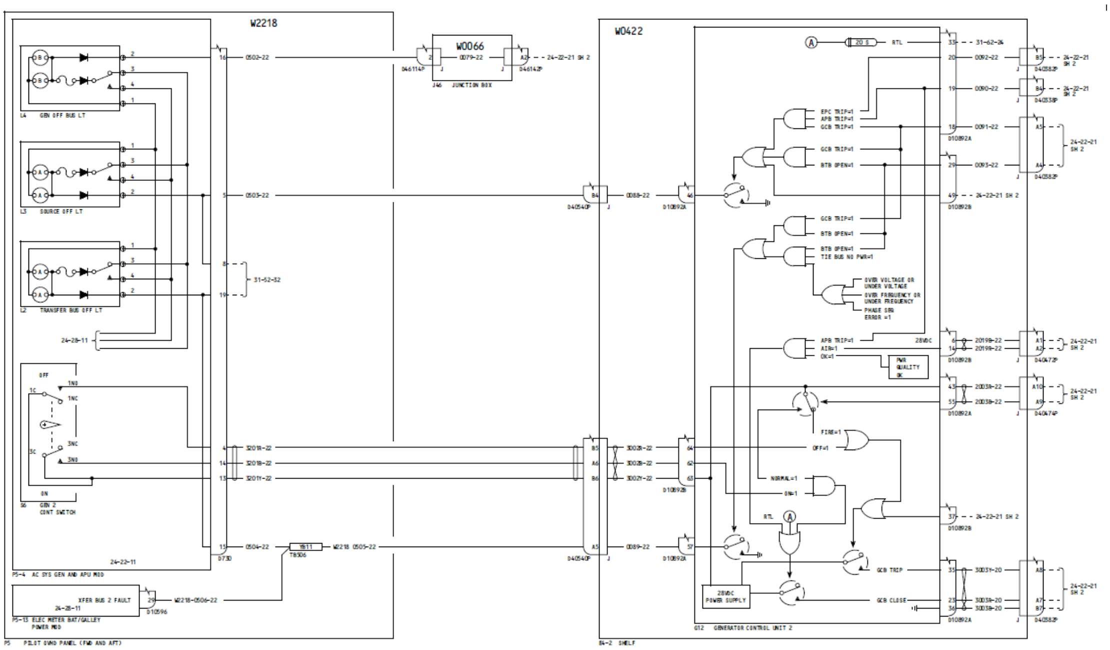


Fig. 13. Parts of the logic in the GCU.

The BITE function of the GCU is a diagnostic function which is independent of other GCU functions. It localizes and identifies faults in the GCU with peripheral equipment and saves these in a memory and presents the faults via lights on the front of the GCU. There are seven status lights and one non-locking test button – see Figure 14. Six of the lights are such that they illuminate when various faults have been detected. The seventh light illuminates after a self-test when no fault has been detected. When starting up, the BITE function performs a self-test, which is the same as when the test button on the front of the GCU is pressed.

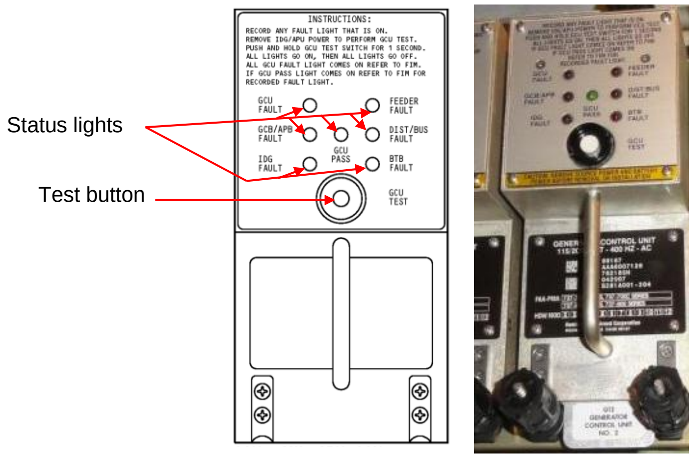


Fig. 14. Front of GCU. The image on the right shows how the status is presented following self-test on GCU2.

Only one status light can be illuminated at a time; in cases where the BITE function has detected several faults, only the fault with the highest priority is presented. The order of priority and faults are described in the table below.

PRIO	LIGHT (Colour)	MEANING
1	**GCU**	Internal fault in GCU or fault in the voltage control function
2	**IDG**	Short circuit in the IDG diodes, or frequency outside of the limit values, or voltage below limit value (voltage control function OK).
3	**GCB/APB**	GCB or APB did not switch to the commanded position.
4	**BTB**	BTB did not switch to the commanded position.
5	**FEEDER**	Difference in current originating from IDG and received by GCB above limit value, or incorrect phase sequence, or voltage below limit value (voltage control function OK).
6	**DIST/BUS**	Power consumption above limit value, current imbalance between the phases.
7	**GCU PASS**	No faults detected after test button has been pressed.

After the test button has been pressed, old faults are erased, and the light presenting these are extinguished.

There is only one BPCU in the system. It receives signals from other control units and breakers in the system and, based on these, coordinates the measures to be taken. BPCU receives status signals concerning the breaker positions of GCB, BTB, EPC and APB. BPCU sends signals to the GCUs. These include control signals which tell the respective BTB whether to open or close.

The BPCU monitors the quality of the current from the external power source. It also monitors the power consumption. When the load exceeds the permitted limit values, it disconnects non-essential users such as the galley.

In the event of a loss of current to an X-bus, the BPCU sends control signals to GCU1 and GCU2 which tell the BTB breakers to close and thereby interconnect AC system 1 and AC system 2. The output signals are determined by the BPCU's internal logic and, as with GCU, they are based on the level of the input signals. In order to gain a perception of the number of inputs and outputs and the structure of the BPCU's logic, the connections are shown in Figure 15 and parts of the internal logic in Figure 16.

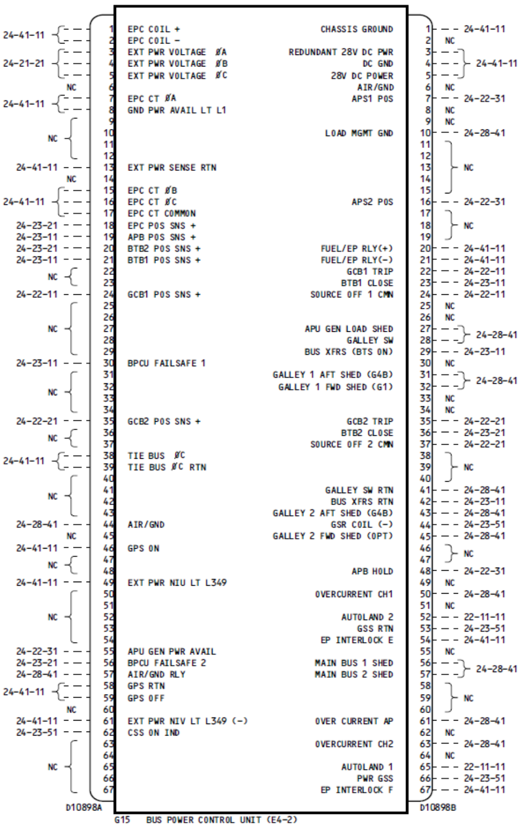


Fig. 15. Inputs and outputs to BPCU.

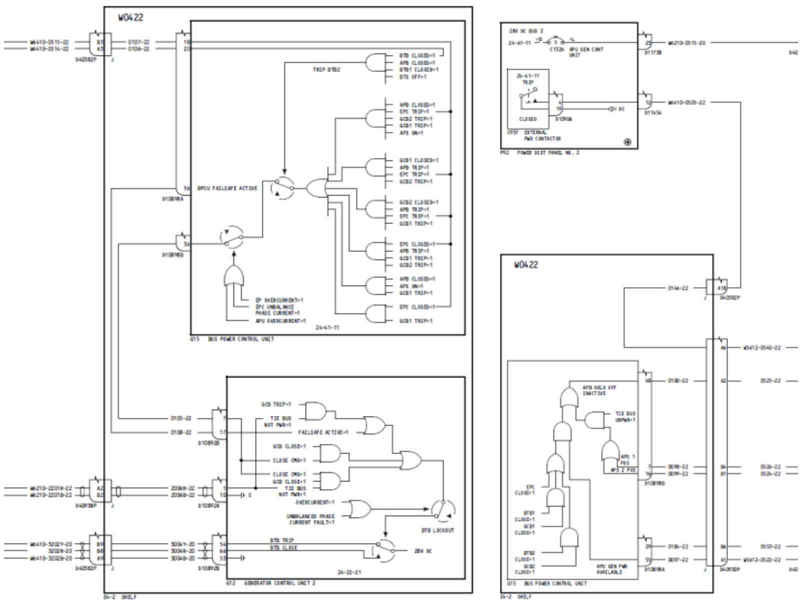


Fig. 16. Parts of the BPCU's logic together with parts of the GCU2 outputs to the left go to BTB2.

Here is an example of normal signal activity when a power source is to be connected:

The non-locking switch for connecting a power source is pushed to the “on” position. The GCU senses the position of the respective switch. When this signal is high, GCU sends a signal to the respective BTB to enable it to open. GCU monitors the BTB position. It sends a signal to the GCB to enable it to close when it senses that the BTB status indicates open and the following conditions are met:

- The quality of the current is within its limit values.
- The quality of the current has been within the limit values for the last 20 seconds, or the RTL[26] signal is "high".
- The fire handle is in the "normal" position.
- Status signal "open" from BTB.

GCB will then close and connect the power source with its X-bus. The status signal indicating that GCB is no longer open goes from GCB to the respective GCU.

As the non-locking switch for connecting the power supply is pushed to the "off" position, GCU responds by sending an open command to the respective GCB.

1.6.6. *The DC system*

The DC system, shown in Figure 17, is divided into two main buses, two battery buses and a "standby" bus.

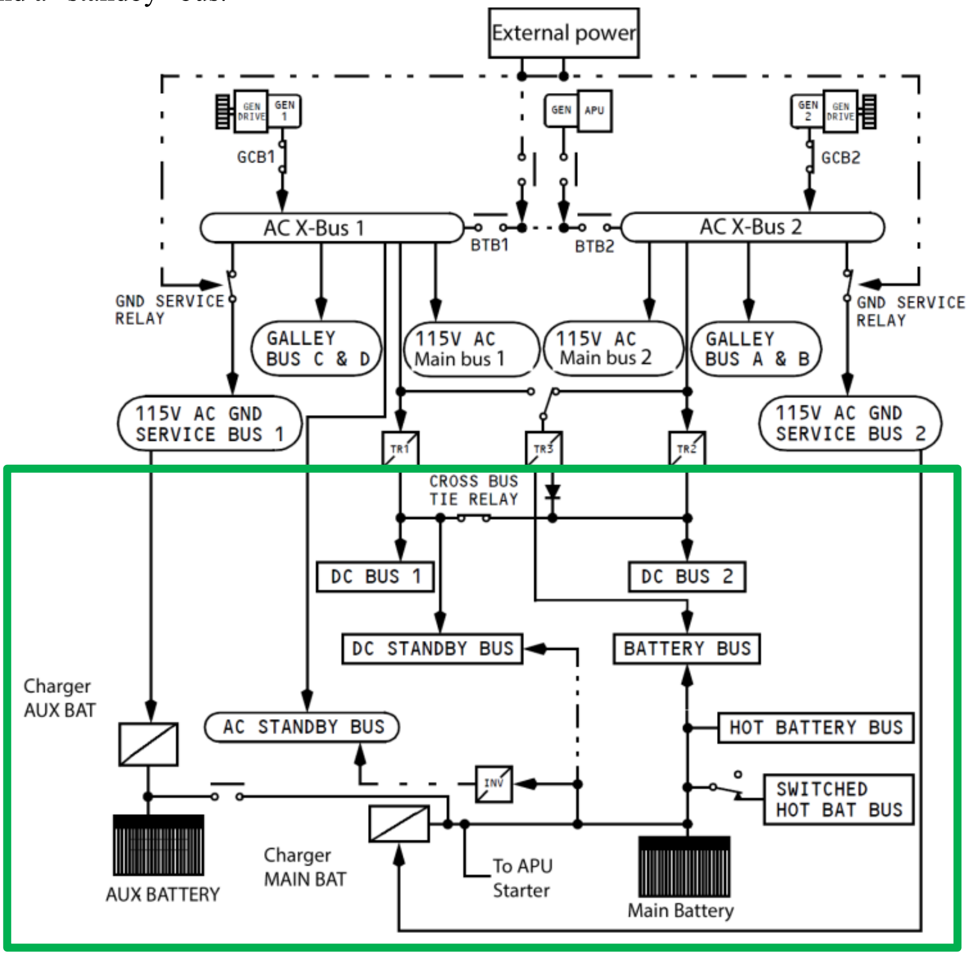


Fig. 17. The DC system is indicated by the green frame.

The DC system operates on a voltage of 28 V direct current. The system can be supplied with current by three TRUs, battery charger or battery. The main supply of current is handled by the three transformers, TRU, which convert 115 V alternating current to direct current. The battery charger and the battery supply current in the event that the main supply of current fails. TRU 1 is fed with alternating current from X-bus1 and supplies direct current to DC-bus 1. TRU 2 is fed with alternating current from X-bus2 and supplies direct current to DC-bus 2. TRU 3 is normally fed with alternating current from X-bus2 but can also be fed by X-bus1 when X-bus2 is without current. TRU3 supplies direct current to the battery bus. The aircraft was equipped

[26] RTL – Ready To Load. Signal indicating that the power source is ready to be connected (rpm not below idle rpm).

with two batteries; one main battery and one auxiliary battery, each with a capacity of 48 Ah and 24 V. The batteries each have their own charger. The main battery is intended to supply APU with starting current and the DC system with emergency power to the Standby buses. It shall also provide reserve power for the AC system's protection and control system.

The auxiliary battery supports the main battery with emergency power to the Standby buses. The buses “Hot battery bus” and “Switched hot battery bus” are supplied with current by the battery. “Switched hot battery bus” is connected to the main battery via a relay when the battery switch is in the “ON” position, while “Hot battery bus” is always connected to the main battery.

From full charge, the batteries can supply current to the Standby buses for at least 60 minutes.

The purpose of the main battery's charger is to ensure that the main battery is fully charged and to supply current to the battery buses. This is achieved by the battery charger working in two different modes; a charging mode and a transformer mode (TRU mode). In charging mode, the charger feeds the battery with a constant current and variable voltage. During charging, the voltage can be as high as 33 V. The charger charges the battery when the battery voltage drops below 23 V or when the charger has been without current for more than one second.

The “BAT DISCHARGE” light on panel P5-13 illuminates when current flows from the main battery in excess of 5 Amperes for 95 seconds, 15 Amperes for 25 seconds or 100 Amperes for 1.2 seconds.

1.6.7 Availability and serviceableness of ACAS/TCAS/GPWS/TAWS

Not applicable.

1.7 Meteorological information

According to SMHI's analysis: west-north-westerly wind, 5 kts, visibility >10 km, no clouds below 5000 feet, temp/dewpoint 8/5 °C, QNH 1024 hPa

1.8 Aids to navigation

Not applicable.

1.9 Radio communications

Not applicable.

1.10 Aerodrome information

The airport had operational status in accordance with the Swedish AIP[27].

1.11 Flight recorders

Information on the incident reached SHK on 29 April, i.e., four days after the incident. Due to the long period of time which passed between the incident taking place and SHK being informed, some data was lost.

[27] AIP – Aeronautical Information Publication

1.11.1 Flight Data Recorder (FDR, QAR[28])

The FDR was overwritten by the time SHK was informed of the incident. However, many modern aircraft have a QAR, which generally stores more parameters than an FDR. In the present case, the QAR could be obtained.

Through QAR, SHK had hoped to find information on the position of the breakers in BTB and GCB, as well as status signals for control units. These parameters were however not recorded in QAR.

1.11.2 Cockpit Voice Recorder (CVR)

The operator has clear instructions in its approved OM concerning when CVR data is to be secured by the pilots. The pilots followed the instructions and pulled the circuit breaker to the CVR in order to facilitate investigation. However, the circuit breaker to the CVR was reset in accordance with a decision within the operator's organization. It has not been possible to establish where in the organization this decision was made and why. The CVR is powered via the X-bus2.

1.12 Site of occurrence

Stockholm Skavsta Airport, ESKN.

1.13 Medical information

Nothing indicates that the mental and physical condition of the pilots were impaired before or during the flight.

1.14 Fire

There was no fire.

1.15 Survival aspects

1.15.1 The rescue operation

The Air Rescue Coordination Centre at JRCC[29] received information from Stockholm ATCC[30] at 07.43 hrs about the aircraft in question. It was explained that the aircraft was returning to Stockholm Skavsta Airport due to an electrical fault. Six minutes later they were informed that the aircraft had multiple electrical faults, and that the air traffic controller in the tower at Skavsta had therefore triggered the alert signal.

The airport rescue services, the municipal rescue services and two ambulances were standing by on the runway system from half an hour before the aircraft landed at 0828 hrs. The landing was executed without any injuries, and the rescue operation could therefore be concluded.

1.15.2 Location of the cabin crew and passengers, and injuries

Not applicable.

1.15.3 Evacuation

Not applicable.

---

[28] QAR – Quick Access Recorder
[29] JRCC: Joint Rescue Coordination Centre
[30] ATCC: Air Traffic Control Centre

1.16 Tests and research

1.16.1 Fault isolation carried out by maintenance personnel in connection with the incident and similar incidents involving EI-DAD

The aircraft technicians commenced fault isolation immediately after the aircraft had landed and parked and ground power (external power source) had been connected. It was established at this point that the fault had ceased and it was not possible to recreate it. GCU2 presented the fault "BTB fault" and after a BITE test, "GCU PASS" was indicated, which means that GCU-BITE does not detect any faults in the system. As a safety measure, BTB2 and GCU2 were replaced with new units.

Six days before the present incident, the "Source off" light for AC system 2 had illuminated and GCU2 had presented the same fault - "BTB fault". Also on that occasion, BTB2 was replaced with a new unit, which was in turn, as mentioned, replaced again after the present incident.

SHK looked into the status of EI-DAD before and after the incident. This showed that several similar incidents had occurred, in which the "Source off" light for AC system 2 illuminated and one of the power sources could not be connected to X-bus2. In several of these cases, the fault disappeared once the control units (BPCU, GCU2) and other components (cabling, breakers, panels) had been inspected or replaced and a BITE test had been carried out. On one of the occasions, an emergency landing was necessary. It can be noted that after the incident, EI-DAD flew 20 consecutive days without this symptoms being manifested.

After several extensive fault isolation tests, Ryanair's technicians could finally trace the primary cause of the fault to a short circuit between the phases in the feeder cabling from IDG2. The reason for the X-buses not being interconnected during the present incident was never found.

1.16.2 SHK investigation

SHK has examined and analyzed the incident. Focus has been placed on why the two X-buses were not interconnected.

To begin with, a simpler analysis of the incident was performed with the help of, among other things, Boeing's Fault Isolation Manual (FIM), but it soon became clear that a more in-depth analysis of the system was required. A large number of aircraft of the same series has been delivered, all with the same construction of the electrical system (3,622 aircraft in April 2011). SHK also became aware that incidents of the same type and with the same symptoms had occurred both before and after the incident now under investigation.

During the investigation, it is primarily the system's logic that was analysed, and how this responded to certain faults. This is a way of testing the system's robustness. Among other things, faults in the status signals were analysed, whereby SHK arrived at a possible explanation for the symptoms during the incident. In order to verify the results of the analysis and see how the system responded to these, SHK attempted to conduct tests in a Boeing 737-800 simulator. But neither the operator nor the designer of the simulator facility could introduce these faults. The simulator was quite simply not built with a view to these faults being able to arise or be simulated.

The suspicion that an erroneous status signal could cause the symptom during the incident became stronger when SHK received information on an incident in which the cause of the X-buses not being interconnected was verified as a loose connection in the auxiliary contact in GCB.

In order to obtain a further analysis of the system and the incident, SHK contacted the Swedish Defence Research Agency, FOI. FOI's assignment was to analyse the logic of the aircraft's AC system and to write a program which simulated relevant parts of the AC system. The program had to be general, with the possibility of introducing faults in the logical signals. The program was to have a graphical user interface (GUI) where the presentation of the electrical system would emulate that found at the pilot seat. The work is reported in an appendix to this report.

The program was written in LabView, a graphical programming language that suits the purpose very well. All relevant components were programmed, where values of the inputs and outputs could be set arbitrarily. During the programming, WDM[31], upon which the program was to a great extent based, was found to contain faults which meant that gates turned the wrong way. The function of the units with the gates turned the wrong way differed from what was described in AMM[32]. During a test run of the program, this did not work at all as it had been coded in exact accordance with WDM. When the gates were turned the "right" way, the program functioned correctly in accordance with the intended description in WDM and according to AMM. In order to provide an overview of parts of the program code, this is shown in Figure 18.

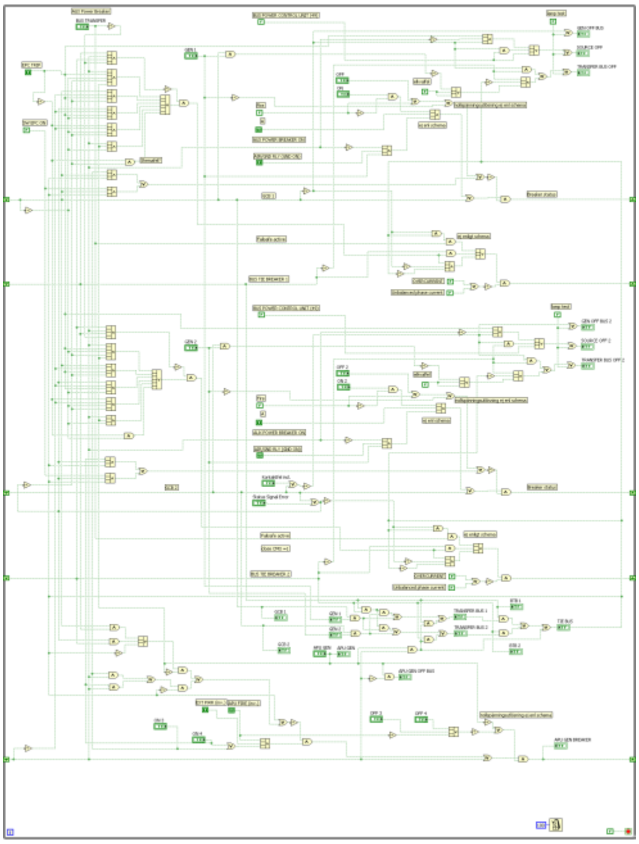


Fig. 18. Parts of code for the program for simulation of the electrical system.

The GUI has a structure of virtual switches and indicator lamps – see Figure 19. On the GUI, it is also possible to introduce faults in status signals. Green indicator lights show parts powered by 115 V alternating current.

---

31 WDM – Wiring Diagram Manual.
32 AMM – Aircraft Maintenance Manual, which includes system and function descriptions.

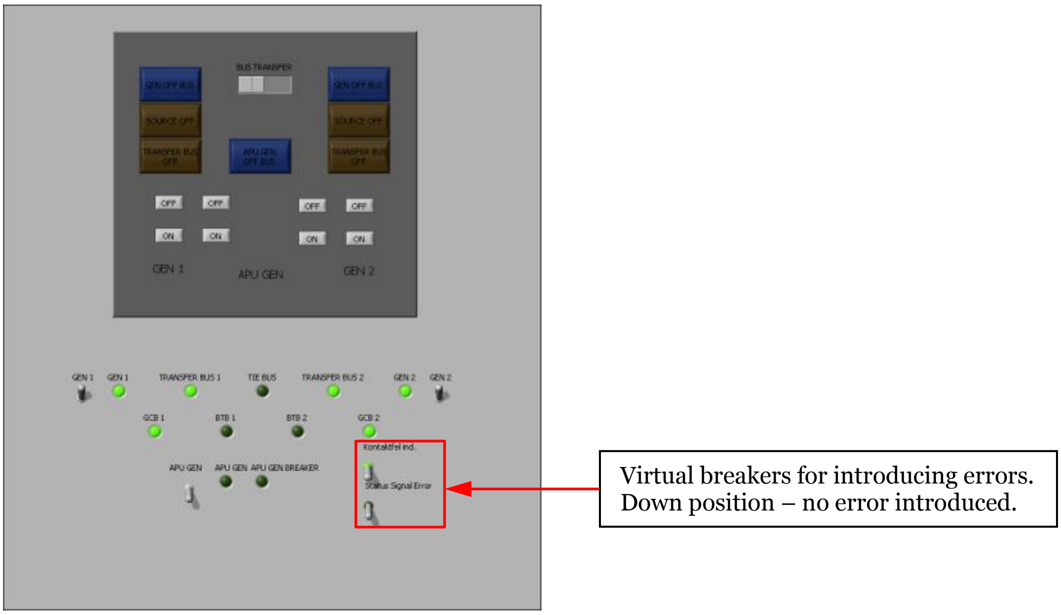


Fig. 19. GUI for the program for simulation of the electrical system of the Boeing 737-800

1.17 Organizational and management information

Ryanair has an Irish AOC[33] and has its headquarters in Dublin. Ryanair operates services to three Swedish airports. Ryanair has one operational Base located at Stockholm Skavsta Airport.-At the time of the incident, Priority Air Maintenance was responsible for the inspection and maintenance of those of Ryanair's aircraft operating from Skavsta

1.18 Additional information

1.18.1 Gender equality issues

Not applicable.

1.18.2 Environmental aspects

Not applicable.

1.18.3 Procedure for reconnecting IDG

As stated in section 1.1 the crew action was in accordance with the QRH as applicable. However it can be worth noting that during an interview with a former aircraft captain who had flown on this type of aircraft among others, it emerged that with other operators, and above all among older pilots with experience of aircraft with relay logic, it is common practice to put the non-locking switch on panel 5-4 for connecting IDG in the “OFF” position first and then in the “ON” position. This was done in order to force the GCB to open and then after to attempt to reconnect. On the Boeing 777, for example, which has a similarly structured electrical system, it is this very procedure that is prescribed when reconnecting IDG in QRH.

[33] AOC: Air Operators Certificate

2. ANALYSIS

2.1 The flight

Both pilots had a great deal of experience of the type B737 and followed the check-lists as far as was practically possible. It is very likely that they would not have been able to rectify the problems by following QRH for Transfer Bus Off.

The choice to return to Skavsta was probably reinforced by the "Battery discharge" light being illuminated. When the screens no longer functioned on the first officer's side and with a large number of systems not functioning, as well as other warning lights, it was easy to suspect that the battery was being drained of power.

The air traffic controller who gave the aircraft clearance to the NDB PEO instead of immediately providing vectoring was probably not fully aware at the time of the problems with the instrumentation. It is very common for air traffic control to initially give clearance to a beacon that is known in the area and then towards the end give vectors for an approach. It would however be appropriate to discuss within the ATS[34] concerned what is meant by a request for vectoring.

It was unfortunate from an investigatory viewpoint that FDR were not secured. However the fact that the CVR was set operational after the incident showed to be of less importance. This because the CVR has its power supply from X-bus 2 and therefor there would not have been any recordings of the incident. It is normal when a serious incident is reported that the report takes the same path as for a lesser incident in accordance with the EU Directive on occurrence reporting in civil aviation, 2003/42. Since 2010, however, Regulation no. 996/2010 applies, which prescribes, in addition to the occurrence reporting directive, that accidents and serious incidents shall be reported immediately to the accident investigation authority of the State of Occurrence. If SHK had been informed of the incident earlier, there might possibly have been time to prevent the FDR from being overwritten. However this is likely due to that the fault was believed cleared by Ryanair.

2.2 The incident

At around 110 kts, the "source off" light for AC system 2 illuminated. This meant that GCU2 sensed that one of the monitored variables for quality of the current from IDG2 was outside of the limit values. GCU2 then sent a signal to GCB2 to tell it to open. BPCU then received the signal that GCB2 was open at the same time as BTB1 and BTB2 were open, which resulted in BPCU sending a signal to GCU1 and GCU2 that both BTB breakers should close. GCU1 and GCU2 carried out this request after all necessary conditions were met, and a control signal that both BTB breakers should close was sent. The system functioned as intended and was at this point powered only by IDG1.

The two pilots' descriptions of the order in which things took place differ on one point. This has however proved to be unimportant. The following course of events is a total appraisal of the pilots descriptions: Upon "Source off", the chosen power source, in this case IDG2, was according to QRH to be reconnected to the system, which was achieved by pushing the non-locking switch on panel 5-4 to the "on" position. On this occasion, X-bus2 and its subsystem lost power supply, which resulted in the "Transfer Bus Off" light for system 2 and the warning lights for the unpowered subsystems il-

[34] ATS: Air Traffic Service

luminating. The pilots continued with QRH where the APU was started up and an attempt was made to connect it to the system, though without success.

At this point there is a difference in the pilots' accounts; one stated that X-bus2 lost power supply when they attempted to connect IDG2 while the other pilot stated that this occurred only when they attempted to connect the APU to the system. The latter case can be explained by the quality of the current still not being within its limit values during the attempt to connect IDG2.

The system was at this point unpowered at X-bus2 and its subsystem, which is explained by both BTB2 and GCB2 being open – see Figure 20.

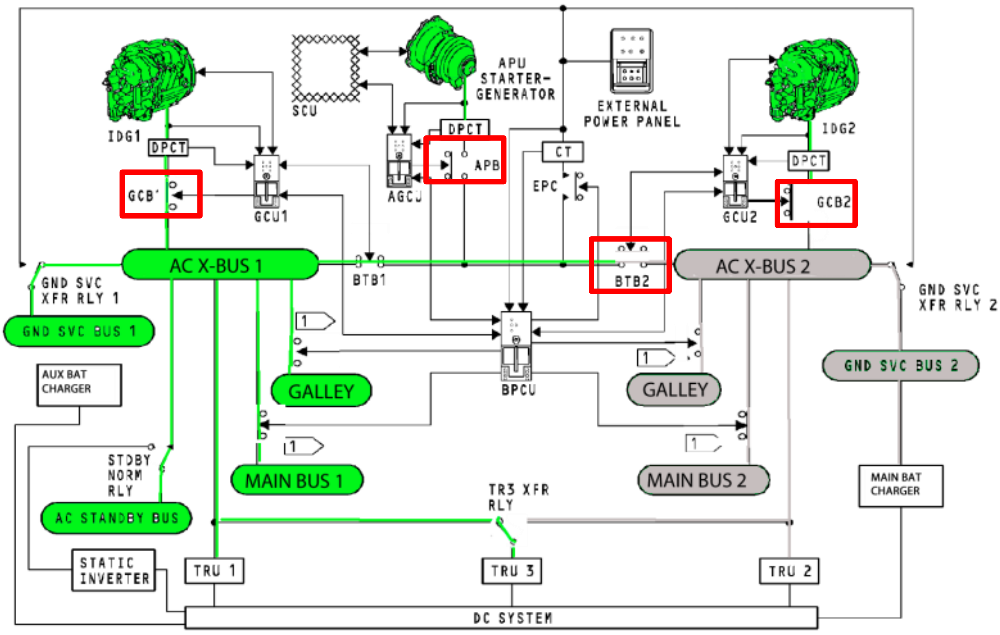


Fig. 20. Electrical system with open BTB2 and GCB2 or APB, which was the situation in the incident.

It can be established that GCB2 did not close and connect IDG2. When X-bus2 lost electrical power, BTB1 and BTB2 should have closed.

2.3 Analysis of the electrical system

BITE on GCU2 indicated that BTB2 had not moved to its commanded position. Possible causes for this may have been:

1) Fault in the BTB2 breaker. The fault is according to FIM rectified by replacing BTB with a new unit.
2) Fault in GCU2. The fault is according to FIM rectified by replacing GCU with a new unit.

BTB2 was replaced with a new unit six days before the incident. BTB2 and GCU2 were replaced with new units immediately after the incident. None of the measures solved the problems.

It was also not possible to connect APU as a power source, despite the quality of the current from APU being within the limit values.

According to SHK, it is likely that when GCU2 has received an erroneous signal that GCB2 is closed, the system and its logic – see 1.6.3 – will via GCU2 prevent BTB2 from closing. This could be due to either a fault in GCU2 or incorrect status information from GCB2.

BTB2, GCU2, BPCU and a number of other components were replaced during fault isolation, while GCB2 was left unmoved. It is probable that the fault originated from this very unit. SHK has attempted several times throughout the investigation, without success, to gain access to the GCB2 that was mounted during the incident and other breakers with the same part number for examination.

If GCB2 is open but its status signal to GCU2 has the value “not closed”, the system responds with the same symptoms as in the incident. This is confirmed by the analysis and the program run by FOI, and is supported by the incident, in which the connection of the auxiliary contact to GCB was loose.

Simulation of the incident with erroneous status signals from GCB2 is shown by means of FOI's program in Figures 21 – 25. The green “lights” indicate that 115 V alternating current is flowing through the unit. It is also shown here that APU too will not be able to be connected, and the symptoms are the same. It is also worth noting that this latent fault manifests when there is an initial “trigger-fault”.

One possible measure in order to get BTB2 to show the correct status signal could have been to cycle it, that is, to force it into an open position, which would mean that the buses would be allowed to interconnect or that APU would be allowed to supply power to X-bus2. It would also be possible to issue a close command in order to try connecting IDG2. This could be achieved by pushing the non-locking switch on panel 5-4 for connecting IDG first to the “OFF” position and then to the “ON” position. Such a measure can be described as normal in the event of a relay fault.

The certification criteria of the breaker units do not specify the demands of functionality of the auxiliary contacts, however this is part of the system design certification. The fault in this incident was most probably not covered in the fault tree analysis and thus the correct failure assessment could not be made. The guidance text in FAR-part 25 and JAR-25 shows that this incident can be classified as on the borderline of a major failure condition.

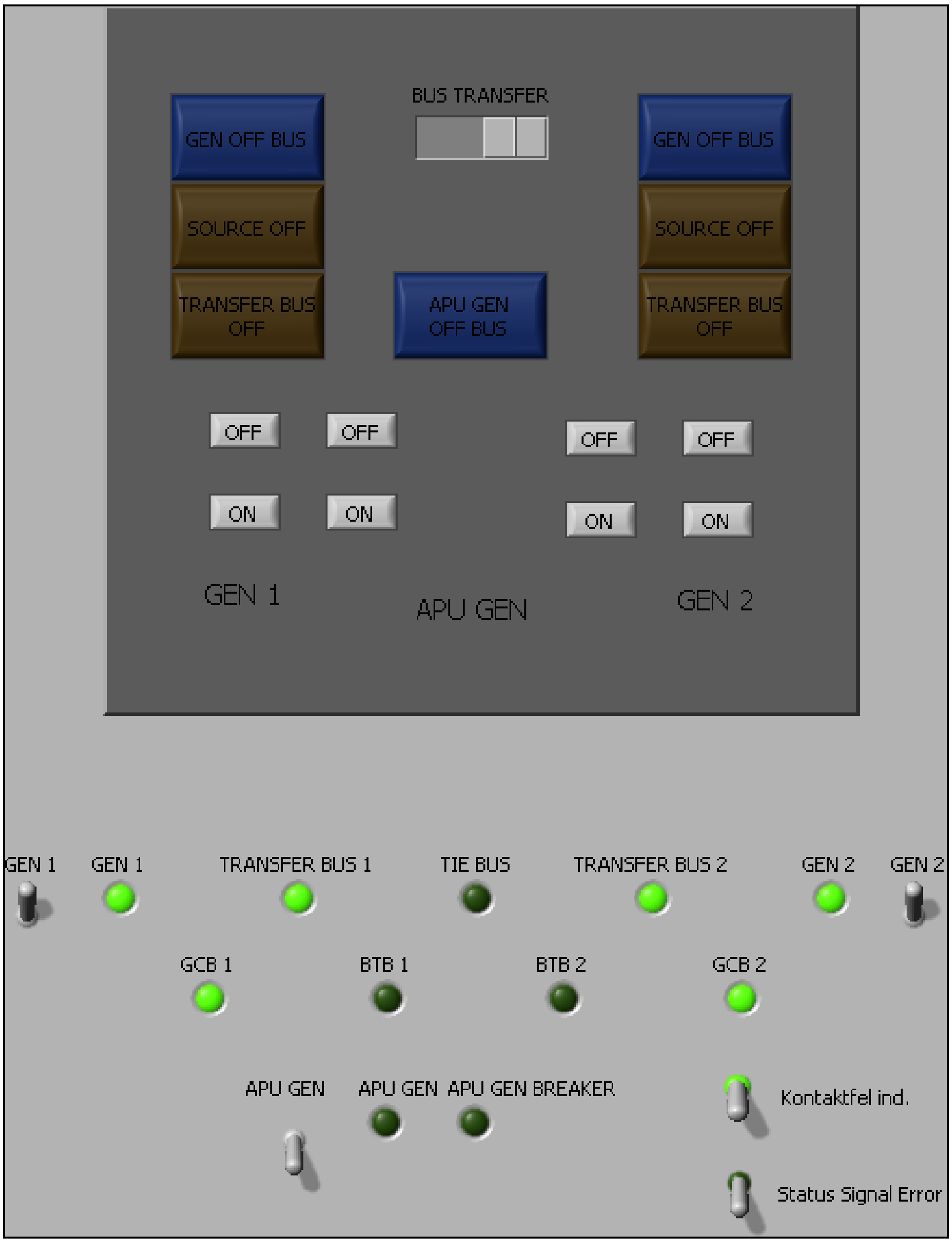


Fig. 21. GUI showing normal operating conditions.

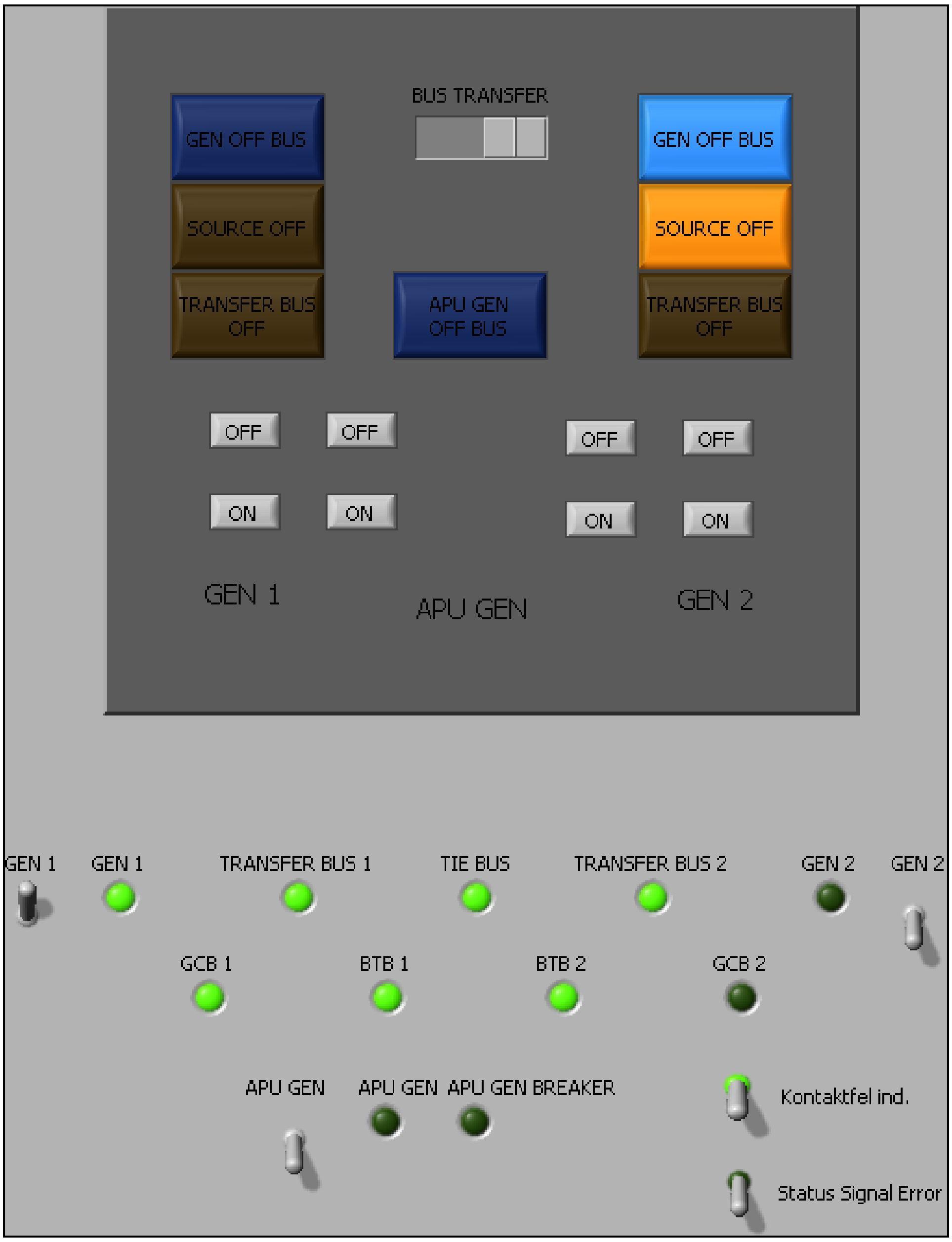


Fig. 22. GUI showing operating conditions when generator 2 has been disconnected from the system

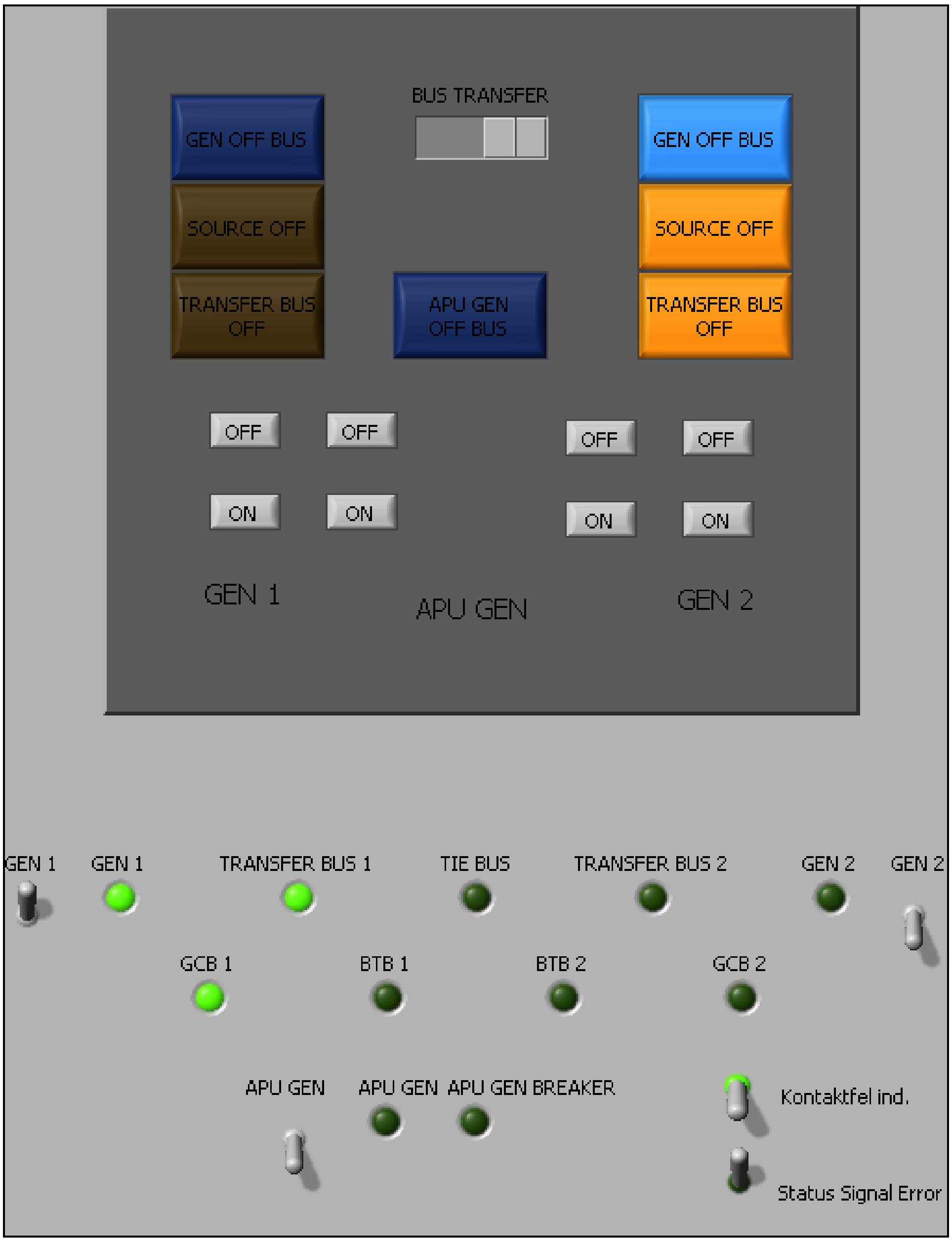


Fig. 23. GUI showing operating conditions when generator 2 has been disconnected from the system and a status signal fault has been introduced to BCB2.

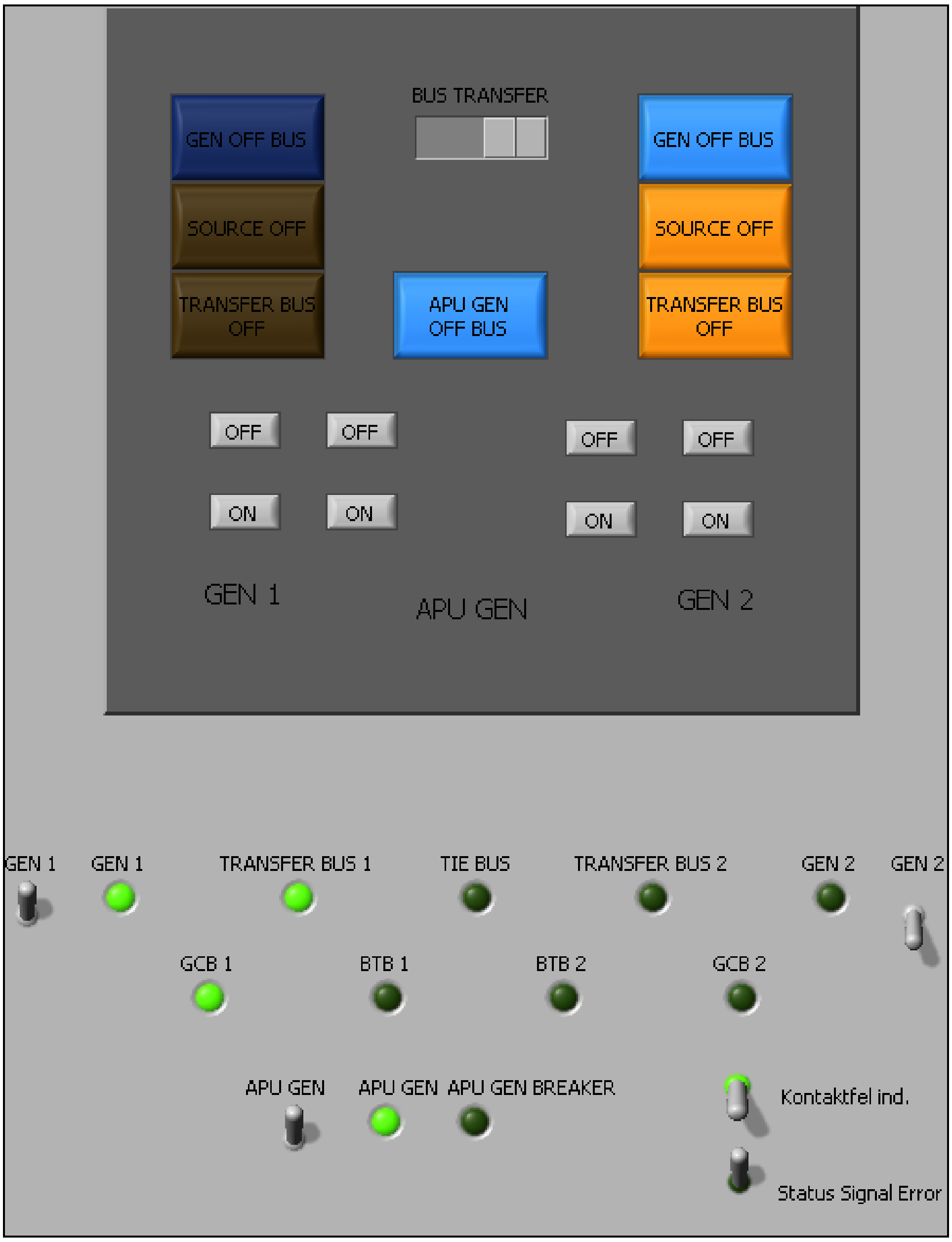


Fig. 24. GUI showing operating conditions when generator2 has been disconnected from supplying current to the system, APU has been started and a status signal fault has been introduced to GCB2.

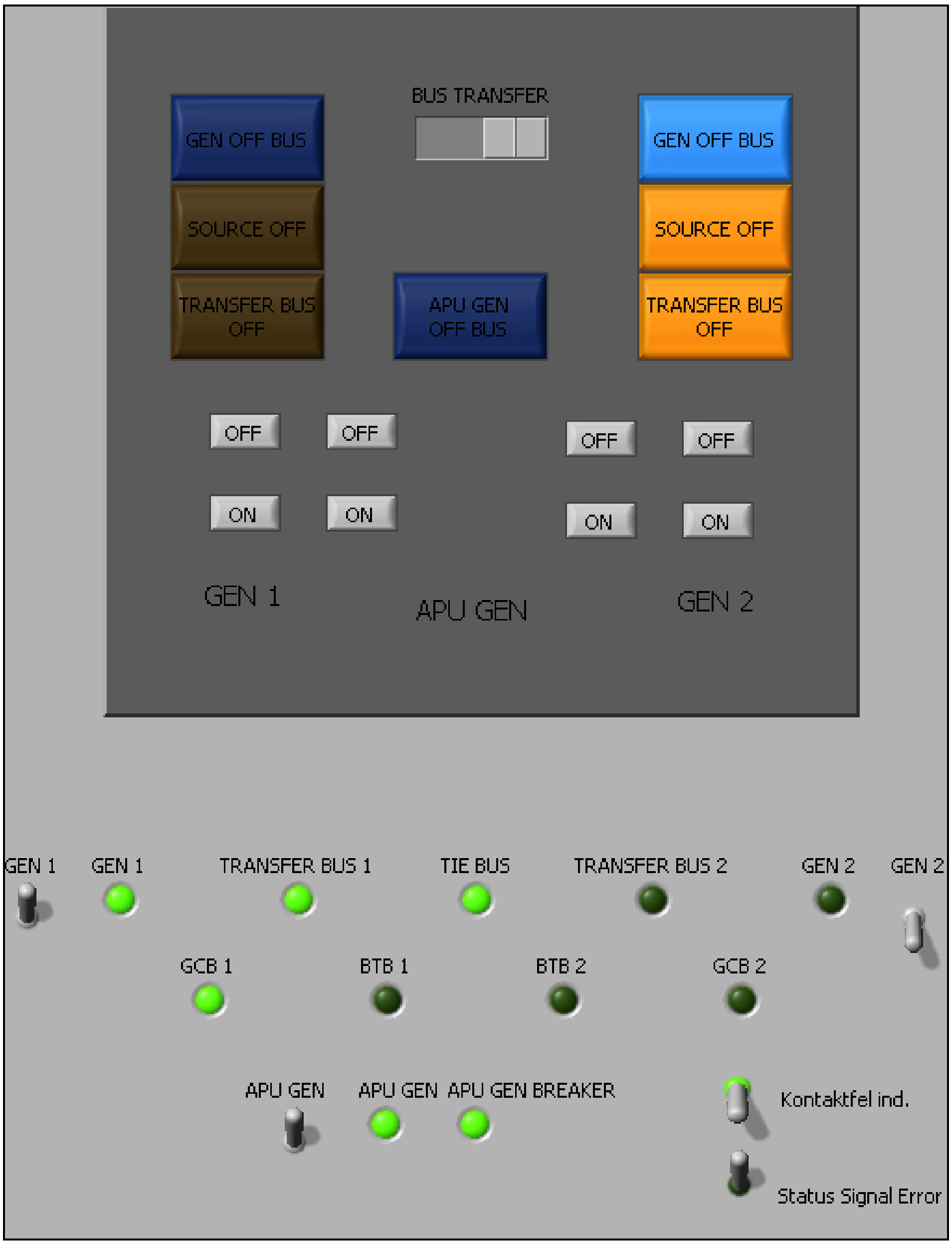


Fig. 25. GUI showing operating conditions when generator2 has been disconnected from supplying current to the system, APU has been started and connected at the same time as a status signal fault has been introduced to GCB2.

The fact that the warning light “Bat Discharge” illuminated, to be extinguished later without any other noticeable change in the system, can be explained by the battery charger probably being in charging mode when it lost its AC power supply. In that case, this resulted in the battery voltage being higher than the nominal voltage in the DC system, which caused current to flow from the battery until the voltage potential was balanced. This explanation is confirmed by various sources, including representatives from Boeing. In addition, the battery began supplying current to users on, e.g., the “Hot Battery Bus”, “Switched Hot Battery Bus” and to the control unit AGCU.

It can be concluded that an intermittent short circuit between the phases in the feeder lines from IDG2 resulted in GCU2 disconnecting IDG2 as a power source. When an attempt was made to reconnect IDG2 as a power source, the interconnection between the X-buses was broken and X-bus2 lost electrical power. This in turn was probably caused by the response of the GCU and BPCU logic to an erroneous status signal from GCB2 concerning its position.

3 CONCLUSIONS

3.1 Findings

a) The pilots were qualified to perform the flight.
b) The aircraft had a valid Certificate of Airworthiness.
c) The two X-buses were not interconnected.
d) Problems with the power supply to X-bus2 were present both before and after the incident.
e) Following extensive fault isolation, the primary cause of the power supply problem could be identified as a short circuit between the phases in the feeder lines from IDG2.
f) The logic of GCU and BPCU makes it possible for an erroneous status signal from GCB to place X-bus2 in an unpowered state.
g) The breakers GCB, BTB, EPC and APB have no inspection interval.
h) The prescribed procedure in QRH for reconnecting IDG differs from the prescribed procedure in QRH for aircraft with similar electrical systems and from the understanding of the procedure by pilots on the type.

3.2 Causes

The incident was caused by the system logic for the Generator Control Unit (GCU) and the Bus Power Control Unit (BPCU) enabling erroneous status signals from the breaker (Generator Control Breaker, GCB) to lead to a transfer bus losing power.

4. RECOMMENDATIONS

<u>The FAA/EASA are recommended to:</u>

- Ensure that Boeing introduces measures so that the logic in the electrical system prevents an X-bus from losing power as a result of an erroneous status signal from GCB. (RL 2012:20 R1)

- Ensure that Boeing investigates whether a revision of the procedure in QRH for reconnecting IDG can rectify erroneous status signals from GCB. (RL 2012:20 R2)

Enclosure 1

FOI MEMO

Projekt/Project		Sidnr/Page no
Simulering och analys av flygplans generatorbrytare		1 (1)
Uppdragsnummer/Project no	Kund/Customer	
E28246	Statens haverikommission	
FoT område		
Handläggare/Our reference	Datum/Date	Memo nummer/number
Per Davidsson		FOI Memo

Simulering av styrkretsar för den centrala elfördelningen på flygplantypen Boeing 737-800

Föreliggande program har utvecklats i det grafiska programmeringsspråket "LabView" från National Instruments; versionen är "LabView 2010". Kodgenereringen är helt grafisk och påminner starkt om ett ordinärt kretsschema med helt obetydliga skillnader i form av att speciella ikoner som ersätter vedertagna schemasymboler samt det faktum att tidsutvecklingen måste kunna klargöras. Ett LabViewprogram består alltid av två fönster på datorskärmen, dels den egentliga koden i form av ett diagram dels en frontpanel där virtuella styrorgan och visande instrument kan placeras ut för att bilda en "instrumentbräda". Varje panelorgan har en korresponderande terminal i diagramfönstret till viken kan kopplas ledningar för att hämta eller lämna data.

Det kompletta diagrammet körs en gång vid programstart, upprepad körning av delar (programslingor) åstadkommes genom att omge önskad del av programkoden med någon av ett antal typer av ramar som ger en funktionalitet som svarar mot konventionella språks "FOR" eller "WHILE"- -slingor. Utdata från en genomkörning kan göras tillgängliga för nästa varv genom en särskild skiftregisterkonstruktion.

Koden består av två distinkta delar, en del modellerar tillståndet i flygplanets huvudkretsar utifrån aktuellt kopplingsläge och generatorernas drifttillstånd (till eller från). På frontpanelen har man här möjlighet att direkt via styrenheter ställa in huruvida var och en av huvudgeneratorerna respektive reservgeneratorn (APU) lämnar spänning eller ej. Uppstartsprocedurer för dessa ligger utanför här aktuellt uppdrag och har därför ej simulerats i detalj. På panelen finns dessutom "signallampor" som visar de simulerade brytarnas lägen (GCB1, GCB2, BTB1, BTB2 och APB) liksom spänningssättningstillståndet på generatorledningar och de olika samlingsskensegmenten (transfer bus 1, transfer bus 2 och tie bus).

I övrigt består koden av en i möjligaste mån exakt avskrift av de principscheman för styrkretsar och styrenheter (GCU1, CGU2, AGCU, och AGCU) som ingår i översänd dokumentation. Till denna del av schemat har fogats en del av frontpanelen vilken utgör en avbild av flygplanets styrpanel för motsvarande ändamål. Denna styrpanel tar alltså upp manöverdon för generatorbrytare (GCB) Reservgeneratorbrytare (APB), omkopplare för automatisk respektive manuell växling av skenskiljebrytare (BTB) utifrån aktuellt kopplingstillstånd samt de signallampor som ingår.

I simuleringsprogramet har följande tekniska skillnader från faktiskt utförande införts:

- De i vekligheten använda återfjädrande vippströmbrytarna för manövrering av generatorbrytarna har ersatts med "till" och "från" –knappar då lämplig vippbrytarsymbol saknad i LabView, detta påverkar ej funktionen.
- Reläfunktioner har genomgående ersatts med logiska funktioner med motsvarande verkan.
- Effektbrytarna (GCB, BTB och APB) har simulerats av logiska tillstånd med minnesfunktion; en tillorder gör brytartillståndet sant, en frånorder återtar brytartillståndet till falskt.
- Avläsning av brytarlägen vilka i verkligheten sker via hjälpkontakter har grupperats i enlighet med de verkliga kontakternas funktioner. På några platser har införts extra simulering av misstänkta kontaktfel för att möjliggöra undersökning av sådanas logiska följdverkan. Styrning av simulerade kontaktfel sker från frontpanelen och kan således vid önskan kopplas in eller ur.
- Ett antal styringångar som härrör från funktioner utanför detta arbete (extern kraftinmatning, brandlarm mm.) har matats från programmässiga konstanter för att göra koden så fullständig som möjligt.

Vi har förstått att dokumentationens beskrivning av styrenheternas inre endast är principiell och inte återspeglar verkligt utförande. Som en följd av detta kan simuleringen inte ge svar på verkan av funktioner hos dessa som ej överensstämmer med principschemorna.

Under arbetets gång har ett par egenomligheter upptäckts vilka har justerats för att funktion i enlighet med beskrivning överhuvudtaget skulle kunna uppnås:

- I huvudgeneratorbrytarnas (GCB1, GCB2) tillslagskretsar är beskrivet en orimlig logik vilken justerats (det förefaller som om "och" respektive "eller" – grindar blivit förväxlade).
- I styrvilkoren för skensektioneringsbrytarna (BTB1, BTB2) finns en omotiverad skillnad mellan de båda sidorna, Vi har efter analys antagit att styrningen av BTB1 är korrekt återgiven, funktionen för BTB2 har därför korrigerats till likhet.

Sändlista/Distribution: Statens haverikommission, Kristoffer Danel