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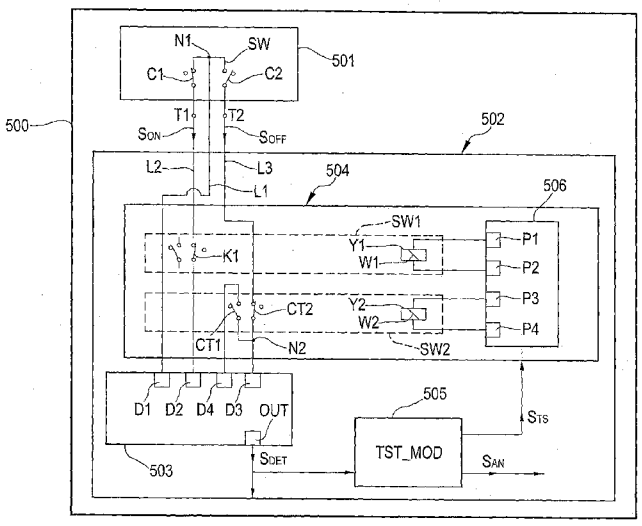
(54) Title: GAS TURBINE CONTROL APPARATUS AND CONTROL SYSTEM

FIG.2



(57) Abstract: It is described a gas turbine control apparatus (502) comprising: first and second terminals (T1, T2), connectable to a flame sensor device (501) associable with a gas turbine (200), and structured to selectively provide a flame presence detection signal (S_{ON}) in a flame configuration and a flame absence detection signal (S_{OFF}) in a flame absence configuration; a status decision module (503) configured to detect a switching from the flame configuration to the flame absence configuration and produce an extinguished flame signal (S_{DET}); and a switch module (504) operable by a test signal (S_{TS}) to simulate a switching from the flame configuration to the flame absence configuration. The gas turbine control apparatus further incudes an anomaly sensing module (505) configured to generate said test signal (S_{TS}) and sense the extinguished flame signal (S_{DET}) to detect anomalies of the status decision module (503).

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GAS TURBINE CONTROL APPARATUS AND CONTROL SYSTEM

The present invention relates to control systems of gas turbines and, particularly, refers to the apparatuses detecting the presence or the absence of the flame in turbine combustion chambers.

Gas turbines can be used in electrical power generation plants. The gas turbine is provided with a combustion chamber (or flame holder) wherein air is fed by a compression system. A flame obtained by a combustor heats this air at constant pressure and, after heating, air passes from the combustion chamber to the turbine.

In order to avoid dangerous situations, the presence of the flame in the combustion chamber is monitored by one or more flame sensors. The flame sensors are connected to control circuits which detect the flame status from electrical signals provided by the sensors and possibly trigger safety procedures. If the flame absence is ascertained, a block of the turbine operation is normally performed.

Particularly, in electrical power generation plants the so called common mode failure can occur: a single initial fault can cause failures in multiple parts of a system.

The Applicant has observed that the known control circuits associated with the flame sensors can show

malfunctions or anomaly behaviours that could cause dangerous situations or reduce the availability of the gas turbine.

The Applicant has noticed that improvements in the reliability of the control apparatuses associated with the flame sensors in gas turbine could reduce risk and disruptions, such as an example, the ones related to the common mode failure.

According to an embodiment of the invention, a gas turbine control apparatus is provided as depicted by the appended claim 1. Further embodiments of the apparatus are described by the dependent claims 2-11.

In accordance with another embodiment of the invention a gas turbine control system is defined by the independent claim 12; a particular embodiment of the gas turbine control system is described by the dependent claim 13.

Further characteristics and advantages will be more apparent from the following description of preferred embodiment and of its alternatives given as a way of an example with reference to the enclosed drawings in which:

FIG. 1 schematically shows an electrical power generation plant comprising a gas turbine control and

monitoring system, a gas turbine and an electrical generator;

FIG. 2 shows a gas turbine control system implementable in said electrical power generation plant, in a normal operation mode;

FIG. 3 shows the gas turbine control system, in a test operation mode.

FIG. 1 shows schematically an example of an electrical power generation plant 1000 comprising a gas turbine control and monitoring system 100, a gas turbine 200 (GT) and an electrical generator 300 (G).

Particularly, the control and monitoring system 100 can be structured to perform automation, control and protection of the gas turbine 200. The control and monitoring system 100 shown in FIG. 1 comprises at least one control unit 400 including: a first power supply module 401A, a first processing and control apparatus 402A (CPU), a first communication module 403A (COM) and one or more input/output electronic modules 404 (I/O).

The first supply module 401A is, as an example, a AC/DC converter connected to an input AC power supply line 405 (e.g. at 230 V) and to an output DC supply bus 406 (e.g. at 24 V).

The first processing and control apparatus 402A includes, as an example, a control and processing unit,

and is electrically fed by the output DC supply bus 406. Moreover, the first processing and control apparatus 402A is connected to the input/output electronic modules 404 for exchanging data or control signals via an input/output communication bus 407. The input/output electronic modules 404 can be electronic cards connected to sensor devices associated with the gas turbine 200 or to the electrical power generator 300.

The first communication module 403A (COM) is electrically fed by the output DC supply bus 406 and is configured to allow communications, via a communication bus 408, between the first processing and control apparatus 402A and other processing and control apparatuses (not shown) and/or at least one Human Machine interfaces 409, such as computer and display devices.

It is observed that the control and monitoring system 100 shown in FIG.1 can be designed with redundancy so duplicating critical components to increase reliability. Accordingly, the control unit 400 can also include: a second power supply module 401B, a second processing and control apparatus 402B and a second communication module 403B.

The gas turbine 200, which can be a known apparatus, is provided with a combustion chamber or flame holder wherein air is fed by a compression system. A flame obtained by a combustor then heats this air at constant pressure. After heating, air passes from the combustion chamber to the turbine.

The control unit 400 is configured to implement a monitoring of the flame presence in the combustion chamber of the gas turbine 200 together with a safety policy in case that a flame absence is detected.

FIG. 2 schematically shows a gas turbine control system 500 implementable in the electrical power generation plant 1000 and configured to monitor and manage the conditions of presence and absence of the flame in the combustion chamber of the gas turbine 200.

The gas turbine control system 500 includes a flame sensor device 501 and a gas turbine control apparatus 502 comprising: a status decision module 503, a switch module 504 and an anomaly sensing module 505 (TST-MOD).

The flame sensor device 501 can be a device known to the skilled in the art and comprising, as an example, a sensing element (not shown) adapted to detect the frequencies of the radiation emitted by the flame and a corresponding processing module (not shown) configured to recognize the presence or the absence of

the flame in the combustion chamber from signals provided by the sensing element. Particularly, the flame sensor device 501 is configured to selectively assume a flame configuration and a flame absence configuration.

In the flame configuration, the flame sensor device 501 is structured to generate a flame presence signal S_{ON} at a first terminal T1. In the flame absence configuration, the flame sensor device 501 is structured to generate a flame absence signal S_{OFF} on a second terminal T2.

With reference to the example of FIG. 2, the flame sensor device 501 includes a sensor switch SW provided with a supply node N1, a first movable contact C1 and a second movable contact C2.

The supply node N1 is connected by a first conductive line L1 to a first detection terminal D1 of the status decision module 503, which provides an electrical voltage (e.g. an electrical voltage at 24 V). Moreover, the first movable contact C1 allows connecting/disconnecting the supply node N1 to/from the first terminal T1. The second movable contact C2 allows connecting/disconnecting the supply node N1 to/from the second terminal T2. Particularly, the sensor switch SW can be a relay with two movable contacts in which one

contact is normally closed and the other contact is normally open.

The first terminal T1 of the flame sensor device 501 is connectable by a second conductive line L2 to a second detection terminal D2 of the status decision module 503. The second terminal T2 of the flame sensor device 501 is connectable by a third conductive line L3 to a third detection terminal D3 of the status decision module 503.

The status decision module 503 is configured to detect, by selectively receiving the flame presence signal S_{ON} and the flame absence signal S_{OFF}, a switching of the flame sensor device 501 from the flame configuration to the flame absence configuration and produce an extinguished flame signal S_{DET} on a first output terminal OU1.

Moreover, the status decision module 503 is provided with a fourth detection terminal D4 connectable to the third line L3, at which an electrical supply voltage is applied (e.g. 24 V) by the status decision module 503. According to the described example, the status decision module 503 is configured to recognize the flame configuration when the flame presence signal S_{ON} (i.e. an electrical current) is flowing into a first electrical circuit comprising the

first line L1 (the first movable contact C1 is closed), the first detection terminal D1, the second detection terminal D2 and the second line L2.

In that situation, there is no electrical current circulation into a second electrical circuit comprising the third conductive line L3 (the second movable contact C2 is open) and the third and fourth detection terminals D3 and D4.

The status decision module 503 can be an electronic card including hardware and/or software modules, such as a printed circuit board carrying an integrated circuit. Particularly, the status decision module 503 can be one of the input/output electronic modules 404 shown in FIG. 1.

The switch module 504 is connected between the flame sensor device 501 and the status decision module 503 and is operable by a test signal S_{TS} to simulate a switching of the flame sensor device 501 from the flame configuration to the flame absence configuration.

Particularly, the switch module 504 shows input terminals connected to the first terminal T1, the supply node N1 and the second terminal T2 and output terminals connected to the first D1, the second D2, the third D3 and the fourth D4 detection terminals.

According to a particular example, the switch module 502 includes a first switch device SW1 and a second switch device SW2 which share a drive module 506. Particularly, the first switch device SW1 can be an electromagnetic relay having a first electromagnet including a first yoke Y1, around which a first coil W1 is wound, and at least one respective movable contact K1.

The first coil W1 shows two respective terminals each connected to a first drive terminal P1 and a second drive terminal P2 of the drive module 506. The movable contact K1 of the first switch device SW1 is connected along the second conductive line L2 and is configured to connect/disconnect the first terminal T1 of the flame sensor device 501 to/from the second detection terminal D2 of the status decision module 503.

In accordance with the specific example shown in FIG. 2, the first switch device SW1 is an electromagnetic relay with two movable contacts for which only the movable contact K1 is employed.

Moreover, in accordance with the example described, the second switch device SW2 can be an electromagnetic relay having a second electromagnet provided with a second yoke Y2, around which a second

coil W2 is wound, a respective first movable contact CT1 and a respective second movable contact CT2.

The second coil W2 shows two respective terminals each connected to a third drive terminal P3 and a fourth drive terminal P4 of the drive module 506.

The first movable contact CT1 of the second switch SW2 is connected between the fourth detection terminal D4 of the status decision module 503 and a switching node N2 connected to the second movable contact CT2 of the second switch SW2 and the third detection terminal D3. The second movable contact CT2 of the second switch SW2 is connected along the third conductive line L3 and is configured to connect/disconnect the second terminal T2 to the third detection terminal D3 of the status decision module 503.

It is observed that the first switch SW1 and second switch SW2 can be electromagnetic relays having one of the movable contact normally closed and the other movable contact normally open.

The anomaly sensing module 505 is configured to generate the test signal S_{TS}, to be provided to the switch module 504. Particularly, the anomaly sensing module 505 is configured to manage test operations in order to evaluate the correct or anomalous behaviour of the status decision module 503.

As will be discussed later, the anomaly sensing module 505 periodically activates, by means of the test signal S_{TS}, the switch module 504 to simulate a switching of the flame sensor 501 from the flame configuration to the flame absence configuration and senses the extinguished flame signal S_{DET} to verify if the configuration switching has been actually detected by the status decision module 503. The anomaly sensing module 505 is structured to generate an anomaly signal S_{AN} indicated the correct or anomalous behaviour of the status decision module 503.

The anomaly sensing module 505 includes hardware and/or software modules and can comprise a control and processing unit, such as a microprocessor, executing a specific software. The functionalities of the anomaly sensing module 505 can be also implemented by a finite-state machine. According to an example, the anomaly sensing module 505 is implemented into the first processing and control apparatus 402A of FIG. 1.

With reference to the operation, it has to be observed that the gas turbine control system 500 can operate in a normal mode and in a test mode.

In the normal operation mode, the switch module 504 is not activated and (as indicated in FIG. 2) the movable contact K1 of the first switch device SW1 is

closed, the first movable contact CT1 of the second switch device SW2 is opened and the second movable contact CT2 of the second switch device SW2 is closed.

In the above situation and in the flame configuration of the flame sensor device 501 (as represented in FIG. 2), the first contact C1 is closed and the second contact C2 is opened. The electrical current, corresponding to the flame presence signal S_{ON}, flows in the first conductive line L1 and in the second conductive line L2 and is sensed by the status decision module 503, at the first and second detection terminals D1 and D2.

In the third conductive line L3 there is no electrical current circulation since the the second contact C2 is opened. The extinguished flame signal S_{DET} produced by the status decision module 503 can carry a first digital value indicating flame presence.

With reference again to the normal mode, if the flame sensor device 501 performs a switching towards the flame absence configuration, the corresponding first movable contact C1 is opened, while the second movable contact C2 is closed (contrary to the situation represent in FIG.1). In this condition, the electrical current flowing into the first conductive line L1 and in the second conductive line L2 is interrupted and an

electrical current (corresponding to the flame absence signal S_{OFF}) start circulate into the third conductive line L3. It is observed that the fourth detection terminal D4 is connected to the first detection terminal D1 by an electrical connection included into the status decision module 503.

This electrical current (flame absence signal S_{OFF}) is sensed by the status decision module 503 at the third and fourth detection terminals D3 and D4 which generates, if it operates correctly, the extinguished flame signal S_{DET} carrying a second digital value representing the detected flame absence condition.

It is observed that when the flame absence condition is detected safety procedures can be implemented to avoid risks in the gas turbine 200. Particularly, the gas turbine control and monitoring system 100 may include two or more gas turbine control system 500 analogous to the one above described with reference to FIG. 2. According to this example, if two extinguished flame signals S_{DET} indicating the flame absence condition are generated by the two gas turbine control system 500, a block of the gas turbine 200 can be carried out.

Reference is now made to the test operation mode. Initially, the gas turbine control system 500 is in the

condition depicted in FIG. 2: the flame sensor device 501 is in the flame configuration (the first contact C1 is closed and flame presence signal S_{ON} is generated) and the switch module 504 is deactivated.

To execute the periodic test, the anomaly sensing module 505 sends the test signal S_{TS} to the drive module 506 of switch module 504 which supplies electrical currents to the first coil W1 of the first switch device SW1 and the second coil W2 of the second switch device SW2.

In this condition (depicted in FIG.3), the movable contact K1 of the first switch device SW1 is opened, the first movable contact CT1 of the second switch device SW2 is closed and the second movable contact CT2 of the second switch device SW2 is opened.

Particularly, the first electrical current flowing into the first and second conductive lines L1 and L2 is interrupted and a simulation electrical current start flowing from the fourth detection terminal D4 (which provides a supply electrical voltage), through the first movable contact CT1 of the second switch device SW2 and the switching node N2, towards the third detection terminal D3: in this particular manner, a simulation of the flame absence configuration is performed.

If the status decision module 503 detects the switching from the initial flame presence configuration to the simulated flame absence configuration and generates a corresponding extinguished flame signal S_{DET}, the anomaly sensing module 505 detects the correct behaviour of the status decision module 503 and provides a corresponding anomaly signal S_{AN}.

On the contrary, if the status decision module 503 does not detect the switching from the initial flame presence configuration to the simulated flame absence configuration, the same extinguished flame signal S_{DET}, indicating flame presence as previously generated, is provided. In this case, the anomaly sensing module 505 senses the digital value carried by the extinguished flame signal S_{DET} and detects an anomaly behaviour of the status decision module 503, so generating a corresponding anomaly signal S_{AN}.

The anomaly signal S_{AN} can trigger safety procedures including, as an example, the replacement of the defective status decision module 503. It is noticed that the anomalous behavior of the status decision module 503 can be due to a non-detectable failure in its input cards.

The gas turbine control system 500 shows the advantage of guarantee a high level of availability of

the electrical power generation plant 1000, without any significant circuit complexity increasing.

The test on the status decision module 503 performed by the switch module 502 and by the anomaly sensing module 505 allows to fulfill the law requirements, such as the ones ruled by European Machinery Directive 2006/42/EC. It is observed that the European Machinery Directive 2006/42/EC refers to the standard ISO 13849-1: this standard deals with the design and integration of Safety-Related Parts of Control Systems (SRP/CS) independently from the technology used.

Moreover, the described control apparatus allows to increase the performance level (PL) defined by the standard ISO 13849-1. Particularly, it is noted that the implemented solution can minimize or cancel the common mode failure that could generate a dangerous failure in the electrical power generation plant 1000.

Claims

1. A gas turbine control apparatus (502) comprising:

first and second terminals (T1, T2), connectable to a flame sensor device (501) associable with a gas turbine (200), and structured to selectively provide a flame presence detection signal (S_{ON}) in a flame configuration and a flame absence detection signal (S_{OFF}) in a flame absence configuration;

a status decision module (503) configured to detect, from the flame presence (S_{ON}) and the flame absence detection signals (S_{OFF}), a switching from the flame configuration to the flame absence configuration and produce an extinguished flame signal (S_{DET});

a switch module (504) connected between said first and second terminals (T1, T2) and the status decision module (503) and operable by a test signal (S_{TS}) to simulate a switching from the flame configuration to the flame absence configuration;

an anomaly sensing module (505) configured to generate said test signal (S_{TS}) and sense the extinguished flame signal (S_{DET}) to detect anomalies of the status decision module (503).

2. The control apparatus (502) of claim 1, wherein:

the status decision module (503) comprises a first detection terminal (D2) structured to receive the flame

presence detection signal (S_{ON}) and a second detection terminal (D3) structured to receive the flame absence detection signal (S_{OFF});

the switch module (502) is configured to interrupt, in the flame configuration, the flame presence detection signal (S_{ON}) and connect the second detection terminal (D3) to a first supply terminal (D4) of the status decision module (503) to simulate the flame absence configuration.

3. The control apparatus (502) of claim 2, wherein:

the switch module (504) comprises movable contacts (K1, CT1) operable by said test signal (S_{TS}) to disconnect the first terminal (T1) from the first detection terminal (D2) and connect the second detection terminal (D3) to the to the first supply terminal (D4).

4. The control apparatus (502) of claim 3, wherein the switch module (504) comprises a drive module (506) structured to receive said test signal (S_{TS}) and activate the movable contacts.

5. The control apparatus (502) of claim 4, wherein the switch module (504) comprises:

a first switch device (SW1) structured to connect/disconnect the first terminal (T1) to/from the first detection terminal (D2);

a second switch device (SW2) structured to connect/disconnect the second detection terminal (D3) to/from the second second terminal (T2).

6. The control apparatus (502) of claim 5, wherein at least one of said first switch device (SW1) and second switch device (SW2) is an electromagnetic relay.

7. The control apparatus (502) of claim 5, wherein the first switch device (SW1) comprises at least one movable contact (K1) configured to connect/disconnect said first terminal (T1) to/from the first detection terminal (D2).

8. The control apparatus (502) of claim 7, wherein the second switch device (SW2) comprises:

a first movable contact (CT1) structured to connect/disconnect the first supply terminal (D4) to/from a switching node (N2) connected to the second detection terminal (D3);

a second movable contact (CT2) structured to connect/disconnect the second terminal (T2) to/from said switching node (N2).

9. The control apparatus (502) of claim 8, wherein:

the first switch (SW1) comprises a first electromagnet including a first coil (W1) wound on a first yoke (Y1);

the second switch (SW2) comprises a second electromagnet including a second coil (W1) wound on a second yoke (Y2).

10. The control apparatus (502) of claim 1, wherein said anomaly sensing module (505) is configured to evaluate the extinguished flame signal (S_{DET}) and generate an anomaly detection signal (S_{AN}) representing a correct or an anomalous behaviour of the status detection module (503).

11. The control apparatus (502) of claim 10, wherein said anomaly sensing module (505) is configured to periodically generate said test signal (S_{TS}) to simulate a switching from the flame configuration to the flame absence configuration.

12. A gas turbine control system (500) comprising:

a flame sensor device (501) associable with a gas turbine (20) and structured to selectively provide a flame presence detection signal (S_{ON}) in a first configuration and a flame absence detection signal in a second configuration;

a status decision module (503) configured to detect, from the flame presence (S_{ON}) and the flame absence detection signals (S_{OFF}), a switching from the flame configuration to the flame absence configuration and produce an extinguished flame signal (S_{DET});

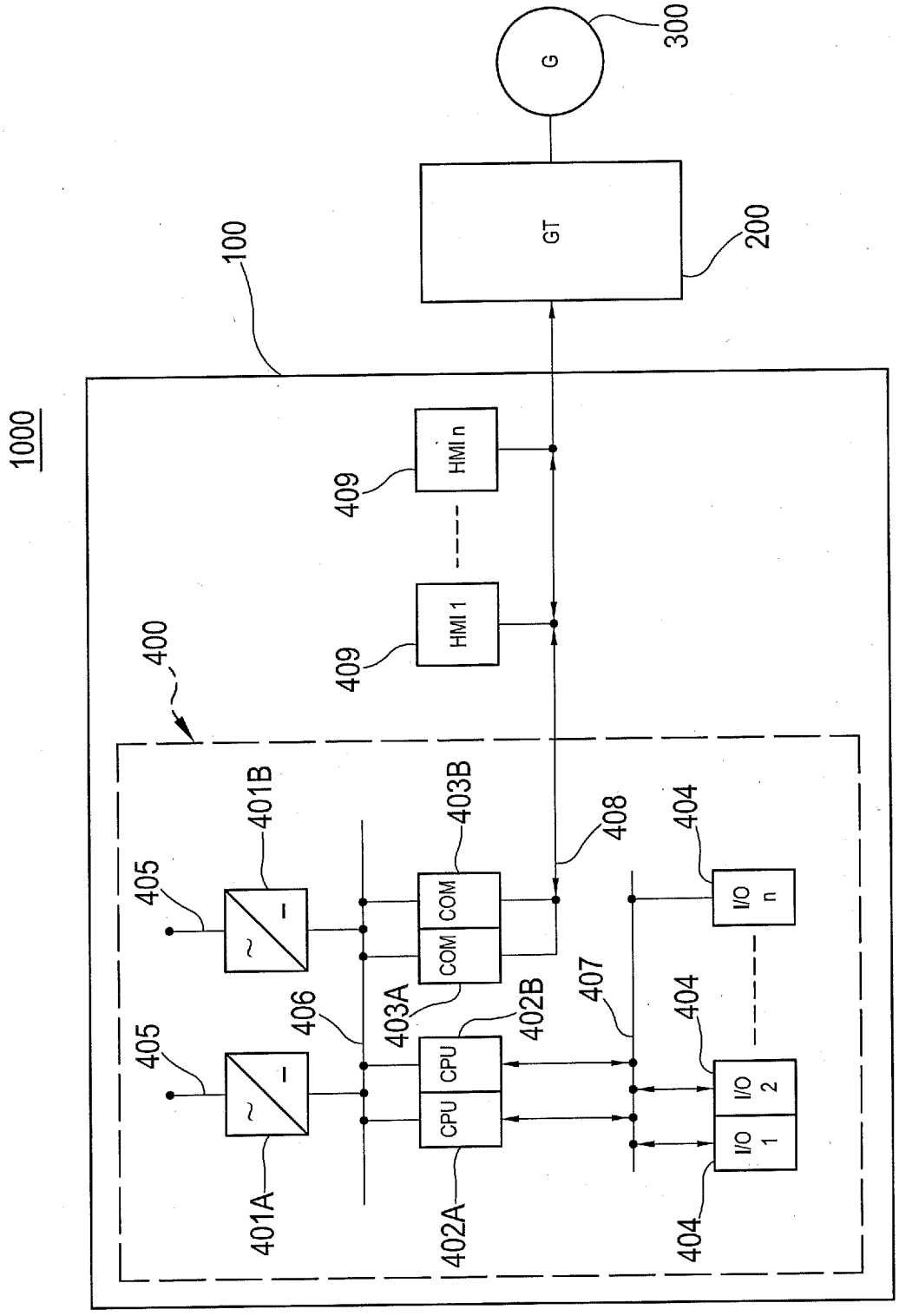
a switch module (504) connected between flame sensor device (501) and the status decision module (503) and operable by a test signal (S_{TS}) to simulate a switching from the flame configuration to the flame absence configuration;

an anomaly sensing module (505) configured to generate said test signal (S_{TS}) and sense the extinguished flame signal (S_{DET}) to detect anomalies of the status decision module (503).

13. The control system (500) of claim 12, wherein the flame sensor device (501) comprises a switch device (SW) including a

a respective first movable contact (C1) to connect/disconnect a voltage supply node (N1) to/from a first terminal (T1) configured to provide the flame presence detection signal (S_{ON});

a respective second movable contact (C2) to connect/disconnect the voltage supply node (N1) to/from a second terminal (T2) configured to provide the flame absence detection signal (S_{OFF}).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100
G
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409
400
401B
403B
408
404
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COM
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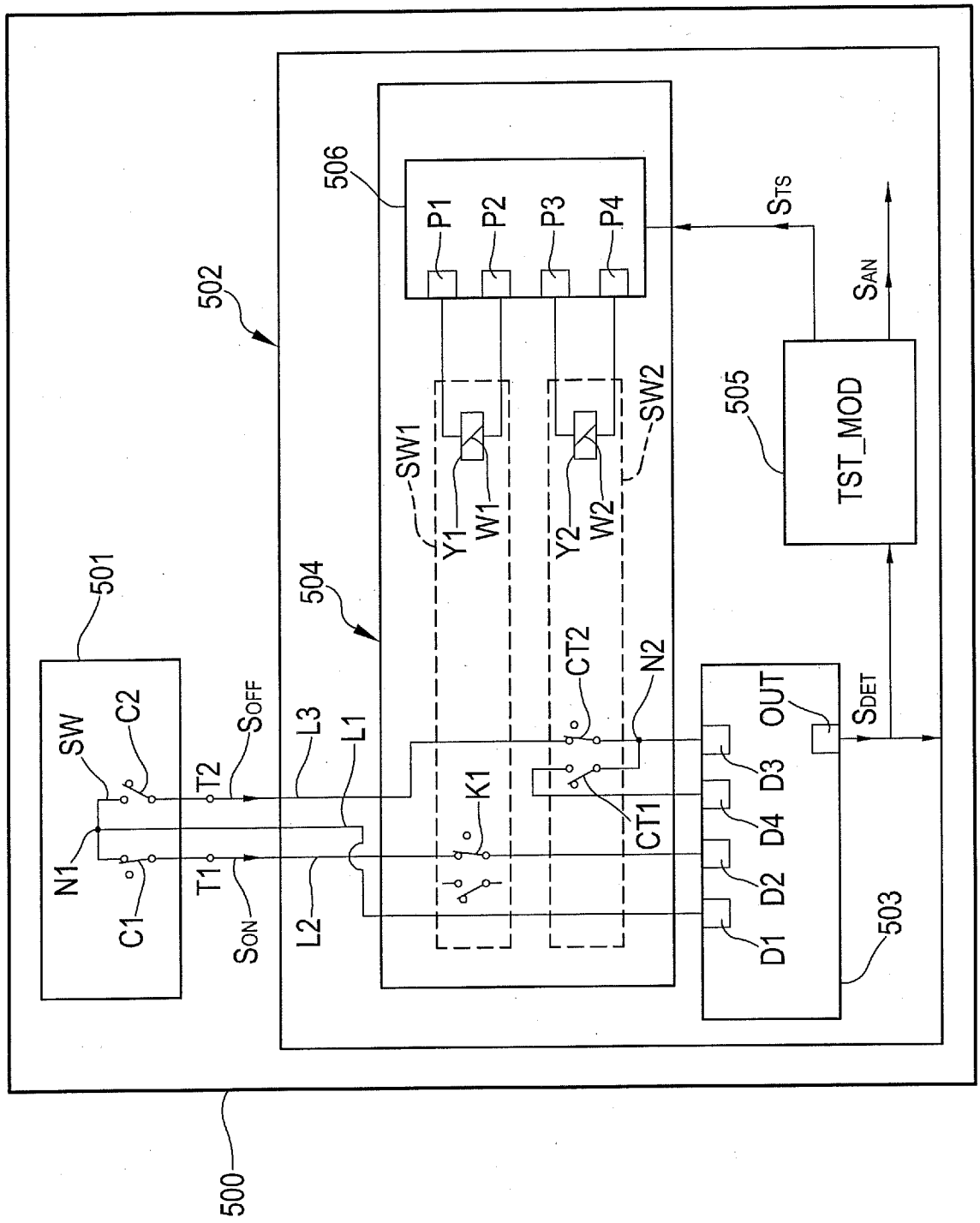
407
406
403A
402B
CPU
I/O 2
I/O 1
401A
402A

FIG.1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L1
K1
SW1
SW2
Y1
W1
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W2
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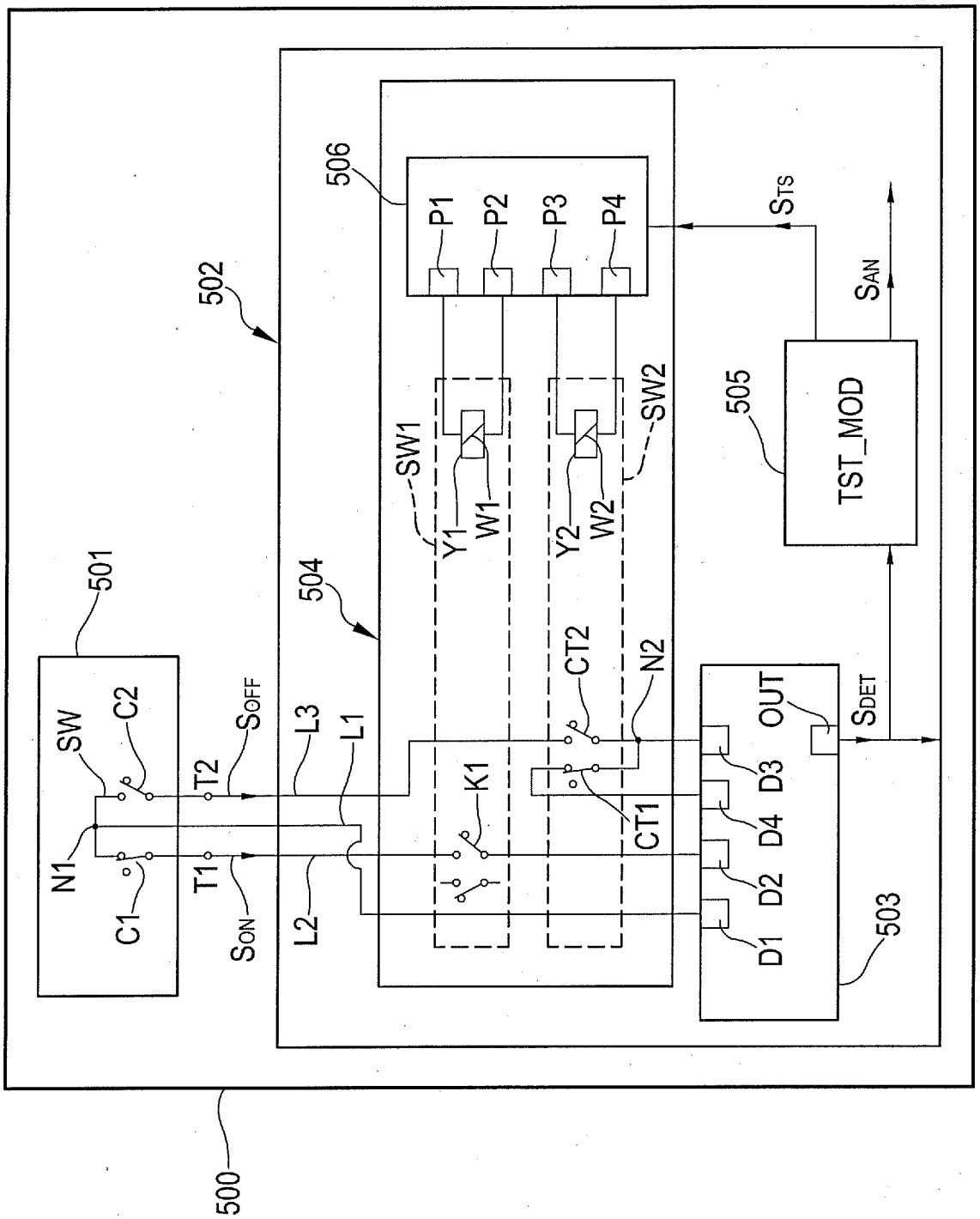
D2
D3
D4

FIG.2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503
504
505
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TST_MOD
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C1
N1
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SOFF
SON
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L2
K1
SW1
SW2
Y1
W1
Y2
W2
CT2
CT1
N2
P1
P2
P3
P4
STS
SAN
SDET
OUT
D1
D2
D3
D4

FIG.3

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2015/059883

A. CLASSIFICATION OF SUBJECT MATTER
INV. F23N5/12 F23N5/26 F23N5/24 F23N5/08
ADD.

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F23N

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 308 831 A2 (HONEYWELL INC [US]) 29 March 1989 (1989-03-29) column 3, line 49 - column 7, line 42; figure 1	1-13
X	WO 98/21450 A1 (WESTINGHOUSE ELECTRIC CORP [US]) 22 May 1998 (1998-05-22) the whole document	1-13
Y	US 2008/092826 A1 (KISHIMOTO TOMOKI [JP] ET AL) 24 April 2008 (2008-04-24)	2-13
A	the whole document	1
Y	DE 196 45 555 A1 (LANDIS & GYR TECH INNOVAT [CH]) 15 May 1997 (1997-05-15)	2-13
A	abstract	1

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

* Special categories of cited documents :

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Date of the actual completion of the international search	Date of mailing of the international search report
7 January 2016	15/01/2016

Name and mailing address of the ISA/	Authorized officer
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1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2015/059883

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0308831 A2	29-03-1989	AU 1974488 A	23-03-1989
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