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(54) Title: SYSTEM AND METHOD FOR CONTROLLING LIQUID GAS STORAGE FOR A VEHICLE POWERED BY LIQUID GAS

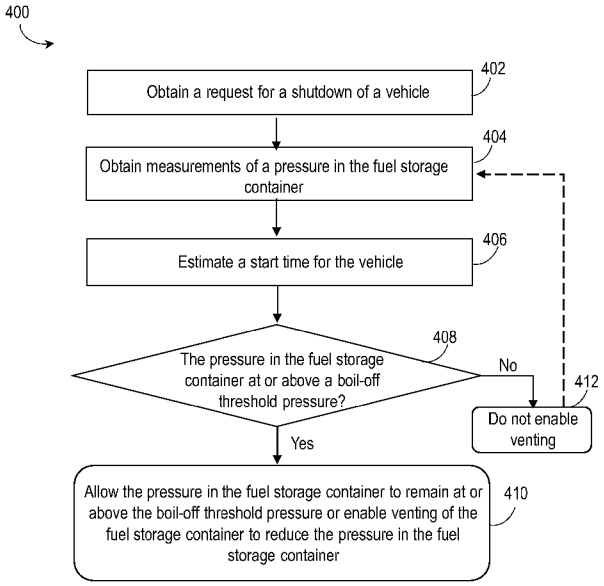


FIG. 4A

(57) Abstract: A system and method for controlling a fuel storage system configured to store a liquid fuel in a fuel storage container of a vehicle powered by the liquid fuel are provided. The control system comprises processing circuitry configured to obtain a request for a shutdown of the vehicle, obtain measurements of a pressure in the fuel storage container, estimate an expected start time for the vehicle that is shut down, and, responsive to detecting that the pressure in the fuel storage container is at or above a boil-off threshold pressure, allow the pressure in the fuel storage container to remain at or above the boil-off threshold pressure or enable venting of the fuel storage container to reduce the pressure in the fuel storage container in dependence on whether or not the expected start time is within a time threshold interval.

[Continued on next page]

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TITLE

SYSTEM AND METHOD FOR CONTROLLING LIQUID GAS STORAGE FOR A VEHICLE POWERED BY LIQUID GAS

TECHNICAL FIELD

[0001] The disclosure relates generally to a system and method for storing liquid gas onboard of a vehicle. More particularly, techniques are provided for determining whether and when to perform venting of a fuel storage container storing the liquid gas.

[0002] The disclosure can be applied in heavy-duty vehicles, such as trucks, buses, and construction equipment.

BACKGROUND

[0003] Certain types of vehicles use liquid gas, e.g., Liquefied Natural Gas (LNG) or hydrogen, as a fuel. The fuel is stored onboard and is used to fuel the vehicle. LNG is natural gas that has been cooled to −161 °C or −162 °C. In its liquid state, the cryogenic LNG may be reduced to approximately one-six hundredth (1/600th) of its volume compared to the gaseous form, which facilitates storage and transportation of the gas.

[0004] Hydrogen can be stored in a liquified or liquid form which is increasingly becoming a more preferable method of storing hydrogen since it is suitable for long-distance transportation of hydrogen. Liquefaction of hydrogen requires low temperatures, such as −253 °C, at atmospheric pressure.

[0005] Liquid gases such as e.g. LNG and hydrogen, are stored at cryogenic tanks at temperatures below their boiling point. Due to heat leaking through insulation of the tank, the liquid gas evaporates whereby a boil-off gas is generated.

[0006] The liquified hydrogen evaporates much easier than LNG, and the liquified hydrogen's evaporation rate per volume, or a boil-off rate, may be 10 times that of LNG. Accordingly, during storage or transportation, even at proper cryogenic conditions and using tanks with e.g. several levels of containment, it is challenging to maintain a sufficiently low temperature of the liquid hydrogen. There is natural continuous boil-off due to warming during storage or transportation. It is similarly challenging to avoid a boil-off of LNG during storage and transportation.

[0007] Thus, as it is stored in a cryogenic storage tank, liquid gas evaporates, whereby a so-called boil-off occurs as the evaporated gas, also referred to as a boil-off gas, is released from the liquid. The boil-off increases the pressure in the storage tank and the excessive pressure build up can lead to the risk of explosion. Potential consequences of an uncontrolled boil-off can thus be devastating. Furthermore, with the increasing use of liquid hydrogen, e.g., in fuel cell vehicles, addressing problems relating to undesirable boil-off becomes more critical.

[0008] Accordingly, the boil-off gas needs to be vented in order to decrease the pressure build-up in a storage tank. This however may result in losses of hydrogen gas, which is costly and may be detrimental to the environment. The LNG can also be subject to boil-off, which results in emissions of methane which is a highly potent greenhouse effect gas.

[0009] Accordingly, there is a need in improved approaches to managing boil-off during storage of liquified hydrogen, LNG, and other gases.

SUMMARY

[0010] Accordingly, a method and system are provided that allow proactively controlling boil-off and pressure build-up in fuel storage containers storing liquid gas such as e.g. liquid hydrogen, LNG, or another liquid or liquified gas. The method, performed by a control system comprising processing circuitry, comprises executing the processing circuitry to determine when and whether to perform venting of a fuel storage container storing liquid gas.

[0011] In an aspect, a control system for controlling a fuel storage system configured to store a liquid fuel in a fuel storage container of a vehicle powered by the liquid fuel is provided. The control system comprises processing circuitry configured to obtain a request for a shutdown of the vehicle, obtain measurements of a pressure in the fuel storage container, estimate an expected start time for the vehicle that is shut down, and, responsive to detecting that the pressure in the fuel storage container is at or above a boil-off threshold pressure, allow the pressure in the fuel storage container to remain at or above the boil-off threshold pressure or enable venting of the fuel storage container to reduce the pressure in the fuel storage container in dependence on whether or not the expected start time is within a time threshold interval.

[0012] In some examples, the expected start time for the vehicle may be determined before the vehicle has been shut down.

[0013] In some examples, the processing circuitry of the control system is configured to, responsive to detecting that the pressure in the fuel storage container is not at or above the boil-off threshold pressure, i.e. below the boil-off threshold pressure, not enable venting of the fuel storage container.

[0014] In some examples, the processing circuitry of the control system is configured to allow the pressure in the fuel storage container to exceed the boil-off threshold pressure responsive to determining that the expected start time is within a time threshold interval.

[0015] In some examples, the processing circuitry of the control system is configured to direct at least a portion of the pressure in the fuel storage container to at least one pressure-consuming device to thereby cause the pressure in the fuel storage container to remain at or above the boil-off threshold pressure.

[0016] In some examples, the processing circuitry of the control system is configured to determine whether the vehicle has started within the time threshold interval. In some examples, the processing circuitry is configured to, responsive to determining that the vehicle has not started within the time threshold interval, enable venting of the fuel storage container.

[0017] In some examples, the processing circuitry is configured to estimate the time threshold interval based on a duration of time required for the pressure in the fuel storage container to decrease below the boil-off threshold pressure when the vehicle starts.

[0018] In some examples, the expected start time is estimated using one or more out of a driver history, vehicle use history, timing data, vehicle location data, and vehicle power consumption data. In some examples, the expected start time is estimated using a prediction model.

[0019] In an aspect, a vehicle is provided that comprises the control system in accordance with examples of the present disclosure. The control system is for controlling a fuel storage system configured to store a liquid fuel in a fuel storage container for a vehicle powered by the liquid fuel. The control system comprises processing circuitry configured to obtain a request for a shutdown of the vehicle, obtain measurements of a pressure in the fuel storage container, estimate an expected start time for the vehicle that is shut down, and, responsive to detecting that the pressure in the fuel storage container is at or above a boil-off threshold pressure, allow the pressure in the fuel storage container to remain at or above the boil-off threshold pressure or enable venting of the fuel storage container to reduce the pressure in the fuel storage container in dependence on whether or not the expected start time is within a time threshold interval.

[0020] In some examples, the expected start time for the vehicle may be determined before the vehicle has been shut down.

[0021] In an aspect, a method for controlling a fuel storage system configured to store a liquid fuel in a fuel storage container of a vehicle powered by the liquid fuel is provided. The method comprises obtaining a request for a shutdown of the vehicle, obtaining measurements of a pressure in the fuel storage container, estimating an expected start time for the vehicle that is shut down, and, responsive to detecting that the pressure in the fuel storage container is at or above a boil-off threshold pressure, allowing the pressure in the fuel storage container to remain at or above the boil-off threshold pressure or enabling venting of the fuel storage container to reduce the pressure in the fuel storage container, in dependence on whether or not the expected start time is within a time threshold interval.

[0022] In some examples, the method comprises allowing the pressure in the fuel storage container to exceed the boil-off threshold pressure responsive to determining that the expected start time is within a time threshold interval.

[0023] In some examples, the method comprises directing at least a portion of the pressure in the fuel storage container from the fuel storage container to at least one pressure-consuming device to thereby cause the pressure in the fuel storage container to remain at or above the boil-off threshold pressure. The at least one pressure-consuming device may thus be pressurized with boil-off gas generated from the liquid gas. In some examples, when the pressure in the fuel storage container is directed to the at least one pressure-consuming device, the pressure in the fuel storage container may reduce to below the boil-off threshold pressure.

[0024] In some examples, the method comprises determining whether the vehicle has started within the time threshold interval.

[0025] In some examples, the method comprises, responsive to determining that the vehicle has not started within the time threshold interval, enabling venting of the fuel storage container.

[0026] In some examples, the method comprises estimating the time threshold interval based on a duration of time required for the pressure in the fuel storage container to decrease below the boil-off threshold pressure when the vehicle starts.

[0027] In some examples, the expected start time may be estimated using one or more out of a driver history, vehicle use history, timing data, vehicle location data, and vehicle power consumption data. In some examples, the expected start time may be estimated using a prediction model.

[0028] In some examples, the liquid fuel is a fluid that is subject to boil-off. In some examples, the liquid fuel is a liquid natural gas (LNG), or hydrogen, or another fluid. Examples of the present disclosure apply to storage of any liquefied gas, which may also be referred to as liquid gas, which is a gas that has been turned into a liquid by cooling, compressing, applying pressure, or using any combination thereof.

[0029] Accordingly, in examples in accordance with the present disclosure, the control over storage of the liquid gas onboard a vehicle is improved. The technical benefits include controlling venting of the fuel storage container such that the liquid gas fuel, in the form of a boil-off gas generated during the liquid gas storage, is saved rather than simply released into the environment and thereby wasted. A decision is made regarding whether and when to perform venting of the fuel storage container so that a number of venting events is decreased while maintaining a required level of safety at which the liquid fuel is stored in the fuel storage container in a vehicle. Another related advantage is that, because less boil-off gas is released into the environmental, its detrimental environmental impact is reduced. The system and method herein advantageously allow less methane to be released into the environment as a result of venting of boil-off gas produced by LNG.

[0030] According to an aspect of the disclosure, a computer program product is provided that comprises computer-executable instructions, which, when executed by processing circuity, cause the processing circuity to perform the method in accordance with examples of the present disclosure.

[0031] According to an aspect of the disclosure, a computer-readable storage medium is provided. The computer-readable storage medium has stored thereon a computer program product comprising computer-executable instructions which, when executed by processing circuity, cause the processing circuity to perform the method in accordance with examples of the present disclosure.

[0032] Additional features and advantages are disclosed in the following description, claims, and drawings. Furthermore, additional advantages will be readily apparent from the present disclosure to those skilled in the art or recognized by practicing the disclosure as described herein. There are also disclosed herein control units, computer program products, and computer-readable media associated with the above discussed technical effects and corresponding advantages.

BRIEF DESCRIPTION OF THE DRAWINGS

[0033] With reference to the appended drawings, below follows a more detailed description of aspects of the disclosure cited as examples.

[0034] **FIG. 1A** is a schematic diagram illustrating an example of a system comprising a fuel storage container in a vehicle with an internal combustion engine (ICE).

[0035] **FIG. 1B** is a schematic diagram illustrating an example of a system comprising a fuel storage container in a fuel cell vehicle.

[0036] **FIG. 2** illustrates a side view of an example of a fuel cell vehicle in which a method in accordance with aspects of the present disclosure may be implemented, in accordance with an example.

[0037] **FIG. 3** is a diagram illustrating a fuel cell system and a control system of the vehicle of FIG. 2, in accordance with an example.

[0038] **FIGs. 4A** and **4B** are flow charts illustrating a method for storing a liquid fuel in a fuel storage container of a vehicle, in accordance with an example.

[0039] **FIG. 5** is a graph illustrating an example of a pressure build-up over time in a fuel storage container, in accordance with an example.

[0040] **FIG. 6** is a graph illustrating another example of a pressure build-up over time in a fuel storage container, in accordance with an example.

[0041] **FIGs. 7A** and **7B** are schematic block diagrams illustrating examples of a control system, in accordance with examples of the present disclosure.

DETAILED DESCRIPTION

[0042] Storing gas in a liquid state, e.g., in a fuel storage container in a vehicle, may result in boil-off of the liquified or liquid gas. The boil-off gas is typically generated due to heat flow from the ambient environment, to the inside of the fuel storage container. The boil-off gas may need to be vented in order to eliminate a pressure build-up in the fuel storage container. Boil-off events usually occur when the vehicle is not in use and is thus not consuming any fuel such as the liquid gas. Typically, to reduce a risk of boil-off, when the pressure in the fuel storage container reaches a certain preset limit, the fuel storage container is vented to reduce the pressure in the container. This however results in a loss of gas that is wasted. Moreover, if the gas is LNG, its venting results in emissions of methane which are detrimental to the environment. Release of other gases may also be not desirable.

[0043] Accordingly, the method and system are provided that allow controlling boil-off and pressure build-up in containers storing liquid gas such as e.g. liquid hydrogen, or LNG, or another liquid gas. The method allows determining when and whether to perform venting of a fuel storage container that stores liquid gas. The venting is performed in a controlled manner, responsive to a decision to perform the venting which is based not only on pressure in the fuel storage container, but also in dependence on such factors as a predicted usage of the vehicle. In this way, advantageously, less gas is wasted for venting, which increases the efficiency of operating the vehicle. Moreover, a harmful impact of boil-off gas released into the ambient environment, e.g., the methane reduced during venting of the LNG, is reduced.

[0044] **FIG. 1A** depicts an example of a fuel storage and supply system 10a for a vehicle 100a in which a method in accordance with examples of the present disclosure may be implemented. The fuel storage and supply system 10a may be included in the vehicle 100a, e.g., in an internal combustion engine (ICE) vehicle which may be fueled by LNG, hydrogen, or another liquid gas. As shown in FIG. 1A, the fuel storage and supply system 10a may comprise a fuel storage container 30a configured to store liquid fuel for consumption by an ICE 14. The delivery of the liquid fuel from the fuel storage container 30a to the ICE 14 may be controlled, e.g., via a

valve 16, or via other one or more features that may be used in addition or alternatively. A pressure sensor 15 may be configured to measure internal pressure in the fuel storage container 30a, and a venting valve 18 may be configured to be operated to vent the fuel storage container 30a, by releasing a certain amount of boil-off gas from the fuel storage container 30a via a ventilation pipe or conduit 17. The pressure sensor 15 may comprise one or more pressure sensors. In some examples, the one or more pressure sensors may be one or more electronic pressure sensors.

[0045] A control system 40a may be configured to control the fuel storage and supply system 10a, such that the control system 40a may determine when a venting event is allowed and control operation of the venting valve 18 accordingly. The venting valve 18, or another suitable component, may be operated to allow a certain amount of boil-off gas be released from the fuel storage container 30a to thereby reduce the pressure in the fuel storage container 30a. The control system 40a may be part of the fuel storage and supply system 10a or it may be a separate component.

[0046] **FIG. 1B** depicts an example of a fuel storage and supply system 10b for a fuel cell vehicle 100b in which a method in accordance with examples of the present disclosure may be implemented. The fuel storage and supply system 10b may be included in the fuel cell vehicle 100b such as, e.g., a fuel cell electrical vehicle (FCEV) or a hybrid vehicle comprising a fuel cell system and a fuel storage and supply system comprising at least one fuel storage container for storage and supply of liquid fuel. As shown in FIG. 1B, the fuel storage and supply system 10b may comprise a fuel storage container 30b configured to store liquid fuel for consumption by a fuel cell system 20b. The liquid fuel, also referred to as a liquid gas fuel, such as hydrogen in this example, is supplied to anode or anode side of one or more fuel cell stacks of the fuel cell system 20b. The delivery of the liquid fuel from the fuel storage container 30b to the fuel cell system 20b may be controlled, e.g., via a valve 26, or via other one or more features that may be used in addition or alternatively. A pressure sensor 25 may be configured to measure internal pressure in the fuel storage container 30b, and a venting valve 28 may be configured to be operated to vent the fuel storage container 30b, by releasing a certain amount of boil-off gas from the fuel storage container 30b via a ventilation pipe or conduit 27. The pressure sensor 25 may comprise one or more pressure sensors. In some examples, the one or more pressure sensors 25 may be one or more electronic pressure sensors.

[0047] A control system 40b may be configured to control the fuel storage and supply system 10b, such that the control system 40b may determine when a venting event is allowed and may control operation of the venting valve 28 accordingly. The venting valve 28, or another suitable component, may be operated to allow a certain amount of boil-off gas be released from the fuel storage container 30b to thereby reduce the pressure in the fuel storage container 30b. The control system 40b may be part of the fuel storage and supply system 10b or it may be a separate component. Furthermore, in the fuel cell vehicle, the fuel storage and supply system 10b may be part of the fuel cell system 20b, or the fuel storage and supply system 10b may comprise the fuel cell system 20b, or the fuel cell system 20b may comprise fuel storage and supply system 10b.

[0048] It should be noted that the fuel storage and supply system 10a (FIG. 1A) and fuel storage and supply system 10b (FIG. 1B) are shown only to illustrate schematically systems in which a method in accordance

with examples of the present disclosure may be implemented. Components shown in FIG. 1A and 1B, and positions of the components, are illustrated as an example only and not to present any specific system in a vehicle having a fuel storage and supply system onboard.

[0049] **FIG. 2** depicts a side view of a vehicle 100 according to an example of the present disclosure. The vehicle 100 may be similar to vehicle 100b of FIG. 1B. The vehicle 100 is shown in FIG. 2 as a truck, such as a heavy-duty truck for towing one or more trailers (not shown). The vehicle 100 may be a fuel cell electric vehicle (FCEV) or a hybrid vehicle. It should be appreciated that the present disclosure is not limited to any specific type of vehicle, and may be used for any other type of vehicle, such as a bus, construction equipment, e.g. a wheel loader or an excavator, a passenger car, an aircraft, and a marine vessel. The present disclosure may be also applicable for other applications not relating to vehicles.

[0050] As shown schematically in FIG. 2, the vehicle 100 comprises a fuel cell system 20, which may be similar to fuel cell system 20b of FIG. 1B. The fuel cell system 20 may be used for powering one or more electric drive motors (not shown) which are used for creating a propulsion and/or traction force to the vehicle 100. The fuel cell system 20 may additionally or alternatively be used for powering other electric power consumers (not shown) of the vehicle 100, such as an electric motor for a crane, an electric motor for a refrigerator system, an electric motor for an air conditioning system, or any other electric power consuming function of the vehicle 100. The fuel cell system 20 may thus additionally or alternatively be used for powering a power take-off (PTO) device that is a device that transfers an electric motor's power to another piece of equipment.

[0051] The fuel cell system 20 comprises two or more fuel cells which together form a fuel cell stack 22 as shown in FIG. 2. The fuel cell system 20 is arranged to provide the fuel cells with necessary supply of hydrogen fuel (H_2) and air, cooling, heating, etc., and the fuel cell system 20 may include various components which are not shown herein. The fuel cell system 20 may comprise multiple fuel cell systems, and each fuel cell system may comprise its own control system, which may be communicatively connected to a controller or control unit. In some examples, the fuel cell system 20 includes two fuel cell systems. In some examples, the fuel cell system 20 comprises more than two fuel cell systems, such as three or more than three fuel cell systems.

[0052] As also shown schematically in FIG. 2, the vehicle 100 comprises a fuel storage and supply system 12 comprising a fuel storage container 30, which may be similar to fuel storage container 30b of FIG. 1A. The fuel storage container 30 is configured to store compressed fuel, such as hydrogen in a liquid form. The hydrogen is supplied to the fuel cell system 20 in controllable manner. Furthermore, the fuel storage container 30 may be vented to release a certain amount of boil-off hydrogen gas, which may be released to the environment.

[0053] The fuel storage container 30 may encompass more than one fuel storage containers. In some examples, the fuel storage container 30 may be configured as a cartridge or array of fuel storage containers or tanks. The fuel storage container 30 may include and/or may be associated with various other components not shown herein, including feature for refilling the fuel storage container 30. In some examples, the fuel storage container 30 may be replaceable. The fuel storage container 30 may include features, e.g., one or more nozzles for connecting to a fuel pump at a fueling station, or any other connectors. In examples herein, the fuel storage container 30 may have any suitable configuration and size, and it may have any suitable features.

[0054] The vehicle 100 further comprises a controller or control system 40 according to an example of the present disclosure. The control system 40, which may be similar to control system 40b of FIG. 1B, may be used for controlling the fuel storage and supply system 12 and the fuel cell system 20. Even though an on-board control system 40 is shown, it shall be understood that the control system 40 may also be a remote control system, e.g., an off-board control unit or a combination of an on-board and off-board control unit or units. The control system 40 may be configured to control the fuel storage and supply system 12 and the fuel cell system 20 by issuing control signals and by receiving status information relating to the fuel storage and supply system 12 and the fuel cell system 20. Thus, the control unit 40 may be configured to receive information such as sensor measurements from various sensors, including one or more out of pressure sensors, temperature sensors, moisture sensors, and other sensors included in or associated with the fuel storage container 30 and other components of the fuel storage and supply system 12, the fuel cell system 20, and other components of the vehicle 100. Non-limiting examples of the sensors comprise a pressure sensor configured to measure pressure in the fuel storage container 30, a temperature sensor configured to measure temperature of the fuel cell system 20, a temperature sensor configured to measure temperature in the fuel storage container 30, etc. Various sensors may acquire measurements regarding the fuel storage container 30 and the fuel cell system 20. The vehicle may also be equipped with one or more sensors configured to acquire measurements of temperature outside of the vehicle.

[0055] The vehicle 100 may comprise a Global Navigation Satellite System (GNSS) receiver such as e.g. a Global Positioning System (GPS) receiver.

[0056] The control system 40 may be communicatively coupled to an internal database, an external database, or a combination thereof, to receive historical data related to driver's driving pattern, historical data on the vehicle operation e.g. locations traveled by the vehicle, frequency and locations of stops, historical data on speed with which the vehicle is driven, historical data on ambient conditions at locations traveled by the vehicle and/or by other vehicles, current and predicted ambient conditions, etc.

[0057] The control system 40 may receive data from a weather service which may include data on actual and predicted weather conditions, and other types of data. The data on weather conditions, such as actual and/or predicted weather conditions, may include data on actual and/or predicted ambient temperature, as well as data on other environmental conditions such as e.g. altitude, and wind speeds at a certain location e.g. a vehicle current location and locations to be traveled by the vehicle. The control system 40 may be aware of specifics of a location in which the vehicle is stopped, such as e.g. whether the vehicle is parked indoors or outdoors.

[0058] The control system 40 may be configured to determine or predict a next start time for the vehicle that has been stopped. Accordingly, in some examples, once the vehicle stops, it may be determined or predicted when the vehicle is expected to start again.

[0059] The control system 40 may be an electronic control unit that comprises processing circuitry which is adapted and configured to execute a computer program such as computer-executable instructions to perform a method according to aspects of the present disclosure. The control system 40 may comprise hardware, firmware,

and/or software for performing the method according to aspects of the present disclosure. The control system 40 may be denoted a computer. The control system 40 may be constituted by one or more unit or sub-units, and the control system 40 may communicate by use of wired and/or wireless communication technology with components of the vehicle 100 and with outside systems.

[0060] In some examples, as shown in FIG. 1A, the vehicle may be an ICE vehicle. A method described herein applies to ICE vehicles comprising a fuel storage container configured for storing and supplying liquid fuel such as e.g., LNG, hydrogen, or another fluid that is subject to boil-off. The control system, e.g. control system 40a configured to control the fuel storage and supply system 10a shown in FIG. 1A, may be configured to control the fuel storage and supply system 10a in accordance with examples of aspects of the present disclosure, as described herein.

[0061] Although the present disclosure is described with respect to a vehicle such as a truck, aspects of the present disclosure are not restricted to this particular vehicle, but may also be used in other vehicles such as passenger cars, off-road vehicles, aircrafts, and marine vehicles. The present disclosure may also be applied in vessels and in stationary applications, such as in grid-connected supplemental power generators or in grid-independent power generators.

[0062] **FIG. 3** additionally illustrates an example of a configuration of the vehicle 100 comprising the fuel cell system 20 and the fuel storage and supply system 12 comprising the fuel storage container 30 shown in FIG. 2. As shown, the fuel cell system 20 comprises a fuel cell stack 22 comprising an anode or anode side 24, a cathode or cathode side 26, and an electrolyte 28 such as e.g. a proton exchange membrane (PEM) sandwiched between the anode and cathode 24, 26. The anode side 24 receives fuel such as hydrogen fuel that can be supplied from the fuel storage container 30 e.g. a hydrogen container or tank for storing hydrogen in a liquid phase. Delivery of hydrogen from the fuel storage container 30 to the anode 24 of the fuel cell stack may be controlled by e.g. a valve 36 shown in FIG. 2 by way of example, or via another component. The valve 36 may be e.g. a proportional valve, or any other type of valve.

[0063] Release or venting of boil-off hydrogen formed in the fuel storage container 30 may be performed via a separate venting conduit 37 comprising a venting valve 38 that is operable to control release of the boil-off hydrogen from the fuel storage container 30 at a venting event. As shown in FIG. 3, a pressure sensor 35 may be coupled to the fuel storage container 30. The pressure sensor 35 may be positioned so as to measure internal pressure in the fuel storage container 30, and the control system 40 is configured to receive measurements acquired by the pressure sensor. In some examples, more than one pressure sensor may be employed. Other one or more sensors may be coupled to or otherwise associated with the fuel storage container 30, e.g., a sensor configured to measure a level of gas in the liquid state in the fuel storage container 30, a temperature sensor, and/or other sensors. The pressure sensor 35, which may comprise one or more pressure sensors, may be an electronic pressure sensor. Any other sensor in the fuel storage and supply system 12 and the fuel cell system 20 may be an electronic sensor.

[0064] The hydrogen is supplied to the anode side 24 of the fuel cell stack 22 from the fuel storage container 30 during operation of the fuel cell system 20, i.e. when the fuel cell system 20 generates electrical

energy as the vehicle 100 is moving. When the vehicle 100 is stopped and the fuel cell 20 system is shut down, hydrogen is not supplied to the fuel cell system 20 from the fuel storage container 30 and, as a result, the pressure in the fuel storage container 30 may build up due to boil-off gas. In some cases, with the vehicle 100 being stopped, the fuel cell system may still be operating and excess energy produced by the fuel cell system may be stored in an energy storage system (ESS) such as e.g., one or more batteries. For example, one or more PTO devices may require the fuel cell system to be operational, depending on the PTO load and/or the ability of the ESS to provide sufficient power for operation of the PTO devices. But even with the fuel cell system operating, boil-off gas may be generated, with time, while the vehicle is stopped.

[0065] The cathode side 26 of the fuel cell stack 22 is configured to receive air or oxygen from the ambient environment, as shown by line 34. The ambient air is pressurized e.g. by a compressor 39 before being delivered to the fuel cell stack 22.

[0066] As shown in FIG. 3, the vehicle 100 comprises the energy storage system (ESS) 50 configured to store electrical energy or power. The ESS 50 may comprise, e.g., one or more batteries and/or one or more supercapacitors.

[0067] In the example of FIG. 3, electric power generated by the fuel cell stack 22 may be supplied to a junction box or unit 46, e.g. through a converter (not shown) that converts and stabilizes the voltage. The power is supplied, via the junction unit 46, to an electric motor or machine 48, also referred to herein as an electric traction machine, for propelling one or more sets of wheels 52 of the vehicle. The junction unit 46 serves as a communal meeting spot for electrical connections between the fuel cell stack 42, the ESS 50, and the electric machine 48. Propulsion power to the wheels 52 is delivered by the electric machine 48 supplied by one or both the ESS 50 and the fuel cell stack 22. Electrical connections are shown by dotted lines in FIG. 3.

[0068] The pressure in the fuel storage container 30 is typically maintained, when the vehicle is stopped, so that the pressure is allowed to fluctuate up to an upper pressure limit. When a venting event occurs, it is typically performed so that the pressure is decreased to a pressure limit, also referred to herein as a lower venting pressure limit. In examples herein, using the method in accordance with aspects of the present disclosure, the pressure in the fuel storage container 30 may be allowed to exceed the upper pressure limit in certain circumstances.

[0069] **FIGs. 4A** and **4B** are flow charts illustrating a process or method 400 for controlling a fuel storage and supply system configured to store a liquid fuel in a fuel storage container of a vehicle powered by the liquid fuel such as a liquid gas fuel. In some examples, the liquid fuel may be LNG or liquefied hydrogen stored in a fuel storage container of an ICE vehicle, e.g., ICE vehicle 10a of FIG. 1A. In some examples, the liquid fuel may be, e.g., liquefied hydrogen stored in a fuel storage container of a fuel cell vehicle, e.g., fuel cell vehicle 10b shown in FIG. 1B or fuel cell vehicle 100 shown in FIGs. 2 and 3. The liquid fuel may other liquid or liquified gas.

[0070] The method 400 may be performed by a controller or control system, such as e.g. any of control system 40a (FIG. 1A), control system 40b (FIG. 1B), and control system 40 (FIGs. 2 and 3). The control system comprises processing circuity, e.g., one or more processors, configured to perform the method 400. It may interchangeably be stated that the control system comprises memory device storing computer-executable

instructions that, when executed by the processing circuity, are operable to cause the processing circuity to perform the method 400.

[0071] The fuel storage container in the vehicle may store the fuel at 350 bar, 700 bar, 800 bar, or at any other pressure. In some examples, hydrogen may be cryo-compressed. The cryo-compressed hydrogen is typically stored at a pressure up to 300 or 350 bar. In some cases, the cryo-compressed hydrogen may be further compressed to higher pressures. In any case, stored cryo-compressed hydrogen may eventually boil-off.

[0072] The vehicle may be traveling a route which may in some cases be assigned to the vehicle. In some examples, the vehicle may be part of a fleet of vehicles where one or more vehicles are assigned missions to perform, e.g., routes to travel. In some examples, the vehicle may deviate from the assigned route in dependence on circumstances encountered during the travel and other factors.

[0073] At **block 402** of FIG. 4A, the control system obtains a request for a shutdown of the vehicle powered by the liquid gas fuel. The request may be obtained, received, or detected when the vehicle is keyed-off or when another instruction is received by the vehicle instructing it to shut off. An instruction to shut down the vehicle may be received from a driver of the vehicle or it may be an automatic instruction. The vehicle is shut off or shut down at the request for the shutdown or shortly thereafter, and the vehicle is in a stop mode once it is shut down.

[0074] In examples in which the vehicle is a fuel cell vehicle comprising a fuel cell system, when the vehicle is shut down, the fuel cell system may also shut down, such that the vehicle does not require power and thus does not consume hydrogen. The fuel cell vehicle and the fuel cell system may be shut down at the same time. In some examples, as mentioned above, the fuel cell system may be operational while the vehicle is shut down. Boil-off gas may still be produced in some cases, even with the fuel cell system being operational during the vehicle shutdown.

[0075] At **block 404**, the control system obtains measurements of a pressure in the fuel storage container. The fuel storage container stores liquid fuel such as liquid gas that may evaporate or transition to a gaseous form or phase, as a boil-off gas. The liquid gas is stored in the fuel storage container at cryogenic conditions i.e. at temperatures below their boiling point. For example, LNG is cooled to −161 °C or −162 °C for storage, and hydrogen is cooled to −253 °C for storage. When heat enters the cryogenic fuel storage container during storage, some of the product in the fuel storage container continuously evaporates and boils off.

[0076] One or more sensors may be employed to monitor or measure the pressure in the fuel storage container by acquiring measurements of the pressure. For example, FIGs. 1A, 1B, and 3 illustrate examples of pressure sensors. The pressure sensors may be electronic pressure sensors. The monitoring of the pressure in the fuel storage container is performed as the vehicle is shut down i.e. is in the stop mode. The pressure can also be monitored while the vehicle is moving and the fuel is being supplied from the fuel storage container to the fuel cell system or to the ICE. Thus, one or more pressure sensors may be operated to monitor or measure the pressure in the fuel storage container, continuously or at time intervals. The control system may obtain the measurements, continuously or at time intervals.

[0077] The pressure in the fuel storage container increases as the amount of the boil-off gas in the fuel storage container increases. A venting, also referred to herein as a venting event, may be performed to decrease the pressure in the fuel storage container when the vehicle is shut off. When the vehicle is moving, no venting is required since the fuel is being consumed. The venting may involve releasing a predetermined amount of boil-off gas from the fuel storage container. In some examples, the amount of the boil-off gas that is released from the fuel storage container in a particular venting event may vary depending on such factors as e.g. a current pressure in the fuel storage container, a temperature in the fuel storage container, etc.

[0078] The measurements of the pressure in the fuel storage container may be obtained independently of obtaining the request for the shutdown of the vehicle at block 402. In some examples, when the vehicle is shut down, measurements of the pressure inside the fuel storage container may be obtained more frequently than when the vehicle is moving.

[0079] Furthermore, the fuel storage container may have coupled thereto, and/or may be associated with other sensors, such as e.g. temperature sensors configured to measure a temperature in the fuel storage container, and/or liquid level sensors configured to measure a level of the liquid gas in the fuel storage container. The temperature sensors and liquid level sensors may be used, e.g. in combination with the pressure sensor(s), to determine a current state of the fuel storage container.

[0080] At **block 406**, the control system estimates an expected start time for the vehicle that is shut down. A prediction is generated regarding the expected start time, or an expected next start time, i.e. a time when the vehicle, which is currently stopped, is expected to start, such that the vehicle will consume fuel. The estimated next start time may be a duration of time during which the vehicle is expected to be stopped.

[0081] The vehicle may be stopped at a certain location referred to as a current location. In some examples, the vehicle may be assigned a route comprising a start point and an end or destination point. In some examples, when the vehicle is stopped, depending on how far and with which speed the vehicle has been traveling up to the current location, the control system may determine the expected start time for the vehicle.

[0082] In some examples, the expected start time for the vehicle may be determined before the vehicle has been shut down. It should be noted that the expected start time for the vehicle may be determined before the vehicle has been shut down and/or before the request for a vehicle shutdown has been received. For example, it may be determined by the control system at which locations, e.g., along the route assigned to the vehicle, the vehicle is expected to stop. A duration of one or more stops that the vehicle may make may thus be predetermined.

[0083] In some examples, the expected start time for the vehicle may be estimated using data comprising one or more out of a driver history, vehicle use history, timing data, vehicle location data, vehicle speed data, and vehicle power consumption data. In some examples, the expected start time for the vehicle may be determined or estimated based on timing data e.g. a current time and location data e.g. a current vehicle location. For example, it may be known based on historical data that, at a certain location, the vehicle is typically parked overnight. Accordingly, if the vehicle is at that location, in dependence on the current time, it may be predicted that the start-up time is the next morning. In some examples, the vehicle use history may comprise historical data

on vehicle start and stop patterns, e.g., while traveling the same or similar route, and the historical data on the vehicle start and stop patterns may be used by the control system to determine at which locations and for how long the vehicle is expected to stop.

[0084] The vehicle location data may include a vehicle location determined using a Global Positioning System (GPS) and/or another Global Navigation Satellite System (GNSS). The timing data may comprise one or more out of a current time, a current day of the week, a time associated with a particular past, current, and/or future event that is relevant to determining when the vehicle is expected to start next, and other timing data.

[0085] In some cases, the current location may be a location of a mandatory stop for the vehicle, for example, according to regulations. A duration of the mandatory stop may also be set in accordance with regulations, such that a time until the start may be predetermined at a certain location or at a certain day and/or time. In some examples, the duration of the vehicle stop may depend on a duration of time during which the driver has been driving up until the stop. In other words, regardless of a current location, it may be time for a stop of a certain duration, which may be in accordance with regulations that apply to the vehicle and/or the driver. In some cases, the driver of the vehicle may not be allowed to stay at a current location for a duration of time that is longer than a certain, e.g. preset, duration.

[0086] In some examples, the prediction regarding the expected start time may be generated using driver input. For example, an explicit driver input may be received by the control system, the explicit driver input indicating the time of the next start of the vehicle or the time until the start. The driver input may be received via a vehicle input device e.g. a vehicle console, or via a driver's device such as a smartphone, or in any other way.

[0087] In some examples, the expected start time may additionally or alternatively be estimated in dependence on current and/or predicted weather conditions. For example, an inclement weather may require a stop at a certain location, which may be for a certain duration of time. Weather conditions may in some cases affect an estimated start time. Other circumstances may affect the duration of time until the start of the vehicle, such as e.g., road conditions, road construction, obstacles ahead, speed limits including speed limit changes, vehicle condition e.g. a need for maintenance and/or repair, driver needs, etc.

[0088] In some examples, the start time of the vehicle may be estimated using a prediction model that may be a suitable machine learning model. The machine learning model may be trained to predict or estimate a time for the next vehicle start-up, or a time until the next vehicle start-up. The prediction model may be trained using data, such as multi-dimensional data, related to prior use of the vehicle, and/or prior use of similar vehicles, including historical data on durations of vehicle stopovers. The machine learning model may use data comprising one or more out of a driver history, vehicle use history, timing data, vehicle location data, vehicle speed data, vehicle power consumption data, and any other data. The machine learning model may also use data on historical stop and start pattern for the vehicle and/or other vehicles traveled a route currently being traveled by the vehicle or traveled similar routes. In some examples, the vehicles may be e.g. vehicles in a fleet of vehicles.

[0089] The prediction model learns using historical statistical data and makes a prediction from this data, based on previous outcomes. The prediction model may be updated as more relevant data becomes available.

The trained model is applied to generate a prediction regarding the next start time for the vehicle, using current relevant information related to the vehicle and/or the driver.

[0090] In some examples, the prediction model comprises one or more out of a neural network algorithm, deep leaning, a support vector machine algorithm, a Naive Bayes algorithm, a nearest neighbor algorithm, a boosted trees algorithm, a random forest algorithm, a decision tree algorithm, a multinomial logistic regression algorithm, a linear model, or a linear regression algorithm. The prediction model may be used in combination with any other approaches, including those described herein.

[0091] A combination of any other above-described features, including historical and current location data, historical and current timing data, historical and current weather data, driving pattern data, vehicle stop and start data, regulations, etc., may be used to determine or estimate an expected start time indicating when the vehicle, which has stopped, is expected to start next.

[0092] At decision **block 408**, the method 400 comprises determining whether the pressure in the fuel storage container is at or above a boil-off threshold pressure. The pressure in the fuel storage container increases as part of the liquid fuel evaporates into the gas phase, as a boil-off gas.

[0093] The monitoring of the pressure in the fuel storage container, at block 404, allows detecting a current pressure in the fuel storage container. The boil-off threshold pressure depends on one or more out of properties of the liquid fuel, characteristics of the fuel storage container, conditions at which the vehicle is currently located e.g. ambient temperature, and other factors that affect evaporation rate of the liquid fuel as heat is leaked into the liquid phase of the liquid fuel.

[0094] The characteristics of the fuel storage container, e.g. the material(s) it is made of, pressurization of the fuel storage container, heat insulation properties, a level of containment, and other characteristics, may affect the pressure in the fuel storage container and the boil-off threshold pressure. As the fuel storage container is exposed to increased temperatures, i.e. heat leaks into fuel storage container, the amount of the liquid fuel that is transitioned into the gas phase increases.

[0095] The boil-off threshold pressure is defined herein as a pressure in the fuel storage container at which venting of the fuel storage container, to release excess boil-off gas, is required. The boil-off threshold pressure may be set as a pressure that is excessively high given the current circumstances and that thus creates a risk of undesirable consequences, including a possible explosion.

[0096] It should be noted that the processing at decision block 408 may be performed before the processing at block 406. Furthermore, as mentioned above, measurements of the pressure in the fuel storage container may be obtained continuously, and therefore independently of obtaining the request for the shutdown of the vehicle 402.

[0097] At **block 410** of FIG. 4A, responsive to determining or detecting at block 408 that the pressure in the fuel storage container is at or above the boil-off threshold pressure, the method 400 comprises allowing the pressure in the fuel storage container to remain at or above the boil-off threshold pressure, or enabling venting of the fuel storage container to reduce the pressure in the fuel storage container, in dependence on whether or not the expected start time is within a time threshold interval.

[0098] The control system may control the fuel storage and supply system so that, even when the pressure in the fuel storage container is at or above the boil-off threshold pressure, a decision may be made not to perform venting of the fuel storage container and thereby allow the pressure in the fuel storage container to remain at or above the boil-off threshold pressure. The pressure may be allowed to exceed the boil-off threshold pressure. In some examples, the pressure may be allowed to continue increasing to a certain level above the boil-off threshold pressure. In some examples, the pressure may be maintained to remain at or above the boil-off threshold pressure, e.g. such that the pressure does not exceed or only slightly exceeds e.g. up to 5%, the boil-off threshold pressure.

[0099] The pressure in the fuel storage container may be allowed to exceed the boil-off threshold pressure when the expected start time for the vehicle is within the time threshold interval, such that the vehicle is expected to start, and consume fuel stored in the fuel storage container, within a period of time that allows waiting for the vehicle to start rather than performing the venting. In such cases, the pressure in the fuel storage container is allowed to exceed the boil-off threshold pressure for the duration of time until the vehicle starts again.

[00100] As another approach, the pressure in the fuel storage container, which is at or above the boil-off threshold pressure, may be allowed to remain at or above the boil-off threshold pressure when the expected start time is within the time threshold interval. The pressure in the fuel storage container may be controlled by directing the pressure, from the fuel storage container to one or more devices or systems in the vehicle. The one or more devices or systems may be configured to have a capacity to store the boil-off gas, or, in other words, they have a gas storage potential. Thus, instead of releasing the boil-off gas to the ambient atmosphere, the gas is used to pressurize devices or systems such as e.g. driveline components, e.g., pipes, fuel injectors, and regulators. The device or system may be part of the fuel storage system or any suitable system of the vehicle. Non-limiting examples of components, configured to be pressurized by the boil-off gas, include one or more out of driveline components and gas driven heaters, e.g., heaters configured to warm one or more out of the engine, a vehicle cabin, an energy storage system such as e.g. one or more batteries. A heater may also be a heater configured to warm up an engine and/or a fuel cell system. The heaters may be fueled before the vehicle is started, for preheating. In this way, the pressure in the fuel storage container may be maintained at or above the boil-off threshold pressure, e.g., without exceeding the boil-off threshold pressure or slightly exceeding the boil-off threshold pressure, and the venting event is advantageously avoided.

[00101] In some examples, the control system may control the fuel storage and supply system to enable venting of the fuel storage container to reduce the pressure in the fuel storage container, when the expected start time is not within the time threshold interval. Thus, when the vehicle is not expected to start soon enough, such that there is a risk of the pressure in the fuel storage container raising to a certain level above the boil-off threshold pressure, which creates a risk of explosion, the control system may determine that the venting of the fuel storage container needs to be performed.

[00102] The processing at block 410 is discussed in more detail in connection with FIG. 4B.

[00103] Continuing with FIG. 4A, **at block 412**, responsive to determining or detecting at block 408 that the pressure in the fuel storage container is not at or below the boil-off threshold pressure, i.e. below the boil-off

threshold pressure, the control system controls the fuel storage and supply system not to enable venting of the fuel storage container. As used herein, not enabling the venting of the fuel storage container refers to not instructing the fuel storage and supply system comprising the fuel storage container to perform venting of the fuel storage container. Thus, no venting event occurs at this point. The process 400 may optionally return to block 404, as shown by a dashed line in FIG. 4A, where the control system continues acquiring measurements of the pressure in the fuel storage container as the vehicle remains to be stationary such that it is not moving.

[00104] **FIG. 4B** is an additional illustration of the method 400 of FIG. 4A, and examples of the processing performed as part of the method 400 of FIG. 4A are described in more detail in FIG. 4B. It should be noted that the description of processing at acts of FIG. 4B, which are similar to corresponding acts of FIG. 4A, is not repeated in connection with FIG. 4B for brevity. The description of the acts of FIG. 4A applies to the description of the corresponding acts of FIG. 4B, and vice versa.

[00105] At block 402 of FIG. 4B, the control system obtains a request for a shutdown of the vehicle. At block 404, the control system obtains measurements of the pressure in the fuel storage container. At block 406, the control system estimates the expected start time for the vehicle that is shut down. At block 408, it is determined whether the pressure in the fuel storage container is at or above the boil-off threshold pressure.

[00106] At **block 410**, the control system controls the fuel storage and supply system to allow the pressure in the fuel storage container to remain at or above the boil-off threshold pressure or enable venting of the fuel storage container to reduce the pressure in the fuel storage container. in dependence on whether or not the expected start time for the vehicle is within a time threshold interval. As shown in FIG. 4B by a dot-dashed line, the processing at block 410 may include the processing at one or more out of blocks 414, 415, 416, 420, and 422. The processing at block 424 may or may not be included in the processing at block 410.

[00107] At **block 412**, responsive to determining or detecting at block 408 that the pressure in the fuel storage container is not at or below the boil-off threshold pressure, i.e. below the boil-off threshold pressure, the control system controls the fuel storage and supply system to not enable venting of the fuel storage container.

[00108] At decision **block 414**, responsive to detecting that the pressure in the fuel storage container is at or above the boil-off threshold pressure, the control system determines whether the expected start time for the vehicle is within the time threshold interval.

[00109] The time threshold interval may be a certain duration of time within which a certain pressure build-up in the fuel storage container may be allowed. In some examples, the time threshold interval may be a range of time durations. The time threshold interval may be selected such that, unless the vehicle starts by the expiration of the time threshold interval, measures need to be taken to reduce the pressure in the fuel storage container. In other words, the time threshold interval is a duration of time during which the boil-off threshold pressure, even though increasing, will not reach a dangerously high level. At the same time, the vehicle is expected to start at the expiration of the time threshold interval; otherwise, an event needs to occur in order to decrease the pressure in the fuel storage container.

[00110] At optional **block 415**, as shown in FIG. 4B, the method 400 comprises estimating the time threshold interval. In some examples, the time threshold interval may be determined in dependence on a

duration of time required for the pressure in the fuel storage container to decrease below the boil-off threshold pressure when the vehicle starts. The method 400 may include estimating the duration of time required for the pressure in the fuel storage container to decrease below the boil-off threshold pressure once the vehicle starts or is started. This may be performed based on historic data on vehicle operation e.g., based on power consumption data by the fuel cell system of the vehicle or by the ICE, depending on the type of the vehicle and other factors. The vehicle fuel consumption is typically known, and a time required for the pressure to drop to a level below the boil-off threshold pressure may be calculated in dependence on the vehicle fuel consumption.

[00111] In some examples, the time threshold interval may be shorter if the estimated duration of time required for the pressure in the fuel storage container to decrease below the boil-off threshold pressure is longer. Thus, if it takes longer for the pressure in the fuel storage container to decrease to a level where the pressure does not raise concerns, e.g., below the boil-off threshold pressure, the pressure is allowed to increase to above the boil-off threshold pressure for a shorter duration of time before the vehicle is expected to start again. The time threshold interval may be longer if the estimated duration of time required for the pressure in the fuel storage container to decrease below the boil-off threshold pressure is shorter. Thus, if it takes a shorter time for the pressure in the fuel storage container to decrease to a level below the boil-off threshold pressure, the pressure is allowed to increase to above the boil-off threshold pressure for a longer duration of time before the vehicle is expected to start again, since the pressure will decrease quickly once the vehicle is started.

[00112] At **block 416**, responsive to determining that the expected start time of the vehicle is not within the time threshold interval, the control system controls the fuel storage and supply system to enable venting of the fuel storage container to reduce the pressure in the fuel storage container. Thus, when the vehicle is not expected to start within the time threshold interval, it is determined that the fuel storage container needs to be vented. For example, when it is predicted that the vehicle will remain stopped at a certain location for a period of time during which the pressure in the fuel storage container may increase excessively high, thereby creating potentially dangerous conditions, the control system may determine that a venting event needs to occur, to reduce the pressure in the fuel storage container.

[00113] At **block 418**, responsive to determining that the expected start time of the vehicle is within the time threshold interval, the control system controls the fuel storage and supply system to allow the pressure in the fuel storage container to remain at or above the boil-off threshold pressure. The pressure in the fuel storage container may be allowed to remain at a level of the boil-off threshold pressure or exceed the level of the boil-off threshold pressure, at block 420. In some examples, as shown at block 422 discussed below, the pressure may be actively controlled to remain at or above the level of the boil-off threshold pressure, i.e. the pressure may not be increased further once it is detected that the pressure is at or above the boil-off threshold pressure and that the expected start time of the vehicle is within the time threshold interval.

[00114] Accordingly, if the vehicle is expected to start at an expected start time that is within the time threshold interval, some pressure build-up in the fuel storage container is allowed. The pressure in the fuel storage container may be allowed to exceed the boil-off threshold provided that a start of the vehicle is expected

soon enough, which leads to the pressure reduction as the vehicle consumes fuel. In this way, a venting event is avoided and the fuel is advantageously saved.

[00115] At **block 420**, the control system controls the fuel storage and supply system to allow the pressure in the fuel storage container to exceed the boil-off threshold pressure.

[00116] **FIG. 5** illustrates an example of a pressure in a fuel storage container as a function of time, shown as a graph 502. The fuel storage container may be for any type of a vehicle including a fuel storage and supply system comprising the fuel storage container and controlled in accordance with examples of the present disclosure. As shown in FIG. 5 for illustration, the pressure in the fuel storage container changes as, at each pressure build-up to an upper pressure limit, which may also be referred to as an upper venting pressure limit 506, shown by a dashed line 506, a venting event occurs, and the pressure decreases to a lower venting pressure limit 504, shown by a dashed line 504. For example, as the pressure reaches the upper limit at point 508 on the graph 502, a venting of the fuel storage container is performed, causing the pressure in the fuel storage container to fall to the lower venting pressure limit 504. At each venting event, the gas is wasted since it is simply released into the atmosphere i.e. the outside environment.

[00117] The upper pressure limit 506 may be a boil-off threshold pressure. As shown in FIG. 5, the pressure reaches the upper limit at point 514 on the graph 502, at a time point t1. The method as described herein allows predicting that, at a time point td, sometime after the time point t1, the vehicle is expected to start and consume the fuel stored in the fuel storage container. In the example illustrated in FIG. 5, the expected start time, td, is within a time threshold interval. As long as the vehicle is expected to start within a certain time interval, shown by an arrow 518 in FIG. 5, which is within the time threshold interval, the pressure in the fuel storage container is allowed to increase. Accordingly, the pressure in the fuel storage container is allowed to increase above the upper pressure limit 506. By the time the vehicle is expected to start at the time td, the pressure in the fuel storage container may reach a point 516 on the graph 502, which is above the upper pressure limit 506 i.e. above the boil-off threshold pressure. When the vehicle is started at the time point td and consumes fuel, the pressure in the fuel storage container decreases after the point 516, as shown in FIG. 5. As the vehicle is moving and the fuel is consumed, the pressure in the fuel storage container may fall to below the lower venting pressure limit 504, as shown in this example.

[00118] At **block 422**, the control system controls the fuel storage and supply system to direct at least a portion of the pressure in the fuel storage container to at least one pressure-consuming device to thereby cause the pressure in the fuel storage container to remain at or above the boil-off threshold pressure. In some examples, the processing at block 422 may be performed as an alternative to the processing at block 420. In some examples, the processing at block 422 may be performed in combination with the processing at block 420. For example, the pressure in the fuel storage container may be allowed to increase, e.g. above the boil-off threshold pressure, for a certain amount of time that is shorter than a time remaining until the expected vehicle start-up. After that, the control system may control the fuel storage and supply system to direct at least a portion of the pressure, built-up in the fuel storage container due to a boil-off gas, from the fuel storage container to at least one pressure-consuming device of the vehicle that is configured to be pressurized with the boil-off gas. The

pressure-consuming device thus gets pressurized with the boil-off gas. Examples of pressure-consuming components which are configured to store a certain amount of boil-off gas before it is used as the vehicle moves, include components of a driveline that transfers the power i.e. torque from the vehicle engine and transmission to the wheels that ultimately move the vehicle. Non-limiting examples of driveline components, which may be pressurized with boil-off gas, include pipes, fuel injectors, and regulators.

[00119] The at least one pressure-consuming device may be supplied with the boil-off gas from the fuel storage container, whereby the at least one pressure-consuming device is pressurized. Thus, the pressure in the fuel storage container is maintained at the same or approximately the same level, wherein the level may be at or above the boil-off threshold pressure. In some examples, the pressure in the fuel storage container may decrease to a level below the boil-off threshold pressure.

[00120] The at least one pressure-consuming device may be part of the fuel storage and supply system and/or any component of the vehicle configured to be pressurized by the boil-off gas supplied from the fuel storage container. Non-limiting examples of such components include one or more driveline components, gas-driven heaters, e.g., heaters used to warm one or more out of the engine e.g. an ICE or another type of an engine, heaters used to control temperature in a vehicle cabin, heaters used to control temperature in an energy storage system such as e.g. one or more batteries, and one or more heaters configured to warm up a fuel cell system for a fuel cell vehicle.

[00121] **FIG. 6** illustrates another example of a pressure in a fuel storage container as a function of time, shown as a graph 602. As shown in FIG. 6 for illustration, the pressure in the fuel storage container changes as, at each pressure build-up to an upper pressure limit or upper venting pressure limit 606, shown by a dashed line 606, a venting event occurs such that the pressure decreases to a lower venting pressure limit 604, shown by a dashed line 604. For example, as the pressure reaches the upper limit at point 608 on the graph 602, a venting of the fuel storage container is performed, causing the pressure in the fuel storage container to reduce to the lower venting pressure limit 604. The gas is wasted at each venting event.

[00122] The upper pressure limit 606 may be e.g. a boil-off threshold pressure. In some examples, the boil-off threshold pressure may be lower than the upper pressure limit 606, but greater than the lower venting pressure limit 604.

[00123] As shown in FIG. 6, the pressure in the fuel storage container may reach the upper limit at point 620 on the graph 602, at a time point t2. The method as described herein allows predicting that the vehicle is expected to start at a time point td after the time point t2, i.e. after a time period or interval shown by a double-pointed arrow 618 in FIG. 6. In this example, the expected start time, i.e. the time point td, is within the time threshold interval. Responsive to determining that the expected start time of the vehicle is within the time threshold interval, the control system may control the fuel storage and supply system to supply or provide at least a portion of the pressure from the fuel storage container to at least one pressure-consuming device to thereby cause the pressure in the fuel storage container to remain at or above the boil-off threshold pressure. Thus, as shown in FIG. 6, after the point 620 at which the pressure is directed to the at least one pressure-consuming device, the pressure in the fuel storage container remains at the same level, i.e. remains constant or

approximately constant. At point 622 on the graph 602, at the time td, the vehicle starts as expected and begins consuming fuel stored in the fuel storage container, the pressure in the fuel storage container decreases, as shown in FIG. 6.

[00124] Referring back to FIG. 4B, the vehicle may or may not start at the expected start time that is predicted to be within the time threshold interval. In other words, circumstances may occur when the vehicle does not start at the expected start time. This possibility needs to be accounted for by the control system, to avoid a situation when the pressure in the fuel storage container is above the boil-off threshold pressure and keeps increasing, without the vehicle starting at a predicted time i.e. the expected start time.

[00125] Accordingly, at decision **block 424**, the control system may determine whether the vehicle has started within the time threshold interval. As shown in FIG. 4B, the processing at block 424 may be performed when the control system controls, at block 420, the fuel storage and supply system to allow the pressure in the fuel storage container to exceed the boil-off threshold pressure and/or when the control system controls, at block 422, the fuel storage and supply system to provide at least a portion of the pressure from the fuel storage container to at least one pressure-consuming device. The vehicle may start, or may be started, earlier than expected, i.e. within the time threshold interval. In some cases however the vehicle may not be started at the expected start time that is predicted to be within the time threshold interval. Thus, at the end of the time threshold interval, the control system may determine whether the vehicle has started.

[00126] Responsive to determining that the vehicle has not started within the time threshold interval, the control system may control the fuel storage and supply system to enable venting of the fuel storage container. Accordingly, as shown in FIG. 4B, the method 400 may return to block 416 where the venting is enabled.

[00127] As also shown in FIG. 4B, responsive to determining that the vehicle has started within the time threshold interval as expected, the method 400 may return to block 412 where the venting is not enabled. The control system may continue, at block 408, acquiring measurements of pressure in the fuel storage container from one or more pressure sensors configured to measure the pressure in the fuel storage container. It should be noted that the control system may similarly continue, at block 408, acquiring measurements of pressure in the fuel storage container after the venting is enabled at block 416. As mentioned above, the pressure in the fuel storage container may be controlled independently of whether the vehicle is moving or stopped. The fuel cell system, in a fuel cell vehicle, may or may not be running while the vehicle is stopped.

[00128] To perform the method steps described herein, a control system 40, such as e.g. any of the control systems 40a, 40b, and 40, collectively represented by a control system 700 in this example, may be configured to perform the processing described in connection with FIGs. 4A and 4B, and/or any other examples in accordance with the present disclosure. The control system 700 may have a configuration as depicted in **FIGs. 7A** and **7B**. The control system 700 may be configured to be positioned in any suitable location of a vehicle, which may be vehicle fueled by LNG, hydrogen, or any other fluid that is subject to boil-off at ambient temperatures. Examples of the present disclosure are not limited to vehicles powered by LNG and hydrogen, and the described approach of controlling a boil-off event applies to a vehicle powered by another fluid e.g. a liquid or liquified gas.

[00129] As shown in **FIG. 7A**, the control system 700 comprises processing circuitry 760, memory 770, and an input and output interface 701 configured to communicate with any necessary components. The input and output interface 701 may comprise a wireless and/or wired receiver and a wireless and/or wired transmitter. In some examples, the input and output interface 701 may comprise a wireless and/or wired transceiver. The control system 700 may use the input and output interface 701 to control and communicate with various sensors, actuators, subsystems, and/or interfaces of the fuel storage and supply system and other systems of the vehicle by using any one or more out of a Controller Area Network (CAN) bus, ethernet cables, Wi-Fi, Bluetooth, and/or other network interfaces.

[00130] The method described herein may be implemented using processing circuitry, e.g., one or more processors, such as the processing circuitry 760 of the control system 700, together with computer program code stored in a computer-readable storage medium for performing the functions and actions of the examples herein.

[00131] The memory 770 may comprise one or more memory units. The memory 770 comprises computer-executable instructions executable by the processing circuitry 760 of the control system 700. The memory 770 is configured to store, e.g., information, data, etc., and computer-executable instructions that, when executed by the processing circuitry 760, cause the processing circuitry 760 to perform the methods in accordance with examples of the present disclosure. The control system 700 may additionally obtain information from an external memory, including from a cloud storage.

[00132] The methods according to the aspects of the present disclosure may be implemented by e.g. a computer program product 780 or a computer program, comprising computer-executable instructions, which, when executed on at least one processor, e.g., the processing circuitry 760, cause the at least one processor to perform the method as described herein, as performed by the control system 700.

[00133] In some examples, the computer program product 780 is stored on a computer-readable storage medium 790. The computer-readable storage medium 790 may be, e.g., a disc, a universal serial bus (USB) stick, or similar device. The computer-readable storage medium 790, having stored thereon the computer program product, may comprise computer-executable instructions which, when executed on at least one processor, e.g., the processing circuitry 760, cause the at least one processor to perform methods in accordance with examples of the present disclosure, as performed by the control system 700.

[00134] As shown in **FIG. 7B**, the control system 700 may comprise **an obtaining unit 702**. The control system 700, the processing circuitry 760, and/or the obtaining unit 702 are configured to obtain a request for a shutdown of the vehicle. The request to shut down the vehicle may be obtained at a time when the vehicle is shut down or before the vehicle is shut down.

[00135] The control system 700, the processing circuitry 760, and/or the obtaining unit 702 are also configured to obtain measurements of a pressure in the fuel storage container. The measurements may be obtained from one or more pressure sensors configured to measure the pressure in the fuel storage container.

[00136] As further shown in **FIG. 7B**, the control system 700 may comprise **an estimating unit 704**. The control system 700, the processing circuitry 760, and/or the estimating unit 704 are configured to estimate an expected start time for the vehicle that is shut down. The expected start time may be estimated using one or

more out of a driver history, vehicle use history, timing data, vehicle location data, vehicle speed data and vehicle power consumption data. Any other data may be used in estimating the expected start time for the vehicle, as discussed in connection with block 406 of FIG. 4A.

[00137] In some examples, additionally or alternatively, the expected start time is estimated using a prediction model such as a machine-learning model. The prediction model, e.g. a vehicle start time prediction model, may be trained using one or more out of the driver history, vehicle use history, timing data, vehicle location data, vehicle speed data and vehicle power consumption data. In some examples, the prediction model may be used in combination with one or more out of the driver history, vehicle use history, timing data, vehicle location data, vehicle speed data and vehicle power consumption data. The trained prediction model may be applied to current data related to the vehicle and/or the driver, such as vehicle's current location, current day and time, etc.

[00138] In some examples, the estimating unit 704 may comprise a machine learning engine or unit 705 configured to execute the prediction model. The prediction model may be trained by the control system 700 and/or the processing circuitry 760, e.g., by the machine learning engine or unit 705. In some examples, additionally or alternatively, the prediction model may be trained outside of the control system 700 and the vehicle, e.g., by a server. The server may be e.g. a cloud server or another remote computer or a system of computers. The server may acquire data from one or more, multiple in some cases, vehicles, and the data may be used to train the prediction model. The prediction model may be trained in advance, such as before the vehicle is traveling the route during which storage of liquid fuel in the vehicle's fuel storage container is controlled in accordance with examples of the present disclosure. The prediction model may be updated as further relevant data is acquired.

[00139] The control system 700, the processing circuitry 760, and/or the estimating unit 704 are configured to estimate the time threshold interval. In some examples, the time threshold interval may be determined in dependence on a duration of time required for the pressure in the fuel storage container to decrease below the boil-off threshold pressure when the vehicle starts. In other words, the time threshold interval may be determined in dependence on a duration of time that is expected to be required for the pressure in the fuel storage container to decrease below the boil-off threshold pressure once the vehicle starts or is started.

[00140] The control system 700 may comprise **a determining unit 706**. The control system 700, the processing circuitry 760, and/or the determining unit 706 may be configured to determine or detect whether the pressure in the fuel storage container is at or above a boil-off threshold pressure. The determining comprises comparing the pressure in the fuel storage container with a value of the boil-off threshold pressure. The comparison may be made as the measurements of the pressure in the fuel storage container are obtained when the vehicle is in a stop mode, to detect it when the pressure in the fuel storage container is at or exceeds the boil-off threshold pressure.

[00141] The control system 700, the processing circuitry 760, and/or the determining unit 706 may be configured to determine whether the expected start time is within the time threshold interval. This may be

performed responsive to detecting that the pressure in the fuel storage container is at or above the boil-off threshold pressure.

[00142] The control system 700 may comprise **a venting control unit 708** that is configured to enable venting of the fuel storage container or to not enable venting of the fuel storage container. When the venting is not enabled, the pressure in the fuel storage container may be allowed to increase, including in some cases to increase above the boil-off threshold pressure. The control system 700, the processing circuitry 760, and/or the venting control unit 708 are configured to, responsive to detecting that the pressure in the fuel storage container is at or above a boil-off threshold pressure, allow the pressure in the fuel storage container to remain at or above the boil-off threshold pressure or enable venting of the fuel storage container to reduce the pressure in the fuel storage container in dependence on whether or not the expected start time is within a time threshold interval.

[00143] The control system 700 may comprise **a fuel supplying control unit 710** configured to control supplying of the fuel from the fuel storage container of the fuel storage and supply system. The fuel may be supplied to an internal combustion engine or to a fuel cell system.

[00144] Allowing the pressure in the fuel storage container to remain at or above the boil-off threshold pressure may comprise allowing the pressure in the fuel storage container to exceed the boil-off threshold pressure. Additionally or alternatively, allowing the pressure in the fuel storage container to remain at or above the boil-off threshold pressure may comprise controlling the pressure in the fuel storage container to remain at or above the boil-off threshold pressure, e.g. not to exceed or only slightly exceed the boil-off threshold pressure. Accordingly, in some examples, the control system 700, the processing circuitry 760, and/or the venting control unit 708 may be configured to allow the pressure in the fuel storage container to exceed the boil-off threshold pressure responsive to determining that the expected start time is within a time threshold interval. In some examples, additionally or alternatively, the control system 700, the processing circuitry 760, and/or the fuel supplying control unit 710 may be configured to provide at least a portion of the pressure from the fuel storage container to at least one pressure-consuming device to thereby cause the pressure in the fuel storage container to remain at or above the boil-off threshold pressure.

[00145] In some examples, the control system 700, the processing circuitry 760, and/or the determining unit 706 may be configured to determine the time threshold interval. The time threshold interval may be determined based on a duration of time required for the pressure in the fuel storage container to decrease below the boil-off threshold pressure when the vehicle starts.

[00146] In some examples, the control system 700, the processing circuitry 760, and/or the determining unit 706 may be configured to determine whether the vehicle has started within the time threshold interval. This may be performed when it is predicted that the vehicle is expected to start within the time threshold interval. The vehicle may start within the time threshold interval as predicted, but in some cases the vehicle may not start within the time threshold interval. The control system 700, the processing circuitry 760, and/or the venting control unit 708 may be configured to enable venting of the fuel storage container. Thus, the control system may control the fuel storage and supply system to enable venting of the fuel storage container. For example, any of venting valves 18 (FIG. 1A), 28 (FIG. 1B), and 38 (FIG. 3) may be controlled to release some amount of boil-off gas from

the fuel storage container. The valves, or other components with a similar function, may be configured to release a predetermined amount of boil-off gas. In some examples, the amount of the released boil-off gas may vary e.g. in dependance on a difference between the current pressure in the fuel storage container and the boil-off threshold pressure. The amount of the released boil-off gas may vary depending on ambient factors such as, e.g., one or more out of an ambient temperature, heating from sunlight and pressure.

[00147] Those skilled in the art will appreciate that the units of the control system 700 described above may refer to a combination of analogue and digital circuits, and/or one or more processors or processing circuity configured with software and/or firmware, e.g., stored in the control system 700, that, when executed by the respective one or more processors, may perform the methods in accordance with examples of the present disclosure. One or more of these processors, as well as the other digital hardware, may be included in a single Application-Specific Integrated Circuitry (ASIC), or several processors and various digital hardware may be distributed among several separate components, whether individually packaged or assembled into a system-on-a-chip. Furthermore, the units of the control system 700 are shown in FIG. 7B included in the processing circuitry 760 as an example. Computer-executable instructions that may be executed by the processing circuitry 760 to cause the processing circuitry 760 to perform the method in accordance with examples of the present disclosure, such as to perform the processing performed by the units shown in FIG. 7B, may be stored in the memory 770.

[00148] The operational steps or acts described in any of the exemplary aspects herein are described to provide examples and discussion. The steps or acts may be performed by hardware components, may be embodied in machine-executable instructions to cause a processor to perform the steps, or may be performed by a combination of hardware and software. Although a specific order of method steps or acts may be shown or described, the order of the steps or acts may differ. In addition, two or more steps may be performed concurrently or with partial concurrence.

[00149] The terminology used herein is for the purpose of describing particular examples only and is not intended to be limiting of the disclosure. As used herein, the singular forms “a,” “an,” and “the” are intended to include the plural forms as well, unless the context clearly indicates otherwise. As used herein, the term “and/or” includes any and all combinations of one or more of the associated listed items. It will be further understood that the terms “comprises,” “comprising,” “includes,” and/or “including,” when used herein, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

[00150] It will be understood that, although the terms first, second, etc., may be used herein to describe various elements, these elements should not be limited by these terms. These terms are only used to distinguish one element from another. For example, a first element could be termed a second element, and, similarly, a second element could be termed a first element without departing from the scope of the present disclosure.

[00151] Relative terms such as “below” or “above” or “upper” or “lower” or “horizontal” or “vertical” may be used herein to describe a relationship of one element to another element as illustrated in the Figures. It will be understood that these terms and those discussed above are intended to encompass different orientations of the device in addition to the orientation depicted in the Figures. It will be understood that when an element is referred

to as being “connected” or “coupled” to another element, it can be directly connected or coupled to the other element, or intervening elements may be present. In contrast, when an element is referred to as being “directly connected” or “directly coupled” to another element, there are no intervening elements present.

[00152] Unless otherwise defined, all terms (including technical and scientific terms) used herein have the same meaning as commonly understood by one of ordinary skill in the art to which this disclosure belongs. It will be further understood that terms used herein should be interpreted as having a meaning consistent with their meaning in the context of this specification and the relevant art and will not be interpreted in an idealized or overly formal sense unless expressly so defined herein.

[00153] It is to be understood that the present disclosure is not limited to the aspects described above and illustrated in the drawings; rather, the skilled person will recognize that many changes and modifications may be made within the scope of the present disclosure and appended claims. In the drawings and specification, there have been disclosed aspects for purposes of illustration only and not for purposes of limitation, the scope of the inventive concepts being set forth in the following claims.

CLAIMS

What is claimed is:

1. A control system (700) for controlling a fuel storage system (10a, 10b, 12) configured to store a liquid fuel in a fuel storage container (30a, 30b, 30) of a vehicle (100a, 100b, 100) powered by the liquid fuel, the control system comprising processing circuitry configured to:

obtain a request for a shutdown of the vehicle;

obtain measurements of a pressure in the fuel storage container;

estimate an expected start time for the vehicle that is shut down; and

responsive to detecting that the pressure in the fuel storage container is at or above a boil-off threshold pressure,

allow the pressure in the fuel storage container to remain at or above the boil-off threshold pressure or enable venting of the fuel storage container to reduce the pressure in the fuel storage container in dependence on whether or not the expected start time is within a time threshold interval.

2. The control system (700) of claim 1, wherein the processing circuitry is configured to allow the pressure in the fuel storage container to exceed the boil-off threshold pressure responsive to determining that the expected start time is within a time threshold interval.

3. The control system (700) of claim 1 or 2, wherein the processing circuitry is configured to direct at least a portion of the pressure in the fuel storage container to at least one pressure-consuming device to thereby cause the pressure in the fuel storage container to remain at or above the boil-off threshold pressure.

4. The control system (700) of any one of claims 1 to 3, wherein the processing circuitry is configured to determine whether the vehicle has started within the time threshold interval.

5. The control system (700) of claim 4, wherein the processing circuitry is configured to, responsive to determining that the vehicle has not started within the time threshold interval, enable venting of the fuel storage container.

6. The control system (700) of any one of claims 1 to 5, wherein the processing circuitry is configured to estimate the time threshold interval based on a duration of time required for the pressure in the fuel storage container to decrease below the boil-off threshold pressure when the vehicle starts.

7. The control system (700) of any one of claims 1 to 6, wherein the expected start time is estimated using one or more out of a driver history, vehicle use history, timing data, vehicle location data, and vehicle power consumption data.

8. The control system (700) of any one of claims 1 to 7, wherein the expected start time for the vehicle is estimated using a prediction model.

9. A vehicle (100a, 100b, 100) comprising the control system (700) of any one of claims 1 to 8.

10. A method (400) for controlling a fuel storage system configured to store a liquid fuel in a fuel storage container of a vehicle powered by the liquid fuel, the method comprising:

obtaining (402) a request for a shutdown of the vehicle;

obtaining (404) measurements of a pressure in the fuel storage container;

estimating (406) an expected start time for the vehicle that is shut down; and

responsive to detecting (408) that the pressure in the fuel storage container is at or above a boil-off threshold pressure,

allowing (410) the pressure in the fuel storage container to remain at or above the boil-off threshold pressure or enabling venting of the fuel storage container to reduce the pressure in the fuel storage container in dependence on whether or not the expected start time is within a time threshold interval.

11. The method (400) of claim 10, comprising allowing (420) the pressure in the fuel storage container to exceed the boil-off threshold pressure responsive to determining that the expected start time is within a time threshold interval.

12. The method (400) of claim 10 or 11, comprising directing (422) at least a portion of the pressure in the fuel storage container from the fuel storage container to at least one pressure-consuming device to thereby cause the pressure in the fuel storage container to remain at or above the boil-off threshold pressure.

13. The method (400) of any one of claims 10 to 12, comprising determining (424) whether the vehicle has started within the time threshold interval.

14. The method (400) of claim 13, further comprising, responsive to determining that the vehicle has not started within the time threshold interval, enabling venting (416) of the fuel storage container.

15. The method (400) of any one of claims 10 to 14, comprising estimating (415) the time threshold interval based on a duration of time required for the pressure in the fuel storage container to decrease below the boil-off threshold pressure when the vehicle starts.

16. The method (400) of any one of claims 10 to 15, wherein the expected start time is estimated using one or more out of a driver history, vehicle use history, timing data, vehicle location data, and vehicle power consumption data.

17. The method (400) of any one of claims 10 to 16, wherein the expected start time for the vehicle is estimated using a prediction model.

18. The method (400) of any one of claims 10 to 17, wherein the liquid fuel is a fluid that is subject to boil-off.

19. A computer program product comprising instructions, which, when executed by processing circuitry, cause the processing circuitry to perform the method of any one of claims 10 to 18.

20. A computer-readable storage medium, having stored thereon a computer program product comprising computer-executable instructions which, when executed by processing circuitry, cause the processing circuitry to perform the method of any one of claims 10 to 18.

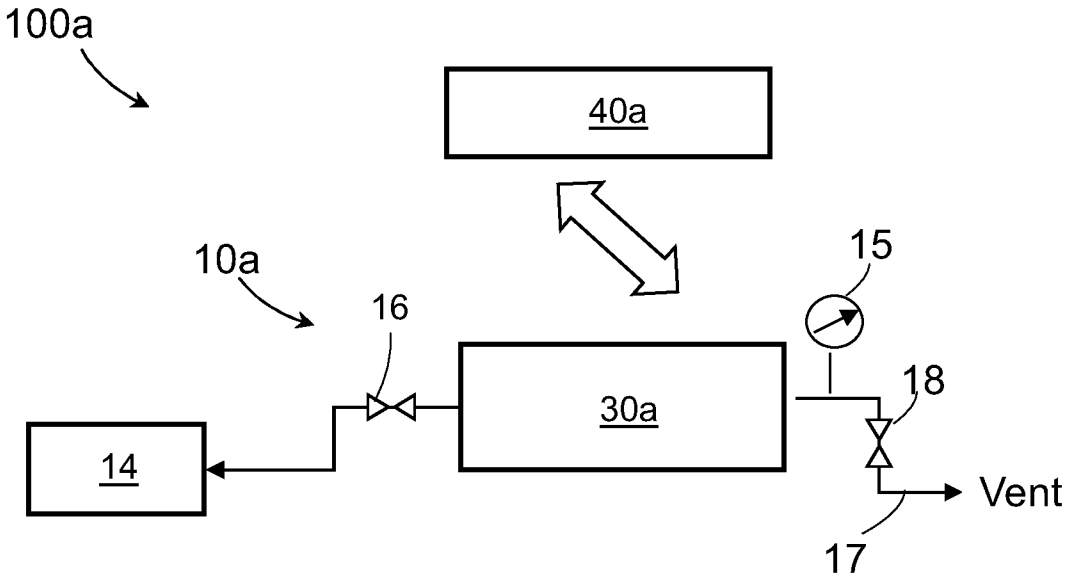

100a
40a
10a
16
15
18
30a
14
Vent
17

FIG. 1A

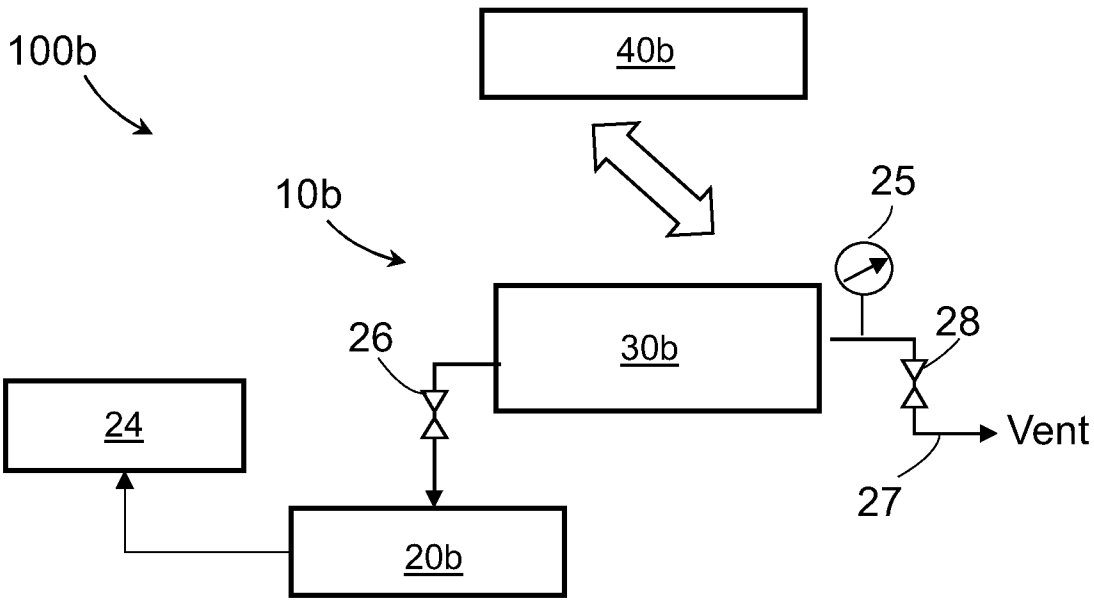

100b
40b
10b
25
26
30b
28
24
Vent
27
20b

FIG. 1B

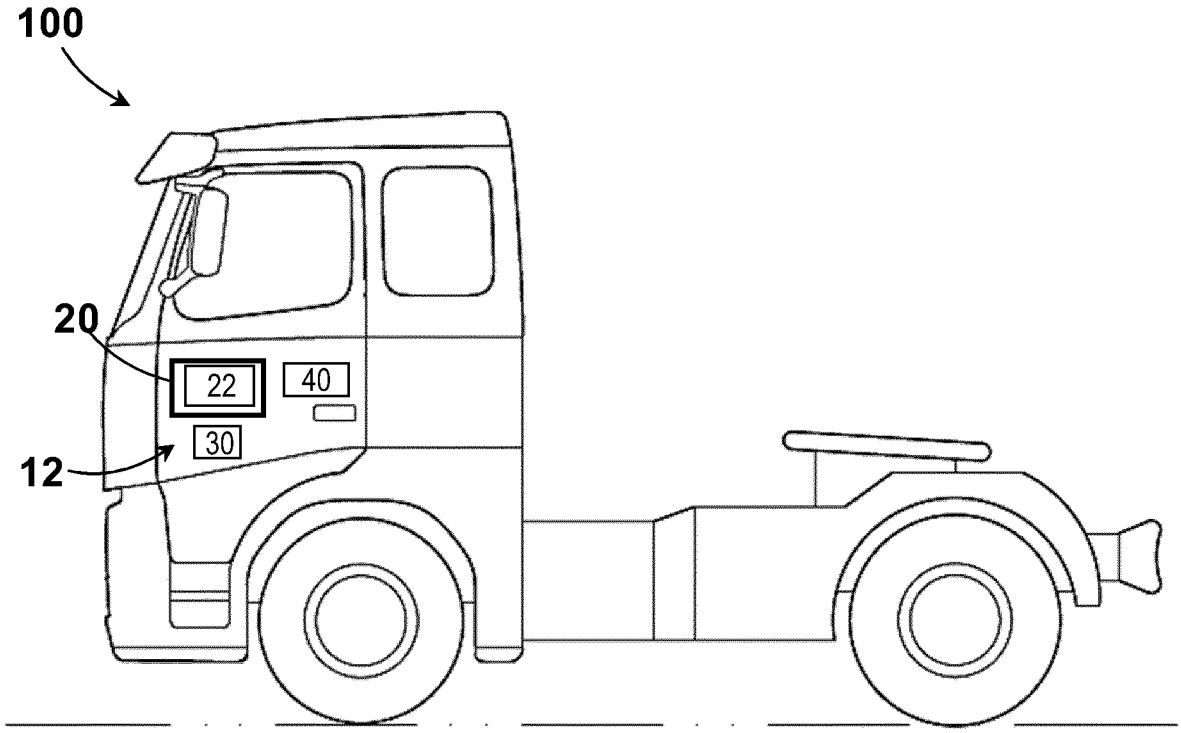


FIG. 2

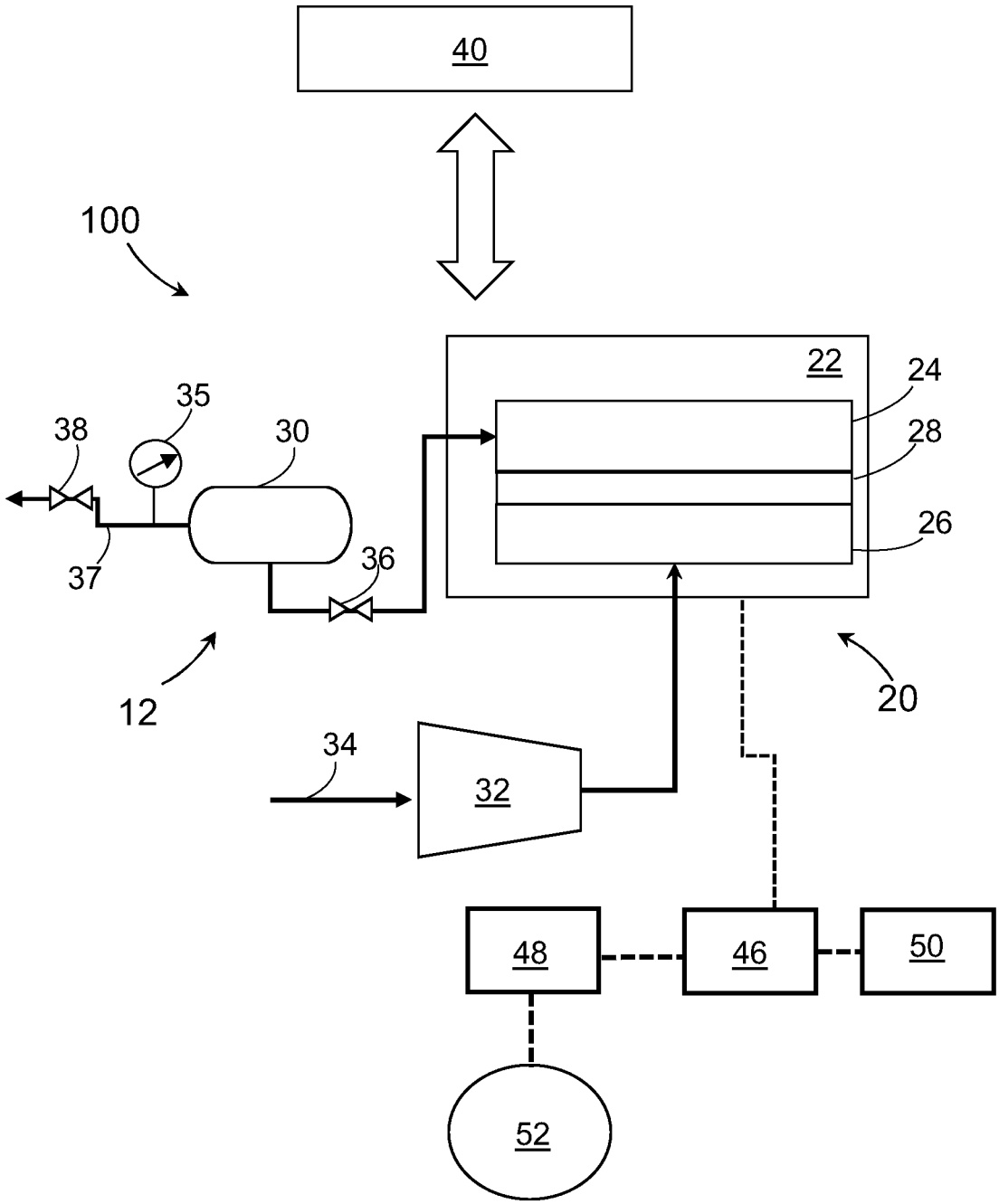


FIG. 3

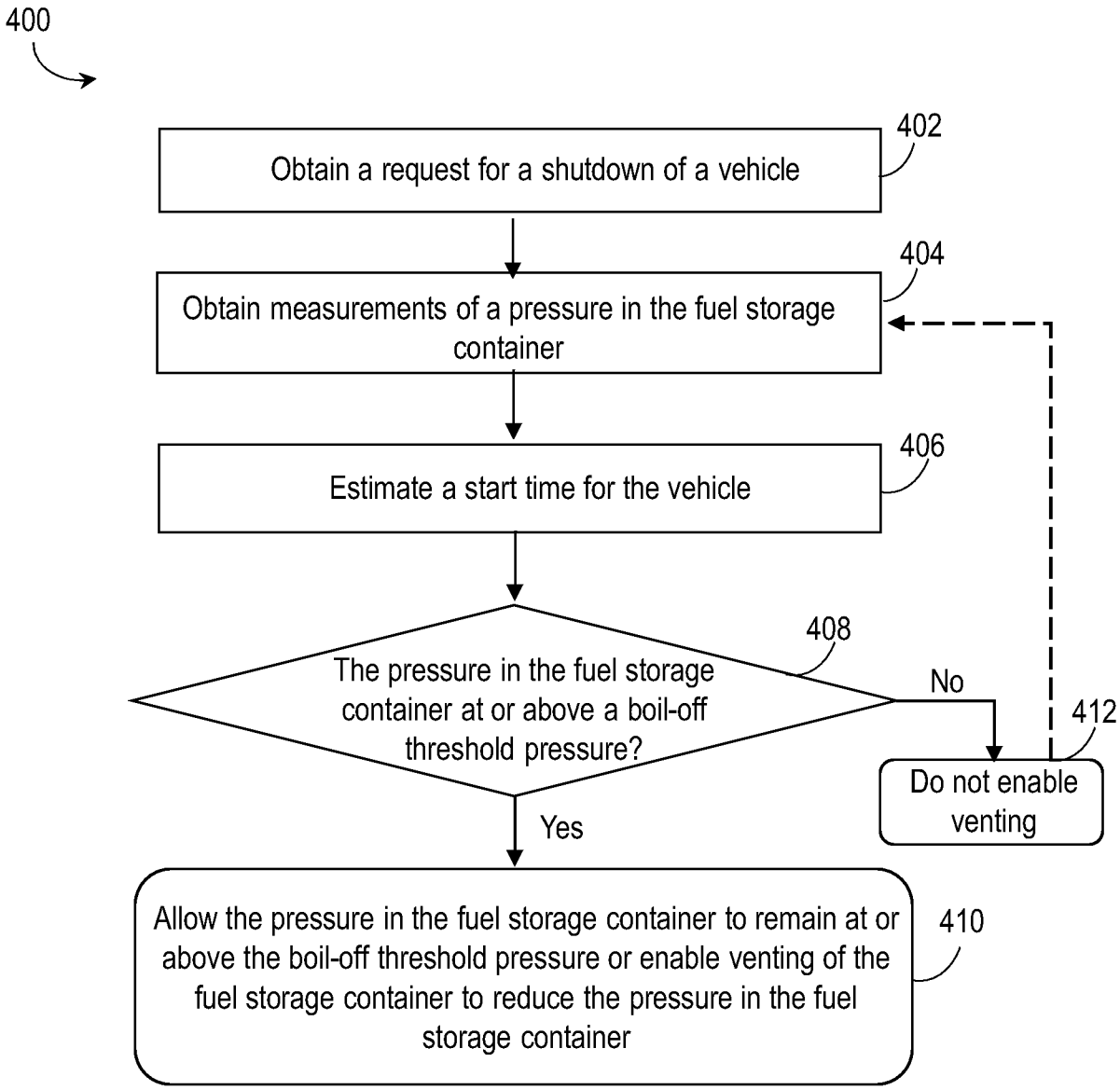

400
Obtain a request for a shutdown of a vehicle
402
Obtain measurements of a pressure in the fuel storage container
404
Estimate a start time for the vehicle
406
The pressure in the fuel storage container at or above a boil-off threshold pressure?
408
No
Yes
Do not enable venting
412
Allow the pressure in the fuel storage container to remain at or above the boil-off threshold pressure or enable venting of the fuel storage container to reduce the pressure in the fuel storage container
410

FIG. 4A

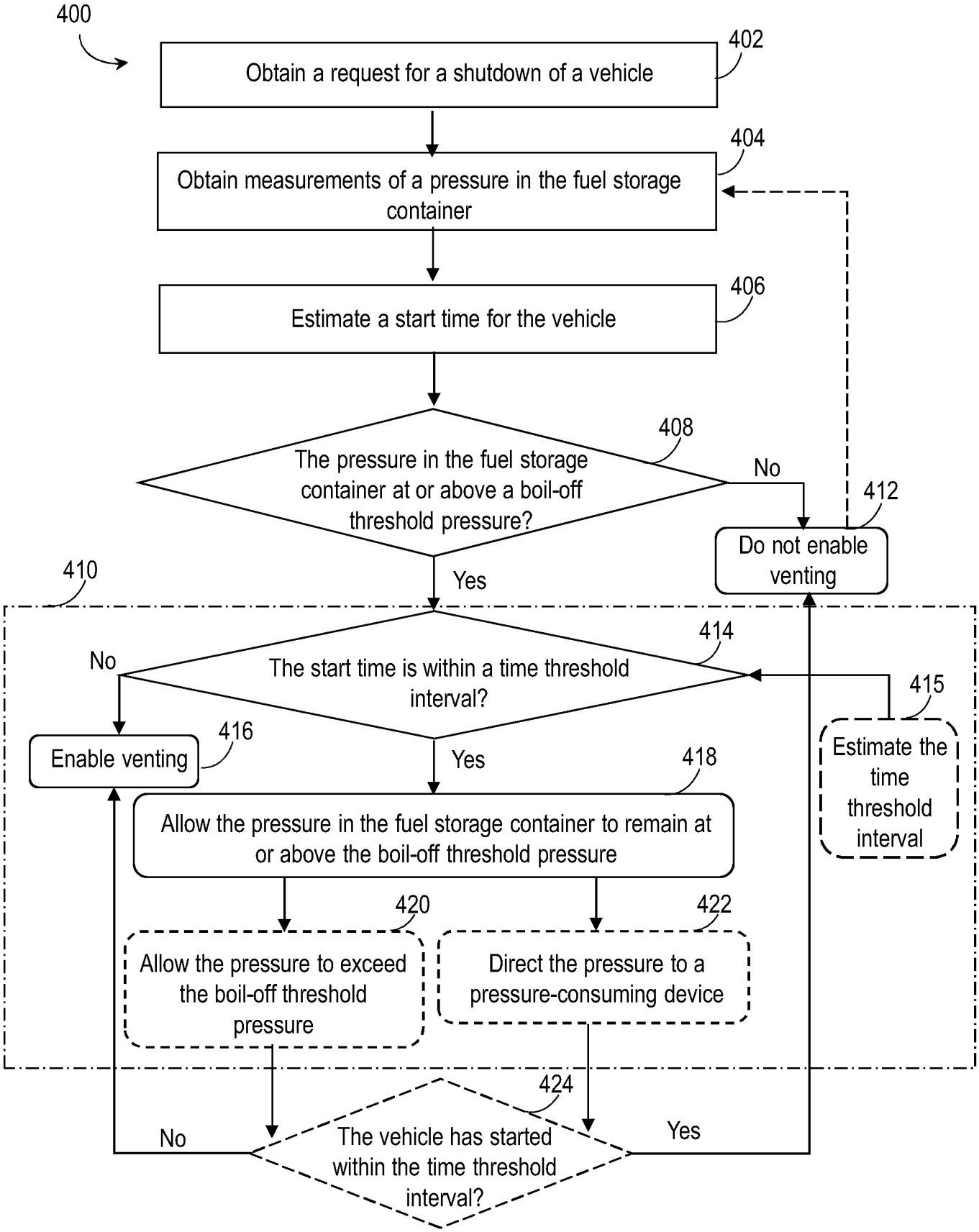

400
Obtain a request for a shutdown of a vehicle
402
Obtain measurements of a pressure in the fuel storage container
404
Estimate a start time for the vehicle
406
The pressure in the fuel storage container at or above a boil-off threshold pressure?
408
No
Yes
Do not enable venting
412
410
The start time is within a time threshold interval?
414
No
Yes
Enable venting
416
Estimate the time threshold interval
415
Allow the pressure in the fuel storage container to remain at or above the boil-off threshold pressure
418
Allow the pressure to exceed the boil-off threshold pressure
420
Direct the pressure to a pressure-consuming device
422
The vehicle has started within the time threshold interval?
424
No
Yes

FIG. 4B

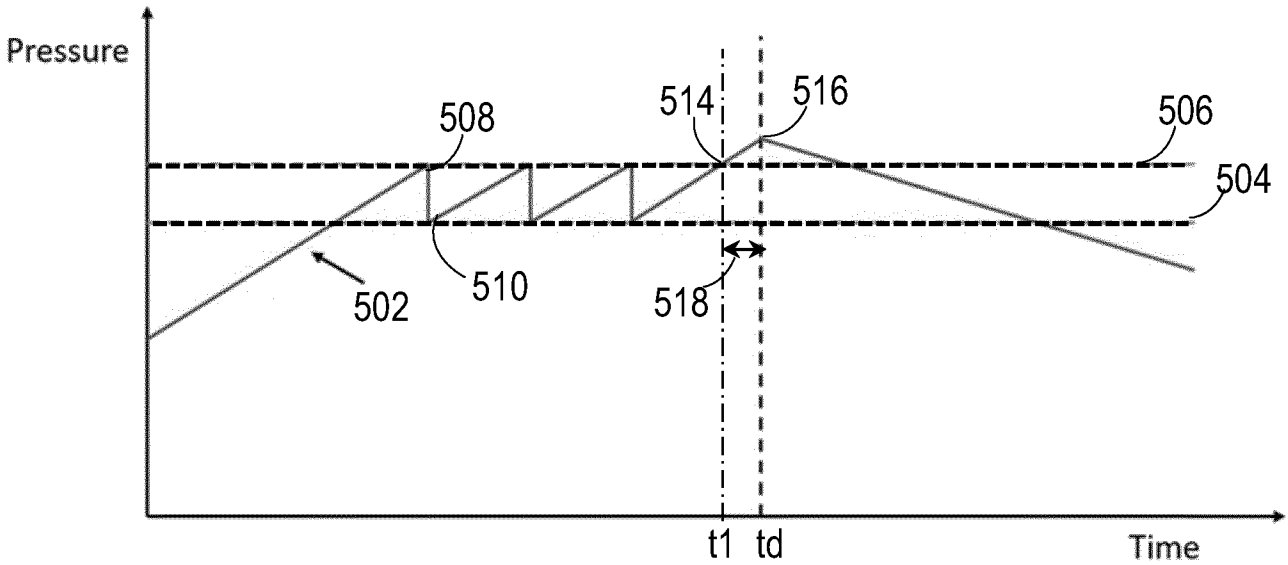

Pressure
508
514
516
506
504
502
510
518
t1
td
Time

FIG. 5

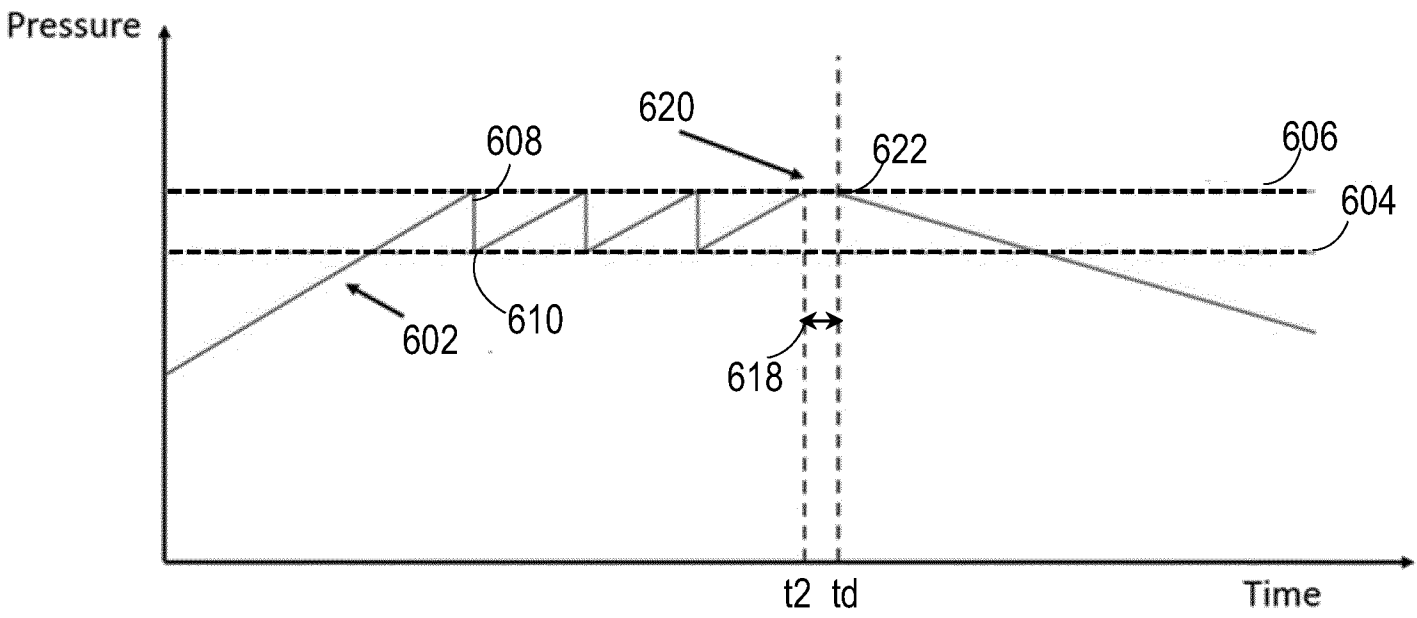

Pressure
620
608
622
606
604
602
610
618
t2
td
Time

FIG. 6

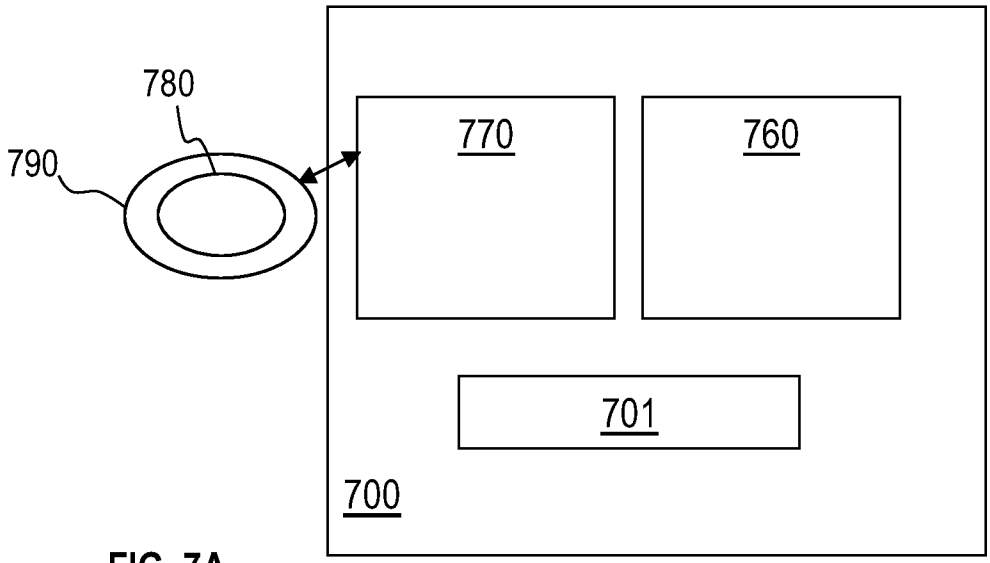


FIG. 7A

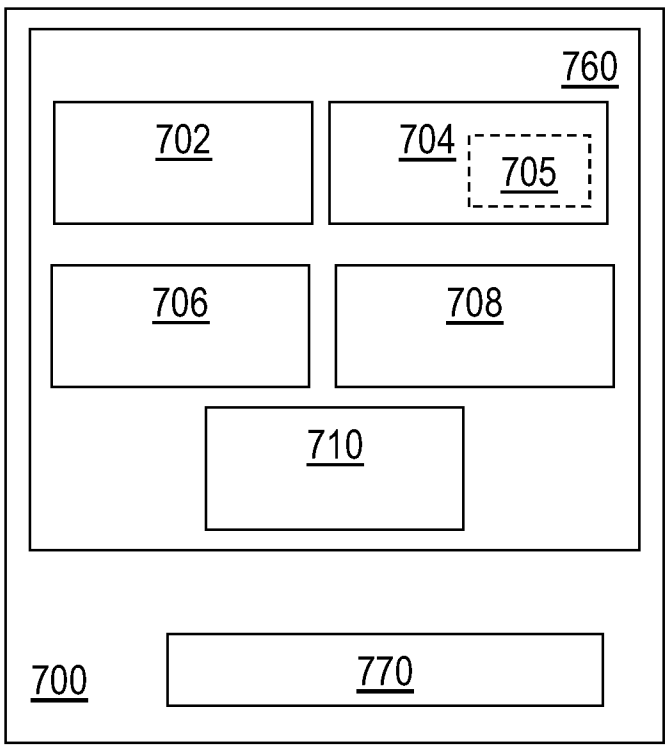


FIG. 7B

INTERNATIONAL SEARCH REPORT

International application No
PCT/EP2023/068751

A. CLASSIFICATION OF SUBJECT MATTER
INV. B60K15/03
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)
B60K

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

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2019/072055 A1 (HERZENJAK FLORIAN [DE]) 7 March 2019 (2019-03-07) paragraphs [0019], [0020]; figure 1	1-20
A	SE 1 851 232 A1 (SCANIA CV AB [SE]) 10 April 2020 (2020-04-10) page 8, lines 6-13; figure 1	1-20
A	DE 10 2018 209969 A1 (BOSCH GMBH ROBERT [DE]) 24 December 2019 (2019-12-24) paragraph [0007]; figure 1	1-20
A	CN 115 111 525 A (ZIDUNG ENERGY SYSTEMS PTE LTD) 27 September 2022 (2022-09-27) figures 1,3	1-20
A	US 2019/248228 A1 (WALLENGREN MÅRTEN [SE] ET AL) 15 August 2019 (2019-08-15) paragraph [0075]; figures 2a,3	1-20

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

☒ See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance;; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance;; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
13 February 2024	26/02/2024

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Eriksson, Jonas

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2023/068751

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