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(54) **Title:** BATTERY PACK SELECTION FOR PRE-CHARGING OF DC BUS

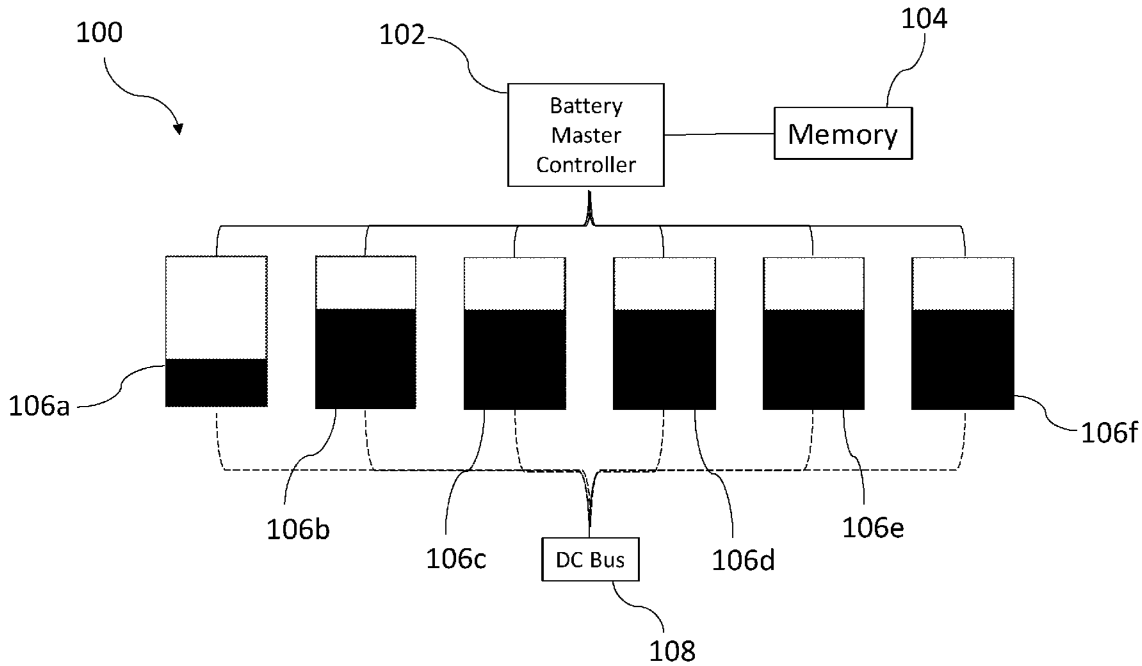

FIG. 1

(57) **Abstract:** The present disclosure provides a system and method for selecting a battery pack that is used to pre-charge a high-voltage DC bus of an electric vehicle. A round-robin architecture is disclosed that prevents repeat selection of battery packs in order to prevent burnout of a resistor of the battery pack resulting from rapid subsequent pre-charging events. The system and method provided includes an easy solution that is scalable to a system with any number of battery packs, does not require any additional hardware, and is an inexpensive technique to protect an expensive component of the electric vehicle.

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BATTERY PACK SELECTION FOR PRE-CHARGING OF DC BUS

TECHNICAL FIELD OF THE PRESENT DISCLOSURE

[0001] The present disclosure relates to the pre-charging of a DC bus in an electric or hybrid vehicle. More specifically, the present disclosure relates to a system and method of selecting a battery pack for pre-charging the DC bus of an electric or hybrid vehicle.

BACKGROUND OF THE PRESENT DISCLOSURE

[0002] In vehicles having multiple battery packs connected in a parallel configuration, pre-charging a high-voltage DC bus must be completed by at least one of the battery packs before any of the battery packs within the configuration can close their contactors to allow for vehicle operation. Each battery pack includes one pre-charge circuit comprising a resistor, which dissipates power through heat. As a result, overuse of a resistor causes the overused resistor to burnout.

[0003] Because each battery pack includes a single pre-charge circuit, using the same battery pack to pre-charge the high-voltage DC bus repeatedly in quick succession will damage the resistor, leading to an inoperable battery pack, which is expensive to replace and otherwise complicated to fix. This problem is particularly prevalent and significant in electric vehicles, especially where operator behavior determines how often pre-charging of the high-voltage DC bus will occur. For example, if the contactors in each battery pack must close with every key switch-on to operate the vehicle, the pre-charge of the high-voltage DC bus must occur with every key switch-on. To avoid premature resistor burnout and battery pack failure, solutions including additional hardware or software or hardware add-ons for individual battery packs have been proposed. However, these solutions are not ideal and improvements are desired.

SUMMARY OF THE PRESENT DISCLOSURE

[0004] The present disclosure provides a system and method for selecting a battery pack that is used to pre-charge a high-voltage DC bus of an electric vehicle. A round-robin architecture is disclosed that prevents repeat selection of battery packs in order to prevent burnout of a resistor of the battery pack resulting from rapid subsequent pre-charging events.

The system and method provided includes an easy solution that is scalable to a system with any number of battery packs, does not require any additional hardware, and is an inexpensive technique to protect an expensive component of the electric vehicle.

[0005] In an embodiment of the present disclosure, a system for selecting a battery pack of a vehicle is disclosed. The system comprises a plurality of battery packs connected to each other in parallel; a controller operably coupled to the plurality of battery packs; a memory operably coupled to the controller; and a DC bus operably coupled to the plurality batter packs so that at least one of the plurality of battery packs is configured to selectively pre-charge the DC bus in a DC bus pre-charge event. The controller is configured to assemble a queue according to usage of the plurality of battery packs to pre-charge the DC bus and save the queue to the memory for subsequent usage.

[0006] A head of the queue may include a battery pack of the plurality of battery packs having a lowest state-of-charge than the remaining battery packs. The controller may be configured to receive a saved queue from the memory for a subsequent DC bus pre-charge event. The controller may be configured to receive a health index of any of one battery pack of the plurality of battery packs to determine if any one battery pack of the plurality of battery packs is faulty. A different queue may be assembled after every DC bus pre-charge event relative to an immediately previously used queue.

[0007] In another embodiment of the present disclosure, a method for selecting a battery pack for a vehicle is disclose, the method comprising retrieving a queue from a memory; requesting an identification of a battery pack positioned at a head of a queue; instructing the identified battery pack to complete pre-charge of a DC bus; and pushing the identified battery pack to a tail of the queue to create a second queue.

[0008] The method may further comprise determining whether the pre-charge of the Dc bus was successfully completed. When the pre-charge of the DC bus is not successfully completed, the method may further comprise requesting a second identification of a second battery pack positioned at a head of the second queue; instructing the second battery pack to complete pre-charge of the DC bus; determining whether pre-charge of the DC bus was successfully completed; pushing the second battery pack to a tail of the second queue to create a third queue; and repeating until the pre-charge of the DC bus is successfully completed. When the pre-charge of the DC bus is successfully completed, the method may further comprise initiating operation of the vehicle.

[0009] The method may further comprise reviewing a health index of the identified battery pack prior to instructing the identified battery pack to complete pre-charge of the DC bus to determine whether the identified battery pack is faulty. When the battery pack is faulty, the method may further comprise requesting a second identification of a second battery pack positioned at a head of the second queue; reviewing a health index of the second battery pack; and determining whether the second battery pack is faulty. When the second battery pack is faulty, the method may further comprise pushing the second battery pack to a tail of the second queue to create a third queue and repeating until an operable battery pack is identified. When the identified battery pack is operable, the method may further comprise initiating vehicle operation after the pre-charge of the DC bus is completed.

[0010] In yet another embodiment of the present disclosure, a method for selecting a battery pack for a vehicle is disclosed, the method comprising: identifying a battery pack of a plurality of battery packs having a lowest state-of charge than the remaining battery packs; instructing the identified battery pack to pre-charge a DC bus; storing the identified battery pack within a memory; creating a queue, wherein the identified battery pack is positioned at a head of the queue; and pushing the identified battery pack to a tail of the queue to create a subsequent queue. The method may further comprise reviewing a health index of the identified battery pack to determine whether the identified battery pack is faulty.

[0011] Additional features and advantages of the present disclosure will become apparent to those skilled in the art upon consideration of the following detailed description of the illustrative embodiments exemplifying the disclosure as presently perceived.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The detailed description of the drawings particularly refers to the accompanying figures in which:

[0013] FIG. **1** illustrates an exemplary system of the present disclosure for pre-charging a high-voltage DC bus, the system including a plurality of battery packs connected in parallel, a controller, and a memory;

[0014] FIG. **2** illustrates an exemplary method of the present disclosure for selecting a battery pack from a plurality of battery packs connected in parallel to complete pre-charge of a high-voltage DC bus during a first vehicle operation initiation by a user;

[0015] FIG. **3** illustrates exemplary queues for selecting a battery pack from a plurality of battery packs connected in parallel;

[0016] FIG. **4A** illustrates an exemplary method of the present disclosure for selecting a battery pack from a plurality of battery packs connected in parallel to complete pre-charge of a high-voltage DC bus during subsequent vehicle operation initiations by the user;

[0017] FIG. **4B** illustrates another embodiment of the exemplary method of FIG. **4A**;

[0018] FIG. **5A** illustrates another exemplary method of the present disclosure for selecting a battery pack from a plurality of battery packs connected in parallel to complete pre-charge of a high-voltage DC bus during subsequent vehicle operation initiations by the user, wherein a controller reviews a health index of each battery pack of the plurality of battery packs;

[0019] FIG. **5B** illustrates another embodiment of the exemplary method of FIG. **5B**.

[0020] Corresponding reference characters indicate corresponding parts throughout the several views. Although the drawings represent embodiments of various features and components according to the present disclosure, the drawings are not necessarily to scale, and certain features may be exaggerated in order to better illustrate and explain the present disclosure. The exemplification set out herein illustrates an embodiment of the invention, and such an exemplification is not to be construed as limiting the scope of the invention in any manner.

DETAILED DESCRIPTION OF THE DRAWINGS

[0021] Referring initially to FIG. **1**, a system **100** of a vehicle is disclosed. The system **100** includes a battery master controller **102**, a non-volatile memory **104**, and a plurality of battery packs **106**, wherein the battery packs **106** are illustratively connected in a parallel configuration. Although the illustrated embodiment discloses six battery packs **106**, the method and system described herein is scalable and can be applied to a vehicle with any number of battery packs **106**. The battery packs **106** may have varying levels of state-of-charge percentages. For example, as shown, battery pack **106a** may have a lower state-of-charge percentage than battery pack **106b**. Any battery pack **106** may have a lower, higher, or equal state-of-charge percentage relative to any other battery pack **106**.

[0022] The battery packs **106** are operably connected with the battery master controller **102** and selectively operably connected with a high-voltage DC bus **108**, wherein the battery master controller **102** can communicate with each respective battery pack **106** to initiate pre-charge of the DC bus **108** using a selected battery pack **106** as discussed further herein. The battery master controller **102** may further communicate with each respective battery pack **106** to control the closing of contactors of the battery packs **106** for operation of the vehicle once pre-charge of the high-voltage DC bus **108** is complete. The battery master controller **102** is also operably connected to the memory **104** to store pre-charge events as discussed further herein.

[0023] Now referring to FIG. **2**, in view of the components disclosed in FIG. **1**, a method **200** for initiating a first DC bus pre-charge event is disclosed. At box **202**, a user initiates operation of a vehicle. The user may initiate the pre-charge event using any method known in the art to initiate operation of a vehicle. For example, the user may utilize a switch, button, key-on using a standard key, remote start mechanism, use of a smart device application, use of a smart assistant, Bluetooth, key card, fingerprint identification, digital key, voice start, application of the Internet of things, or other mechanisms to initiate the pre-charge event. Before operation of the vehicle occurs, the DC bus **108** must be pre-charged using one of the plurality of battery packs **106**.

[0024] After user initiation at box **202**, the controller **102** identifies the battery pack **106** having the lowest state-of-charge percentage at box **204**. For example, referring briefly to FIG. **1**, the controller **102** chooses battery pack **106a**, as battery pack **106a** has the lowest state-of-charge percentage among the battery packs **106**. Referring again to FIG. **2** in view of the components disclosed in FIG. **1**, the controller **102** then sends instructions to the selected battery pack **106a** at box **206** to pre-charge the DC bus **108** during the DC bus pre-charge event indicated at box **208**. At any point after battery pack **106** selection at box **204**, the controller **102** stores the identity of the pack **106a** within the memory **104** to track the completion of the pre-charge event at box **210**. At box **212**, at any point after battery pack **106** selection at box **204** the controller **102** additionally creates a queue **302** (FIG. **3**), which is stored in the memory **104** as indicated by box **212**. Once the pre-charge event is completed, vehicle operation is initiated at box **214**. Ideally, the contactors of the remaining battery packs **106** are closed to allow full vehicle operation at box **214**.

[0025] However, such contactors are only closed upon determination by the controller **102** that the remaining battery packs **106** are operable as further discussed herein. In some instances, any number of battery packs **106** fewer than the remaining battery packs **106** may be determined by the controller **102** to be non-operable. If any battery packs **106** are considered non-operable, the contactors of only the operable battery packs **106** are closed for vehicle operation. In the event less than all of the battery packs **106** are operable, the vehicle operates at a performance percentage corresponding to the percentage of battery packs **106** that are operable.

[0026] FIG. **3** illustrates a round robin architecture **300**, including the mentioned queue **302** and additional queues **304**, **306** that are generated with repeat instances of user initiation. For example, referring to FIGS. **1-3**, after the controller **102** chooses the battery pack **106** having the lowest state-of-charge percentage (i.e. battery pack **106a**) at box **204** of the method **200**, the controller **102** generates the queue **302** as mentioned above. Because battery pack **106a** is the first selected battery pack, battery pack **106a** is initially positioned at the head **308** of the queue **302**. Upon pre-charge of the DC bus **108**, the controller **102** instructs the memory **104** to move the battery pack **106a** is to the tail **310** of the queue, as shown by queue **304**, to avoid immediate repeat use of the battery pack **106a** with the next user initiation. For example, if the memory **104** has queue **304** stored for use upon next user initiation, the next user initiation will cause the controller **102** to instruct the battery pack **106b** to pre-charge the DC bus. Upon pre-charge of the DC bus **108**, the controller **102** instructs the memory to move the battery pack **106b** to the tail **310** of the queue, as shown by queue **306**, to avoid immediate repeat use of the battery pack **106b** with the next user initiation. The controller **102** continues to instruct the battery pack **106** at the head **308** of the queue in such a matter until all battery packs **106** have been utilized for a DC bus pre-charge event. At that period, the queue restarts and battery pack **106a** is again selected.

[0027] Now referring to FIG. **4A** in view of the components of FIGS. **1** and **3**, a method **400** is provided for completing subsequent DC bus pre-charge events, following the initial DC bus pre-charge event method **200** of FIG. **2**. In other words, method **200** is used for the first user initiation of a vehicle, i.e. first vehicle use, first vehicle use after a system reset, first vehicle use after a component of the system has been replaced, or any other instance in which a queue is not saved to memory. After the completion of method **200**, subsequent user initiation events cause initiation of method **400** of FIG. **4A** until circumstances require a system reset or other event which dictates the use of method **200**.

[0028] Method **400** begins at box **402**, when a user initiates operation of a vehicle. User initiation may occur in any of the ways discussed herein in reference to method **200**. After user initiation at box **402**, the controller **102** retrieves the queue (i.e. any of queues **302, 304, 306** or another, subsequent queue) from the memory **104** at box **404**. Identification of the battery pack **106** at the head **308** of the queue is also requested at box **406**. Once the proper battery pack **106** has been identified at box **404**, the controller **102** instructs the respective battery pack **106** to complete pre-charge of the DC bus **108** at box **408**. After a predetermined period of time in which the pre-charge event should be completed, the controller **102** determines whether the pre-charge of the DC bus **108** has been completed at box **410**.

[0029] If the pre-charge event has been completed at box **410**, the battery pack **106** used during the pre-charge event is pushed to the tail **310** of the queue at box **412**, and the resulting queue is saved to the memory **104** at box **416**. If the pre-charge event has not been completed at box **410**, a pre-charge error has occurred and the faulty battery pack **106** is pushed to the tail **310** of the queue at box **414**. The resulting queue is saved to the memory **104** at box **416** and the method **400** restarts at box **404** until the pre-charge event is successfully completed. Once the pre-charge event is successfully completed, the contactors of the remaining operable battery packs **106** are closed to allow vehicle operation at box **418** as discussed above.

[0030] In some embodiments, as shown by FIG. **4B**, a method **400b** may be utilized. Method **400b** is substantially the same as method **400** illustrated by FIG. **4A**, with the exceptions described herein. In method **400b**, if the pre-charge event has not been completed at box **410**, the processor **102** may immediately retrieve identification of the next battery pack **106** at box **406b**, which simultaneously pushes the faulty battery pack **106** to the tail **310** of the queue as shown at box **414**. The method **400b** repeats until the pre-charge event is successfully completed at box **410**. Once the pre-charge event is successfully completed, the battery pack **106** used during the pre-charge event is pushed to the tail **310** of the queue at box **412**, and the resulting queue is saved to memory at box **416**. The contactors of the remaining operable battery packs **106** are closed to allow vehicle operation at box **418** as discussed above. Utilization of method **400b** may result in greater efficiency when pre-charging the DC bus of the vehicle.

[0031] In some embodiments, the controller **102** may pre-emptively identify any battery pack issues before the pre-charge event is initiated to avoid pre-charge failure. For example, referring to FIG. **5A** in view of the components of FIGS. **1** and **3**, method **500** is provided for completing subsequent DC bus pre-charge events, following the initial DC bus pre-charge event method **200** of FIG. **2**, wherein the controller **102** conducts a review of the battery pack health index of the selected battery pack **106** before initiating the pre-charge of the DC bus.

[0032] Method **500** begins with a user initiation at box **502**, wherein the user initiation **502** is similar to the user initiation **402** of method **400** and user initiation **202** of method **200**. At box **504**, the controller **102** retrieves the pre-charge queue (i.e. any of queues **302, 304, 306** or another, subsequent queue) from the memory **104** and further requests the identification of the battery pack **106** at the head **308** of the queue. The controller **102** then conducts a review of the health index of the identified battery pack **106** at box **506**. If the identified battery pack **106** is determined to be faulty at box **508**, the identified battery pack **106** is pushed to the tail **310** of the queue at box **510**, resulting in a subsequent queue that is saved to the memory **104** at box **516**. The method **500** then restarts at box **504** until the pre-charge event is successfully completed as described further herein.

[0033] If the identified battery pack **106** is determined not to be faulty at box **508**, the controller **102** instructs the identified battery pack **106** to complete the pre-charge of the DC bus at box **512**. The battery pack **106** is then pushed to the tail **310** of the queue at box **514**, resulting in a subsequent queue that is saved to the memory **104** at box **516**. Once the pre-charge event is successfully completed, the contactors of the remaining operable battery packs **106** are closed to allow vehicle operation at box **518** as discussed above.

[0034] In some embodiments, as shown by FIG. **5B**, a method **500b** may be utilized. Method **500b** is substantially the same as method **500** illustrated by FIG. **5A**, with the exceptions described herein. In method **500b**, if the battery pack has been identified as faulty at box **508**, the processor **102** may immediately retrieve identification of the next battery pack **106** at box **505b**, which simultaneously pushes the faulty battery pack **106** to the tail **310** of the queue as shown at box **510**. The method **500b** repeats until an operable battery pack **106** is identified at box **508**. Once an operable battery pack is identified, the remainder of method **500b** follows the same steps as method **500** as discussed above.

[0035] While the invention has been described by reference to various specific embodiments it should be understood that numerous changes may be made within the spirit and scope of the inventive concepts described, accordingly, it is intended that the invention not be limited to the described embodiments but will have full scope defined by the language of the following claims.

WHAT IS CLAIMED IS:

1. A system for selecting a battery pack of a vehicle, the system comprising:
a plurality of battery packs connected to each other in parallel;
a controller operably coupled to the plurality of battery packs;
a memory operably coupled to the controller; and
a DC bus operably coupled to the plurality of battery packs, so that at least one of the plurality of battery packs is configured to selectively pre-charge the DC bus in a DC bus pre-charge event;
wherein the controller is configured to assemble a queue according to usage of the plurality of battery packs to pre-charge the DC bus, the queue saved to the memory for subsequent usage.

2. The system of claim 1, wherein a head of the queue includes a battery pack of the plurality of battery packs having a lowest state-of-charge than the remaining battery packs.

3. The system of claim 1, wherein the controller is configured to receive a saved queue from the memory for a subsequent DC bus pre-charge event.

4. The system of claim 1, wherein the controller is configured to receive a health index of any of one battery pack of the plurality of battery packs to determine if any one battery pack of the plurality of battery packs is faulty.

5. The system of claim 1, wherein a different queue is assembled after every DC bus pre-charge event relative to an immediately previously used queue.

6. A method for selecting a battery pack for a vehicle, the method comprising:
retrieving a queue from a memory;
requesting an identification of a battery pack positioned at a head of a queue;
instructing the identified battery pack to complete pre-charge of a DC bus;
pushing the identified battery pack to a tail of the queue to create a second queue; and

saving the second queue to the memory.

7. The method of claim 6, further comprising determining whether the pre-charge of the DC bus was successfully completed.

8. The method of claim 7, wherein the pre-charge of the DC bus is not successfully completed, further comprising:

retrieving the second queue from the memory;

requesting a second identification of a second battery pack positioned at a head of the second queue;

instructing the second battery pack to complete pre-charge of the DC bus;

determining whether the pre-charge of the DC bus was successfully completed;

pushing the second battery pack to a tail of the second queue to create a third queue;

saving the third queue to memory; and

repeating until the pre-charge of the DC bus is successfully completed.

9. The method of claim 7, wherein the pre-charge of the DC bus is successfully completed, further comprising initiating operation of the vehicle.

10. The method of claim 6, further comprising reviewing a health index of the identified battery pack prior to instructing the identified battery pack to complete pre-charge of the DC bus to determine whether the identified battery pack is faulty.

11. The method of claim 10, wherein the identified battery pack is faulty, further comprising:

requesting a second identification of a second battery pack positioned at a head of the second queue;

reviewing a health index of the second battery pack; and

determining whether the second battery pack is faulty.

12. The method of claim 11, wherein the second battery pack is faulty, further comprising: pushing the second battery pack to a tail of the second queue to create a third queue and repeating until an operable battery pack is identified.

13. The method of claim 10, wherein the identified battery pack is operable, further comprising initiating vehicle operation after the pre-charge of the DC bus is completed.

14. A method for selecting a battery pack for a vehicle, the method comprising:

identifying a battery pack of a plurality of battery packs having a lowest state-of-charge than the remaining battery packs;

instructing the identified battery pack to pre-charge a DC bus;

storing the identified battery pack within a memory;

creating a queue, wherein the identified battery pack is positioned at a head of the queue; and

pushing the identified battery pack to a tail of the queue to create a subsequent queue.

15. The method of claim 14, further comprising reviewing a health index of the identified battery pack to determine whether the identified battery pack is faulty.

16. A controller of a vehicle operably coupled to a plurality of battery packs, the controller configured to:

assemble a queue according to usage of the plurality of battery packs;

identify a battery pack positioned at a head of the queue;

instruct an identified battery pack to complete pre-charge of a DC bus; and

push the identified battery pack to a tail of the queue to create a second queue.

17. The controller of claim 16, wherein the controller is further configured to determine whether the pre-charge DC bus was successfully completed.

18. The controller of claim 17, wherein the pre-charge of the DC bus is not successfully completed and the controller is further configured to identify a second battery pack at a head of the second queue.

19. The controller of claim 16, wherein the controller is further configured to review a health index of the identified battery pack prior to instructing the identified battery pack to complete pre-charge of the DC bus to determine whether the identified battery pack is faulty.

20. The controller of claim 16, wherein the controller is further configured to identify a single battery pack of the plurality of battery packs having the lowest state-of-charge and place the single battery pack at the head of the queue.

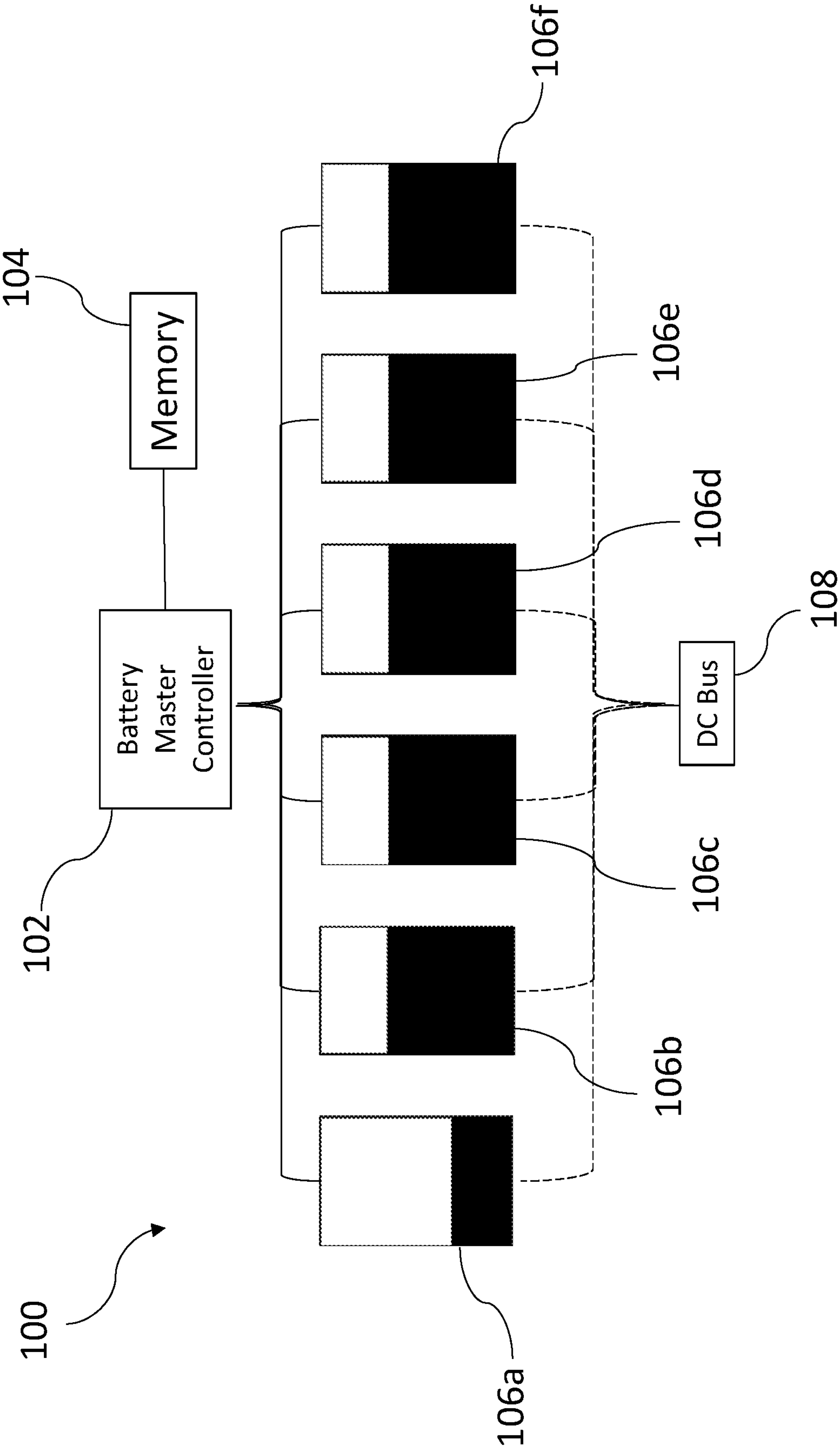
100
102
104
Memory
Battery Master Controller
106a
106b
106c
106d
106e
106f
108
DC Bus

FIG. 1

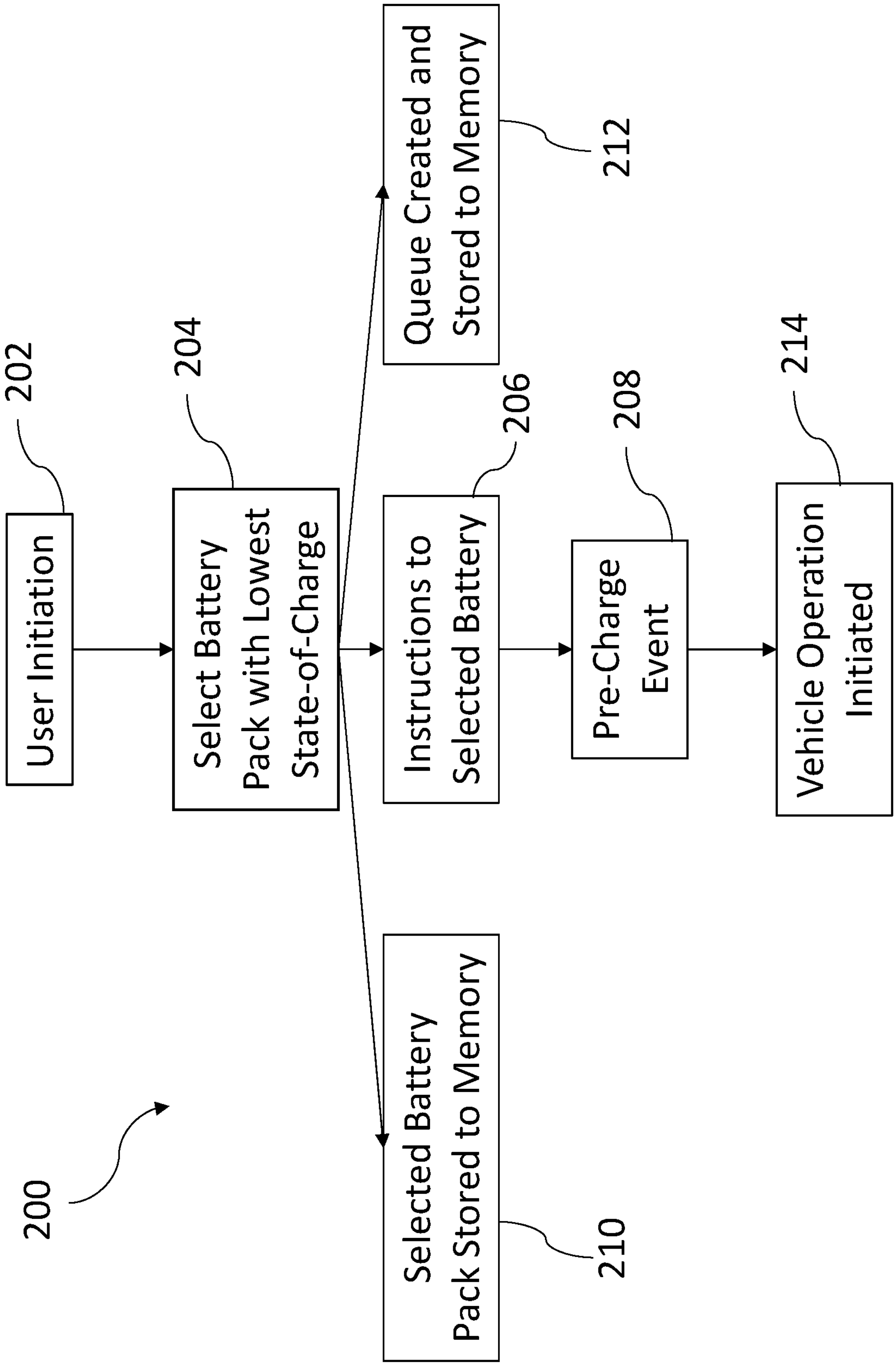
200
202
User Initiation
204
Select Battery Pack with Lowest State-of-Charge
206
Instructions to Selected Battery
208
Pre-Charge Event
214
Vehicle Operation Initiated
212
Queue Created and Stored to Memory
210
Selected Battery Pack Stored to Memory

FIG. 2

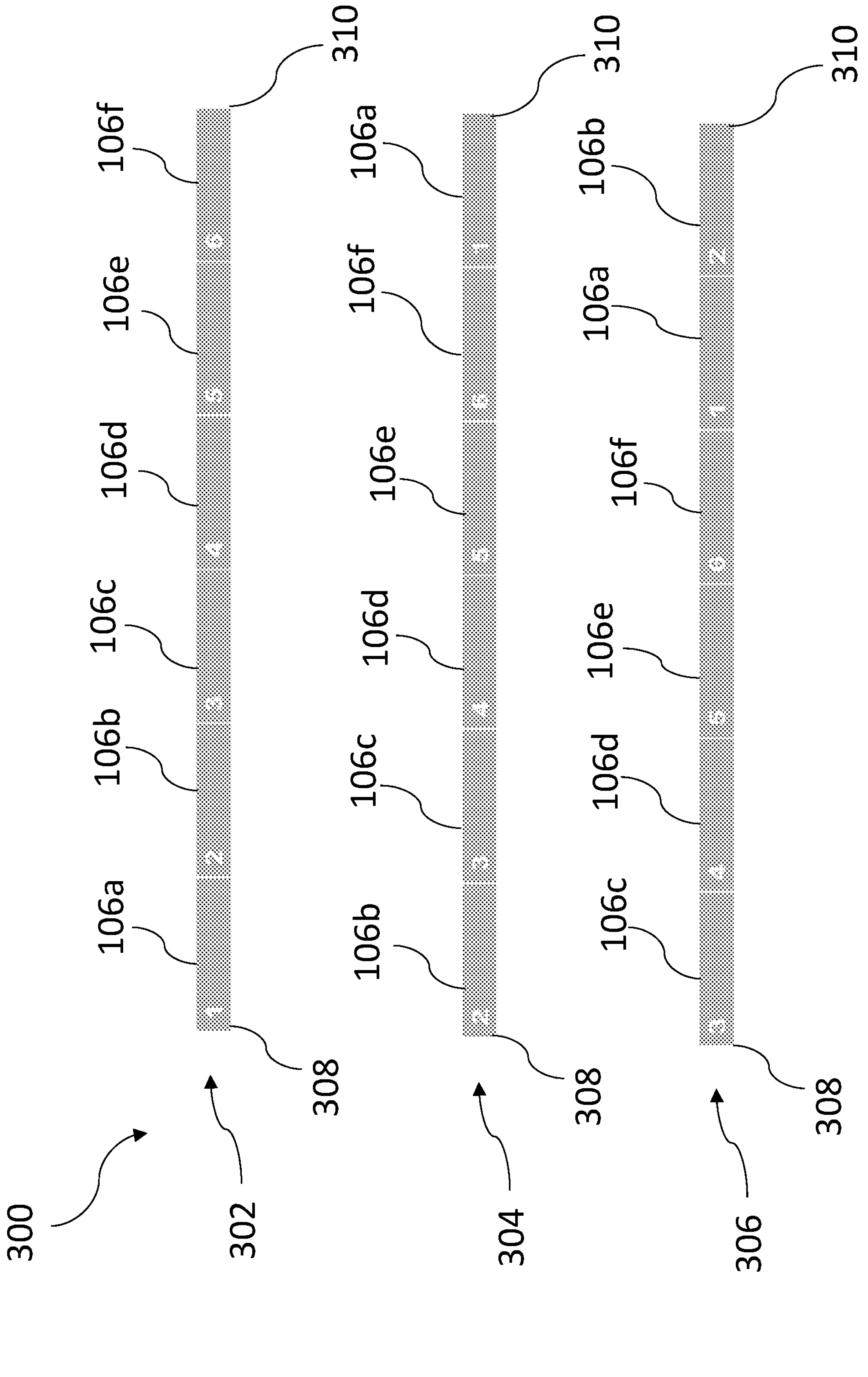

FIG. 3

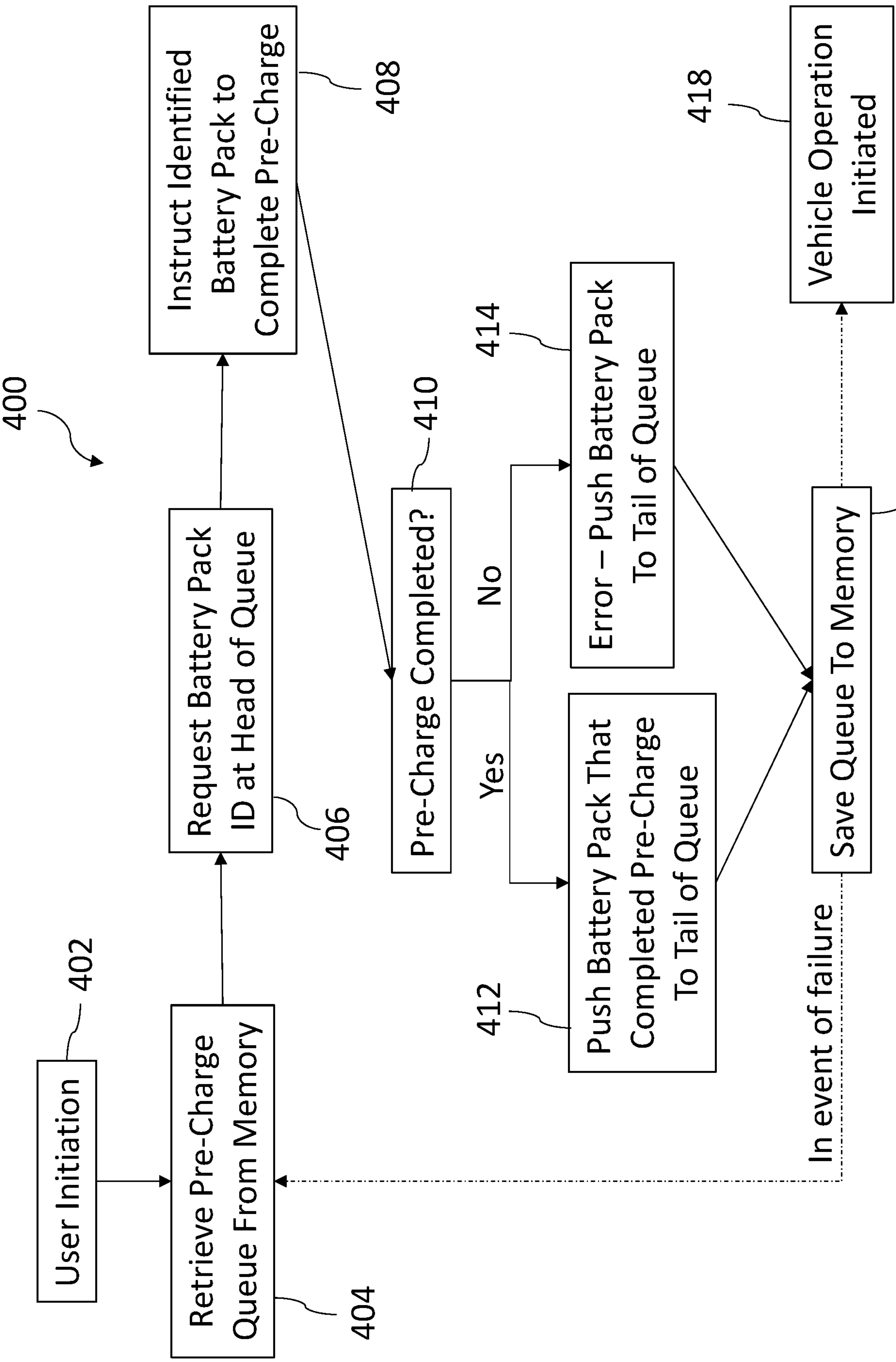
400
User Initiation
402
Retrieve Pre-Charge Queue From Memory
404
Request Battery Pack ID at Head of Queue
406
Instruct Identified Battery Pack to Complete Pre-Charge
408
Pre-Charge Completed?
410
Yes
No
Push Battery Pack That Completed Pre-Charge To Tail of Queue
412
Error – Push Battery Pack To Tail of Queue
414
Save Queue To Memory
416
In event of failure
Vehicle Operation Initiated
418

FIG. 4A

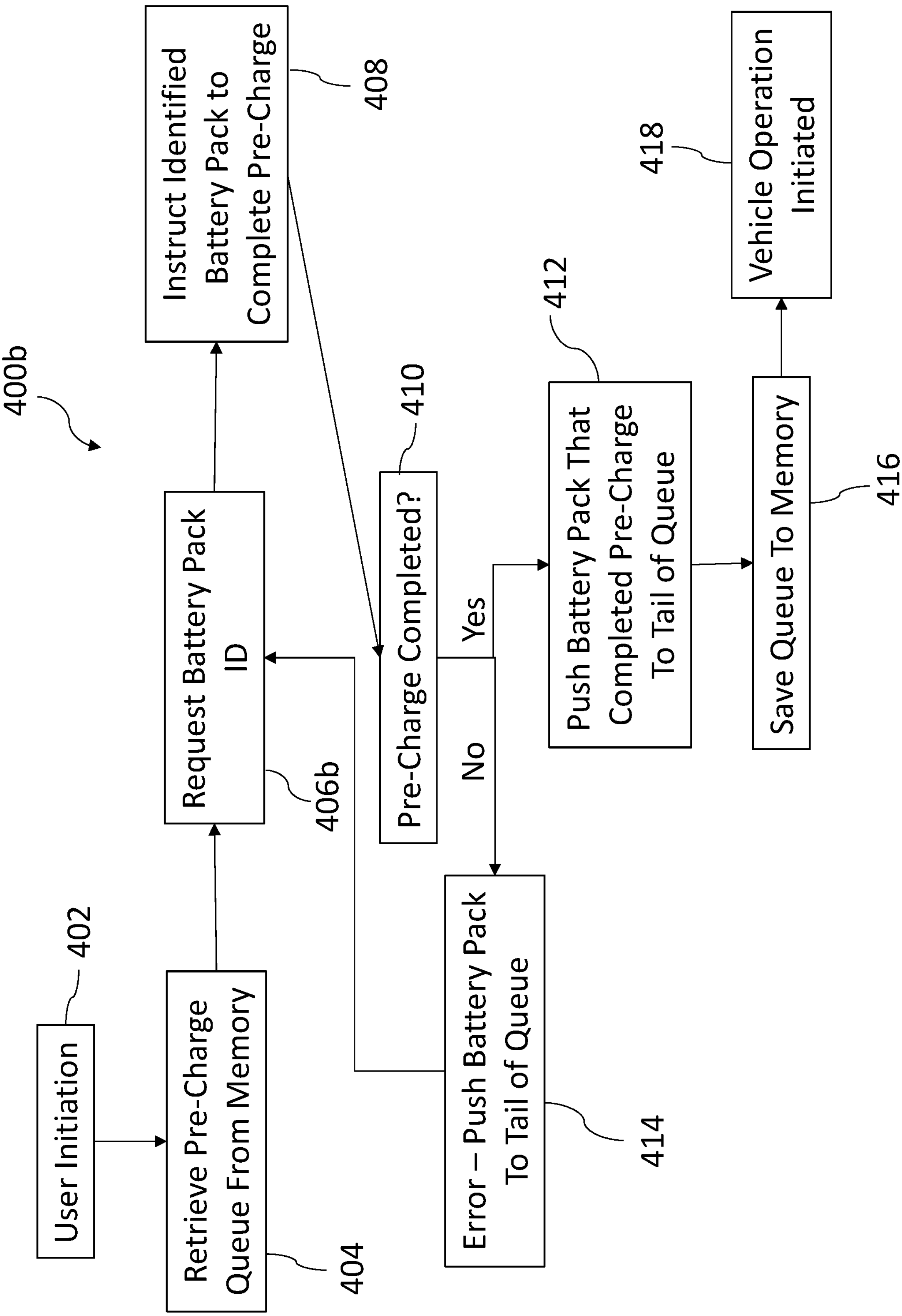
400b
User Initiation
402
Retrieve Pre-Charge Queue From Memory
404
Request Battery Pack ID
406b
Instruct Identified Battery Pack to Complete Pre-Charge
408
Pre-Charge Completed?
410
Yes
No
Error – Push Battery Pack To Tail of Queue
414
Push Battery Pack That Completed Pre-Charge To Tail of Queue
412
Save Queue To Memory
416
Vehicle Operation Initiated
418

FIG. 4B

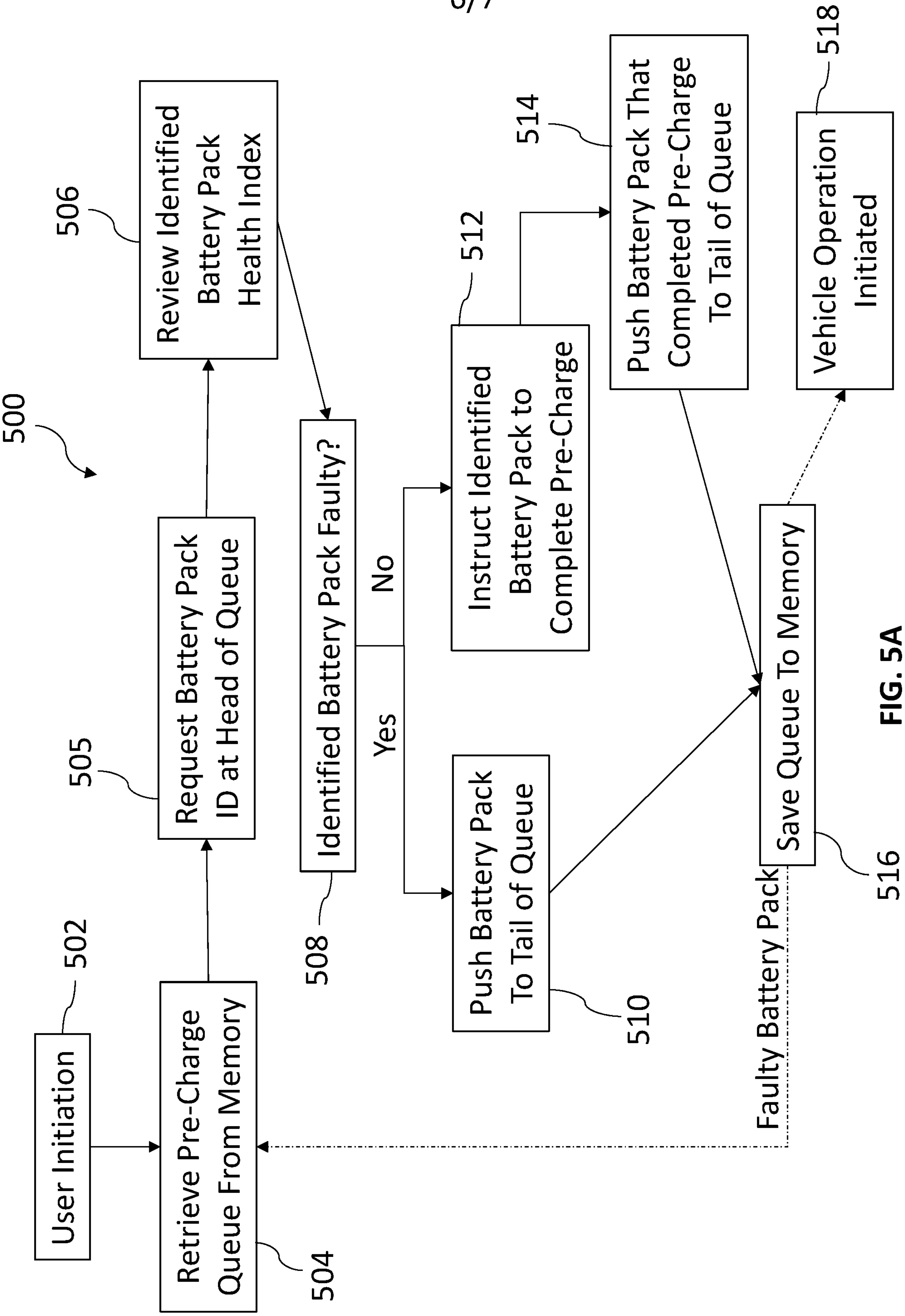
500
User Initiation
502
Retrieve Pre-Charge Queue From Memory
504
Request Battery Pack ID at Head of Queue
505
Review Identified Battery Pack Health Index
506
Identified Battery Pack Faulty?
508
Yes
No
Push Battery Pack To Tail of Queue
510
Instruct Identified Battery Pack to Complete Pre-Charge
512
Push Battery Pack That Completed Pre-Charge To Tail of Queue
514
Save Queue To Memory
516
Faulty Battery Pack
Vehicle Operation Initiated
518

FIG. 5A

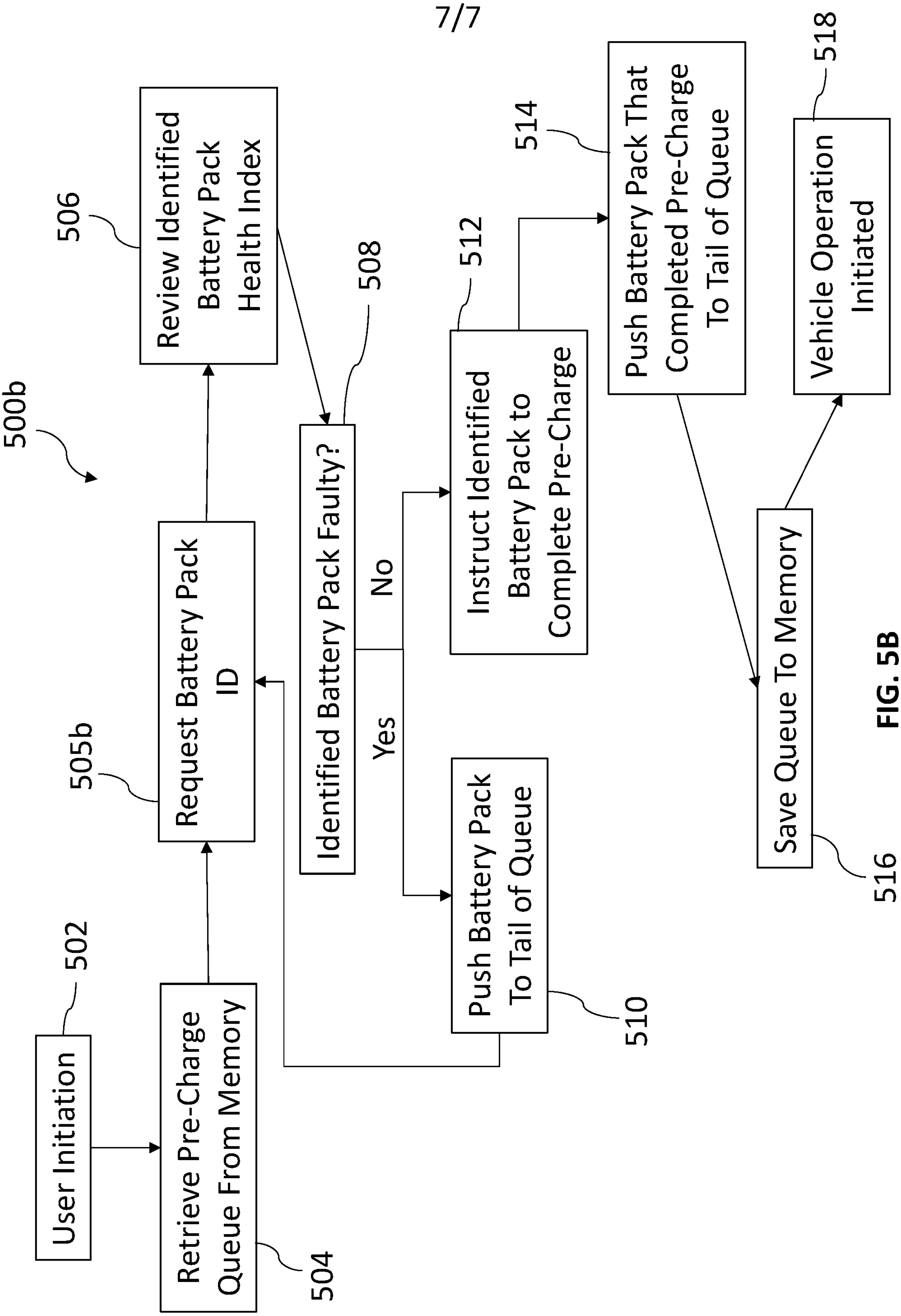
500b
User Initiation
502
Retrieve Pre-Charge Queue From Memory
504
Request Battery Pack ID
505b
Review Identified Battery Pack Health Index
506
Identified Battery Pack Faulty?
508
Yes
No
Push Battery Pack To Tail of Queue
510
Instruct Identified Battery Pack to Complete Pre-Charge
512
Push Battery Pack That Completed Pre-Charge To Tail of Queue
514
Save Queue To Memory
516
Vehicle Operation Initiated
518

FIG. 5B

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US20/20197

A. CLASSIFICATION OF SUBJECT MATTER

IPC - B60L 58/18, 58/12, 58/14, 58/10, 58/16, 58/22; H01M 10/44, 10/42; H02J 7/00 (2020.01)

CPC - B60L 58/18, 58/12, 58/14, 58/10, 58/16, 58/22; H02J 7/0071, 7/0068, 7/0063, 7/0021, 7/005, 7/007; H01M 10/441, 10/44, 10/42, 10/4207, 10/625

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)
See Search History document

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

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2017/0166075 A1 (FARADAY&FUTURE INC.) 15 June 2017; FIG. 2, paragraphs [0016], [0035]-[0050]	1-2 --- 3, 5, & 14-20
X --- Y	US 2013/0175857 A1 (JOHNSON CONTROLS TECHNOLOGY LLC) 11 July 2013; FIGs. 7B-7C, paragraphs [0023], [0028]-[0035], [0047]-[0051], claims 1 & 5	1 & 4 --- 6-8 & 10-12
Y	WO 2019/234348 A1 (COMMISSARIAT A L'ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES) 12 December 2019; see machine translation	3, 5-8, 10-12
Y	US 2015/0171638 A1 (GO-TECH ENERGY CO., LTD.) 18 June 2015; FIG. 5, paragraphs [0031]-[0035]	6-20
A	US 2018/0026456 A1 (SAMSUNG SDI CO., LTD.) 25 January 2018; entire document	1-20
A	US 2016/0028263 A1 (TRICOPIAN LLC) 28 January 2016; entire document	1-20

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 April 2020 (23.04.2020)	22 MAY 2020

Name and mailing address of the ISA/US	Authorized officer
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