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Kolamkar et al.

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(54) **ELECTRONIC BATTERY TESTER**

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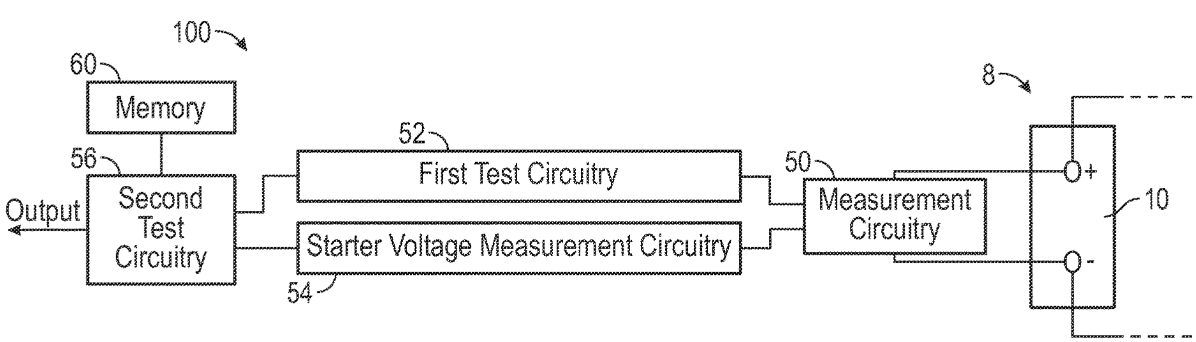
(57) **ABSTRACT**

An electronic battery tester for testing a storage battery in an automotive vehicle includes first test circuitry configured to couple to the storage battery, apply a forcing function to the storage battery, measure a response of the storage battery to the applied forcing function and provide a battery test output related to a condition of the battery based upon the response of the battery to the applied forcing function. Starter voltage measurement circuitry electrically couples to a starter motor of the automotive vehicle and collects starter voltage profile information comprising a plurality of starter voltage measurements obtained at different times while operating the starter motor. Second test circuitry receives the battery test output from the first test circuitry and the starter voltage profile information and provides an enhanced battery test output related to the condition of the battery based upon the battery test output and the starter voltage profile information.

22 Claims, 8 Drawing Sheets



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* cited by examiner

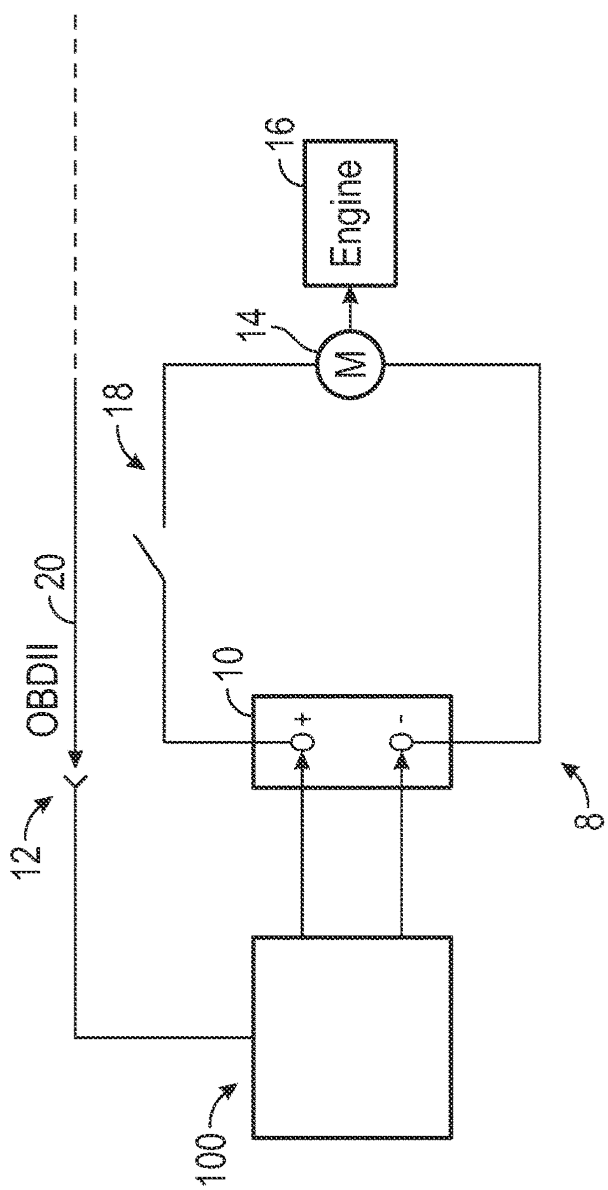
12
OBDII
20
18
14
M
16
Engine
10
+
-
8
100

FIG. 1

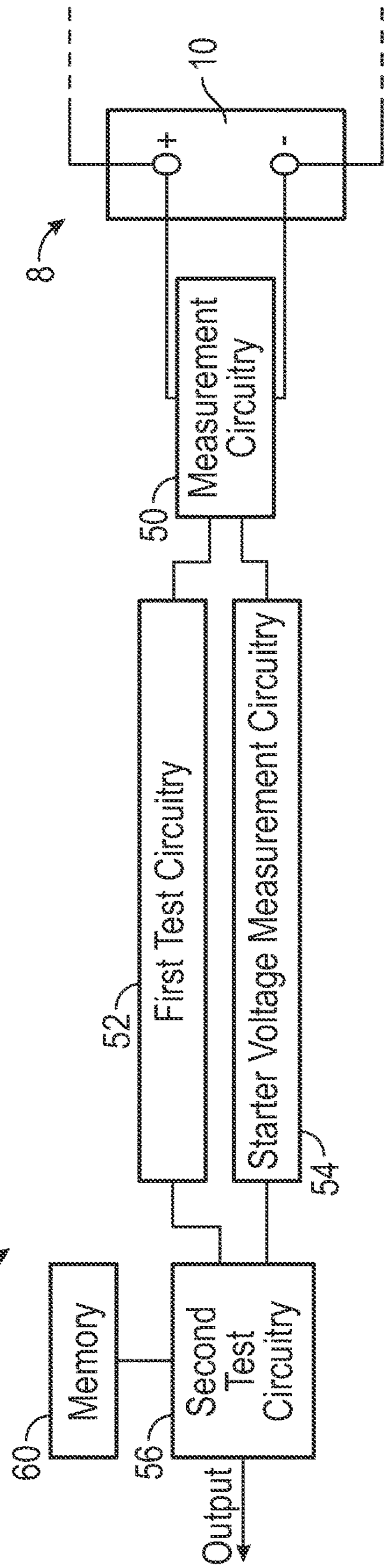
8
10
+
-
50
Measurement Circuitry
52
First Test Circuitry
Starter Voltage Measurement Circuitry
54
100
60
Memory
56
Second Test Circuitry
Output

FIG. 2

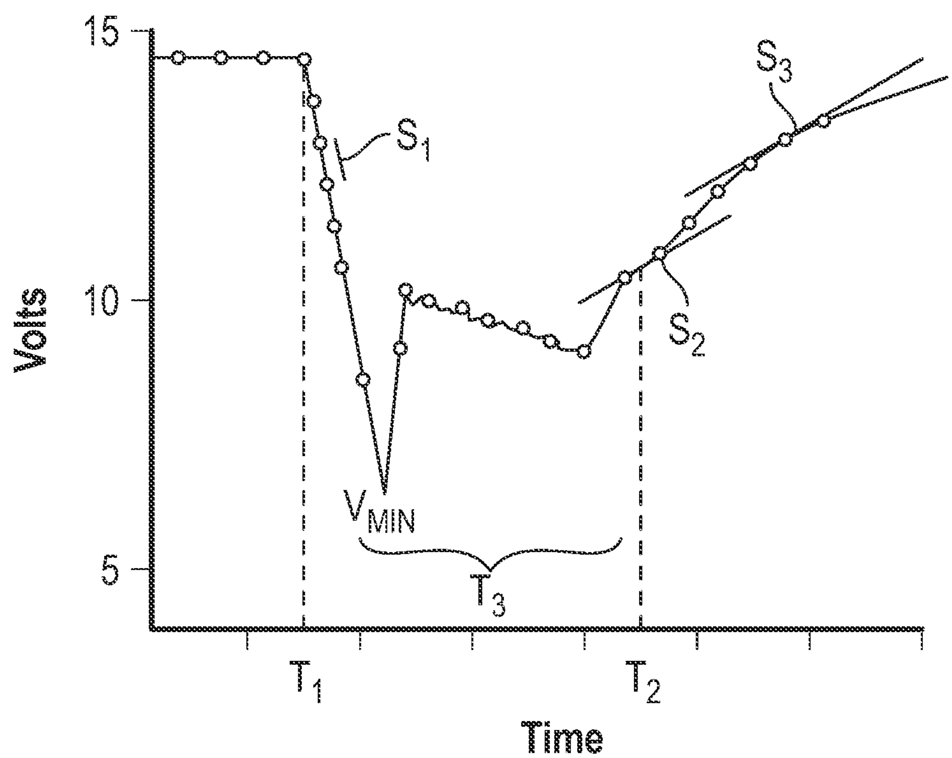
15
10
5
Volts
S1
S2
S3
VMIN
T3
T1
T2
Time

FIG. 3

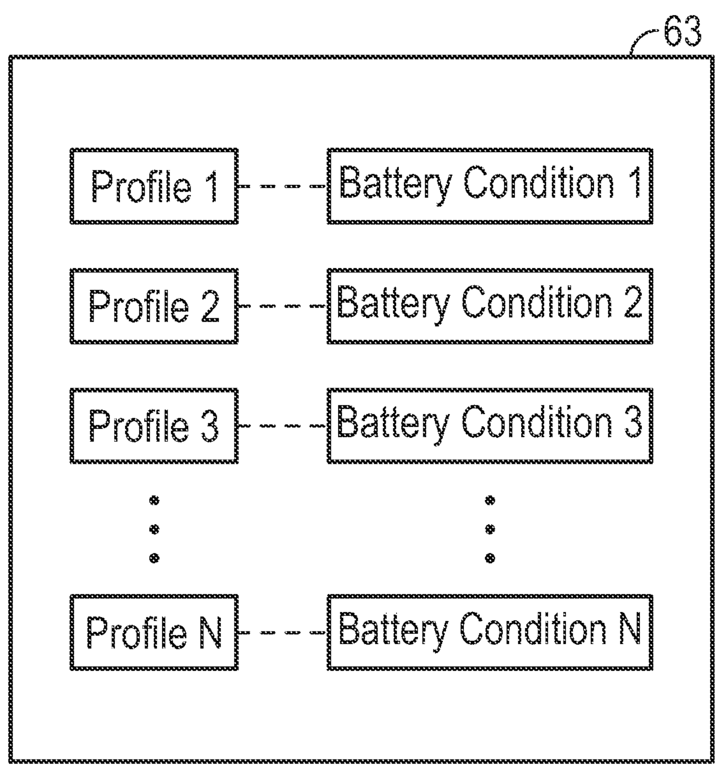
63
Profile 1
Battery Condition 1
Profile 2
Battery Condition 2
Profile 3
Battery Condition 3
Profile N
Battery Condition N

FIG. 4

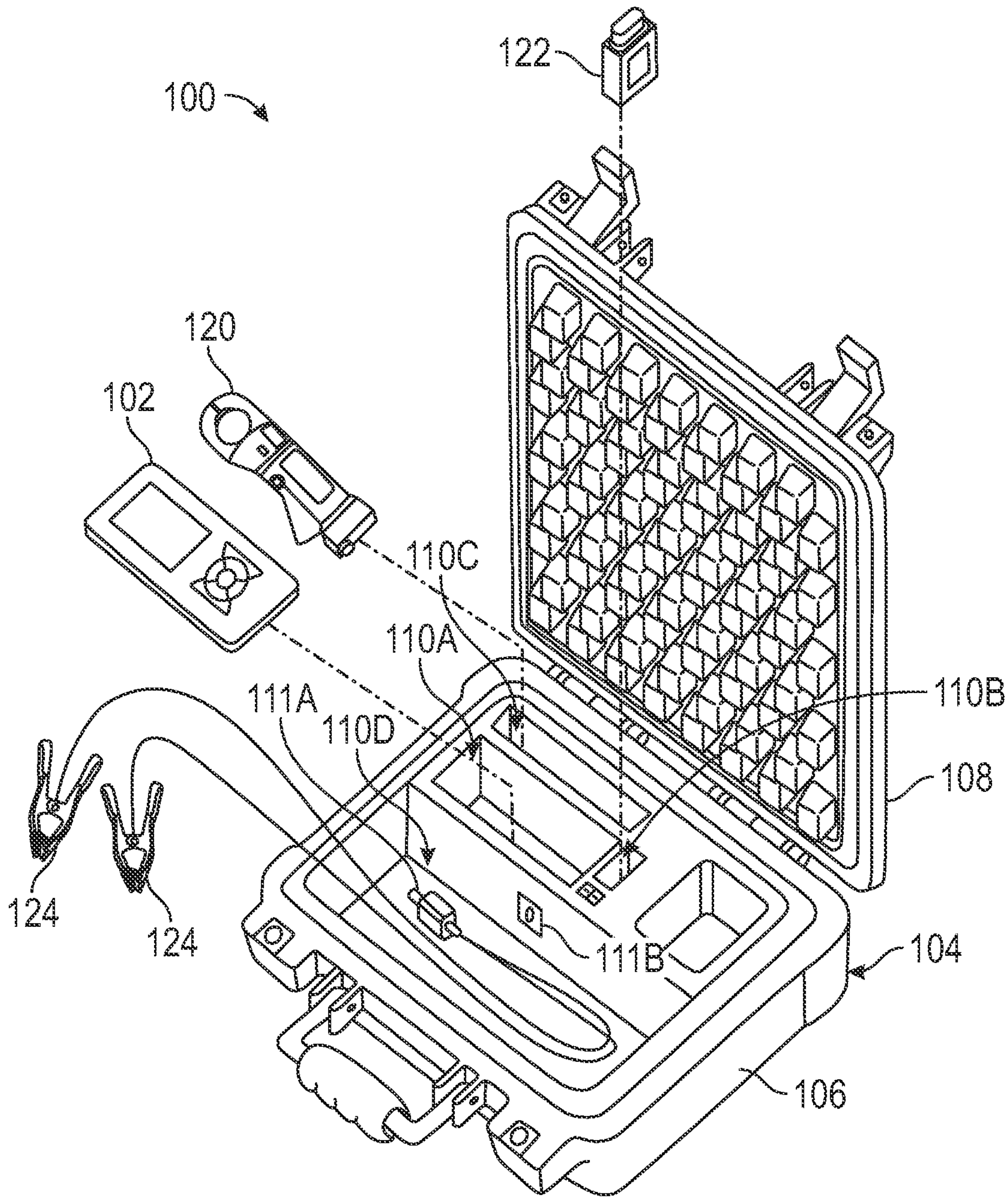
100
122
120
102
110C
110A
111A
110D
110B
108
124
124
111B
104
106

FIG. 5

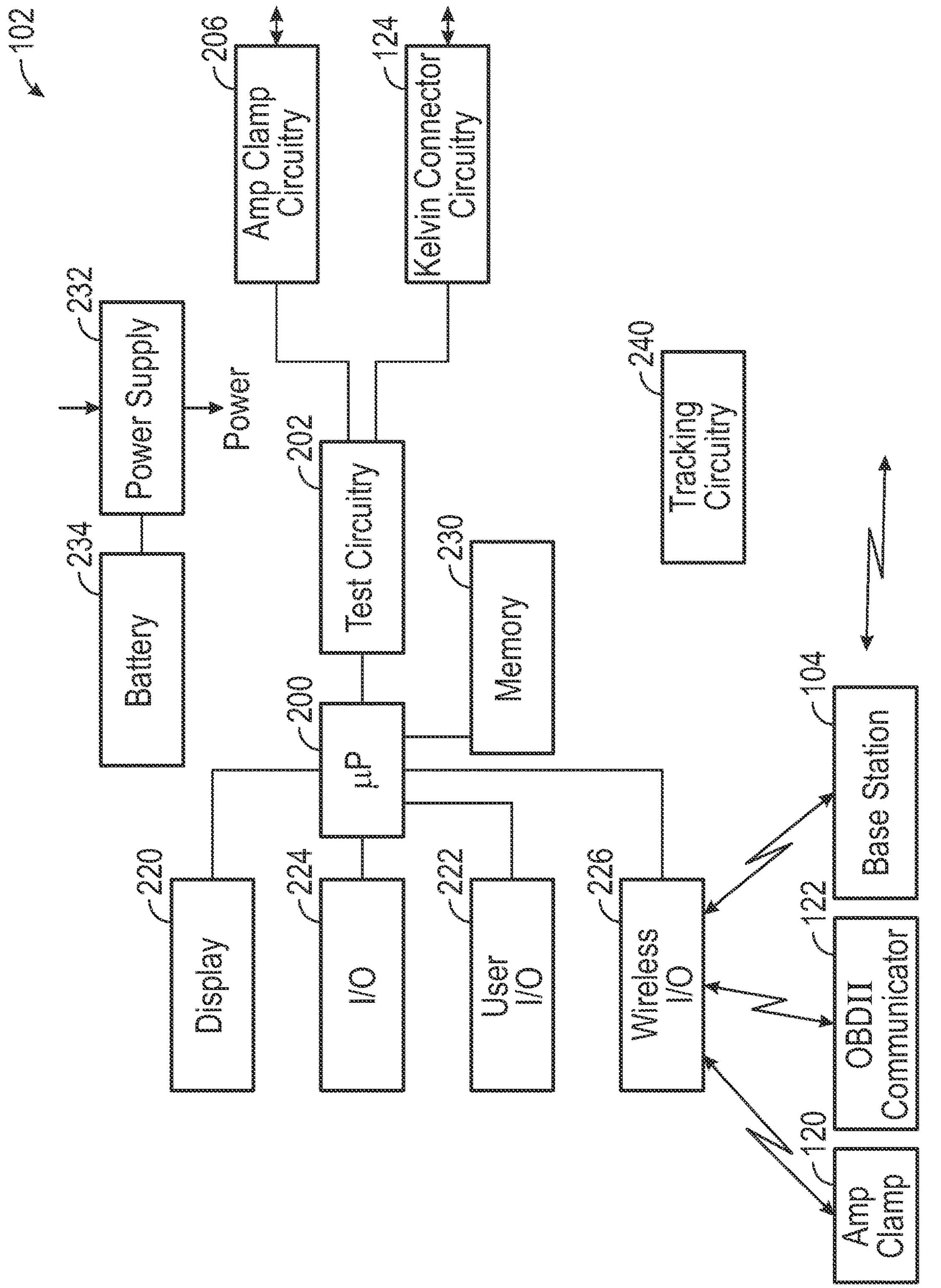
102
Battery
234
Power Supply
232
Power
Amp Clamp Circuitry
206
Kelvin Connector Circuitry
124
Test Circuitry
202
μP
200
Memory
230
Tracking Circuitry
240
Display
220
I/O
224
User I/O
222
Wireless I/O
226
Base Station
104
OBDII Communicator
122
Amp Clamp
120

FIG. 6

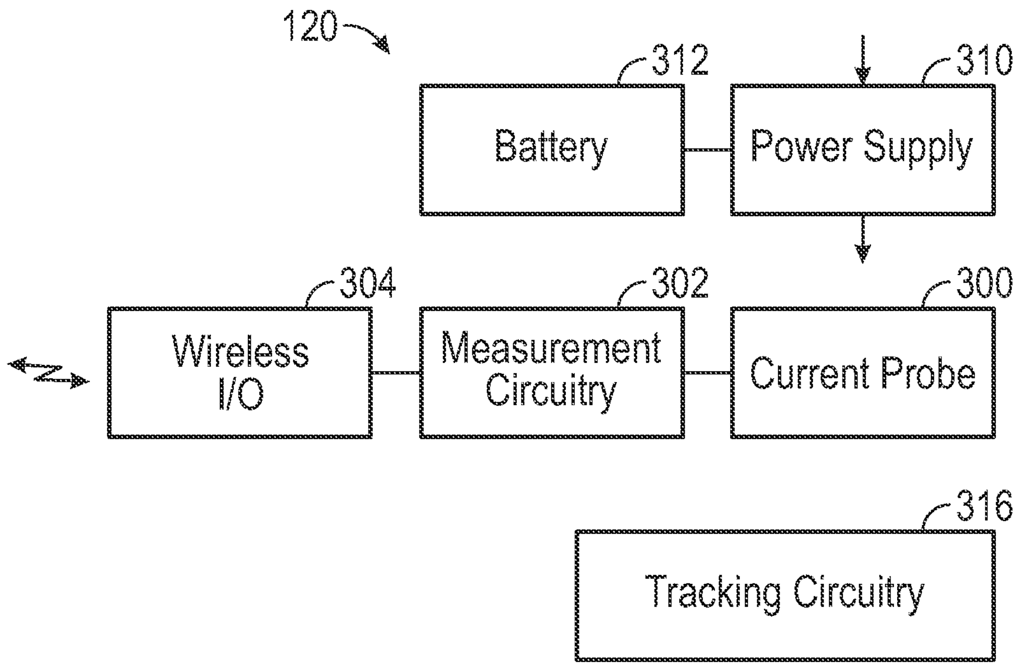
120
312
310
Battery
Power Supply
304
302
300
Wireless I/O
Measurement Circuitry
Current Probe
316
Tracking Circuitry

FIG. 7

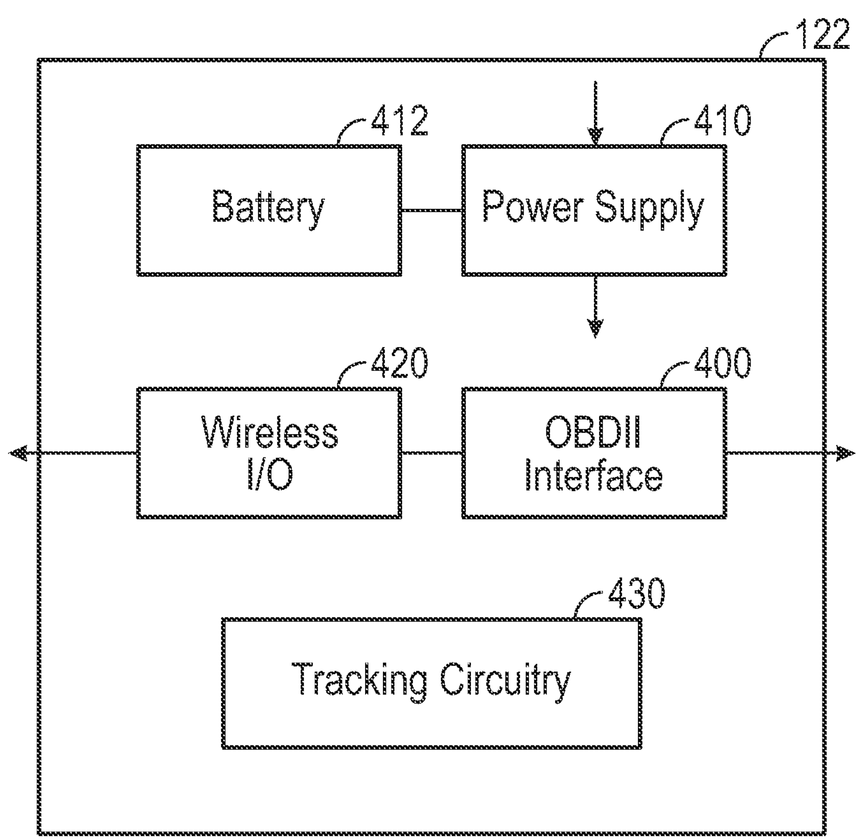
122
412
410
Battery
Power Supply
420
400
Wireless I/O
OBDII Interface
430
Tracking Circuitry

FIG. 8

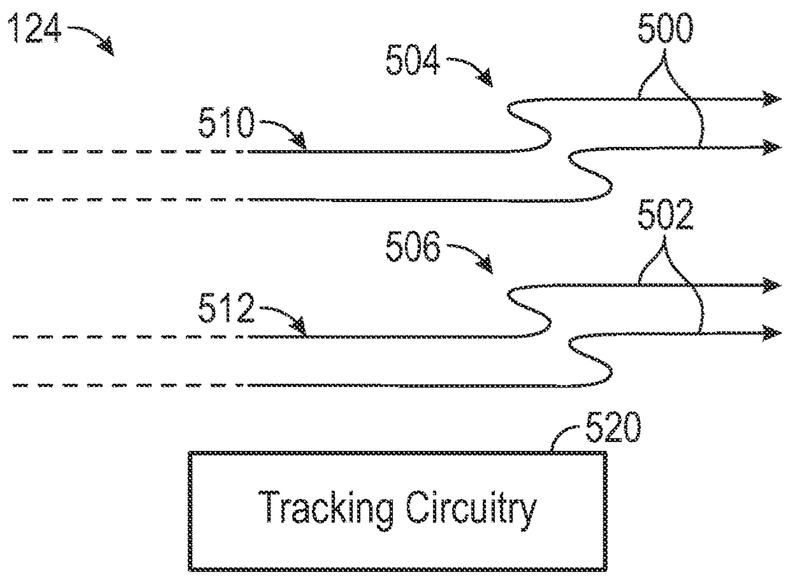
124
504
500
510
506
502
512
520
Tracking Circuitry

FIG. 9

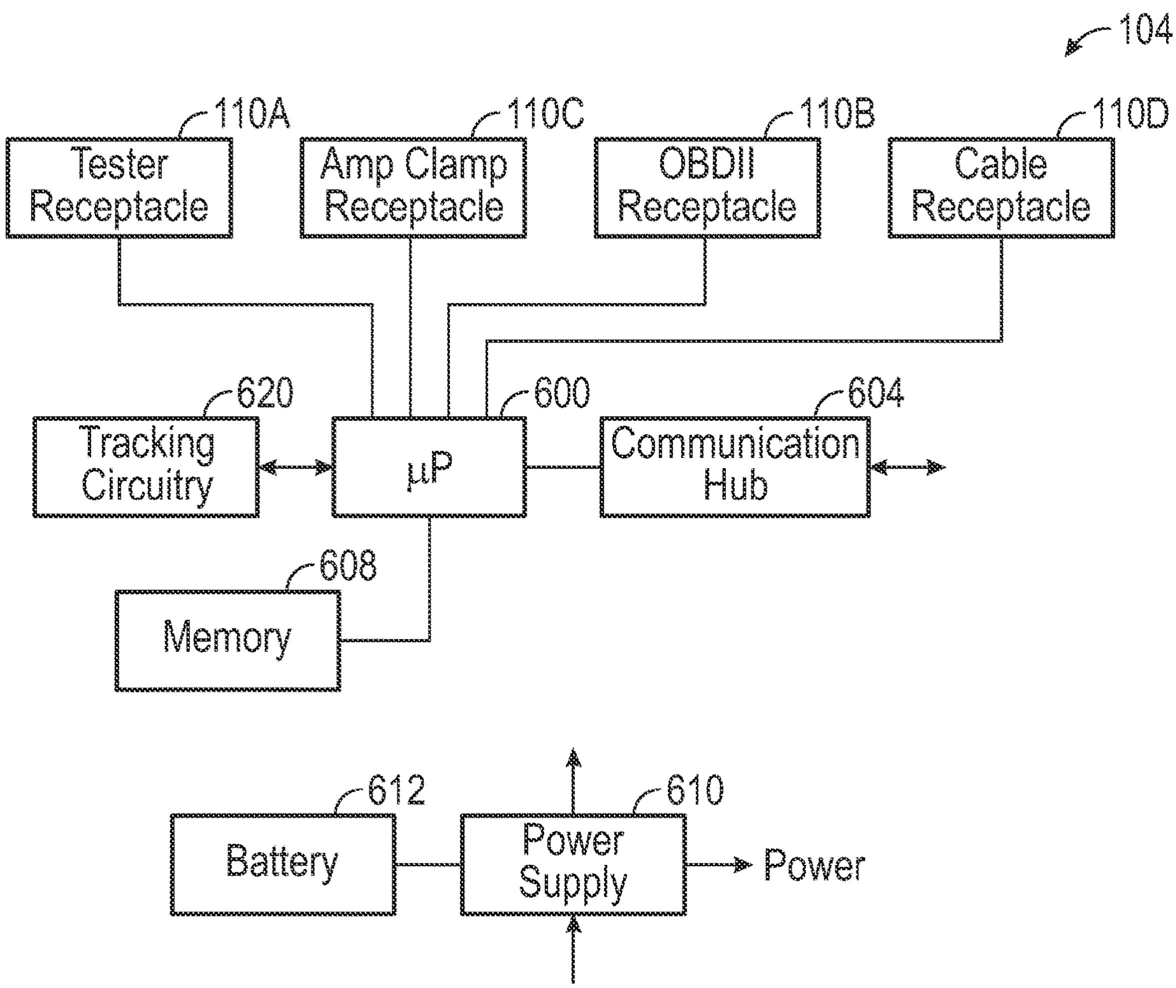
104
110A
Tester Receptacle
110C
Amp Clamp Receptacle
110B
OBDII Receptacle
110D
Cable Receptacle
620
Tracking Circuitry
600
μP
604
Communication Hub
608
Memory
612
Battery
610
Power Supply
Power

FIG. 10

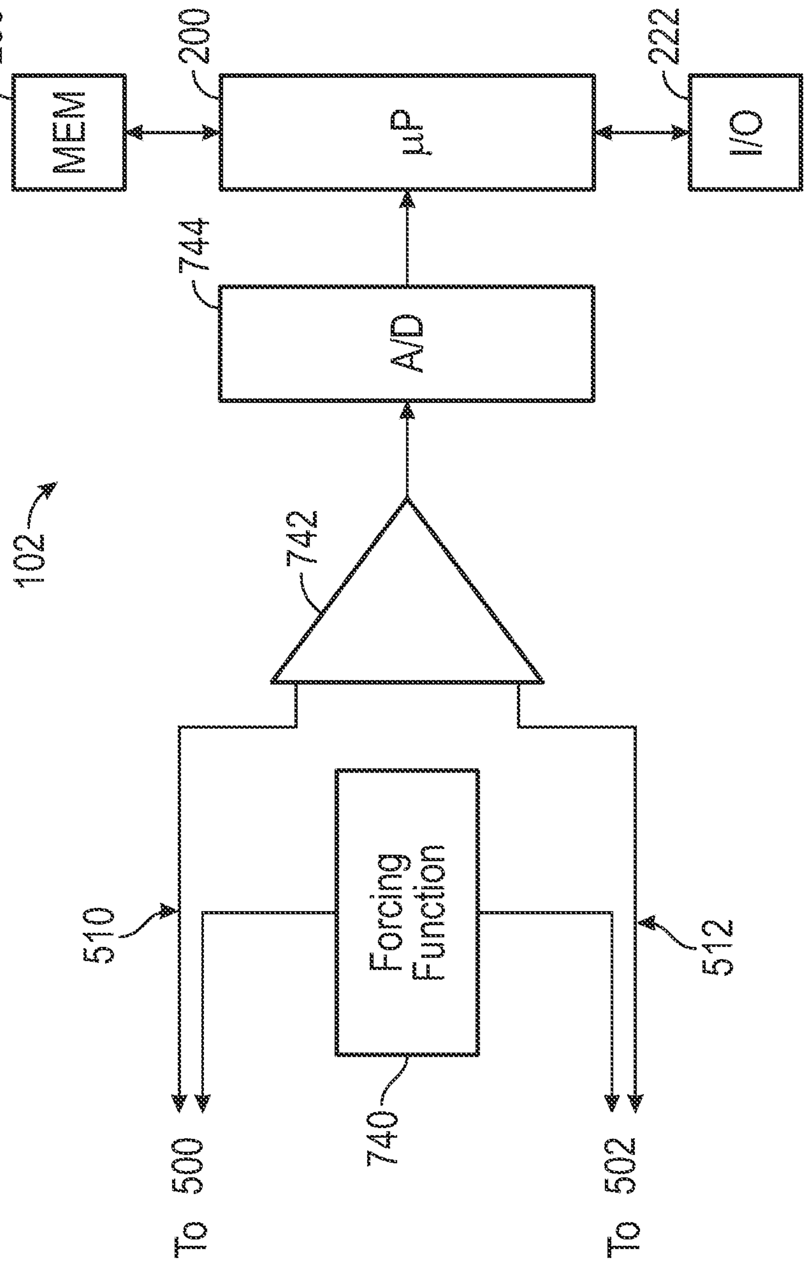
230
MEM
200
μP
222
I/O
744
A/D
102
742
510
Forcing Function
512
740
To 500
To 502

FIG. 11

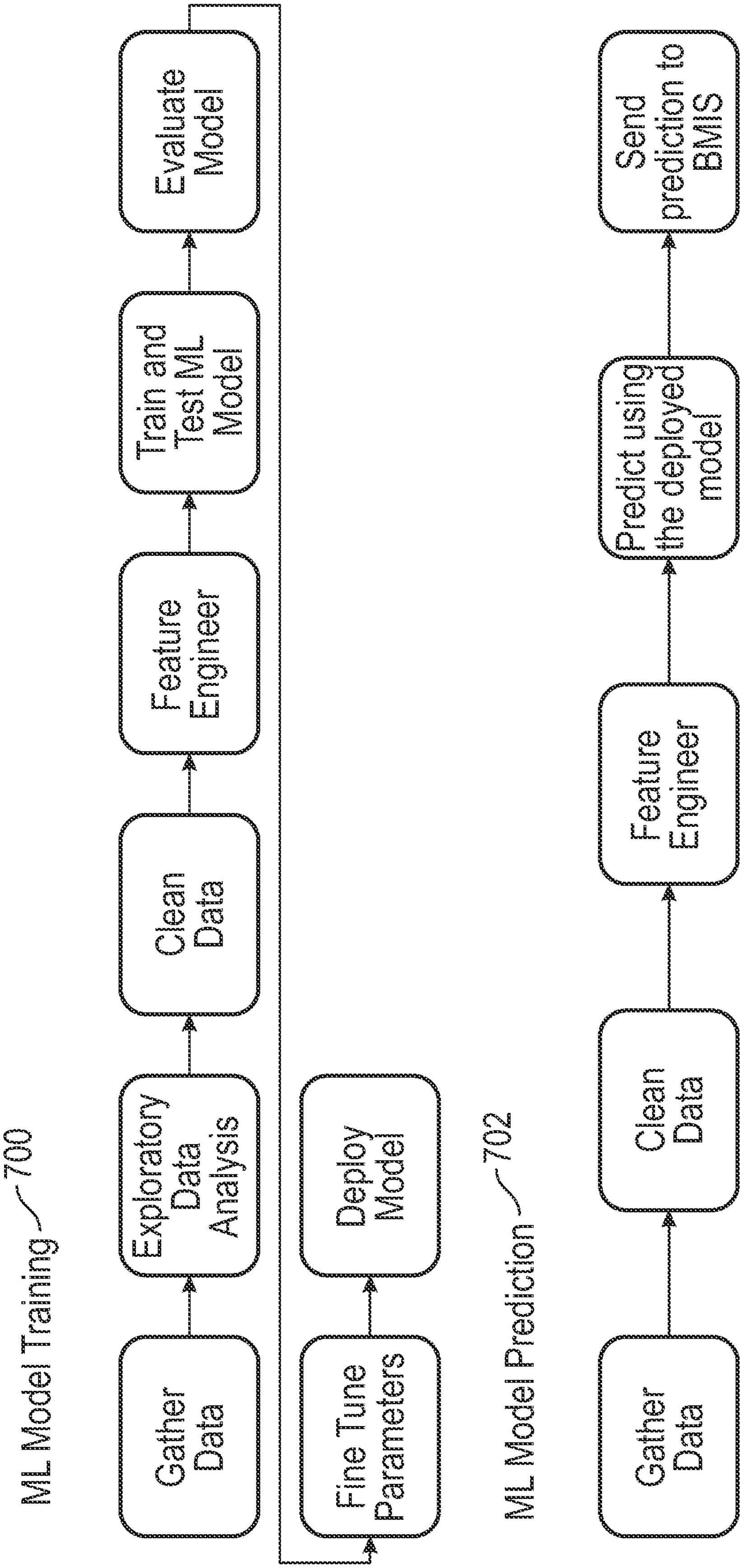
ML Model Training
700
Gather Data
Exploratory Data Analysis
Clean Data
Feature Engineer
Train and Test ML Model
Evaluate Model
Fine Tune Parameters
Deploy Model
ML Model Prediction
702
Gather Data
Clean Data
Feature Engineer
Predict using the deployed model
Send prediction to BMIS

FIG. 12

ELECTRONIC BATTERY TESTER

CROSS-REFERENCE TO RELATED APPLICATION

The present application is based on and claims the benefit of U.S. provisional patent application Ser. No. 63/339,618, filed May 9, 2022, the content of which is hereby incorporated by reference in its entirety.

BACKGROUND

The present invention relates to battery testers of the type used to test storage batteries. More specifically, the present invention relates to a battery maintenance system with improved battery test accuracy.

Electrical systems, such as those that are used in automotive vehicles, consist of a number of discrete components or systems which are interconnected. As used herein, the term "automotive vehicle" includes both vehicles which utilize an internal combustion engine, vehicles which utilize electric motors, as well as hybrid vehicles which include both types of systems. Techniques for measuring and utilizing parameters of electrical systems of automotive vehicles are known. Examples of various types of battery testers, monitors and other related equipment are set forth in U.S. Pat. No. 3,873,911, issued Mar. 25, 1975, to Champlin; U.S. Pat. No. 3,909,708, issued Sep. 30, 1975, to Champlin; U.S. Pat. No. 4,816,768, issued Mar. 28, 1989, to Champlin; U.S. Pat. No. 4,825,170, issued Apr. 25, 1989, to Champlin; U.S. Pat. No. 4,881,038, issued Nov. 14, 1989, to Champlin; U.S. Pat. No. 4,912,416, issued Mar. 27, 1990, to Champlin; U.S. Pat. No. 5,140,269, issued Aug. 18, 1992, to Champlin; U.S. Pat. No. 5,343,380, issued Aug. 30, 1994; U.S. Pat. No. 5,572,136, issued Nov. 5, 1996; U.S. Pat. No. 5,574,355, issued Nov. 12, 1996; U.S. Pat. No. 5,583,416, issued Dec. 10, 1996; U.S. Pat. No. 5,585,728, issued Dec. 17, 1996; U.S. Pat. No. 5,589,757, issued Dec. 31, 1996; U.S. Pat. No. 5,592,093, issued Jan. 7, 1997; U.S. Pat. No. 5,598,098, issued Jan. 28, 1997; U.S. Pat. No. 5,656,920, issued Aug. 12, 1997; U.S. Pat. No. 5,757,192, issued May 26, 1998; U.S. Pat. No. 5,821,756, issued Oct. 13, 1998; U.S. Pat. No. 5,831,435, issued Nov. 3, 1998; U.S. Pat. No. 5,871,858, issued Feb. 16, 1999; U.S. Pat. No. 5,914,605, issued Jun. 22, 1999; U.S. Pat. No. 5,945,829, issued Aug. 31, 1999; U.S. Pat. No. 6,002,238, issued Dec. 14, 1999; U.S. Pat. No. 6,037,751, issued Mar. 14, 2000; U.S. Pat. No. 6,037,777, issued Mar. 14, 2000; U.S. Pat. No. 6,051,976, issued Apr. 18, 2000; U.S. Pat. No. 6,081,098, issued Jun. 27, 2000; U.S. Pat. No. 6,091,245, issued Jul. 18, 2000; U.S. Pat. No. 6,104,167, issued Aug. 15, 2000; U.S. Pat. No. 6,137,269, issued Oct. 24, 2000; U.S. Pat. No. 6,163,156, issued Dec. 19, 2000; U.S. Pat. No. 6,172,483, issued Jan. 9, 2001; U.S. Pat. No. 6,172,505, issued Jan. 9, 2001; U.S. Pat. No. 6,222,369, issued Apr. 24, 2001; U.S. Pat. No. 6,225,808, issued May 1, 2001; U.S. Pat. No. 6,249,124, issued Jun. 19, 2001; U.S. Pat. No. 6,259,254, issued Jul. 10, 2001; U.S. Pat. No. 6,262,563, issued Jul. 17, 2001; U.S. Pat. No. 6,294,896, issued Sep. 25, 2001; U.S. Pat. No. 6,294,897, issued Sep. 25, 2001; U.S. Pat. No. 6,304,087, issued Oct. 16, 2001; U.S. Pat. No. 6,310,481, issued Oct. 30, 2001; U.S. Pat. No. 6,313,607, issued Nov. 6, 2001; U.S. Pat. No. 6,313,608, issued Nov. 6, 2001; U.S. Pat. No. 6,316,914, issued Nov. 13, 2001; U.S. Pat. No. 6,323,650, issued Nov. 27, 2001; U.S. Pat. No. 6,329,793, issued Dec. 11, 2001; U.S. Pat. No. 6,331,762, issued Dec. 18, 2001; U.S. Pat. No. 6,332,113, issued Dec. 18, 2001; U.S. Pat. No. 6,351,102,

issued Feb. 26, 2002; U.S. Pat. No. 6,359,441, issued Mar. 19, 2002; U.S. Pat. No. 6,363,303, issued Mar. 26, 2002; U.S. Pat. No. 6,377,031, issued Apr. 23, 2002; U.S. Pat. No. 6,392,414, issued May 21, 2002; U.S. Pat. No. 6,417,669, issued Jul. 9, 2002; U.S. Pat. No. 6,424,158, issued Jul. 23, 2002; U.S. Pat. No. 6,441,585, issued Aug. 17, 2002; U.S. Pat. No. 6,437,957, issued Aug. 20, 2002; U.S. Pat. No. 6,445,158, issued Sep. 3, 2002; U.S. Pat. Nos. 6,456,045; 6,466,025, issued Oct. 15, 2002; U.S. Pat. No. 6,465,908, issued Oct. 15, 2002; U.S. Pat. No. 6,466,026, issued Oct. 15, 2002; U.S. Pat. No. 6,469,511, issued Nov. 22, 2002; U.S. Pat. No. 6,495,990, issued Dec. 17, 2002; U.S. Pat. No. 6,497,209, issued Dec. 24, 2002; U.S. Pat. No. 6,507,196, issued Jan. 14, 2003; U.S. Pat. No. 6,534,993; issued Mar. 18, 2003; U.S. Pat. No. 6,544,078, issued Apr. 8, 2003; U.S. Pat. No. 6,556,019, issued Apr. 29, 2003; U.S. Pat. No. 6,566,883, issued May 20, 2003; U.S. Pat. No. 6,586,941, issued Jul. 1, 2003; U.S. Pat. No. 6,597,150, issued Jul. 22, 2003; U.S. Pat. No. 6,621,272, issued Sep. 16, 2003; U.S. Pat. No. 6,623,314, issued Sep. 23, 2003; U.S. Pat. No. 6,633,165, issued Oct. 14, 2003; U.S. Pat. No. 6,635,974, issued Oct. 21, 2003; U.S. Pat. No. 6,696,819, issued Feb. 24, 20144; U.S. Pat. No. 6,707,303, issued Mar. 16, 2004; U.S. Pat. No. 6,737,831, issued May 18, 2004; U.S. Pat. No. 6,744,149, issued Jun. 1, 2004; U.S. Pat. No. 6,759,849, issued Jul. 6, 2004; U.S. Pat. No. 6,781,382, issued Aug. 24, 2004; U.S. Pat. No. 6,788,025, filed Sep. 7, 2004; U.S. Pat. No. 6,795,782, issued Sep. 21, 2004; U.S. Pat. No. 6,805,090, filed Oct. 19, 2004; U.S. Pat. No. 6,806,716, filed Oct. 19, 2004; U.S. Pat. No. 6,850,037, filed Feb. 1, 2005; U.S. Pat. No. 6,850,037, issued Feb. 1, 2005; U.S. Pat. No. 6,871,151, issued Mar. 22, 2005; U.S. Pat. No. 6,885,195, issued Apr. 26, 2005; U.S. Pat. No. 6,888,468, issued May 3, 2005; U.S. Pat. No. 6,891,378, issued May 10, 2005; U.S. Pat. No. 6,906,522, issued Jun. 14, 2005; U.S. Pat. No. 6,906,523, issued Jun. 14, 2005; U.S. Pat. No. 6,909,287, issued Jun. 21, 2005; U.S. Pat. No. 6,914,413, issued Jul. 5, 2005; U.S. Pat. No. 6,913,483, issued Jul. 5, 2005; U.S. Pat. No. 6,930,485, issued Aug. 16, 2005; U.S. Pat. No. 6,933,727, issued Aug. 23, 200; U.S. Pat. No. 6,941,234, filed Sep. 6, 2005; U.S. Pat. No. 6,967,484, issued Nov. 22, 2005; U.S. Pat. No. 6,998,847, issued Feb. 14, 2006; U.S. Pat. No. 7,003,410, issued Feb. 21, 2006; U.S. Pat. No. 7,003,411, issued Feb. 21, 2006; U.S. Pat. No. 7,012,433, issued Mar. 14, 2006; U.S. Pat. No. 7,015,674, issued Mar. 21, 2006; U.S. Pat. No. 7,034,541, issued Apr. 25, 2006; U.S. Pat. No. 7,039,533, issued May 2, 2006; U.S. Pat. No. 7,058,525, issued Jun. 6, 2006; U.S. Pat. No. 7,081,755, issued Jul. 25, 2006; U.S. Pat. No. 7,106,070, issued Sep. 12, 2006; U.S. Pat. No. 7,116,109, issued Oct. 3, 2006; U.S. Pat. No. 7,119,686, issued Oct. 10, 2006; and U.S. Pat. No. 7,126,341, issued Oct. 24, 2006; U.S. Pat. No. 7,154,276, issued Dec. 26, 2006; U.S. Pat. No. 7,198,510, issued Apr. 3, 2007; U.S. Pat. No. 7,363,175, issued Apr. 22, 2008; U.S. Pat. No. 7,208,914, issued Apr. 24, 2007; U.S. Pat. No. 7,246,015, issued Jul. 17, 2007; U.S. Pat. No. 7,295,936, issued Nov. 13, 2007; U.S. Pat. No. 7,319,304, issued Jan. 15, 2008; U.S. Pat. No. 7,363,175, issued Apr. 22, 2008; U.S. Pat. No. 7,398,176, issued Jul. 8, 2008; U.S. Pat. No. 7,408,358, issued Aug. 5, 2008; U.S. Pat. No. 7,425,833, issued Sep. 16, 2008; U.S. Pat. No. 7,446,536, issued Nov. 4, 2008; U.S. Pat. No. 7,479,763, issued Jan. 20, 2009; U.S. Pat. No. 7,498,767, issued Mar. 3, 2009; U.S. Pat. No. 7,501,795, issued Mar. 10, 2009; U.S. Pat. No. 7,505,856, issued Mar. 17, 2009; U.S. Pat. No. 7,545,146, issued Jun. 9, 2009; U.S. Pat. No. 7,557,586, issued Jul. 7, 2009; U.S. Pat. No. 7,595,643, issued Sep. 29, 2009; U.S. Pat. No. 7,598,699, issued Oct. 6, 2009; U.S. Pat. No. 7,598,744, issued Oct. 6, 2009; U.S. Pat. No. 7,598,743, issued Oct. 6, 2009; U.S. Pat. No. 7,619,417, issued Nov. 17, 2009; U.S. Pat. No. 7,642,786, issued Jan. 5, 2010; U.S. Pat. No. 7,642,787, issued Jan. 5, 2010; U.S. Pat. No. 7,656,162, issued Feb. 2, 2010; U.S. Pat. No. 7,688,074, issued Mar. 30, 2010; U.S. Pat. No. 7,705,602, issued Apr. 27, 2010; U.S. Pat. No. 7,706,992, issued Apr. 27, 2010; U.S. Pat. No. 7,710,119, issued May 4, 2010; U.S. Pat. No. 7,723,993, issued May 25, 2010; U.S. Pat. No. 7,728,597, issued Jun. 1, 2010; U.S. Pat. No. 7,772,850, issued Aug. 10, 2010; U.S. Pat. No. 7,774,151, issued Aug. 10, 2010; U.S. Pat. No. 7,777,612, issued Aug. 17, 2010; U.S. Pat. No. 7,791,348, issued Sep. 7, 2010; U.S. Pat. No. 7,808,375, issued Oct. 5, 2010; U.S. Pat. No. 7,924,015, issued Apr. 12, 2011; U.S. Pat. No. 7,940,053, issued May 10, 2011; U.S. Pat. No. 7,940,052, issued May 10, 2011; U.S. Pat. No. 7,959,476, issued Jun. 14, 2011; U.S. Pat. No. 7,977,914, issued Jul. 12, 2011; U.S. Pat. No. 7,999,505, issued Aug. 16, 2011; U.S. Pat. No. D643,759, issued Aug. 23, 2011; U.S. Pat. No. 8,164,343, issued Apr. 24, 2012; U.S. Pat. No. 8,198,900, issued Jun. 12, 2012; U.S. Pat. No. 8,203,345, issued Jun. 19, 2012; U.S. Pat. No. 8,237,448, issued Aug. 7, 2012; U.S. Pat. No. 8,306,690, issued Nov. 6, 2012; U.S. Pat. No. 8,344,685, issued Jan. 1, 2013; U.S. Pat. No. 8,436,619, issued May 7, 2013; U.S. Pat. No. 8,442,877, issued May 14, 2013; U.S. Pat. No. 8,493,022, issued Jul. 23, 2013; U.S. Pat. No. D687,727, issued Aug. 13, 2013; U.S. Pat. No. 8,513,949, issued Aug. 20, 2013; U.S. Pat. No. 8,674,654, issued Mar. 18, 2014; U.S. Pat. No. 8,674,711, issued Mar. 18, 2014; U.S. Pat. No. 8,704,483, issued Apr. 22, 2014; U.S. Pat. No. 8,738,309, issued May 27, 2014; U.S. Pat. No. 8,754,653, issued Jun. 17, 2014; U.S. Pat. No. 8,872,516, issued Oct. 28, 2014; U.S. Pat. No. 8,872,517, issued Oct. 28, 2014; U.S. Pat. No. 8,958,998, issued Feb. 17, 2015; U.S. Pat. No. 8,963,550, issued Feb. 24, 2015; U.S. Pat. No. 9,018,958, issued Apr. 28, 2015; U.S. Pat. No. 9,052,366, issued Jun. 9, 2015; U.S. Pat. No. 9,201,120, issued Dec. 1, 2015; U.S. Pat. No. 9,229,062, issued Jan. 5, 20126; U.S. Pat. No. 9,244,100, issued Jan. 26, 2016; U.S. Pat. No. 9,255,955, issued Feb. 9, 2016; U.S. Pat. No. 9,274,157, issued Mar. 1, 2016; U.S. Pat. No. 9,312,575, issued Apr. 12, 2016; U.S. Pat. No. 9,335,362, issued May 10, 2016; U.S. Pat. No. 9,425,487, issued Aug. 23, 2016; U.S. Pat. No. 9,419,311, issued Aug. 16, 2016; U.S. Pat. No. 9,496,720, issued Nov. 15, 2016; U.S. Pat. No. 9,588,185, issued Mar. 7, 2017; U.S. Pat. No. 9,923,289, issued Mar. 20, 2018; U.S. Pat. No. 9,966,676, issued May 8, 2018; U.S. Pat. No. 10,046,649, issued Aug. 14, 2018; U.S. Pat. No. 10,222,397, issued Mar. 5, 2019; U.S. Pat. No. 10,317,468, issued Jun. 11, 2019; U.S. Pat. No. 10,429,449, issued Oct. 1, 2019; U.S. Pat. No. 10,473,555, issued Nov. 12, 2019; U.S. Pat. No. 10,608,353, issued Mar. 31, 2020; U.S. Pat. No. 10,843,574, issued Nov. 24, 2020; U.S. Pat. No. 11,054,480, issued Jul. 6, 2021; U.S. Pat. No. 11,325,479, issued May 10, 2022; U.S. Pat. No. 11,474,153, issued Oct. 18, 2022; U.S. Pat. No. 11,486,930, issued Nov. 1, 2022; U.S. Pat. No. 11,513,160, issued Nov. 29, 2022; U.S. Pat. No. 11,545,839, issued Jan. 3, 2023; U.S. Pat. No. 11,548,404, issued Jan. 10, 2023; U.S. Pat. No. 11,566,972, issued Jan. 31, 2023; U.S. Ser. No. 09/780,146, filed Feb. 9, 2001, entitled STORAGE BATTERY WITH INTEGRAL BATTERY TESTER; U.S. Ser. No. 09/756,638, filed Jan. 8, 2001, entitled METHOD AND APPARATUS FOR DETERMINING BATTERY PROPERTIES FROM COMPLEX IMPEDANCE/ADMITTANCE; U.S. Ser. No. 09/862,783, filed May 21, 2001, entitled METHOD AND APPARATUS FOR TESTING CELLS AND BATTERIES EMBEDDED IN SERIES/PARALLEL SYSTEMS; U.S. Ser. No. 09/880,473, filed Jun. 13, 2001; entitled BATTERY TEST MODULE; U.S. Ser. No. 10/109,734, filed Mar. 28, 2002, entitled APPARATUS AND METHOD FOR COUNTERACTING SELF DISCHARGE IN A STORAGE BATTERY; U.S. Ser. No. 10/263,473, filed Oct. 2, 2002, entitled ELECTRONIC BATTERY TESTER WITH RELATIVE TEST OUTPUT; U.S. Ser. No. 09/653,963, filed Sep. 1, 2000, entitled SYSTEM AND METHOD FOR CONTROLLING POWER GENERATION AND STORAGE; U.S. Ser. No. 10/174,110, filed Jun. 18, 2002, entitled DAYTIME RUNNING LIGHT CONTROL USING AN INTELLIGENT POWER MANAGEMENT SYSTEM; U.S. Ser. No. 10/258,441, filed Apr. 9, 2003, entitled CURRENT MEASURING CIRCUIT SUITED FOR BATTERIES; U.S. Ser. No. 10/681,666, filed Oct. 8, 2003, entitled ELECTRONIC BATTERY TESTER WITH PROBE LIGHT; U.S. Ser. No. 11/207,419, filed Aug. 19, 2005, entitled SYSTEM FOR AUTOMATICALLY GATHERING BATTERY INFORMATION FOR USE DURING BATTERY TESTER/CHARGING, U.S. Ser. No. 11/356,443, filed Feb. 16, 2006, entitled ELECTRONIC BATTERY TESTER WITH NETWORK COMMUNICATION; U.S. Ser. No. 12/697,485, filed Feb. 1, 2010, entitled ELECTRONIC BATTERY TESTER; U.S. Ser. No. 12/769,911, filed Apr. 29, 2010, entitled STATIONARY BATTERY TESTER; U.S. Ser. No. 13/152,711, filed Jun. 3, 2011, entitled BATTERY PACK MAINTENANCE FOR ELECTRIC VEHICLE; U.S. Ser. No. 14/039,746, filed Sep. 27, 2013, entitled BATTERY PACK MAINTENANCE FOR ELECTRIC VEHICLE; U.S. Ser. No. 14/565,589, filed Dec. 10, 2014, entitled BATTERY TESTER AND BATTERY REGISTRATION TOOL; U.S. Ser. No. 15/017,887, filed Feb. 8, 2016, entitled METHOD AND APPARATUS FOR MEASURING A PARAMETER OF A VEHICLE ELECTRICAL SYSTEM; U.S. Ser. No. 15/049,483, filed Feb. 22, 2016, entitled BATTERY TESTER FOR ELECTRIC VEHICLE; U.S. Ser. No. 15/077,975, filed Mar. 23, 2016, entitled BATTERY MAINTENANCE SYSTEM; U.S. Ser. No. 15/149,579, filed May 9, 2016, entitled BATTERY TESTER FOR ELECTRIC VEHICLE; U.S. Ser. No. 16/021,538, filed Jun. 28, 2018, entitled BATTERY PACK MAINTENANCE FOR ELECTRIC VEHICLE; U.S. Ser. No. 16/253,526, filed Jan. 22, 2019, entitled HIGH CAPACITY BATTERY BALANCER; U.S. Ser. No. 16/297,975, filed Mar. 11, 2019, entitled HIGH USE BATTERY PACK MAINTENANCE; U.S. Ser. No. 17/086,629, filed Nov. 2, 2020, entitled HYBRID AND ELECTRIC VEHICLE BATTERY PACK MAINTENANCE DEVICE; U.S. Ser. No. 17/136,600, filed Dec. 29, 2020, entitled INTELLIGENT MODULE INTERFACE FOR BATTERY MAINTENANCE DEVICE; U.S. Ser. No. 17/364,953, filed Jul. 1, 2021, entitled ELECTRICAL LOAD FOR ELECTRONIC BATTERY TESTER AND ELECTRONIC BATTERY TESTER INCLUDING SUCH ELECTRICAL LOAD; U.S. Ser. No. 17/504,897, filed Oct. 19, 2021, entitled HIGH CAPACITY BATTERY BALANCER; U.S. Ser. No. 17/739,393, filed May 9, 2022, entitled HYBRID AND ELECTRIC VEHICLE BATTERY PACK MAINTENANCE DEVICE; U.S. Ser. No. 17/750,719, filed May 23, 2022, entitled BATTERY MONITORING SYSTEM; U.S. Ser. No. 17/893,412, filed Aug. 23, 2022, entitled POWER ADAPTER FOR AUTOMOTIVE VEHICLE MAINTENANCE DEVICE; U.S. Ser. No. 18/166,702, filed Feb. 9, 2023, entitled BATTERY MAINTENANCE DEVICE WITH HIGH VOLTAGE CONNECTOR; all of which are incorporated herein by reference in their entireties.

There is an ongoing need for improved battery testing and diagnostic equipment.

SUMMARY

An electronic battery tester for testing a storage battery in an automotive vehicle includes first test circuitry configured to couple to the storage battery, apply a forcing function to the storage battery, measure a response of the storage battery to the applied forcing function and provide a battery test output related to a condition of the battery based upon the response of the battery to the applied forcing function Starter voltage measurement circuitry electrically couples to a starter motor of the automotive vehicle and collects starter voltage profile information comprising a plurality of starter voltage measurements obtained at different times while operating the starter motor. Second test circuitry receives the battery test output from the first test circuitry and the starter voltage profile information and provides an enhanced battery test output related to the condition of the battery based upon the battery test output and the starter voltage profile information.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a simplified schematic diagram showing a battery maintenance system coupled to a battery of an automotive vehicle.

FIG. **2** is a simplified block diagram of the battery maintenance system of FIG. **1**.

FIG. **3** is a graph of voltage versus time showing a starter voltage profile.

FIG. **4** illustrates a starter voltage profile data set stored with a battery condition data set.

FIG. **5** is a perspective view of the automotive battery diagnostic or maintenance system of FIG. **1** in accordance with one example embodiment.

FIG. **6** is a simplified block diagram of a system of FIG. **1**.

FIG. **7** is a simplified block diagram of an amp clamp/current sensor.

FIG. **8** is a simplified block diagram of an OBDII communicator of FIG. **1**.

FIG. **9** is a diagram showing Kelvin connectors of FIG. **1**.

FIG. **10** is a simplified block diagram of a base station shown in FIG. **1**.

FIG. **11** is a simplified schematic diagram including measurement circuitry of the system of FIG. **1**.

FIG. **12** is a simplified block diagram of a machine learning model training and a machine learning model prediction in accordance with a further embodiment of the invention.

DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

Battery testers are known in the art and used for performing tests on batteries of automotive vehicles. There are various testing technique that are known including physical chemical measurements as well as electronic battery testers. Electronic battery testers generally use two primary techniques for measuring battery state of health and battery condition. One technique is to apply a load or a charge to the battery and observe how energy is removed from the battery, or added to the battery, to make a determination of battery condition. Another technique is to apply a signal to the battery and watch a response of the battery to the applied signal. As discussed in the Background section, Midtronics, Inc. along with Dr. Keith S. Champlin have pioneered the field of electronic battery testing. One technique employed is the application of a forcing function and the observation of the resultant change in a battery electrical dynamic parameter.

However, there is an ongoing need for improved accuracy of battery tests. The battery tests should preferably be able to be performed in a short period of time and deliver accurate results. With the present invention, data is collected from an automotive vehicle while a starter motor of the vehicle is engaged to start an engine of the vehicle. This additional data is used to provide a battery test result. The battery test result can be based solely upon the data collected during the starting sequence or may also include additional data such as additional battery test data, batter charging data, or battery discharging data. The data collected during starting of the vehicle provides a starting voltage profile, which includes voltage information along with time information. This starter voltage profile is then correlated with battery condition. In a more specific configuration, first test circuitry is used to couple to a storage battery of the vehicle, apply a forcing function to the storage battery of the vehicle and measure a response of the storage battery to the applied forcing function. This is used to provide a battery test output related to a condition of the battery. A starter voltage measurement circuit is electrically coupled to the starter motor of the automotive vehicle and collects starter voltage profile information comprising a plurality of starter voltage measurements obtained at different times during operation of the starter motor. Second test circuitry is then configured to receive the battery test output and the starter voltage profile information. The second test circuitry provides an enhanced battery test output related to the condition of the battery which has improved accuracy over the battery test output provided by the first test circuitry.

FIG. **1** is a simplified block diagram showing a battery maintenance system **100** coupled to an automotive vehicle **8**. The automotive vehicle **8** is illustrated as a battery **10**, a starter motor **14**, an engine **16** and a starter relay switch **18**. The vehicle **8** also includes an internal data bus illustrated as an OBDII data bus **20**. The battery maintenance system **100** also includes an OBDII connector **12**. As discussed more herein, battery maintenance system **100** performs electrical measurements on battery **10** using an electrical connection to the battery **10**. To collect starter profile information, the starter relay **18** is closed, which provides an electrical connection to the starter motor **14**. The starter motor **14** is caused to rotate thereby rotating the engine **16** allowing the engine **16** to start. During the starting sequence, data is collected by battery maintenance system **100** using the connection to battery **10**. The profile information includes a plurality of measurements taken over a time period. This time period can include time both before the starter relay switch **18** is closed and after the starter relay switch **18** is opened. Example data measurements include voltage measurements. Another example data measurement is a current measurement, for example, obtained using an amp clamp (not shown in FIG. **1**).

FIG. **2** is a simplified block diagram of battery maintenance system **100** including measurement circuitry **50** connected to storage battery **10**. Measurement circuitry **50** provides outputs to first test circuitry **52** and starter voltage measurement circuitry **54**. As discussed herein, the first test circuitry **52** can perform a battery test on the battery **10** using measurement circuitry **50** by applying a forcing function to the battery **10** and observing a resultant dynamic electrical parameter of the battery **50**. Starter voltage measurement circuitry also couples to measurement circuitry **50** and measures a voltage across the battery **10** while the starter motor **14** shown in FIG. **1** is operated. In one configuration, the device **100** determines that the starter motor is being operated by observing a voltage drop in the measured voltage across the battery **10**. In another example configuration, starting information is collected using the data bus **20** of the vehicle. Further, an operator can be prompted, for example using display **220** illustrated in FIG. **6**, to engage the starter motor. The collected profile data can comprise, for example, a series of data points collected over a period of time at variable or fixed time intervals. Second test circuitry **56** is configured to receive a battery test result from first test circuitry **52** along with the starter profile information provided by the starter voltage measurement circuitry **54**. The second test circuitry provides an enhanced battery test output based upon the battery test result provided by the first test circuitry along with the starter voltage profile information provided by starter voltage measurement circuitry **54**. The second test circuitry **56** couples to a memory **60** which contains data which relates starter voltage profile information to a condition of battery **10**. This data correlates voltages along with profile information such as rate of change of measured voltage, minimum and maximum voltage levels, the shape of the profile, etc., to the condition of battery **10**. The second test circuitry can use this to verify the battery test determination provided by first test circuitry **52** or can use this information to improve the accuracy of the battery test information provided by first test circuitry **52**. In another example configuration, if the battery test result provided by first test circuitry **52** differs significantly from the battery condition determine obtained using the starter voltage profile information, second test circuitry can provide a battery test output based solely on the starter voltage profile information.

FIG. **3** is a graph of voltage versus time and is an illustration of one example starter voltage profile. FIG. **3** shows a series of dots which represent individual samples of voltage at particular times. In this configuration, the time between samples is evenly spaced. However, the data points need not be linearly spaced in time and can vary as desired. Additional data points can be used when the profile is changing rapidly to provide for greater accuracy. The voltage profile provides a number of different types of data. As shown, the profile provides voltages both before the starter motor engages at time T**1** as well as information after power is removed from the starter motor **14** by relay **18** at time T**2**. This allows information to be collected related to the rate at which the voltage drops when the starter motor is engaged illustrated as a slope S**1** along with information related to the rate of voltage recovery illustrated as slopes S**2** and S**3**. Voltage minimums and/or maximums can also be collected. Further, operation of the starter motor **14** introduces noise on the voltage measurements which can be seen during time period T**3**.

FIG. **4** shows an example of datasets stored in array **63** which can be kept in memory **60**. The datasets include a series of starter motor voltage profile measurements indicated as profile **1**, profile **2**, profile **3**, . . . profile N. These profiles are a series of data points such as those discuss in connection with FIG. **3**. If the data points are collected at fixed or known intervals, time information does not need to be stored. Also stored in array **63** is a dataset of battery condition information. This is indicated as battery condition **1**, battery condition **2**, battery condition **3**, . . . battery condition N. The battery condition information is preferably obtained from the same battery from which the starter voltage profile information was obtained. The battery condition information can be obtained using any battery testing technique and can comprise, for example, battery state of charge, battery state of health, a pass/fail determination, or other battery condition. This can be determined, for example, using a measurement of a dynamic parameter in response to an applied forcing function, a load test, a charge acceptance test, a chemical test, a test of a physical property such as specific gravity, or other testing techniques. In one specific configuration, measurement circuitry **50** shown in FIG. **2** is used to apply a load test to battery **10** in which a load is applied across the battery and battery voltage and current flow is monitored as the battery is discharged. This can be used to make an accurate assessment of the amount of charge stored in the battery **10** and also used to determine battery health information. In a similar test, measurement circuitry **50** is used to apply a charge to the battery **10** and charge acceptance is monitored in order to determine battery state of health and battery condition. The starter voltage profile information for the associated battery is also stored in the memory. The array **63** can include other parameters obtained during battery testing such as battery voltage, current draws, temperature, battery type, battery rating, etc. Thus, in one example configuration, a starter voltage profile is obtained as discussed above and compared with the various profiles stored in array **63**. To determine the enhanced battery test output, a starter voltage profile is collected for a battery under test and a stored profile is selected which most closely matches the measured profile. The battery condition of the selected profile is identified and used to provide an enhanced battery test output indicative of the condition of the battery **10**. The particular matching technique can be selected as desired and can be a technique which matches the voltages at various time sequences and identifies the profile which most closely matches. Other techniques include matching slopes or rates of change such as S**1**, S**2** and S**3** illustrated in FIG. **3**. The amount of noise during the time period T**3** and voltage minimums or maximums can also be used in the matching period.

The enhanced battery test output can be determined using any number of techniques, including machine learning. One example technique is a series of steps used to provide the output. For example, if the first battery test provides a battery dynamic conductance which indicates a good battery, but the starter voltage profile shows an unusually large voltage drop, a determination can be made that the battery is actually bad. The data set used to make these determinations can also include battery voltage, battery rating, temperature, current measurements, etc.

FIG. **5** is an exploded view of a battery maintenance system **100** in accordance with one example embodiment. Battery maintenance system **100** includes an electronic battery tester **102** and a base station **104**. Base station **104** includes a base **106** and a cover or lid **108**. In the configuration shown in FIG. **5**, base station **104** is configured for portable operation, however, a fixed or less mobile base station configuration may also be employed.

The base station **104** includes a number of receiving areas **110**A-D for receiving various components (or accessories) of the battery maintenance system **100**. For example, battery tester **102** is received in receiving area **110**A. FIG. **5** also illustrates an amp clamp (current sensor) **120** which is received in receiving area **110**C, a OBDII communicator **122** which is received in receiving area **110**B and Kelvin connectors **124** which are received in receiving area **110**D.

Any number of battery maintenance tools or accessories may be contained in receptacles of the base station **104** and the invention is not limited to those specifically discussed herein. Additionally, the Kelvin connectors **124** are illustrated as being connected to a plug connector **111**A. This plug connector may be used for coupling the cabling to the battery tester **102**. Additionally, the plug **111**A may be plugged into a socket **111**B carried in the base station **104**. The socket **111**B may be used in a configuration in which a battery carried within the base station **104** is used for jump starting the vehicle. In another example configuration, battery testing circuitry, or other testing circuitry is carried in base station **104** and electrically coupled to Kelvin connectors **124** through plug **111**A and socket **111**B.

FIG. **6** is a simplified block diagram showing components and circuitry of the electronic battery tester **102**. Battery tester **102** includes a microprocessor **200** coupled to battery test circuitry **202**. Battery test circuitry **202** may operate in accordance with any battery testing procedure and one example procedure is discussed below in more detail. Battery test circuitry **202** is shown as coupled to Kelvin connector circuitry **204** and amp clamp circuitry **206**. Microprocessor also couples to a display **220** and user input/output **222**. An additional input/output circuitry **224** is illustrated along with wireless input/output circuitry **226**. Microprocessor **200** operates in accordance with instructions stored in memory **230**. A power supply **232** is illustrated and coupled to an optional battery **234**. Power supply **232** may obtain power through the connection to a battery under test, may obtain power through internal battery **234**, may obtain power through the base station **104**, or from some other source. In one configuration, battery **234** is charged when the battery tester **102** is coupled to a battery under test or when the battery tester **102** is coupled to base station **104**.

In the configuration illustrated in FIG. **6**, the various components of the battery maintenance device **100** shown in FIG. **2** are implemented using a number of different blocks in the Figure. For example, measurement circuitry **50** can be implemented in block **202**. This can include, for example, a forcing function, a voltage measurement circuit, and/or a current measurement circuitry. The first test circuitry **52**, starter voltage measurement circuitry **54** and second test circuitry **56** can be implemented in microprocessor **200**. The memory **60** of FIG. **2** can be a wholly or partially implement in memory **230** of FIG. **6**.

During operation, microprocessor **200** performs a test on a storage battery using connector circuitry **204** and optional amp clamp circuitry **206**. The amp clamp circuitry **206** may also be used to test other electrical components of an automotive vehicle such as, for example, a starter motor. The connection to the amp clamp **120** shown in FIG. **5** through amp clamp circuitry **206** may be a wired connection, or, for example, may be a wireless connection through wireless I/O **226**. Wireless I/O circuitry **226** may also be used to communicate with the OBDII communicator **122** and/or base station **104**. Base station **104** may also be used to relay communications to another location, such as a centralized location.

The microprocessor **200** provides information to an operator using, for example, display **220** and may receive commands or other user input through user I/O **222**. I/O **224** may be used for communicating with other components or devices. For example, a remote printer may be accessed using circuitry **224**. The microprocessor can communicate with the OBDII databus of the vehicle using the OBDII communicator **122**. For example, this information can be used to determine information about the vehicle under test, information about usage of the vehicle under test, information about the storage battery of the vehicle or other information related to the vehicle. Further, the communicator **122** may be used to provide data signals onto the OBDII databus of the vehicle. This may also be used to store information or other parameters in the vehicle, or control operation of components of the vehicle.

FIG. **6** also illustrates tracking circuitry **240** which is used by circuitry in base station **104** to identify a location of the battery tester **102**. For example, the tracking circuitry may include addressing information whereby base station **104** may identify a unique battery tester **102** when it is placed into the receiving area **110**A of the base **106** shown in FIG. **5**. Note that the receiving area **110**A illustrated in FIG. **5** may also include an electrical connection for coupling to power supply **232** of the battery tester **102**.

FIG. **7** is a simplified block diagram of amp clamp/current sensor **120**. Sensor **120** includes a current probe **300** coupled to measurement circuitry **302**. Probe **300** may operate in accordance with any appropriate technique for a particular use. Such techniques include inductive coupling, the use of a Hall Effect sensor, or some other technique including a shunt. Measurement circuitry provides an output to wireless I/O circuitry **304** related to the measured current. This information is transmitted wirelessly to the battery tester **102** shown in FIG. **6**. The current sensor **120** includes a power supply circuit **310** for providing power to the device. An internal battery **312** may be used for storing power. The battery **312** may be charged, for example, through a connection through power supply **310** to the receiving area **110**C of base station **104**. Tracking circuitry **326** is also provided.

FIG. **7** also illustrates an optional optical sensor **320** carried by current sensor **120**. Optical sensor **320** may be used to receive optical information such as, for example, information provided by a barcode. The optical sensor **320** can be used to read information from the vehicle, for example, a VIN identification number of the vehicle, as well as information related to various components of the vehicle including serial numbers carried on storage batteries or other components of the vehicle. In another example configuration, optical sensor **320** comprises an infrared sensor for use in sensing temperature of various components of the vehicle or other components. For example, battery temperature can be used as part of a battery test.

In another example configuration, the system **100** can be used for providing a jumpstart to a battery of a vehicle. In one such example configuration, the internal battery **234** of tester **102** is coupled to Kelvin connector circuitry **204** to apply a voltage to the battery for starting the vehicle using Kelvin connectors **124**. In such a configuration, the battery **234** should be able to deliver sufficient current at a high enough voltage to activate the starter motor of the vehicle. For example, a rechargeable lithium battery may be employed. In another related configuration, a "memory saver" function is provided by system **100**. This can be used if the battery of a vehicle is disconnected or removed from the vehicle in order to maintain the memory and other stored information within the vehicle. For example, the vehicle may be powered using battery **234** through the Kelvin connectors **124**. Other connection mechanisms may also be employed such as, for example, a connection to the OBDII databus, a connection through a "cigarette lighter" of the vehicle, etc.

The tracking function discussed herein may also be used as a component of the testing function. For example, in order to ensure that all accessories are returned to their proper location, the system **100** can be configured to only provide a test result once all of the accessories are returned to their proper location within the base station **104**. Batteries or storage systems within the various components can store power during the testing process in which power is received from the battery or the vehicle under test. Other charging techniques may also be employed such as, for example, through an electrical connection to the base station **104**. The amp clamp **120** may also include additional electronic circuitry and input/output circuitry to perform tests of its own. For example, such circuitry can be used to provide an operator with information related to the amount of current being sensed during a particular operation of the vehicle. Other diagnostic functionality may also be implemented.

FIG. **8** is a simplified block diagram of the OBDII communicator **122** shown in FIG. **5**. Communicator **122** includes an OBDII interface **400** for connection to an OBDII data port of an automotive vehicle. This allows a two-way communication with the databus of the vehicle. Although an OBDII interface is illustrated, interface **400** may communicate with any type of vehicle databus or the like. Communicator **122** includes a power supply **410** for use in providing power to the device. An internal battery **412** is used for powering the communicator **122**. The battery of **412** may be charged, for example, when the communicator **122** is placed in the receiving area **110**B shown in FIG. **5**. Wireless communication circuitry **420** is provided for use in wirelessly communicating with the battery tester **102**. The wireless communication circuitry **420** may also be used to communicate with base station **104**. Using this communication circuitry **420**, the devices can communicate with the onboard databus of a vehicle using the OBDII interface **400**. Tracking circuitry **430** is also provided and may include a unique address at which identifies the communicator **122**. Further, the tracking circuitry **430** may be used by base station **104** to identify positioning of the communicator **122** within the receiving area **110**B.

FIG. **9** is a simplified diagram of Kelvin connectors **124** used to connect to battery **10**. Kelvin connectors **124** include a pair of Kelvin connections **500**, **502** each containing two electrical connections. Kelvin connections **500**, **502** may be configured in alligator clamps **504**, **506**, respectively, or the like. Cabling **510**, **512** is used to provide a physical electrical connection to the battery tester **102** shown in FIG. **5**. Tracking circuitry **520** may include a unique address for use in identifying the Kelvin connector **124**. This may also be used for determining placement of the Kelvin connector **124** into the receiving area **110**D of the base station **104**.

FIG. **10** is a simplified block diagram of base station **104**. Base station **104** includes a microprocessor **600** optionally connected to receptacles **110**A-D. Using this optional connection, microprocessor **600** may use a physical connection to the tester **102**, amp clamp **120**, OBDII communicator **122** and Kelvin connectors **124** for communication. This may be for downloading parameters, programming the device, or for other usage. Microprocessor **600** also couples to a communication hub **604**. Communication hub **604** provides both wireless and wired communication. For example, information can be communicated to a remote location including a data "cloud", using wireless or wired communication techniques including WiFi, cellular data transmission, hard wired Ethernet, Bluetooth®, etc. Communication hub **604** may also be used for wirelessly communicating with the various components of the system **100** including the battery tester **102**, amp clamp **120**, OBDII communicator **122** and Kelvin connectors **124**. Optional user input/output may also be provided for the communication hub, for example, for displaying information or receiving a user input. Communication hub **604** may be used for communicating with a local device such as a printer as well as a portable user interface, for example, provided by a tablet computer, cellular phone, or other device including an application specific device. Microprocessor **600** is coupled to a memory **608** which is used to store programming instructions as well as store calibration parameters, etc. Further, test measurements or the like may be stored into the memory **608**. Base station **104** includes a power supply **610** used for powering components of the base station **104**. Power supply **610** may also be used for recharging batteries carried by the battery tester **102**, amp clamp **120**, OBDII communicator **122** and Kelvin connectors **124**. An optional battery **612** is provided for powering the base station **104** when an external power source is not available.

Base station **104** includes tracking circuitry **620**. Tracking circuitry **620** is used to communicate with the tracking circuits carried within the various accessories of the system **100**. In a specific example, the tracking circuitry **620** communicates with the tracking circuit **240** of battery tester **102**, the tracking circuit **430** of OBDII **122**, the tracking circuit **520** of Kelvin connectors **124** for determining when they are placed within their receiving areas **110**A-**110**D of base station **104**. Further, the various components may wirelessly communicate with tester **102** and/or base station **104**.

FIG. **11** is a more detailed block diagram of battery tester **102** which includes a forcing function **740** and an amplifier **742** coupled to connectors **500**. In the illustration of FIG. **7**, connectors **500** are shown as Kelvin connections. The forcing function **740** can be any type of signal which has a time varying component including a transient signal. The forcing function can be through application of a load or by applying an active signal to a battery. A response signal is sensed by amplifier **742** and provided to analog to digital converter **744** which couples to microprocessor **200**. Microprocessor **200** operates in accordance with instructions stored in memory **230**. Microprocessor **200** can store data into memory **230**.

Of course, the illustration of FIG. **11** is simply one simplified embodiment and other embodiments are in accordance with the invention. In the illustrated embodiment microprocessor **200** is configured to measure a dynamic parameter based upon the forcing function **740**. This dynamic parameter can be correlated with battery condition as set forth in the above-mentioned Champlin and Midtronics, Inc. patents. However, other types of battery tests circuitry can be used in the present invention and certain aspects of the invention should not be limited to the specific embodiment illustrated herein. FIG. **11** also illustrates an input/output circuitry **222** which can be any other type of input and/or output coupled to microprocessor **46**. For example, this can be used to couple to external devices or to facilitate user input and/or output. Although a microprocessor **200** is shown, other types of computational or other circuitry can be used to collect and place data into memory **230**. Further, in one configuration, the forcing function **740** can be configured as a large electrical load for performing a load test. In another example configuration, the forcing function **740** provides a battery charging function is which charge is applied to the storage battery and monitored to determine battery condition.

Further, using the system set forth herein, a battery maintenance system which includes machine learning is provided. FIG. **12** is a simplified block diagram of a machine learning model training **700** and a machine learning model prediction **702** in accordance with a further embodiment of the invention. In such a configuration, the test equipment

100 set forth herein is configured to gather data such starter voltage profile information and battery condition information as shown in FIG. 4. The data then is analyzed and acted upon using machine learning techniques performed either locally, remotely, or in a hybrid fashion. As set forth in FIG. 12, the machine learning training mode includes gathering test data followed by exploratory data analysis. The collected data is cleaned if necessary to remove undesired data points. This cleaning function includes removing outlier data, data with excessive noise, etc. A feature engineer step is provided followed by a train and test machine learning model. The feature engineering step can be used to discard bad data. For example, an unusually cold temperature measurement obtained in a warm climate can be identified and discarded. Any appropriate feature engineering technique can be used. The machine learning can be through known neural network or other machine learning techniques. The model is then evaluated but collecting additional starter voltage profile and battery condition information and comparing the results from the model with actual measured battery conditions. Parameters are fine-tuned as desired. A model can then be deployed in service either locally at a test location, remotely at a cloud-based location for example, or in a hybrid combination of such locations.

Similarly, the system includes a machine learning model prediction phase 702 once the model is sufficiently trained and put into service. In this phase, data is gathered and cleaned along with processed through a feature engineer. The data is then used to predict a battery test result or other test result including an alternator test result. This prediction is then output as desired, for example this prediction can be output locally and/or transmitted to a remote location. The steps in accordance with the machine learning model training mode are set forth below in more detail:

Connect tester clamps to battery and perform a battery test and starter test on a vehicle.

Send the battery test and starter test measurement and result data to a test database.

Record corresponding DCA (Dynamic Charge Acceptance) test if battery test result is charge and retest and technician charges the battery on a charger.

Clean the data for bad data, missing data and outliers.

Perform stratified sampling to ensure a good representation of all the decisions in the dataset are present.

Simplify from multiple decision types to a binary decision type (Good battery, Bad battery).

Transform information into a format that can be interpreted by the machine learning model:

- Convert starter data from a single cell colon separated data to an array format with multiple readings per second.
- Feature engineer data to obtain information about battery health, for example, using the array format above to calculate the average voltage of the starter test.
- Transform additional data columns such as temperature to ensure they are in the consistent measurement unit.

Divide this simplified and transformed data into two sets of training data and test data.

Supply this training data to multiple Machine Learning algorithms for building the model.

Apply the ML model to the test data to measure the accuracy and cross validation score.

Evaluate the models for accuracy, sensitivity, specificity, cross validation and log loss.

Fine tune model parameters.

Deploy the model to production for real-time battery decision prediction.

Retrain and redeploy the model with new data if the data distribution deviates significantly from the initial training set.

Similarly, once the machine learning model is deployed into service, a prediction model is implemented as follows:

Connect tester clamps to battery and perform battery and starter test.

Clean the measurement data for bad data, missing data and outliers. e.g., voltages above "x" volts or Temperatures above "y" Fahrenheit.

Transform the data in a format that can be interpreted by the machine learning model.

- Convert starter data from a single cell colon separated data to an array format with multiple readings per second.
- Feature engineer the data e.g. using the array format above to calculate the average voltage of the starter test.
- Additional data columns such as temperature are transformed to ensure they are in the same measurement unit.

Supply transformed data to the machine learning model in production.

Return the predicted battery result to the tester/charger and data cloud.

The particular machine learning can be implemented using standard computer programming techniques which are known in the art such as neural networking techniques. The techniques can be used to test automotive vehicle batteries (including electric and hybrid vehicles), backup power supply batteries, etc., as well as components of automotive vehicles such as starter motors.

In one specific configuration, voltage is measured at a rate of 1000 samples per second. Any number of data points can be collected. In one embodiment, 513 data points are collected. If a training dataset is imbalanced, for example, having disproportionately high number of "good" battery tests compared to "bad" battery tests, the data can be balanced using known techniques. For example, stratified sampling can be used, SMOTE (Synthetic Minority Oversampling Technique) can be used, or others. Further, outlying data in standard deviations, mean and median voltage value, or other parameters can be discarded from the training model. Once a model is trained for example, using the XGBoost method, the model parameters such as Tree depth, minimum child weight, learning rate, etc., can be fine tuned.

Although the present invention has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the invention. The devices described herein, in some embodiments, may be capable of wireless communication. The particular wireless communication technique may be implemented as desired. Examples include Bluetooth® communication techniques, near field communication techniques, WiFi communication techniques, cellular communication techniques or others. The test performed by the battery tester 102 may be a function of information input by a user, or information received from other sources, such as the VIN of the vehicle. The VIN information may be obtained using a barcode scanner or through the connection to the OBDII databus. Based upon a particular vehicle, the battery test can be adjusted accordingly. The amp clamp 120 may be used in conjunction with the battery test, or may be used for performing other tests on the vehicle. Such tests include measuring starter current, phantom current draws, charging current, etc. The testing and measurements circuits and components, along with memory and logic functionality, discussed herein can be implements in shared components and need not be discrete components. For example, the same voltage sensor used to measure a dynamic parameter can be used to collect starter voltage profile information. The memories and logic functionalities illustrated and discussed herein can be implemented locally, remotely, or a combination of local and remote implementations. Although the starter voltage profile is described herein as voltage data, current data may also be used as the two parameters are related. For example, current flowing from the battery while the starter motor is engaged is related to a voltage drop across a series resistance, a voltage output from an amp clamp, etc. In one aspect, the machine learning model eliminates the need to charge the battery and retest the battery, thus reducing the required to complete a battery test.

What is claimed is:

1. An electronic battery tester for testing a storage battery in an automotive vehicle, comprising:

first test circuitry configured to couple to the storage battery, apply a forcing function to the storage battery, measure a response of the storage battery to the applied forcing function and provide a battery test output related to a condition of the battery based upon the response of the battery to the applied forcing function;

starter voltage measurement circuitry configured to electrically couple to a starter motor of the automotive vehicle and collect starter voltage profile information comprising a plurality of starter voltage measurements obtained at different times while operating the starter motor; and

second test circuitry configured to receive the battery test output from the first test circuitry and the starter voltage profile information and provide an enhanced battery test output related to the condition of the battery based upon the battery test output and the starter voltage profile information.

2. The electronic battery tester of claim **1** wherein the starter voltage measurements comprise a voltage across a storage battery of the automotive vehicle.

3. The electronic battery tester of claim **1** including a connection to a databus of the vehicle.

4. The electronic battery tester of claim **3** wherein the starter voltage measurements are obtained through the databus of the vehicle.

5. The electronic battery tester of claim **1** including an output to prompt an operator to engage the starter motor of the vehicle.

6. The electronic battery tester of claim **1** wherein the voltage measurements are obtained at fixed time intervals.

7. The electronic battery tester of claim **1** wherein the voltage measurements are obtained at variable time intervals.

8. The electronic battery tester of claim **1** including a memory configured to store the starter voltage measurements.

9. The electronic battery tester of claim **1** wherein the starter voltage measurements are used to determine a condition of the storage battery.

10. The electronic battery tester of claim **9** wherein the condition of the storage battery determines using the first test circuitry and the condition of the storage battery using the starter voltage measurement circuitry are compared for verification.

11. The electronic battery tester of claim **1** wherein the starter voltage measurements include a measurement obtained before the starter motor is engaged and a measurement obtained while the starter motor is engaged.

12. The electronic battery tester of claim **1** wherein the starter voltage profile information is compared with stored starter voltage profile information to determine a condition of the storage battery.

13. The electronic battery tester of claim **1** including a memory configured to store a plurality of starter voltage profile measurements.

14. The electronic battery tester of claim **13** wherein the plurality of stored starter voltage profile measurements are associated with a condition of the storage battery.

15. The electronic battery tester of claim **1** wherein the condition of the battery is further determined based upon a temperature.

16. The electronic battery tester of claim **1** wherein the condition of the battery is determined using the starter voltage profile information and machine learning implanted by the second test circuitry.

17. The electronic battery tester of claim **1** wherein the enhanced battery test output is a function of a slope in the starter voltage profile information.

18. The electronic battery tester of claim **1** wherein the second test circuitry monitors noise present in the starter voltage profile information.

19. The electronic battery tester of claim **1** wherein if the battery test output from the first test circuitry indicates a good condition of the storage battery and the starter voltage profile information shows an unusually large voltage drop, the enhanced battery test output comprises a bad battery determination.

20. The electronic battery tester of claim **1** wherein the enhanced battery test output is further a function of current measurements.

21. The electronic battery tester of claim **1** wherein the second test circuitry discards starter voltage measurements which are determined to be bad data.

22. The electronic battery tester of claim **1** including communication circuitry to communicate the starter voltage profile information to a remote location for training of machine learning.

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