Provisional Patent Application:

1) **A title for the patent**

   Real-time monitoring for smart predictive maintenance of Li-Ion battery

2) **Contributor**

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3) **A 3 line summary of the invention**

   This invention focuses on early prediction of the required maintenance of Li-Ion batteries. This smart predictive maintenance is achieved by real-time monitoring and leveraging the data science for identification of systematic divergence of Li-Ion battery's cell-voltages.

4) **The entire list of components that will be used to achieve the function (Need not be necessary that these components be ones that can be claimed. Please enlist everything from screws, wiring harness and the specific Iot System used)**

   The entire list of components to achieve data acquisition and smart predictive maintenance of Li-Ion battery:

   1. Battery's cells: Li-Ion cells
   2. Sense wire: copper sense wire, standard size
   3. Screw: 6 mm inner diameter, stainless steel
   4. Washer/Spacer: 6 mm inner diameter, stainless steel
   5. Battery Management System (BMS): standard BMS with current, voltage, and temperature sensors
   6. Data logger: with GSM and GPS chips from Telit
   7. Communication cable: a male coupler is used to connect 3 wires
   8. Server and Database: Amazon AWS server and MongoDB database

4) **Specify how the components will be setup for achieving the function.**

   Step 1: Battery assembly:

Battery assembly is done by putting 16-cells of the same grading (internal impedance and nominal voltage) along with BMS and Data-logger for real-time battery health and performance data collection and monitoring.

Step 2: Battery component calibration:

It is required to check for cells' balancing, voltage and current values calibration for whole battery system to function properly.

Step 3: Server and database settings:

This invention utilizes RESTful API, Amazon AWS server, and MongoDB database for data collection and real-time monitoring of battery health and performance.

5) Industrial Application - Who all can benefit from using this invention?

The described invention focuses on Li-ion batteries used in renewable and electric mobility industries. Key application is in conducting predictive maintenance of batteries proactively with savings on resources and time. This helps in extending Li-ion battery life and in satisfying the customer-base with better control over the maintenance.

6) A step by step process of how the function will be achieved. Please give reference to the components.

Step 1: Assembly of battery and electrical components:

Lithium ion battery is assembled using 16 cells. Each cell have capacity of 72 Ah and operating voltage range of 2.5 to 3.65 volt. Each cell is connected with a sense wire that is further connected with the Battery management System (BMS). BMS is an electronic regulator that monitors and controls the charging and discharging of the battery and report the battery data to Data-Logger via a communication cable. Data-Logger acquires and transfers the battery health and performance data by using GSM 2G/3G network to remote server.

Step 2: Real-time monitoring of battery's data:

Once the Data-Logger transfers the battery data to server, it can be monitored in real-time and can be further analyzed for predictive maintenance. After real-time data collection, multiple data pre-processing steps are processed to sort and clean the raw data for detailed data-analysis.

Step 3: Leveraging data science for smart predictive maintenance to predict state of loose connection by divergence in cell voltages:

This described invention assists in rapid and accurate estimate of maintenance requirements by leveraging data analysis and real-time monitoring.

This invention focuses on detection of potential failure, i.e. shutting of the Li-ion battery or BMS, just by understanding cells' voltage trend and divergence in their numerical values.

If the cells in battery assembly are fully-balanced and of same grading (i.e. similar impedance) to start with, i.e. their voltage and capacity follow similar and expected trends, then divergence in cells' voltages are led by loose state of contact either by loose electrical connections or by increased in roughness at the surface of cells' electrodes.

Process involves continuous monitoring the differences in the numerical values of the individual cell voltages.

Based on testing on multiple Li-ion batteries, it was observed and validated that if a cell's voltage value diverges at a higher rate than the rest, it is an early sign of the loose state of contact at the surface of cells' electrodes for that particular cell (i.e. one with higher divergence) given the cells' are fully balanced.

Please see below mentioned Figure 1 to substantiate the claim that cell voltage divergence can be detected and monitored.

Figure 1: Example of the cell voltage divergence of a lithium-ion battery under discharging state. Data is recorded while vehicle is in the motion. Cell # 5 (v5) is observed to have a significantly higher cell voltages then the rest of the cells.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	only_date	only_t	state	batRe	cap	curren	v1	v10	v11	v12	v13	v14	v15	v16	v2	v3	v4	v5	v6	v7	v8	v9	vol
136671	12/1/2019	8:50:52	-1	99	49.648	1.75	3.33	3.32	3.31	3.31	3.31	3.32	3.32	3.31	3.31	3.31	3.31	4.91	3.07	3.32	3.31	3.31	54.38
136672	12/1/2019	8:50:54	-1	99	49.647	1.75	3.33	3.32	3.31	3.31	3.31	3.32	3.32	3.31	3.31	3.31	3.31	4.91	3.07	3.32	3.31	3.31	54.38
136730	12/1/2019	8:52:22	-1	98	49.431	8.33	3.29	3.29	3.29	3.28	3.28	3.28	3.28	3.28	3.28	3.29	3.29	4.69	4.53	3.2	3.28	3.28	55.09
136797	12/1/2019	8:53:52	-1	1	0.35	0.86	3.29	3.29	3.28	3.28	3.28	3.29	3.28	3.28	3.28	3.29	3.28	4.86	3.28	3.27	3.28	3.27	54.07
136801	12/1/2019	8:53:58	-1	1	0.35	18.71	3.29	3.29	3.29	3.29	3.29	3.29	3.29	3.29	3.29	3.29	3.29	4.97	2.63	3.29	3.28	3.28	53.62
136803	12/1/2019	8:54:01	-1	0	0	7.82	3.29	3.29	3.29	3.29	3.28	3.29	3.29	3.29	3.29	3.29	3.29	4.81	3.21	3.27	3.28	3.29	54.02
137016	12/1/2019	9:06:22	-1	1	0	6.11	3.28	3.29	3.28	3.28	3.27	3.28	3.28	3.28	3.28	3.28	3.28	4.17	2.81	2.91	3.28	3.28	52.54
137077	12/1/2019	9:07:41	-1	1	0	14.53	3.29	3.29	3.29	3.29	3.28	3.29	3.29	3.29	3.29	3.29	3.29	4.87	3.22	3.29	3.29	3.29	54.11
137288	12/1/2019	9:29:22	-1	0	0.17	13.81	3.3	3.3	3.3	3.29	3.29	3.29	3.29	3.29	3.29	3.3	3.01	4.86	2.85	3.29	3.29	3.29	53.54
137730	12/1/2019	9:53:24	-1	1	0	18.94	3.29	3.29	3.29	3.29	3.29	3.3	3.3	3.29	3.29	3.29	3.25	4.9	4.93	2.6	3.28	3.28	55.17
137754	12/1/2019	9:53:57	-1	1	0	16.08	3.29	3.29	3.29	3.29	3.28	3.29	3.28	3.28	3.29	3.29	5.02	4.9	3.29	3.29	3.29	3.29	55.96
137773	12/1/2019	9:54:24	-1	1	0	4.44	3.3	3.3	3.3	3.3	3.29	3.3	3.3	3.17	3.3	3.3	3.3	4.9	3.31	3.3	3.3	3.3	54.29
137856	12/1/2019	10:07:11	-1	1	0	23.34	3.29	3.28	3.28	3.28	3.27	3.28	3.28	3.28	3.28	3.29	3.28	4.93	4.96	3.28	3.28	3.28	55.84
138018	12/1/2019	10:11:03	-1	1	0	25.6	3.29	3.29	3.29	3.28	3.28	3.29	3.29	3.29	3.28	3.29	3.29	4.88	2.58	3.09	3.27	3.29	53.24
138036	12/1/2019	10:11:26	-1	1	0	6.13	3.27	3.29	3.29	3.29	3.28	3.29	3.29	3.29	3.3	2.83	2.6	4.86	3.29	3.29	3.29	3.29	53.02
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In this example (Figure 1), it was found that the connections of the cells' under consideration (i.e. with higher divergence of cell voltages) were loose. Based on the similar observations with multiple batteries, logic and state of loose contact/ connection were empirically quantified as summarized in the Table 1.

If voltage of any cell is greater than 0.5 volt for about 5 seconds during the charging or discharging state of the battery then that particular cell connection may be loose (given that battery is fully balanced as mentioned above) indicating the loose state of contact/connection at electrodes. In addition, this method allows early identification of type of maintenance required.

Table 1: Description of logic and state of loose contact/connection

Difference in cells' voltages w.r.t minimum cell voltage (per 5 seconds)	State of loose contact/ connections	Does it require predictive maintenance?
(0 – 0.05)	No cell is under loose state and electrical connections are tight	No
[0.05 – 0.2)	Electrical connections are okay	No immediate maintenance is required.
[0.2 – 0.5)	Cell is under loose state and electrical connections are loose	Yes. Indication of early prediction of maintenance.
[0.5 +)	Cell is under loose state and electrical connections are very loose	Yes. Immediate maintenance is required to avoid shut-down of the BMS or Battery.

Notes:

1. Battery mode is under either charging or discharging state
2. Time duration for monitoring the cell voltages is 5 seconds
3. Difference of the cell voltages are w.r.t minimum cell voltage
4. State of loose contact/connection is at the electrodes of the cells
5. Battery shall be fully-balanced and all cells should be of same grading

Based on the listed method/process in Table 1, early-prediction of battery-maintenance can be performed.

7) Flow chart or drawings.

Figure 1: Hardware settings

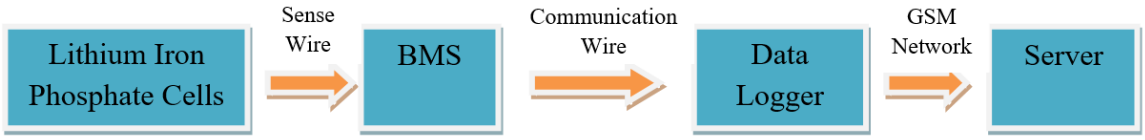
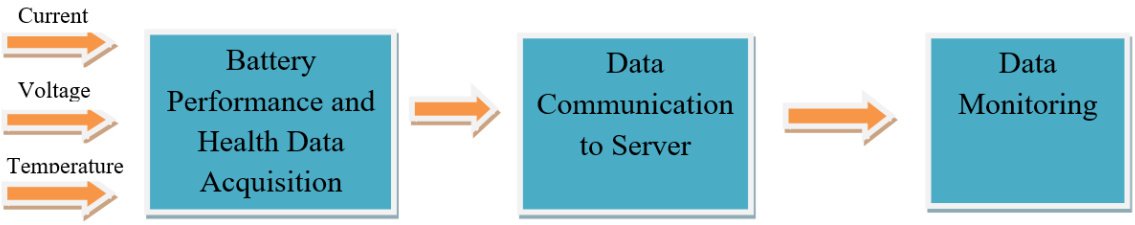


Figure 2: Data flow for predictive maintenance



8) Claims - Please state the process, part of the process or a function that you think will be entirely novel to this invention.

Claim 1: Process of predicting requirements of early-maintenance of Li-ion batteries from diverging voltages of cells (described earlier in the document)

Claim 2: The method of claim 1, wherein includes the analysis of the voltage values of cells in a battery w.r.t minimum cell voltage at any given time.

Claim 3: The method of claim 1, wherein includes transferring the data to servers via battery component and require GSM network.

Claim 4: The method of claim 1, wherein includes battery cells' to be fully balanced and individual cells' are of same grade.

Claim 5: The method of claim 1, wherein includes following conditions to achieve the full function of the

(a) Battery mode is charging state

(b) Time duration for monitoring the cell voltages is 5 seconds

(c) Difference of the cell voltages are w.r.t minimum cell voltage

(d) State of loose contact/connection is at the electrodes of the cells

<u>Comparison with prior arts</u>

Patent 1:

Title: System and method for predictive maintenance of a battery assembly using temporal signal processing
Pub. No.: US 2009/0009183 A
Pub. Date: Jan. 8, 2009
Office: United States Patent Application Publication

Similarity:
1. Technical field: to predict faults in the battery assembly.
2. Upper and lower operational boundary to predict a fault condition of the battery.

Dissimilarity:
1. Claim: Art in comparison focused on the Lead acid battery. Current patent under review focused on Lithium ion battery.
2. Method: patent enlists a generic technique focused on absolute parameters like voltage or impedance. Current patent under review focused on differential voltages (i.e., delta values of voltages) and it is only specific to voltage.
3. Art in comparison also does not mention steps to fix the battery assembly after the needs for predictive maintenance identified.

Patent 2:

Title: Método de mantenimiento predictivo de baterías
Pub. No.: ES 2 338 091 B1
Pub. Date: 01.06.2011
Office: Oficina Espanola de Patentes Y Marcas, Espana.

Similarity:
1. Technical field: predictive maintenance in the battery assembly.
2. Upper and lower operational boundary to predict a fault condition of the battery.

Dissimilarity:
1. Claim: Art in comparison focused on the Lead acid battery. Current patent under review focused on Lithium ion battery.
2. Method: patent enlists advanced statistical methods based on the values of the impedance. Current patent under review focused on differential voltages (i.e., delta values of voltages); it is only specific to voltage and requires simple algebraic functions only.
3. Art in comparison also does not mention steps to fix the battery assembly after the needs for predictive maintenance identified.