A Review: Diagnosis and Classification of Faults in Electric Vehicle for Energy Storage and Electric Motor System

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***Abstract*— Transport is the largest consuming sector representing 40 per cent of total energy in the world. The recent development of electric and hybrid vehicles is potentially providing effective solutions to the reduction of the use in fossil fuel. As per forecast by International Energy Agency (IEA) in its Global Outlook 2018 report, electric car stock will be ~ 70 million by 2025. World Bank announced that it will stop financing upstream oil and gas projects after 2019 to raise funds to finance a shift towards clean energy. In this paper the research challenge is to optimize a novel framework for managing electric vehicle telemetry data through a process of AI based Algorithm to translate this data into useful engineering information for new, model-based, control system solutions for the vehicles performance. Current and voltage are the most commonly used detection parameters for EVs. Apart from these, temperature, vibration, power, noises, and torque are also utilized on the basis of different detecting techniques. Overheating of electrical machines leads to rapid failure. Hence, the main limitation on electrical generators and drive is a temperature limit, which is generally enforced with an electrical fuse (current limit). The smart sensors once integrated into system give real time information allowing an unparalleled understanding. Furthermore, they may be used to investigate fast charging protocols and ageing. For any specific faults in Electric Vehicle like over charge / overheating, short circuit / open circuit of cell etc in Energy storage fault and abnormal connection of stator winding, O.C. or S.C. of stator winding, bearing failure, S.C. of rotor winding etc in Electric Motor fault. We can consider n no. of case and optimize the value of that specific fault by analyzing data of fault. By doing feasibility study and design optimization of all faults in Electric Vehicle for specific condition we can build prototype for mathematical model of EV and validate simulation results with experimental data through Lab demonstration model.**

Keywords-Electric Vehicle; Energy Storage; Fault Analysis; Electric Motor; Octive/Matlab;

I. INTRODUCTION

Transport is the largest consuming sector representing 40 per cent of total energy in the world. The recent development of electric and hybrid vehicles is potentially providing effective solutions to the reduction of the use in fossil fuel. Global electric car stock surpassed 2 million vehicles in 2016. Various countries such as Norway, Netherlands, Germany, France, UK have set targets for migrating to total electric transportation by 2030 –2040. Various vehicle manufacturers such as Volvo, Daimler, Volkswagen, have announced plans to go for only electric power train for future models. As per forecast by International Energy Agency (IEA) in its Global Outlook 2018 report, electric car stock will be ~ 70 million by 2025. World Bank announced that it will stop financing upstream oil and gas projects after 2019 to raise funds to finance a shift towards clean energy.[4]

Electric Mobility in India

- National Electric Mobility Mission Plan (NEMMP)
- Faster Adoption and Manufacturing of Electric (& Hybrid) Vehicles in India (FAME-India Scheme)

The scheme has 4 focus areas:

- Technology development
- Demand creation
- Pilot projects

- Charging infrastructure

India can save 64% of anticipated road based mobility related energy demand and 37% of carbon emissions in 2030 by pursuing a shared electric and connected mobility resulting in a net savings of roughly Rs 3.9 lakh crore (approximately 60 billion USD) in 2030.

India has focused on electrification of transportation.

- Early EV penetration in public transport E-rickshaw, E-auto, Taxis, Buses
- Strategy – Aggregation of demand (by EESL) for cost economisation instead of cash incentives
- EESL tender for 10,000 EV sedan cars and 2000 Bharat EV Chargers
- DHI funding to 11 cities for public EV multi-modal transportation
- Swappable battery (separate vehicle and energy business)
- Private vehicles to leverage the eco-system

II. PURPOSE OF THE STUDY

Energy storage system, power electronics and electric motor are the main components of electric vehicles (EVs). Energy storage is a rapidly growing market, with emerging demands from almost all industrial sectors. However the technologies in energy storage and electric motor have seen great advances, there are still great challenges in the effective integration of different technologies to overcome the practical constraints of power density, flexibility and efficiency and operation range for such vehicles.

A. Energy Storage System (Battery)

Energy storage system is introduced first as it is essential for propulsion of EVs. The damage on the battery influences its operating efficiency, or even life safety threats. Battery system fault can be classified into four groups, namely battery voltage fault, battery current fault, battery temperature fault and battery state of charge (SOC) fault. This paper will investigate an integrated approach with the use of different energy storage methods, power sources as well as optimized power management for electric and hybrid vehicles [5].
This work will explore vehicle dynamics related issues to fully evaluate the energy needs of the vehicles in practical operating conditions (like Overheating, State of Charge, Vibration and Current direction {- , +}), study a range of available technological options, and apply AI at the overall system level to maintain god performance of Energy Storage System [1].

The major faults of electric battery are:

- Over-charge or over-discharge;
- Overheating or under cooling;
- Short circuit or open circuit of inter-cell;
- Inaccurate estimation;

Battery Voltage Fault	Low voltage fault
	Over voltage fault
	High-voltage insulation fault
	High-voltage loop fault
Battery Current Fault	Short circuit fault
Battery Temperature Fault	Low temperature fault
	Over temperature fault
Battery SOC Fault	Pre-charge fault
	Over charge fault
	Over discharge fault

Battery Management System (BMS):

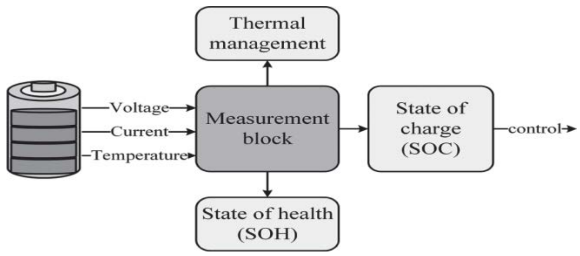

Figure 1: Battery Management System

The BMS has the possibility to monitor and control (directly or indirectly) several different parameters of the battery [1]:

1. Voltage
2. Current
3. State of charge
4. Temperature
5. State of health

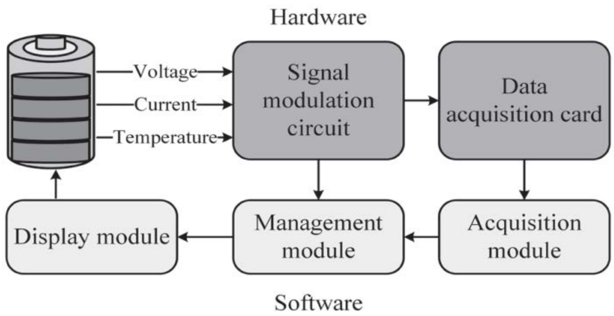

Figure 2: Schematic presentation of Battery Diagnostic system

B. Electric Motors

The first fundamental property on which electric vehicle differ from internal combustion engine cars is the motor. The electric motor is the heart of the electric vehicle while it converts electric power into mechanical power and allows motion. According to the root cause of faults, electric motor faults can be generally categorized into two groups: electrical faults and mechanical faults [9].

Electrical machines are working under stressful conditions in electric vehicles and close to their limits. That is due to the transient character of the drive-cycle as well

the limited space and size restrictions. So, faults may appear which if go undetected will evolve in severity and interrupt the safe, efficient and reliable operation of the vehicle.
The major faults of Electric Motor are:

- Abnormal connection of Stator Winding;
- O.C. and S.C. of Stator Winding;
- Bearing Failure;
- Broken Rotor Bar;
- S.C. of Rotor Winding;

Electrical faults		Mechanical faults	
Rotor-related faults	Stator-related faults	Bearing faults	Eccentricity-related faults
Broken rotor bar	Abnormal connection of stator windings	Outer bearing race defect	Bend shaft
Cracked rotor end rings		Inner bearing race defect	Static air-gap irregularities
Shorted rotor field windings	Open or short circuit of stator windings	Ball defect	Dynamic air-gap irregularities
		Train defect	

This research work will deal with the evaluation of different electromagnetic variables as to their generalized diagnostic ability in traction motors. Moreover, the ability to estimate the fault level severity will be an important parameter of this work.

Types of Motors used in Electric Vehicle:

As per literature survey there are only three types of motors that are being used in EVs today:

- Induction motor
- Permanent magnet motor
- Synchronous reluctance motor

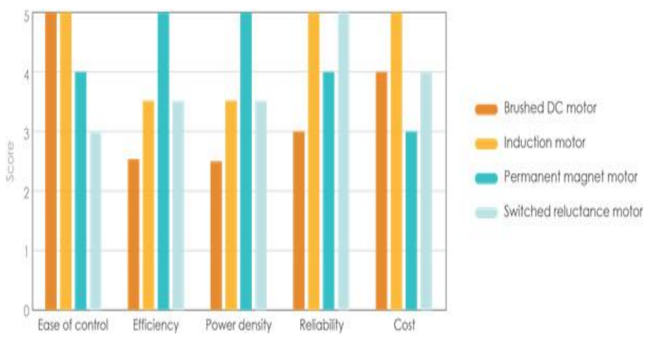

Figure 3: Comparison of different Motor used in Electric Vehicle

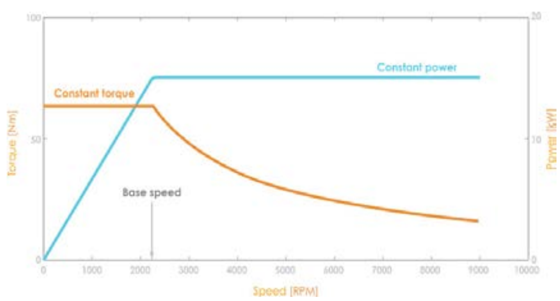

Figure 4: Torque-speed characteristics of a motor

C. Power Electronics Components in EV

The electrical drive train of EVs shown in the figure above involves several conversion steps. It contains DC/DC converters, DC/AC as well as AC/DC converter. To regulate the power between the battery and the electric machines, it is necessary to use a power converter device. The battery is a DC supply source, delivering current at a particular voltage [11]. Power flowing into the battery must be processed to ensure it is being delivered at the correct voltage. Similarly, the power delivered by the battery must be processed to ensure the electric machine can provide the optimum power to propel the vehicle [13].

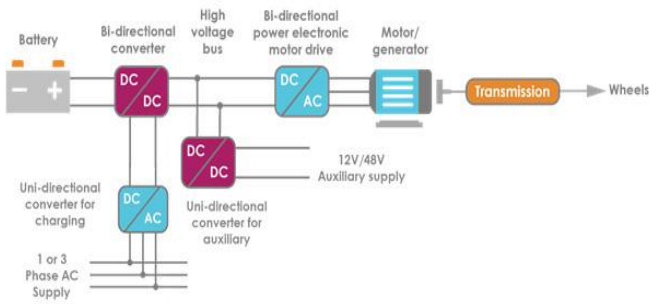

Figure 5: Power Electronics Component in BEV

The figure above shows the typical layout of power electronics components in a Battery Electric Vehicle (BEV). The auxiliary supply provides the necessary power for equipment within the vehicle. This is usually 12V for current vehicles but may be increased to 48V for future vehicles. A three-phase induction motor or a permanent magnet is typically selected to propel the vehicle. In general, the mechanical transmission is based on fixed gearing and a differential, but there are many possibilities for BEV configurations, depending on cost and performance constraints [6].

III. WHY DO WE NEED FAULT DISGNOSIS FOR EV OR BMS?

A BMS has the following priorities:

- Protects safety of the operator of the host application;
- Detects unsafe operating conditions and responds Protects cells of battery from damage in abuse/failure cases Prolongs life of battery (normal operating cases);
- Maintains battery in a state in which it can full fill its functional design requirements
- Informs the host-application control computer how to make the best use of the pack **right now** (e.g., power limits), control charger, etc.

BMS is interconnected with all battery-pack components and with host-application control computer functionality can be broken down into several categories:

1. Sensing and high-voltage control
   Measure voltage, current, temperature; control contactor, pre-charge; ground-fault detection, thermal management
2. Protection against
   Over-charge, over-discharge, over-current, short circuit, extreme temperatures
3. Interface
   Range estimation, communications, data recording, reporting
4. Performance management
   State-of-charge (SOC) estimation, power-limit computation, balance/equalize cells
5. Diagnostics
   Abuse detection, state-of-health (SOH) estimation, state-of-life (SOL) estimation
6. Internal failure detection
   BMS must detect and log Voltage-, current-, temperature-sensor failures, Failures of balancing system Contactor failure, Fan or pump failures, loss of coolant Loss of communications, garbled or missing messages from host
7. State-of-health (SOH)
   BMS must report a battery state-of-health (SOH) estimate Not precisely defined; generally, quantifies cell aging to date Two measurable indicators change as cell ages naturally Capacity decreases 20% to 30%: (capacity fade) Resistance increases 50% to 100%: (power fade) Issue: Future rate of cell abuse and aging may differ from past

IV. BMS ARCHITECTURE

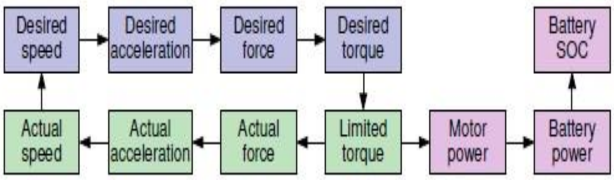

Figure 6: Battery Management System Architecture

A modular battery pack suggests a hierarchical master–slave BMS design as well one "slave" BMS unit is associated with each module. Module's cells welded/bolted to slave PCB, minimizing wiring and wiring losses. Slave has electronics for voltage measurement, cell balancing [2]. There is then normally a single "master" unit for each pack Master measures pack current, controls contactors Communicates with slaves via daisy-chain or star architecture. Master/slave communication uses few (e.g. two) wires—minimizes wiring-harness nightmare [8].

BMS slave role

BMS slave needs to: Measure voltage of every cell within the module, Measure temperatures, Balance the energy stored in every cell within the module, Communicate this information to the master.

BMS master role

BMS master needs to Control contactors that connect battery to load, Monitor pack current, isolation Communicate with BMS, slaves Communicate with host application controller Control thermal-management

A. Battery-pack sensing: Temperature

Battery cell operational characteristics and cell degradation rates are very strong functions of temperature; control thermal management systems to keep temperature in "safe" region. Ideally, we measure each cell's internal temperature; but, with accurate pack thermal model, can place sensors external to one or more cells per module and calibrate internal temperatures

B. Battery-pack sensing: Current:

Battery pack electrical current measurements are required:
To monitor battery-pack safety,
To log abuse conditions
By most state-of-charge and state-of-health algorithms we cannot measure electrical current directly—must convert to voltage and measure via A2D.

Why must we estimate energy, power?

Can't measure available energy or available power instead, must estimate these values. To estimate energy, we must know (at least) all cell states-of-charge and capacities To estimate power, we must know (at least) all cell states-of-charge and resistances.

V. PROPOSED SYSTEM

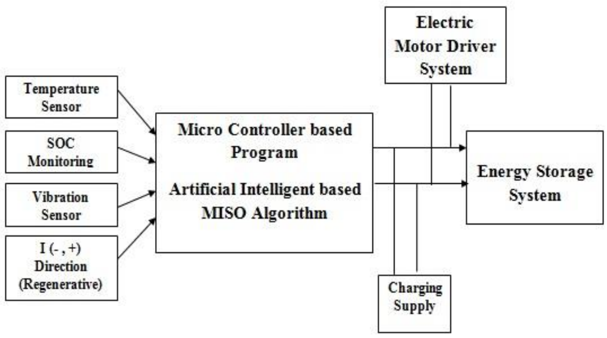

Figure 7: Proposed BMS Architecture

Research Objectives:

- ✓ To develop mathematical models, advance control systems through Micro Controller based program and AI based Algorithm to evaluate the energy needs of EV System using Multi input Single

Output Strategy. Considering practical operating conditions like Overheating, State of Charge (SOC), Vibration and Current direction {- , +}.

- ✓ To Design and develop PCBs with several sensing and communication functions like integrating sensors (stain, thermocouple, optical fibres and reference electrodes).
- ✓ To determine the fault level with specific severity to allow the estimation of the remaining useful life and allow for scheduled maintenance or fault tolerance mechanisms.

A. Simulating an Electric Vehicle:

To simulate electric vehicle, need two things:
1. An accurate description of vehicle itself
2. Task the vehicle is required to accomplish

Vehicle description includes characteristics of battery (cell, module, pack); motor and inverter (motor driving power electronics), drive train, etc. Vehicle's task is to follow desired profile of speed vs. time ("drive cycle")

B. Steps for Simulating an Electric Vehicle

Compute (second-by-second) desired accelerations to match desired speed, therefore desired road forces, motor torques Desired torque and power values restricted by specifications of motor chosen for vehicle, and thus achievable torques and power values may be lower Achievable torques computed, and therefore achieved road force and velocity Battery power computed based on motor power, and battery SOC is updated Vehicle range extrapolated from rate of battery energy depletion

Step 1: Desired acceleration force

Detail: Calculate vehicle desired acceleration [ms $^{-2}$] as
Desired acceleration = (desired speed [ms^{-1}] - actual speed [ms^{-1}] / (1[s])
Compute net desired acceleration force [N] at the road surface
Desired acceleration force=equivalent mass [kg] * desired acceleration

Step 2: Equivalent mass

Equivalent mass [kg] combines maximum vehicle mass [kg] and equivalent mass of rotating inertias [kg]

equiv. mass = maximum vehicle mass + rotating equiv. mass
rotating equiv. mass = ((motor inertia + gearbox inertia) * N^2 + number of wheels * wheel inertia) / (wheel radius)^2
where gearbox ratio N [u/l] = (motor RPM) / (wheel RPM), gearbox inertia [kgm^2] is measured at motor (not output) side Wheel radius [m] is assumed to be that of the rolling wheel; i.e., taking into account flattening due to load

Step 3: Drag forces acting on vehicle

Four other forces are assumed to act on the vehicle
The first two of these forces [N] = [kgms^{-2}] are

Aerodynamic force = 1/2 (air density [kgm^{-3}]) * (frontal area [m^2]) * (drag coefficient C_d[u/l]) * (prior actual speed [ms^{-1}])^2
rolling force = (rolling friction coefficient C_r[u/l]) * (max. vehicle mass [kg]) * (accel. of gravity [9.81 ms^{-2}])

Rolling force is computed to be zero if prior actual speed is zero

Step 4: Computing actual acceleration

Now that motor torque limits have been established, can compute actual acceleration force that is available, actual acceleration, and actual velocity

Compute actual acceleration force [N] = [kgms^{-2}] and actual acceleration [ms^{-2}]

actual acceleration force = limited torque at motor [Nm] *N[u/l]/wheel radius [m] - aerodynamic force [N] - rolling force [N] - grade force [N] - brake drag [N]

actual acceleration = actual acceleration force [N] / equivalent mass [kg]

Step 5: Compute actual vehicle speed

Finally, now that we have calculated limited motor speed, actual vehicle speed is computed as

actual speed [ms^{-1}] = limited motor speed [RPM] * 2π [rev $^{-1}$] * wheel radius [m] / (60 [s min^{-1}] * N [u/l])

Step 6: Computing battery power demand

First, instantaneous power required by the motor is computed motor power [kW] motor speed RPM previous motor speed [RPM] rev^{-1} limited torque at motor Nm 60 s min 11000 W/kW.
Depending on whether motor power is positive (accel.) or negative (regen/decel.) battery power [kW] is calculated as battery power overhead power motor power drive train efficiency u/l acceleration overhead power motor power drive train efficiency u/l decel. Where overhead power is constant power drain from other vehicle systems, such as air conditioners, "infotainment" systems etc.

Step 7: Computing vehicle range

Assuming battery voltage is constant (a poor assumption) battery current [A] battery power 1000 [W/kW] battery nominal voltage [V] Battery state of charge is updated as battery SOC % prior battery SOC % battery current A 1s 3600 s hr 1 battery capacity A hr 100 %.
Driving range is extrapolated from the drive cycle calculations range miles or km total distance of simulated drive cycle miles or km maximum rated battery SOC % min. rated battery SOC % SOC at beginning % SOC at end of drive cycle %

VI. CONCLUSION

After reviewing the proposed system it is easy to identify and diagnose the all kind of faults in electric vehicle. As per the mathematical modeling of calculated parameters of advance control systems, if Micro Controller based program and AI based algorithm developed then it is easy to evaluate the energy needs of EV System using Multi input Single Output Strategy. Considering practical operating conditions like Overheating, State of Charge (SOC), Vibration and Current direction {- , +}. We can consider n no. of case and optimize the value of that specific fault by analyzing data of fault. By doing feasibility study and design optimization of all faults in Electric Vehicle for specific condition we can build prototype for mathematical model of EV and validate simulation results with experimental data through Lab demonstration model.

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