Executive summary (not exceeding 500 words)

This proposal is on the development of Open Intelligent Technologies for Plug-in Hybrid Electric Vehicle (PHEVs) in India for rapid adoption by the OEMs and Tier 1 Suppliers.

Globally, Hybrid EV models are being offered for some years now by the mainstream manufacturers such as Toyota, GM, Tesla, Volkswagen, Honda etc. In India EVs have been launched but are not popular yet, mainly due to their cost. It is expected that by 2020, globally, various variants of EVs would constitute a major segment of choice for customers. With the the large domestic market in their favour, India needs to seize the opportunity timely and reduce the technology gap with developed countries in this area.

The proposal addresses major critical areas of HEVS, namely Batteries, Powertrain, Vehicle Management System including Energy and Health Management (using Open Technologies) and Application Technologies like Autonomous Optimal Drive Modes, as well as aims to develop Open Engineered tools and practices for Calibration, Testing, Traffic Performance Assessment etc.

Under Batteries the focus is to develop technologies for Li-Ion battery prismatic pouch cells and also for development of modules and packs with thermal management. Indian OEMs are in great need of Li-Ion cell development technologies and the existing infrastructure and expertise at IIT Kharagpur has been synergized with facilities set up by TML for pack development. Development of a battery management system with supercapacitors, provision for charging by regeneration, external plug-in power sources or engine driven generator source is also proposed.

Under Powertrain the proposal is to develop a parallel HEV configuration with indigenous copper rotor water cooled high efficiency Induction motor drive, high power density converter-inverters with open technologies for control, an automated manual transmission for autonomous EV modes, power split devices to be integrated with a conventional and available IC engine.

Under Vehicle Management significant new technologies are proposed for : dynamic modeling and simulation, energy management through optimized operating points and configurations, regeneration and coordinated braking, demand management through real-time on-board energy audit, vehicle health management. Open platform based network architecture for realising the above functions for vehicle control and life-cycle management as well as reliable automotive software development have been proposed.

Two major applications have been proposed for PHEVs. The first is to develop technology for autonomous driving modes specifically aimed at improved fuel economy, pollution, driver comfort and safety under typical heavy traffic conditions of Indian cities. Secondly, it is also proposed to develop a multi-domain (encompassing energy, emissions, drive comfort, mobility and safety) traffic performance simulation tools with PHEV Models. This is expected to be useful for OEMs to derive product specifications by assessment of the impacts of such specifications in traffic streams as well as for City planners to develop policies, strategies and infrastructure for mobility management. These applications would enable one to evaluate the best performance of the platform developed under realistic conditions

In all areas it is proposed to take the technologies to TRL 7 through Vehicle integration and testing on test tracks of TML. Once proven, it is expected that OEMs and Tier 1 suppliers in India will enthusiastically adopt the technologies for further innovation and move to higher TRLs towards ARAI certification and commercialization.

Background and motivation (not exceeding 500 words)

HEVs are essential for national fuel security and to address the menace of pollution in the Indian metros. The National Mission on Electric Mobility Mission Plan (NMEMMP) launched by Govt. of India has set a target to achieve sales of 6-7 million hybrid and electric vehicles per year from 2020 to save 9500 Million Liters of crude oil equivalent to INR 62000 Cr. Moreover, technologies such as Object/Signal Recognition, Driver Assist Systems, Real-time Energy Audit for Demand Management, Internet-GPS based Smart Navigators etc. are needed to improve passenger comfort, safety, fuel economy and pollution on the Indian roads at affordable costs. It is recognized that this would require very significant R&D initiatives in the country.

India is has significant vehicle and component manufacturing capabilities but lacks a deep technology base. Among various other things, development of vehicle technologies is severely hindered by the fact that technologies for many of the critical subsystems like ECU, ABS, AMT etc. are not available to Indian companies and are purchased by OEMs as proprietary subsystems at very high costs from global Tier 1 suppliers (Bosch, Magneti Marelli etc.). The Indian automobile market is largely driven by cost and fuel economy. Thus HEVs developed abroad cannot be directly adopted in India for public use. The issue of costs is the major reason that HEVs have not become popular yet in India. Recently Tesla Motors has decided to open its present and future patents. Technologically, it is perfectly possible to develop the complete vehicle control and management functionality on Open Embedded Hardware and Software platforms both in terms of computing capabilities as also because of the easy availability and upgradability of the technology precisely due to the fact that it is open. This is certain to drive costs down significantly.

It is this twin target of developing the indigenous technology base with open technological solutions, tools, standards coupled with that of driving the cost of acquisition, operation and maintenance of vehicles for the Indian customer, that this project has been proposed.

There is adequate R&D competence in the Indian institutions in areas like Power Electronics, Electrical Machines, Electronic Controls and Software, Vehicle Dynamics, Materials and Manufacturing for Light weighting, Internet of Things, Software Engineering etc. The OEMs on the other hand, have considerable expertise and infrastructure in IC Engines, Transmission, Vehicle integration and Testing. It is therefore a golden opportunity for the Indian academia and industry to come together and develop this critical technology base for HEVs in India. In particular, several members of the present team have 5-10 years experience of working on Automotive Controls and Software technologies with General Motors USA (through the erstwhile India Science lab of GM), on IVHM technologies TML through the National Mission Project called NPMASS, on Li-Ion cell development under significant DRDO initiatives, on advanced Manufacturing technologies etc. The industry partner, Tata Motors Limited has been at the forefront of Indian vehicle industry and has been active in developing EV technologies. TML has already developed and exported Series Hybrid Buses.

Project outcomes (please list specific objectives): *The project should address a specific need of the industry/industries and there should be clear expected outcomes from the project. It is expected that joint patents will result from this project.*

The overall outcomes are several HEV technologies matured to TRL 7, Open engineered HEV subsystems and an HEV integrated with the subsystems and tested on test track. Specific outcomes for each work package are listed below.
WP1 :
A. Development of Li-Ion Battery Prismatic Pouch Cells along with its manufacturing process,
B. Integration of Cells into Module and Pack (with cooling)
C. Development of a Battery-Super-Capacitor Management System with charging from multiple energy sources
WP2 :
A. Design of a Copper Rotor Water cooled Induction Motor and its fabrication by industrial manufacturers;
B. Design and development of high power density inverters and converters
C. Design and development open engineered motor controller with regenerative braking coordinated with BMS and ABS and engine driven battery charging in generator mode
D. Design of planetary hybrid automated manual transmission gear box with electrical shift actuators and its development by commercial manufacturers
WP3:
A. Dynamic modeling and simulation, for assessment of performance, energy optimization, sizing of components and diagnostics.
B. Development of a functional Vehicle Control and Management System over open engineered embedded architecture for PHEV using Ethernet-CAN body area network platforms.
C. Development of a Vehicle Control Unit (VCU) (performing energy audit and management, health management etc.
D. Establishment of software engineering tools and methods for design development and validation of safety critical embedded automotive software.
D. Establishing methods and development of tools for integrated HEV calibration
E. Integration and Vehicle level testing.
WP4:
A. Development of an integrated simulation tool for multi-domain (energy, mobility, safety and environmental) performance assessment of HEV technologies under realistic Indian conditions.
B. Development of an Autonomous Drive System integrated with powertrain, brake by wire and object signal detection systems to improve energy, environmental, safety and comfort parameters under heavy traffic conditions.

Scope (not exceeding 1500 words): *The scope should clearly lay out the contributions of the academic partner and the industry partner.*

The scope of activities under the various work packages are given below. The lead and support roles of partners are indicated. The entity in the lead role has primary responsibility of executing the corresponding work sub-package. The work sub-package would get executed mainly in the premises of the lead entity. The responsibility of the overall work-package is jointly held by IIT Kharagpur and TML. This information is indicated under this head since there is no space available to include it in the table provided under the heading "Work packages and Timeline" below.

WP1 :

A. Augmentation of IIT Kharagpur facility for fabrication prismatic pouch cells of about 20Ah capacities required for PHEVs. (IITKGP in lead; TML in support)
B. Cell development and testing including design of material, geometry and thermal management over a targeted temperature range. (IITKGP in lead; TML in support)
C. Development of battery-super-capacitor management system (BMS) and its integration with electric drive for regenerative braking, plug-in charger and engine charging. (IITKGP in lead; TML in support)
D. Pack development and integration (TML as lead; IITKGP in support)
E. Bench testing of battery pack (TML as lead; IITKGP in support)

WP2 :

A. Motor design and outsourced commercial procurement of copper rotor induction motor(TML as lead; IITKGP in support)
B. Motor simulation, Control algorithm development and MIL testing for dynamic transient response. (IITKGP in lead; TML in support)
C. Electrical drives simulation, design, rapid prototyping, manufacturing, MCU development, lab testing(IITKGP in lead; TML in support)
D. Industrial grade MCU development, Validation of motoring/braking performance on HIL. Integration test in Powertrain test bench. (TML as lead; IITKGP in support)
E. Development of Hybrid Automated Manual Transmission for HEV : (TML)
E.1 Development of algorithm for synchronized shifting, Simulation,
E.2 Engineering Design and CAD,
E.3 Outsourced commercial procurement of Gear box and Transmission Control Unit,
F. Motor, MCU, TCU, Gearbox integrated test in Powertrain test bed. (TML as lead; IITKGP in support)

WP3 :

A. Design and development of hi-fidelity dynamic model of vehicle and subsystems of Parallel PHEV suitable for components sizing and diagnostics systems.(TML as lead; IITKGP in support)
B. Energy Management System (EMS) : Estimation of energy recovery from regenerative braking and losses in power train, battery, tyre. Estimation of engine energy efficiency and battery SoC. Computation of optimal energy configurations for hybrid vehicle propulsion system. Energy optimization techniques over multiple sources and loads for hybrid Electric vehicle. Trip energy and cost estimation and optimization. Implementation of EMS for targeted sub-system on open engineered platform. (IITKGP as lead; TML in support)
C. Integrated Vehicle Health Management (IVHM) : Use of diagnostics and prognostics to fix faults at incipient stage. Development of health monitoring system architecture for hybrid power-train. Implementation of IVHM for targeted sub-system on open engineered platform. System life enhancement and warranty cost management (IITKGP as lead; TML in support)
D. Safety and comfort: Development of Hybrid braking system without compromising vehicle dynamics and safety. Preliminary development of an active braking system for Indian market. Integration of braking with regeneration and autonomous high density driving module. (TML as lead; IITKGP in support)
E. Reliable Automotive Software Development : Functional safety & ISO 26262 implementation. Automotive software development environment comply with stringent certification criteria, as mandated in international safety standards like ISO26262. In the proposed project, the design and safety validation of the software for supervisory control of the powertrain, driver assistance and the smart energy management system will be carried out using modern verification and validation tools. Entire embedded software shall be designed coded and validated using the emerging model based development paradigm for embedded software system. (TML as lead; IITKGP in support)
F. PHEV system integration, integrated calibration of multiple source and load operation, and testing in test track. (TML)

WP4 :

A. Development of Traffic Simulation Tools : (IIT)
A.1 Collection of relevant primary and secondary data related to vehicle characteristics, roadway and control conditions.
A.2 Development of a Micro-simulation Framework: Calibration and Validation under Present Scenarios (i.e. without the introduction of the new vehicle type)
A.3 Evaluation of Introduction of new vehicle type on stream behaviour under different roadway, traffic and control conditions.
B. Development of Autonomous Drive System for High Density Traffic (IIT)
B.1 Detection of traffic & road conditions: implemented with a surround viewing system based on inputs from cameras
B.2 Collision detection / avoidance module based on the concepts of proximity detectors using inputs from cameras, radar and ultrasonic devices
B.3 Pedestrians detection module based on inputs from cameras, lidar and radar module of dynamic lane detection based on inputs from cameras
B.4 Road signs detection module based on camera inputs
C. Piloted driving module based on inputs from cameras and radar (IITKGP as lead; TML in support)
D. HIL testing with powertrain ECUs, Field testing in vehicle with integration in vehicle and testing in test track (TML)

Work Packages and Timeline (use tables/Gantt charts): *The key tasks must be listed in the form of work packages with timeline (start and end month from the date of start of the project) and identify who will hold the prime responsibility for each work package and where the works will be conducted.*

WP	Description	1-6 months	7-12 months	13-18 months	19 - 24 months	25 -30 months	31 - 36 months
WP1	Lithium Ion Battery Pack for PHEV	WP1.1: Detailed Project Report, Detailed requirements specifications, Purchase, Recruitment	WP1.2 Battery Cell Simulation.	WP1.3: Battery Cell Design and BMS Simulation	WP1.4: BMS Design and Battery pack design	WP1.5: Cell manufacturing. BMS manufacturing. Pack manufacturing. Testing in Lab.	WP(1.6, 2.6, 3.6,4.6,5.6): Integration in PHEV. Vehicle calibration and testing in TML track.
WP2	Powertrain for PHEV	WP2.1: Detailed Project Report, Detailed requirements specifications, Purchase, Recruitment	WP2.2: Simulation & Design of Dynamic model of High Efficiency Copper Rotor Induction Motor Electrical & Mechanical design, fabrication, Testing	WP2.3: Simulation & Design of High power density and high volumetric efficiency inverters and converters Hardware and Embedded Motor control algorithms (MCU)	WP2.4: Manufacturing of Motor and MCU	WP2.5: Development of Planetary Automated Manual Transmission Gear box with Electrical Shift Actuators. Integrated testing of Motor, MCU, TCU and Gearbox in Powertrain dynamometer	
WP3	Open Power Electronics and Embedded Engineering, Control & Diagnostics, Functional Safety (ISO 26262),	WP3.1: Detailed Project Report, Detailed requirements specifications, Purchase, Recruitment	WP3.2: Dynamic model of vehicle, Systems and Diagnostics .	WP3.3: System development on Open Engineered Platform	WP3.4: Control architecture, Algorithm for PHEV vehicle control, Vehicle controller cum Gateway	WP3.5: Functional Safety and ISO 26262 implementation	
WP 4	Traffic Information & Jam Assist for PHEV	WP4.1: Detailed Project Report, Detailed requirements specifications, Purchase, Recruitment	WP4.2: Development of Traffic Model, Speed estimation, alternate path planning	WP4.3: Software architecture for TJA	WP 4.4: Integration of Radars, Sensors, platform and application software in IIT lab setup	WP4.5: HiL testing including all controllers, Intel IoT board, TJA components over CAN and Ethernet in TML	

Key Milestones (six monthly): *List the key six monthly milestones.*

Month 6: (WP:1.1, 2.1, 3.1, 4.1) Detailed project reports, requirements documents, Specifications, Purchase orders and Resources' names for Li-Ion battery pack development, Powertrain, Open Embedded Engineering, Vehicle Management, Traffic Performance and Driver-assist Application WPs
Month 12: WP1.2: Simulation of Cells WP2.2: Simulation of Motor. WP3.2: Dynamic model of vehicle and diagnostics WP4.2: Traffic model
Month 18: WP1.3:Battery Cell Design document and BMS simulation result WP2.3: Design and drawing of Motor Control Unit WP3.3: List of Open engineering components list, specifications WP4.3: SW architecture document.
Month 24: WP1.4 BMS and Pack design 2.4 Motor & MCU test report WP3.4: Control Algorithm document for PHEV WP4.4: HIL test report of all ECUs
Month 30: WP1.5: Test report of Cell, BMS & Pack WP2.5: Test report of Integrated Powertrain with Motor, MCU and Planetary Gear Box. WP3.5: Software ISO 26262 compliance report. WP4.5: HiL test report of Powertrain and Vehicle controllers.
Month 36: Integrated Test report of PHEV, Drivability & Fuel Economy. Traffic jam assist functional report with traffic condition prediction.

Plan for commercialization (not exceeding 500 words): *The industry partner should show a clear path to commercialization if the proposed work is successful. (letter/communication from the industry partner may be scanned and uploaded)*

TML is already building hybrid and electric vehicles and has a road map towards its commercialization. From the experience so far, it is clear that, for acceptability in Indian market the increased cost of power components of HEVs must be off-set by reduced cost of open engineered vehicle management systems. This project has high significance for TML since it aims to develop open technologies for HEVs and mature them to TRL 6/7. It is clearly expected that TML shall move towards higher TRLs in maturing these technologies further through early engagement with its suppliers and vendors. In fact early engagement of vendors to demonstrate functions in vehicle is already planned as mentioned in the table of WP milestones. Once they reach appropriate maturity levels these will be submitted for certification by ARAI. Simultaneously development of manufacturing facilities by Tier 1 suppliers and OEMs meeting quality and cost criteria will have to be developed. After this the product should be ready for launch in the market.

Benefit to partnering academic institution: *(Please address each of the following items, briefly)*

a) Does the proposal promote innovation in areas that are directly of relevance to industry? Please describe briefly. (not exceeding 250 words)

Everything being developed in the proposal is of direct relevance to the industry. Examples of significant innovations proposed in this project in the Indian automotive context include :

A. Development of Li-Ion Battery Packs with cells, packaging, cooling and BMS (WP1). This is critical for HEV development since currently the industry is completely dependent on imported products from Japan, China etc.
B. Development of IM drive with regeneration and battery integration (WP2). A copper rotor IM drive coupled with an optimized control strategy is expected to deliver much higher efficiency coupled with the rugged performance of an IM.
C. Development of energy and health management systems (WP3). These can critical for product acceptance in terms of fuel economy as well as maintenance costs.
D. Open hardware and software technology platform for vehicle control and management (WP3). This will free the Indian OEM from the compulsions of dealing with the few Tier 1 suppliers who dominate the market today.
E. Reliable automotive software development, validation and testing methods and tools (WP3). Software is a critical and complex component for automotive systems. This ensures quality of the indigenous software that would execute on the open engineered platform.
F. Autonomous drive system in city traffic conditions for optimal energy, emission safety and comfort (WP4). This would be instrumental delivering the final performance in terms of fuel economy, driver comfort and emissions.
G. Multi-domain traffic performance simulator (WP4). This tool is targeted for product definition, specification etc. by assessing the impact of specifications by simulation of realistic traffic conditions.

b) Is the project proposing coordinated R&D between academia and the industry? If so, please describe. (not exceeding 250 words)

The proposal describes a completely coordinated R&D with full participation and investment of both parters. This is apparent from the scope of activity mentioned in the proposal. In all work packages the TML and IITKGP cooperate actively to evolve the outcome demonstrable and deliverables.

c) Does the project strengthen the laboratories and research facilities at IIT or the Industry? (not exceeding 250 words)

Yes.

The project shall strengthen the following facilties at IIT Kharagpur in varying degrees

1. Li-Ion Cell manufacturing facilities at department of MME
2. Electric Drives laboratory at EE
3. Embedded Systems laboratory at EE
4. Systems and information laboratory at EE
5. Software laboratory at CSE
6. IC Engine laboratory of ME

Simultaneously several existing facilities in the above laboratories and other facilities of IIT Kharagpur shall also be used for this project.

It would strengthen the following facilities at ERC TML, Pune in varying degrees

1. Battery pack manufacturing facility
2. HAMT and TCU test facility
3. Vehicle integration and Test facility
4. Advanced Engineering facility

Simultaneously several existing facilities in the above laboratories and other facilities of TML Pune shall also be used for this project.

Publications / patents relevant to the proposal: *List separately (a) publications/patents of PIs, and (b) publications of others, that are relevant to the proposed project. Restrict to relevant publications (ten maximum)*

Publications:

1. Patra, P., J. Ghosh, and A. Patra, "Control Scheme for Reduced Cross Regulation in Single-Inductor Multiple-Output DC-DC Converters", IEEE Transactions on Industrial Electronics, Vol. 60 (11), pp. 5095-5104, (2013).
2. Kamalesh Ghosh, Pallab Dasgupta and S. Ramesh, "Automated Planning as an Early Verification Tool for Distributed Control, Journal of Automated Reasoning", 54 (1), 31-68, 2015.
3. Mahto, Raju P., Bhoje, R., Pal, Surjya K., Joshi, Harshadeep Shyamkant,and Das, S., "A study on mechanical properties in friction stir lap welding of AA 6061-T6 and AISI 304", Material Science and Engineering A, Elsevier Publications. Accepted on November, 2015.
4. A. Dasgupta, A. George, S. L. Happy, A. Routray, and T. Shanker, "An on-board vision based system for drowsiness detection in automotive drivers," Int. J. Adv. Eng. Sci. Appl. Math., vol. 5, no. 2–3, pp. 94–103, 2013.
5. S. Sengupta, S. Mukhopadhyay, A. K. Deb, Kallappa Pattada, "Estimation of within cycle dynamics of an SI gasoline engine using equivalent cycle reconstruction", IEEE Trans. on Instrumentation and Meas. Vol. 63, No. 8, pp. 2072-2092, Aug. 2014.
6. Ghosh, D, Chakravarty, D, Samanta, B, 2014, A Prototype Autonomous Mine Robot For Underground Mine Mapping, CIM Journal, Vol.5, No.3, pp. 185-193
7. Synthesis and characterization of LiMn2O4 nanoparticles using citric acid as chelating agent by Gurpreet Singh, AmrishPanwar, AnjanSil, and Sudipto Ghosh Advanced Materials Research, 67,227 (2009)
8. Basak, S.; Chakraborty, C., "Dual Stator Winding Induction Machine: Problems, Progress, and Future Scope," in Industrial Electronics, IEEE Transactions on , vol.62, no.7, pp.4641-4652, July 2015.
9. Jonathan Vasu, A K Deb, S Mukhopadhyay, "MVEM based Fault Diagnosis of Automotive Engines using Dempster-Shafer Theory and Multiple Hypotheses Testing", IEEE Trans. on Systems, Man, and Cybernetics: Systems. Vol. 45. no. 7, pp. 977-989, July 2015.
10. Sahoo, S.K.; Bhattacharya, T., "Synchronization Strategies in Cascaded H-Bridge Multi Level Inverters for Phase Shifted Carrier Based Sinusoidal PWM Techniques," in National Power Electronics Conference 2015, 21-23 December 2015, IIT Bombay.

Patents:

1. US PATENT No: US 8,082,140, Dec 20, 2011, Parametric Analysis of Real Time Response Guarantees on Interacting Software Components, Inventors: M. Dixit, S. Ramesh, Pallab Dasgupta.
2. US PATENT No: U.S. 8,751,097, June 10, 2014 "State Estimation, Diagnosis and Control using Equivalent Time Sampling", Soumen De, Pattada A. Kallappa, Pulak Bandyopadhyay, Siddhartha Mukhopadhyay, Somnath Sengupta, Alok Kanti Deb
3. US PATENT No: US Patent No. 8,108,728 dated January 31, 2012 "Method and Apparatus for Operational-Level Functional and Degradation Fault Analysis" Partha Pratim Chakrabarti
4. 924/KOL/2013 "A System and a Method for Spark/Arc Detection in Low Voltage Electrical Distribution System: Published" Aurobinda Routray