INTERNATIONAL JOURNAL OF AUTOMOTIVE SCIENCE AND TECHNOLOGY

2022, VOL. 6, NO: 3, 294-301 www.ijastech.org e-ISSN: 2587-0963

Study of Performance Improvement of a Tracked Vehicle Engine with Hybrid Mode

Raj Kumar Aska Joshua[1] and K. A. Subramanian[1*]

0000-0003-2610-9680,0000-0003-3503-4406

[1]*Department of Energy Science and Engineering, Indian Institute of Technology Delhi, India*

Abstract

A study was carried out to analyse the enhanced power and torque characteristics of a diesel engine based tracked vehicle by hybridization of a conventional Internal Combustion Diesel Engine (ICE) with Electric System. A methodology is developed to simulate and validate tractive force and peak power requirement for a given drive cycle (sample drive cycle of 0 to 60 km/h in 61s considered). The performance enhancement was analysed in two different parallel hybrid configurations (EM before and after transmission - Modes 1 and 2 respectively). The existing ICE's power (221 kW) and torque (1030 N-m) was not altered and different Electric Motor (EM) ratings were considered as inputs for Degree of Hybridisation (DoH) (22 kW EM and 50 kW EM power with 72.5 N-m and 167 N-m of torque respectively). The hybrid system performance (with ICE and 50 kW EM) is notably enhanced to a maximum power of 290 kW and torque of 1274 N-m. The result indicates maximum improvement was achieved in Mode 2 configuration (5th gear with ratio 4.24 : 1) as 22% and 38% power output improvement (11% and 24% Torque improvement) with 17.3% and 32.3% DoH respectively.

Keywords: DoH; EM; ICE; Power; Torque; Tractive Force

Research Article

https://doi.org/10.30939/ijastech..1000258

Received 26.09.2021
Revised 13.07.2022
Accepted 24.08.2022

* Corresponding author
K.A. Subramanian
subra@dese.iitd.ac.in
Address: Department of Energy Science and Engineering, Indian Institute of Technology Delhi, India

1. Introduction

Tracked vehicles are specialized self-propelled platforms that are extensively used in farming, military & construction and are mostly diesel engine based. The tracks ensure that the vehicle navigates loose/slushy terrain by increasing the surface area of contact and distributing the normal ground force of the vehicle. Tracked vehicles are propelled forward using sprockets at the drive end, as opposed to wheels and turning is executed by varying the speed of one track in comparison to the other. In recent years the growing interest in hybrid vehicles has encompassed almost all vehicle platforms. However, there is comparatively less focus on the hybridization of tracked vehicles. This study draws inputs regarding growing interest in a hybridization of tracked vehicles from the limited available literature. In this study, a methodology for estimation of enhanced power and torque has been attempted with experimental inputs from IC engine dynamometer tests and simulation of electric components for a sample chosen vehicle for any given drive cycle.

There exist considerable avenues for the employment of Hybrid Electric technology to enhance performance, improve efficiency and reduce emissions in tracked vehicles. The other advantages include engine size reduction with the same total power capability. With a suitable hybrid configuration, braking and steering functions can also be incorporated using the regenerative capability of Electric Motors (EM), thereby obviating the requirement of a traditional gearbox. An option for incorporating a "Limp Home Mode" (based on electric propulsion only) can also be explored for short, limited runs in the event of failure of the main powerplant.

Sivakumar P. et al [1] studied the need and potential benefits of hybridization of military tracked vehicles. The study gives out the technical challenges in the hybridization of a tracked vehicle with specific requirements of high torque and power density traction motors, high operating temperature power electronics and high energy density storage devices. The study also gives out a sample tractive effort calculation.The worldwide scenario of military HEV programs of the UK, US, Germany & France have briefly been touched upon.

Hidetaka T. et al [2] in their report "Development of Tracked Combat Hybrid-Electric Vehicle" explained that EMs have an ideal torque-speed profile for the traction of combat vehicles, i.e., high torque at the acceleration, climbing, and a wide range of high power which suit the performance requirements. The engine size was reduced but total power capability remained the same due to the augmented power from the battery.

In their study "Tracked vehicle physics-based energy modelling and series hybrid system optimisation for the Bradley fighting vehicle", Travis E. McWhirther et al [3] bring out the methodology to determine tracked vehicle energy and fuel requirements, cost, and performance optimization for Bradley fighting vehicle. The optimised system design of a 135 kW generator and 100 kWh battery has been suggested which enables navigation of 130 miles with grades up to 60% and fuel consumption reduced by 15% or greater.

Ali M. et al [4] present a detailed Hybrid Electric Vehicle (HEV) modelling method to provide the capability to investigate the effects of component selection and to develop control systems and automatic optimization processes for HEVs. The drive trainsystem of a series/parallel HEV is developed alongwith aspects of rotational inertial dynamics, friction, damping, and stiffness properties. The interaction between all these modules was simulated in MATLAB/Simulink/Simscapeblockset environment. The numerical simulation results were compared with the analytical results of the same hybrid power train.

In the report "Hybrid electric propulsion for military vehicles" by Per Dalsjo [5], the challenges of military HEVs & advantages of hybrid technology have been explained alongwith parallel comparisons to civilian hybrid vehicles. The report suggests that the growing interest in HEV technology for tracked vehicles results in significant gains.

Eda A. et al [6] have performed a simulation of heavy wheeled and tracked vehicles to obtain a clean and efficient heavy-duty electric vehicle. According to results, the range of the wheeled vehicle is found higher than that of the tracked versions, however, the climbing potential of the tracked vehicle is found more advantageous than that of the wheeled type.

A study has been carried out by Brainislav S. et al [11] which analyses the fuel consumption characteristics of a road vehicle by analyzing selected parameters of the fuel mixture electronic control system via parameters of throttle position and engine speed.
The result is an estimation of the accuracy of such fuel consumption determination and its possible utilisation for a system of assessing the vehicle driving style of drivers

José I H et al [12] have demonstrated the hypothesis that using the fuel-based method, the resulting local Drive cycle exhibits characteristic parameters similar to those that describe the driving pattern of the region under study.

Hasnira et al [13] have simulated a new model for Energy Estimation on BLDC Electric Vehicle using Matlab. This model includes the battery, power electronics converters, electric motors, and transmission systems. In this case, the energy system during regenerative braking breaking is also taken into account.

Mohd T. et al [14] presented a simulation model of a fully electric vehicle on the Matlab-Simulink platform to examine power flow during motoring and regeneration. The torque and speed conditions during motoring and regeneration were used to determine the energy flow, and performance of the drive.

The challenges in the hybridization of tracked vehicles are:

(a) Development of a Hybrid Engine for a tracked vehicle is different from a conventional wheeled vehicle and requires the evolution of specific methodologies during the development process. The space constraints, weight management, and power delivery pose complicated problems and require tailor-made solutions.

(b) The power, torque, and performance characteristics are vastly different compared to passenger vehicles.The weight of the tracked vehicles is considerable (approx 14 Tons & heavier) which entails careful analysis

(c) The configuration of the powerplant & drive train is completely different. The engine drives the sprockets through a gearbox which rotates the sprocket thereby propelling the vehicle forward on its tracks. The hybrid solution will have to cater to the eventuality of turning by varying rpm of either track. Also, the braking and regenerative capabilities of the vehicle require special consideration.

(d) Limited population of such equipment renders restricted access to study materials and research in the field. Military, earthmoving & farming machinery is often not considered a major candidate for hybridization owing to limited population and absence of restrictions with respect to pollution norms.

2. Power, Speed and Torque Requirements

In this study, a sample tracked vehicle was considered. The vehicle is a six-cylinder diesel engine-based tracked vehicle with an overall weight of 14 Tons. The parameters of the vehicle were obtained from available information online and on the Ordnance factory website which is shown in Table 1 [9-10].

Table 1: Sample Tracked Vehicle Performance & Parameters [9, 10]

Parameter	Value
Mass (Tons)	14.0 + 2%
Max Speed (km/h)	65 (on highway), 7.0 (in water)
Avg Fuel Consumption during 1hr of engine operation (L)	31.38 L
Cruising Range on highway	550-600 km
Max Power @ 2600 rpm	285-300 HP 210-221 kW
Max Torque @ 1500-1600 rpm	883-1030 N-m
Specific Fuel Consumption at max power duty	<130.497 gm/kWh
Engine Displacement	15.9 L
Fuel Tank Capacity	462 L
Storage Batteries (02 in series)	24V & 140A (Lead Acid)

The engine performance characteristics of the 300 HP UTD20 engine were mapped experimentally from test results on a hydraulic dynamometer as per the Original Equipment Manufacturer (OEM) specified acceptance test criteria. The torque, power and speed characteristics alongwith fuel consumption data were recorded for various loads. The photographs of the test setup and schematic diagram are depicted in Fig 1 and Fig 2 respectively. The torque peaks at approximately 980 N-m at 1600rpm and power peaks at 210 kW at 2600 rpm as shown in

Fig 3.

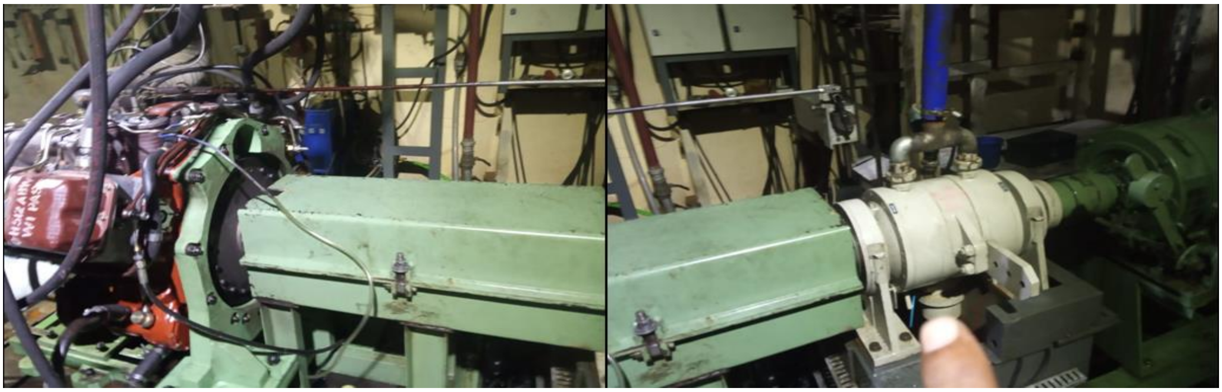


Fig. 1. Engine test setup on hydraulic dynamometer

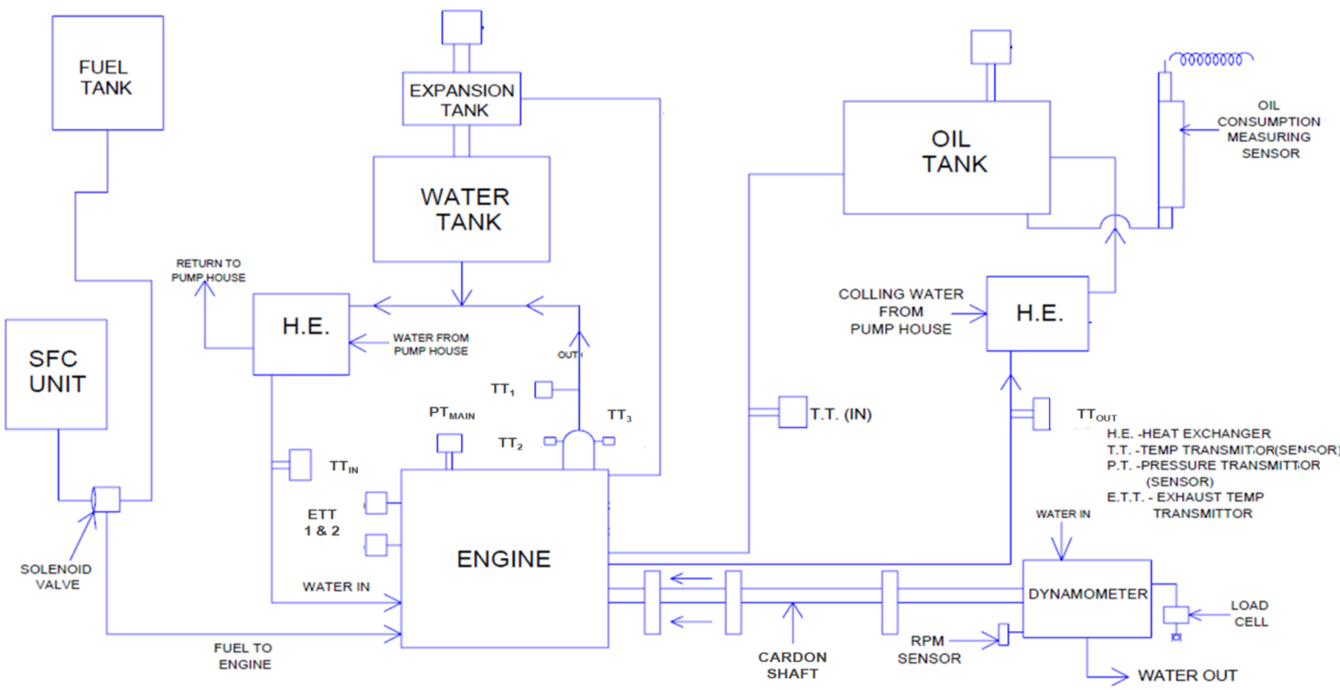
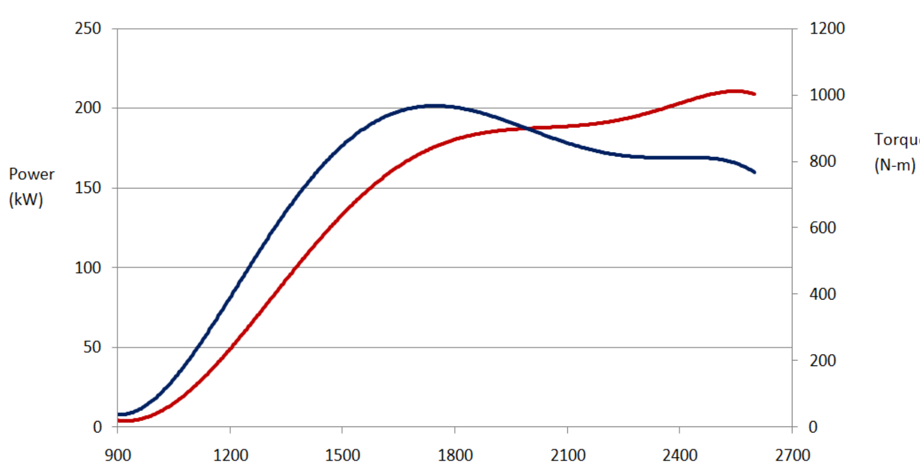


Fig. 2. Schematic diagram of engine test setup



2.1 Tractive Force Estimation

The tractive force requirement is estimated using the governing equation (Eq. 1) based on a particular drive cycle as a reference. According to Newton's Second Law, the tractive force required to propel the vehicle with a given acceleration is governed by the equation of motion in a longitudinal direction which was explained by M. Ali et al [4] (depicted in Fig 4).

Tractive Effort required, $F_{tr} = F_{rr} + F_{gr} + F_{aero} + F_{lin} + F_{ang}$ (1)

where resistance forces are

The Rolling Resistance of a vehicle is proportional to the component of weight normal to the surface of travel

$$F_{rr} = m\ g\ \mu_{rr} \cos\alpha \qquad (1.1)$$

Gradient Resistance composed of gravitational force acting on the vehicle

$$F_g = m\ g\ \sin\alpha \qquad (1.2)$$

Aerodynamic drag resisting motion of vehicle through the air

$$F_a = \tfrac{1}{2}\rho\ C_d\ A_f v^2 = \text{Aerodynamic Drag} \qquad (1.3)$$

Force due to Linear acceleration and Angular acceleration of the vehicle

$$F_{acc} = (M_v + J)\left(\frac{dv}{dt}\right) \qquad (1.4)$$

From Eq. 1

$$F_{tr} = M_v g\ \mu_{rr} \cos\alpha + \tfrac{1}{2}\rho C_d A_f v^2 + (M_v + J)\left(\frac{dv}{dt}\right) \qquad (2)$$

$$P = F_{tr} \times v \qquad (3)$$

where P = Instantaneous Power in Watts & $J = J_{rot}/r_{dyn}$

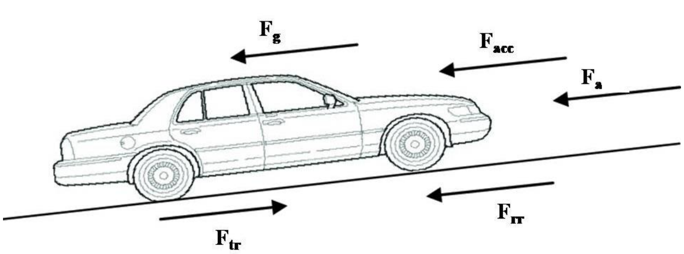


Fig. 4. Forces and torques acting on a vehicle [5]

The tractive effort required to propel the vehicle with linear acceleration from a state of full rest to top speed ie., 0 to 65 km/h (top speed) was mapped (and validated with MATLAB Simulink simulation) and the power requirement is evaluated as shown in Fig 5. The peak power requirement from ICE is 209 kW for this particular drive cycle. Based on the peak power requirement, a 22 kW and 50 kW EM are chosen as partial electric assist as suggested by B. Kim et al [7] due to their compact size, wide operating range & high efficiency. The Degree of Hybridness (DoH) is the ratio of Electric power to the total Power (Eq. 4). Hence theDoH considered for this study is 9.5% & 19.3% in Mode 1 and 17.3% & 32.3% in Mode 2.

Fig. 3. Torque - Power - Speed characteristics

$$\text{Degree of Hybridisation} = \frac{\text{Electric Motor Power}}{\text{Electric Motor Power} + \text{ICE Power}} \qquad (4)$$

The power and torque are related by Eq. 5

$$P\ (\text{in kW}) = \frac{2\ \pi\ N\ T}{60000} \qquad (5)$$

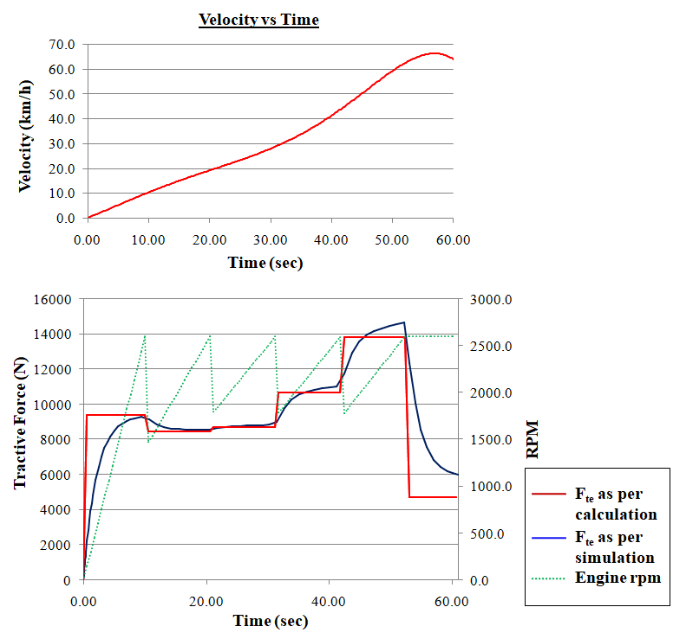


Fig 5: Tractive effort for a given drive cycle

2.2. Selection of Hybrid Configuration

EMs have an ideal torque-speed profile i.e., high torque during acceleration, climbing and a wide range of high power which suits the performance requirements of a tracked vehicle. The Series hybrid layout occupies additional space and considering the energy density of the batteries for powering the EM, it may not be suitable. The main propulsion source remains the ICE and the electric portion of the system can be used to provide a power boost on the requirement. As a result, the Parallel hybrid configuration or Series-Parallel hybrid configuration is more suited for such an application. Two options for hybridization have been assessed in the succeeding paragraphs. The existing drivetrain configuration is shown in Fig 6 and the assessed hybrid configurations are shown in Figs. 7 and 8.

As part of the Parallel Hybrid configuration, the EM can either be coupled at the crankshaft (EM before transmission ie., Mode 1) with suitable gearing to match engine rpm to boost the total power and torque delivery. Alternatively, the electric system can be placed after the transmission (EM after transmission ie., Mode 2) by using two separate motors (left and right bank) as wheel hub motor or wheel side motor drive which was analysed by Yuechao et al [8].

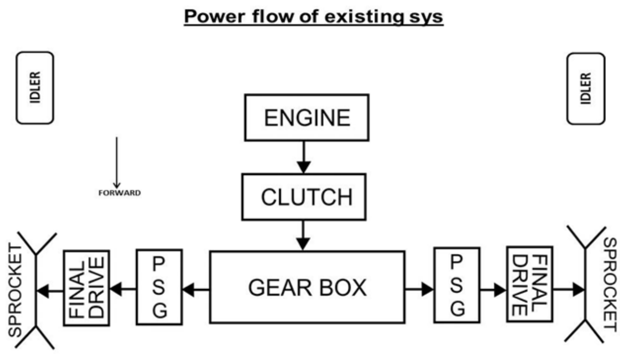


Fig. 6. Existing drive train configuration of tracked vehicle

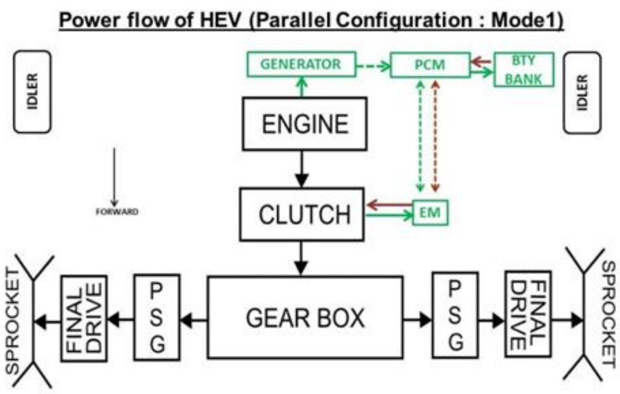


Fig. 7. Parallel hybrid drivetrain configuration (Mode 1)

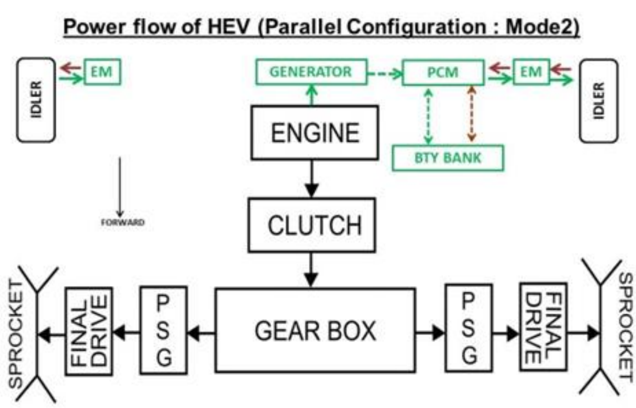


Fig. 8. Parallel hybrid drivetrain configuration (Mode 2)

3. Methodology

The engine performance of IC engine is considered from idling speed to maximum speed. The drive cycle considered is a simple linear acceleration from 0 to 65 km per hour in 60 seconds. The ideal EM Torque-Speed characteristics are illustrated in Fig 9. EM torque is constant in the constant torque region until the critical speed, governed by Eq.5, after which it falls. Power on the other hand increases till critical speed and remains constant till the maximum speed of EM. The performance and enhancements achieved as a result of hybridization in two different configurations with varied motor ratings are being highlighted.The electric motor information was obtained from the study carried out by Byungwhan Kim et al [7].

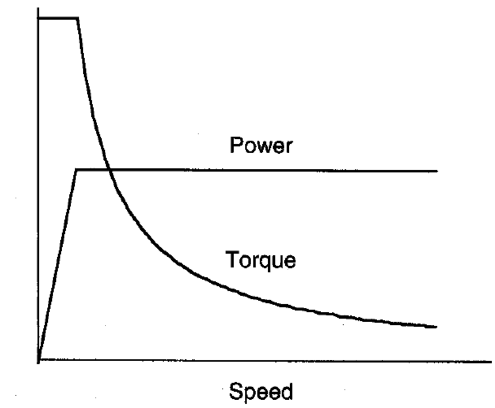


Fig. 9. Ideal performance characteristics of electric motor

3.1. EM before transmission (Mode 1)

The rpm of EM is required to be matched to the ICE rpm since it is coupled before the transmission (with suitable gear reduction). Considering acceleration in 1st gear from 0 to the maximum speed of 10 km/h (max rpm), the torque output of EM is superimposed on the ICE torque contribution resulting in a gain of 13.4% & 23.8% (with 22 kW EM & 50 kW EM respectively) in peak torque at 1600 rpm (Fig 10). The power increase to 231.69kW (10.4% increase) & 249.02 kW (18.8% increase) from that 209 kW of ICE is observed at 2600 rpm (Fig 11).

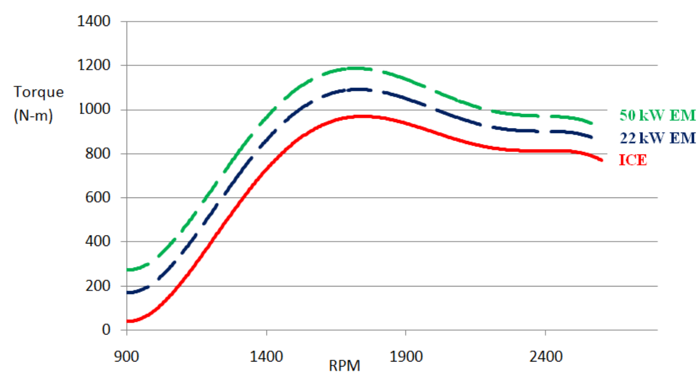


Fig. 10. Enhanced Torque due to Hybridisation (Mode1)

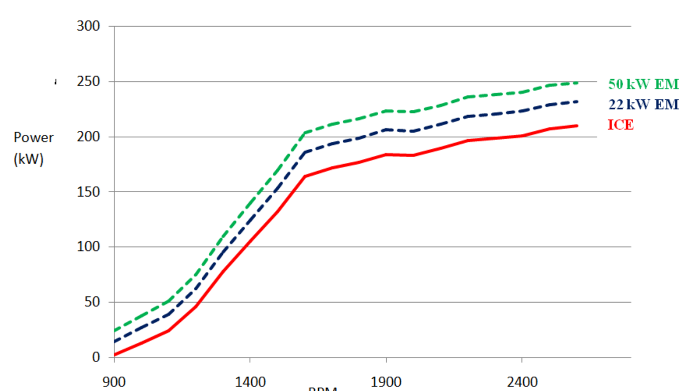


Fig. 11. Enhanced Power due to Hybridisation (Mode1)

3.2. EM after transmission (Mode 2)

Since there are two individual motors (split motor system) at each track, the torque output is coupled. The rpm is required to be matched to the driveshaft. The torque contribution of the split-motor system (after reduction as per gear ratio) is observed to be at 2.4% & 4.8% (with 22 kW EM & 50 kW EM respectively) in the first gear (Fig 12). The power increase to 217 kW (3.3% increase) & 222 kW (5.7% increase) is observed at 2600 rpm in first gear only (Fig 13). However, the effect of a hybrid system on power and torque in higher gears is significant.

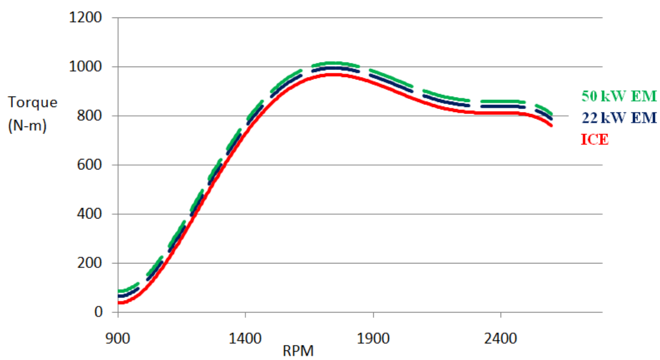


Fig. 12. Enhanced Torque due to Hybridisation (Mode 2)

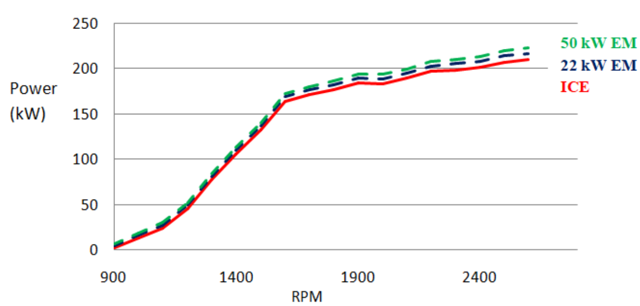


Fig. 13. Enhanced Power due to Hybridisation (Mode 2)

Table 2: Estimated Peak Torque & Power Values [7]

Parameter	Mode 1 (1st - 5th Gears)		Mode 2 (only 5th Gear)	
	22 kW Motor	50 kW Motor	22 kW Motor	50 kW Motor
Torque (Nm)	1111@ 1600rpm	1214@ 1600rpm	1006-1145 @1600rpm	1028-1274 @1600rpm
Power (kW)	231@ 2600rpm	249@ 2600rpm	217-254.6 @2600rpm	222-290 @2600rpm

The first gear power & torque characteristics of both configurations do not give the consolidated assessment of the enhancement in performance. Hence the comparison of Mode 1 & Mode 2 at different gear ratios is shown in Figs 14, 15, 16 & 17. The performance in Mode 1 is observed to be similar at all gear ratios since the EM is coupled before transmission. In Mode 2, the Peak Torque & Peak Power are achieved only in the 5th gear whereas they are estimated to be lesser in the lower gears. This is due to the effect of the gear reduction ratio. The Peak Torque & Peak Power in both modes are shown in Table 2.

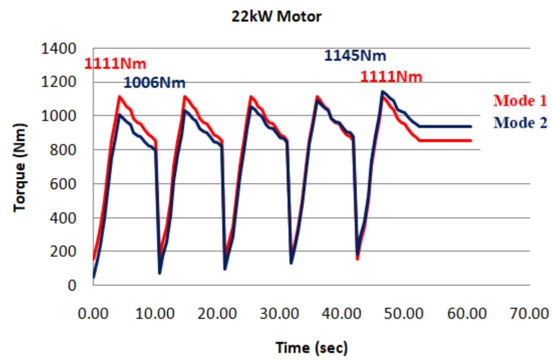


Fig. 14. 22kW EM Torque comparison (Mode 1 vs Mode 2)

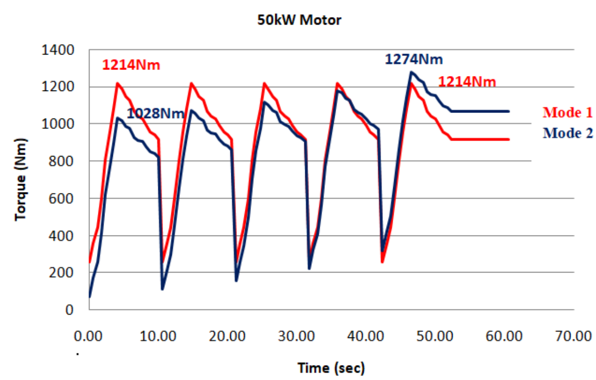


Fig. 15. 50kW EM Torque comparison (Mode 1 vs Mode 2)

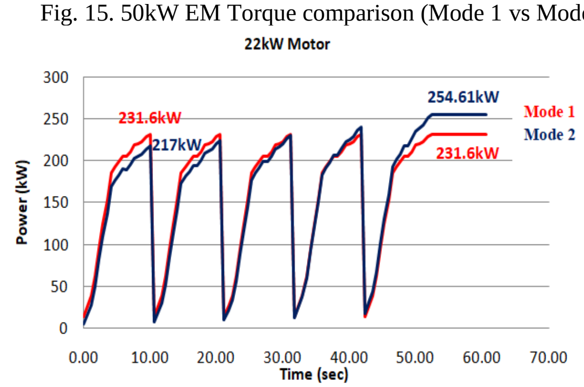


Fig. 16. 22kW EM Power comparison (Mode 1 vs Mode 2)

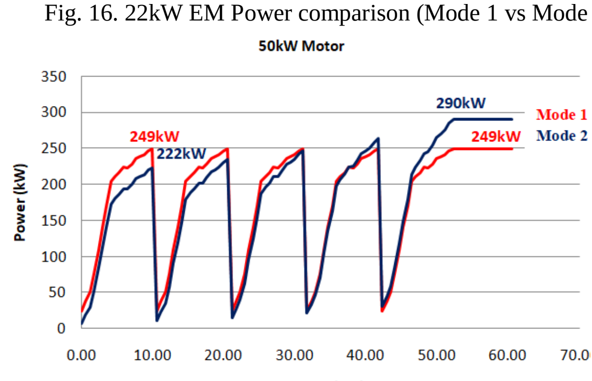


Fig. 17. 50kW EM Power comparison (Mode 1 vs Mode 2)

3.3. Limp Home Mode (Mode 3)

In addition to the above two methodologies, an electric-assist only propulsion mode was considered for emergency runs in case of breakdown of ICE. The vehicle parameters in this mode ie., max speed &energy consumption were assessed in Mode 2.Speeds of upto 10.6 km/h and 13.7 km/h have been estimated with only electric motors (22 kW & 50 kW) using a 250 kW-h battery pack as suggested by Eda A. et al [6]. The energy consumption in electric-only mode works out to be 521.73 kJ and 464.76 kJ per km with 22 kW motor and 50kW motor respectively.

3.4. Comparison of Hybrid Configuration

The advantages and disadvantages of both the Parallel configurations ie., EM before transmission (Mode 1) & EM after transmission (Mode 2) are given below:-

Mode 1

- The power control module can be designed solely for matching EM rpm to ICE rpm for enhancing Torque. The design of power control poses a challenge during the design stage.
- No special requirement of catering for turning is required as the EM is coupled before the transmission. Turning is executed by Planetary Steering Gear (PSG) after the transmission.
- The size of EM will largely require special focus and overheating issues with EM as well as battery configuration.
- Since space available in the engine compartment is limited, this configuration may not be suitable for implementation.

Mode 2

- The power control Module needs a special design for matching EM rpm to wheel rpm/driveshaft rpm and needs to be able to vary the rpm at the left or right bank to execute turning. The power control of such a mode poses an additional challenge.
- A special requirement of the power control system to cater for turning is required as the EM is coupled after the transmission.
- By using split motors, size reduction can be achieved. However, the power requirement for two separate motors is increased and the battery must be designed considering this. Thus it may entail a weight penalty. Overheating issues will be comparatively lesser.
- Since ICE power is delivered at one end of the track through the sprocket, the rear idler wheel is free to be modified and can incorporate a suitable EM with the necessary reduction. The power and torque delivery at both ends of the track requires additional consideration with respect to the power control system.

4. Results and Discussion

The benefits of using the electric assist in a parallel hybrid configuration for a tracked vehicle have been estimated. The tractive force requirement of the vehicle to achieve maximum speed (0 to 65 km/h in 61s) was simulated. The improvement with 22kW and 50 kW EM in Mode 2 configuration (5th gear with ratio :4.24: 1) was 22% and 38% power output improvement and 11% and 24% Torque improvement respectively. The Torque and power improvement for 22 kW and 50 kW EM assist in Mode 1 is significantly better than that of Mode 2 at lower gear ratios and lesser at higher gear rations. In both modes, there is an increase in power and torque as compared to existing ICE performance. Mode 2 ie., EM after transmission using hub motors is preferable due to space constraints in the engine compartment and because it facilitates easier integration. The electric-assist can significantly boost the power and torque resulting in an overall increase in speed or range. In addition, the hybridization of a tracked vehicle can enable a “limp home mode” as an emergency means of propulsion of the vehicle in case of breakdown of ICE. These features would be valuable for short emergency movements.Limited speeds of upto 10.6 km/h and 13.7 km/h have been estimated with only electric motor propulsion (22 kW & 50 kW) using a 250 kW-h battery pack as suggested by Eda A. et al [6]. A standard reduction gearing was considered alongwith the motors to enable optimum utilisation of torque characteristics of electric motors.

5. Conclusions

The hybridization of a tracked vehicle comprises addresses high torque and power density requirements, the high operating temperature of power electronics, high energy density storage devices & drivetrain design since the turning and gearing assume importance in such a vehicle. Tracked vehicles are employed in rough terrain and inclement weather, hence the technology planned for integration must be rugged enough to withstand these tough environmental and operational conditions. However hybrid technology offers tangible advantages over conventional power sources as demonstrated in many automobiles of today. The technology has not yet been fully tapped for tracked vehicle applications and has considerable potential for research and study. Hybridization will allow for greater endurance and energy flexibility in the field. The main findings are given below:

i. Significant improvement in Power & Torque could be achieved about 22% and 38% power output improvement and 11% and 24% Torque improvement with 17.3% and 32.3% DoH respectively in parallel hybrid ICE configuration.
ii. The Torque and power improvement in Mode 1 (EM before transmission) is significantly better than that of Mode 2 (EM after transmission) at lower gear ratios and lesser at higher gear rations.
iii. The hybridization of a tracked vehicle can enable a “limp home mode” as an emergency means of propulsion of the vehicle in case of breakdown of ICE.
iv. Speeds of upto 10.6 km/h and 13.7 km/h have been estimated with only electric motors. The energy consumption in electric only mode works out to be 521.73 kJ/km and 464.76 kJ/km with 22 kW motor and 50 kW motor respectively.

Nomenclature

F_{tr}	:	Tractive Effort required (N)
F_{rr}	:	Rolling Resistance (N)
F_g	:	Gradient Resistance (N)
F_a	:	Aerodynamic Drag (N)
F_{acc}	:	Force due to Linear and angular acceleration (N)
C_d	:	Shape Factor
A	:	Frontal Area (m^2)
P	:	Air density (kg/m^3)
μ_{rr}	:	Co-efficient of Rolling resistance
α	:	Gradient (radians)
M_v	:	Mass (kg)
g	:	Acceleration due to gravity (m/s^2)
J	:	Rotational Inertia component (kg m)
J_{rot}	:	Inertia of rotating components ($kg\text{-}m^2$)
r_{dyn}	:	Dynamic radius of tyre (m)
v	:	Velocity in m/s
P	:	Instantaneous Power in Watts

Conflict of Interest Statement

The authors declare that there is no conflict of interest in the study.

CRediT Author Statement

K. A. Subramanian: Conceptualization, and Evaluation

Raj Kumar Aska Joshua: Conceptualization, Writing-original draft, Data curation and Formal analysis.

References

[1] Sivakumar P, Rajaseeli R, Venkatesan G, Hari V, and Selvathai T. Configuration Study of Hybrid Electric Power Pack for Tracked Combat Vehicles.Defence Science Journal. July 2017:67(4).

[2] Hidetaka T, Takeshi Y and Koki J. Development of Tracked Combat Hybrid-Electric Vehicle. Mobility Research Division, Ground Systems Research Center, Acquisition, Technology and Logistics Agency, Ministry of Defense of Japan.

[3] Travis EM, Torrey JW, John ES, Denise MR and Jada BW. Tracked vehicle physics-based energy modelling and series hybrid system optimisation for the Bradley fighting vehicle.Air Force Institute of Technology (AFIT) USA ; 2020.

[4] Ali M, Kamel H, Sharaf AM and Hegazy SA. Modelling and Simulation of Hybrid Electric Vehicles. Proceedings of the 16th International AMME Conference. 27-29 May 2014.

[5] Dalsjø P. Hybrid electric propulsion for military vehicles. Norwegian Defence Research Establishment. June 2008 ; FFI-rapport 2008/01220.

[6] Eda A., Mustafa K and Ozgur C. Drive Cycle Simulations of Wheeled and Tracked Heavy-Duty Electric Vehicle Powertrains. Dokuz Eylul University Faculty of Engineering Journal of Science and Engineering. DEÜ FMD 23(69), 913-922, 2021.

[7] Byunghwan Kim, Jeongho L, Youngho J, Byunghee K, Kinam K, Yeonho K & Youngju P. Development of 50kW Traction Induction Motor for Electric Vehicle (EV). IEEE Vehicle Power and Propulsion Conference, Seoul, Korea, 9-12 Oct 2012.

[8] Yuechao S, Man L and Cong L. Analysis of Wheel Hub Motor Drive Application in Electric Vehicles. Matec Web of Conferences 2017 ; 100, 01004.

[9] https://ofb.gov.in/unit/pages/EFA/utd-20-engine

[10] https://geek-tips.imtqy.com/articles/6376516440445916 /index.html

[11] Branislav S, Stefania S, Veronika H, Ondrej S, Maria C and Mirosław S. Vehicle fuel consumption prediction based on the data record obtained from an engine control unit. MATEC Web of Conferences 252, 06009, 2019.

[12] José I H, Michael G, Luis FQ and Jenny D. Driving Cycles Based on Fuel Consumption. Energies (MDPI) 11, 3064, 2018.

[13] Hasnira and Didi Istardi. Energy Estimation on BLDC Electric Vehicle Using Matlab. IPTEK, Journal of Proceeding Series, Vol. 1, 2014 (eISSN: 2354-6026).

[14] Mohd T, Hassan MK, Aziz A. Mathematical modeling and simulation of an Electric Vehicle. Journal of Mechanical Engineering and Sciences (JMES), e-ISSN: 2231-8380; Volume 8, pp. 1312-1321, June 2015