

# Electrification of go-kart with second-life lithium-ion batteries: performance analysis and optimisation

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**Abstract.** This research paper presents the design, modelling, and performance analysis of an electric go-kart retrofitted with a second-life lithium-ion battery pack. A 10 kW brushless DC (BLDC) motor and a 50.4 V, 100 Ah repurposed battery pack (14S5P NMC configuration) form the core of the powertrain. Technical performance measurements achieved included a top speed of 67 km/h and peak acceleration of 9 m/s<sup>2</sup>, demonstrating that the electrification of a go-kart with repurposed second-life cells was on par with or even improved over conventional internal combustion engine (ICE) go-karts. Through the first principle, theoretical modelling of resistive forces and drivetrain dynamics, the selection of a 4:1 gear ratio was determined to produce a required wheel torque of 122 N·m to meet performance targets. The pack delivered up to 287 A during peak acceleration with an acceptable voltage sag from 52 V to 41 V. Real-time telemetry monitored speed, current, voltage, and battery temperature, providing insight into the current state of the battery during testing. Thorough safety measures, including a battery management system (BMS), ensure that safety concerns are mitigated. The results demonstrate that second-life lithium-ion cells can be successfully reused in a dynamic, high-power application without significant performance compromise. This work offers a sustainable approach to recreational vehicle electrification and performance optimisation through modelling and simulation, highlighting how battery reuse can reduce costs and environmental impact while delivering competitive performance.

## 1 Introduction

Electric vehicles (EVs) are rapidly increasing in all sectors of transportation due to their efficiency and lower environmental impact [1, 2]. Go-karts, popular in recreational racing and as a training platform for motorsport, have traditionally relied on small-displacement ICE engines, but the move towards eco-friendly alternatives has increased interest in electrification [3, 4]. An electric go-kart can deliver comparable power and torque to ICE counterparts while eliminating emissions. Furthermore, the reuse of second-life lithium-ion battery cells, retired from EVs but still retaining significant capacity, presents an opportunity

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to reduce e-waste and lower costs for electrified go-karts [5, 6]. This paper addresses the conceptual design and performance optimisation of a go-kart converted to an electric drive using second-life batteries, focusing on validating its performance against traditional metrics and ensuring safety and reliability.

This research aims to critically evaluate the design and optimisation of an electric go-kart powered by second-life lithium-ion batteries. The key objectives include: developing a theoretical model for the powertrain to guide component selection including motor power/torque, gearing, battery capacity, integrating the electrical, mechanical, and control components into a working prototype [3, 4], verifying all design calculations (acceleration, resistive forces, energy consumption) through experimental testing [5], and analysing the performance data (speed, acceleration, power draw, thermal behaviour) to assess whether second-life batteries can deliver the required performance reliably [5, 6].

## 2 Literature Review

A go-kart is a compact four-wheeled vehicle with a rigid chassis with no suspension or differential and a single seat. According to the Fédération Internationale de l'Automobile (FIA) for karting [7], typical adult racing go-karts weigh for various categories is between 150–180 kg including the driver. Given the short straightaways and frequent turns of kart tracks, they are geared toward rapid acceleration and agile handling rather than high top speeds [4]. Prior studies have reported average go-kart top speeds on the order of 60 km/h and emphasised acceleration as a key performance metric. For example, a typical 0–60 km/h acceleration times corresponding to roughly 3–5 m/s<sup>2</sup> for competitive electric karts [4]. The performance of an electric go-kart powered by lithium-ion was compared to a nickel-metal hydride batteries, confirming that lithium-ion technology yields superior acceleration and energy efficiency, with top speeds around 60 km/h in tests [5]. These benchmarks informed the performance targets for the design, namely achieving 60 km/h and acceleration >4 m/s<sup>2</sup> to match or exceed ICE kart capabilities [3].

### 2.1 Electric powertrain components

Modern EV powertrains typically consist of a battery pack, a battery management system, one or more electric traction motors, and the required power electronics such as the motor controller/inverter, as described by [7]. For small electric vehicles like go-karts, three motor types are commonly considered: BLDC motors, induction motors, and permanent magnet synchronous motors (PMSM) [8, 9]. BLDC motors offer high efficiency on the order of 90–95% and excellent power-to-weight ratio [8, 10]. In contrast, induction motors, while robust, can suffer from reduced torque at high speeds due to breakdown torque limitations and lower efficiency, and PMSMs require complex control and can lack self-starting capability [10]. Given these factors, a BLDC motor was selected for this research – a decision consistent with recommendations in the literature for EV applications requiring high torque and rapid throttle response [11].

### 2.2 Second-life battery utilisation

Lithium-ion batteries, particularly Nickel Manganese Cobalt (NMC) chemistry cells, dominate EV energy storage due to their high energy density and power capabilities [12, 13]. By the end of their automotive life, which typically occurs when capacity falls to 70–80% of the original, EV batteries can often still deliver substantial current and have many charge

cycles remaining [5]. Instead of recycling these batteries immediately, they can be repurposed for second-life applications where slightly reduced capacity is acceptable [6].

Much existing research on second-life batteries focuses on stationary energy storage, such as grid support or home battery systems, where power demands are more moderate and predictable [6]. In contrast, using aged batteries in a high-discharge, dynamic context like a go-kart is less explored. Prior work has highlighted that increased internal resistance and cell-to-cell imbalance in aged lithium-ion packs can exacerbate voltage sag and heat generation under rapidly varying traction loads [14]. Evidence under motorsport-like duty cycles, however, remains limited. Motivated by this gap, the present project focuses on a controlled evaluation of a second-life NMC pack subjected to go-kart racing load profiles, using a safety architecture that includes BMS-based cell supervision, distributed thermal sensing, and over-current protection to keep operation within safe limits [15].

In this context, the viability of second-life batteries is evaluated by comparing the go-kart's performance and battery behaviour to expected norms, including voltage, thermal response, and capacity usage per run [13]. These findings demonstrate that reused lithium-ion batteries can function effectively in high-power mobile platforms with proper health assessment and safeguards.

### 3 Methodology

By combining insights from the literature with detailed testing, the study seeks to demonstrate that an electric conversion can meet or exceed ICE go-kart performance while offering a pathway to recycle and reuse EV batteries [16]. The following sections detail the methodology of the go-kart design, present theoretical and experimental results, and discuss the implications for performance optimisation and sustainable battery reuse in micromobility [1, 2].

#### 3.1 Theoretical design and performance modelling

The design process commenced with the establishment of key performance targets, as defined in Table 1, followed by the application of analytical models to determine the requisite powertrain specifications. The modelling effort focused on quantifying the resistive forces acting against the motion of the go-kart, thereby informing the sizing of the motor and the selection of an appropriate gear ratio [3, 8, 10].

Three principal resistive forces were considered: aerodynamic drag, rolling resistance, and grade (incline) resistance. The aerodynamic drag force, significant at elevated velocities, was computed as:

$$F_{drag} = \frac{1}{2} \rho C_d A v^2 \quad (1)$$

Where  $\rho$  is the air density,  $C_d$  the drag coefficient,  $A$  the frontal area of the kart and driver, and  $v$  the velocity. The rolling resistance, which arises due to tyre deformation and contact with the track surface, was expressed as:

$$F_{roll} = \mu_r M g \quad (2)$$

With  $\mu_r$  representing the coefficient of rolling resistance,  $M$  the combined mass of the kart and driver, and  $g$  the gravitational constant. To account for scenarios involving non-zero road gradients, the incline or grade resistance was incorporated as:

$$F_{grad} = M g \sin\theta \quad (3)$$

Where  $\theta$  denotes the angle of inclination, the total tractive force required to overcome these resistances is the sum of the individual components, given by:

$$F_{tractive} = F_{drag} + F_{roll} + F_{grad} \quad (4)$$

Standard engineering assumptions were employed to estimate model parameters:  $\rho=1.225 \text{ kg/m}^3$ ,  $C_d \approx 0.6-0.8$ ,  $A \approx 0.3-0.5 \text{ m}^2$ , and  $\mu_r \approx 0.02-0.03$ , consistent with low-profile go-karts fitted with racing slick tyres [5, 11]. A conservative total mass of  $M=200 \text{ kg}$  was selected to accommodate the heaviest practical load condition (kart plus driver), ensuring robust operation under worst-case scenarios as per [7].

Applying these parameters, the total resistive force on level ground at the target speed of  $60 \text{ km/h}$  ( $16.67 \text{ m/s}$ ) was calculated to be  $164 \text{ N}$ . When operating on a  $5$  degree incline, the tractive force requirement increased to approximately  $335 \text{ N}$ , highlighting the additional torque demands under non-ideal conditions. These calculated force values served as the foundational criteria for the specification of the motor's torque output and gearing configuration, ensuring that the drivetrain could meet performance targets across all expected operating regimes [9].

### 3.2 Acceleration requirement

Achieving rapid acceleration was a fundamental requirement in the go-kart's performance specification. Using Newtonian mechanics, a baseline requirement was established: to accelerate a combined mass of  $200 \text{ kg}$  at  $4 \text{ m/s}^2$ , a net tractive force of  $800 \text{ N}$  is needed. At speeds up to  $60 \text{ km/h}$ , aerodynamic drag of  $85.5 \text{ N}$  is negligible, allowing nearly all the force to contribute to linear acceleration. The rolling resistance and other minor resistive forces were included in the total calculated forces for system robustness [4].

To translate this force into mechanical torque at the wheels, the kart's wheel radius of  $0.1524 \text{ m}$  (12-inch tyre diameter) was applied, resulting in a required wheel torque of approximately  $122 \text{ N}\cdot\text{m}$ . Although the tested go-kart's actual weight was closer to  $158 \text{ kg}$ , using the conservative  $200 \text{ kg}$  figure ensured the system could accommodate heavier drivers and maintain consistent acceleration across the range required for a FIA track [5, 8].

This torque demand was validated against the drivetrain's capabilities during dynamic testing, confirming the design had sufficient headroom to overcome resistive forces and still deliver strong acceleration. These calculations served as a reference point throughout the design and optimisation process [7].

### 3.3 Drivetrain gearing

The selected BLDC motor, rated at  $30 \text{ N}\cdot\text{m}$  continuous and  $80 \text{ N}\cdot\text{m}$  peak torque at  $4000 \text{ rpm}$ , necessitated appropriate gearing to meet the required wheel torque calculated during the theoretical design phase. To determine the necessary gear ratio, the angular speed of the wheels at the target top speed of  $60 \text{ km/h}$  ( $16.67 \text{ m/s}$ ) was first established [8, 10]. The wheel circumference  $C$  is given by:

$$C = \pi D = \pi \times 0.3048 = 0.9576 \text{ m} \quad (5)$$

$D=0.3048 \text{ m}$  is the diameter of the kart's rear tyres. The wheel's rotational speed  $n_\omega$  in revolutions per second (rps) at the target speed is:

$$n_{\omega} = \frac{v}{c} = \frac{16.67}{0.9576} = 17.4rps \quad (6)$$

Converted to revolutions per minute (rpm), this yields:

$$n_{\omega(rpm)} = n_{\omega} \times 60 = 1044rpm \quad (7)$$

To match this wheel speed to the motor's optimal operational speed of 4000 rpm, the required gear ratio  $G$  is:

$$G = \frac{n_{motor}}{n_{\omega}} = \frac{4000}{1044} \approx 3.83:1 \quad (8)$$

For design simplicity and improved acceleration response, a slightly higher gear ratio of 4:1 was chosen. This ensures the motor operates within its efficient range while delivering sufficient torque to the wheels. The gear ratio multiplies the motor torque at the axle, assuming negligible drivetrain losses [3, 9]. The peak torque at the wheel is calculated as:

$$\tau_{\omega,peak} = 4 \times 80 = 320Nm \quad (9)$$

And the continuous torque at the wheel:

$$\tau_{\omega,cont} = 4 \times 30 = 120Nm \quad (10)$$

These torque values surpass the minimum requirement of 122 N·m calculated for achieving 4 m/s<sup>2</sup> acceleration at a total mass of 200 kg. For the actual kart mass of 158 kg, the theoretical peak acceleration  $a$ , assuming full traction, is given by:

$$a = \frac{\tau_{\omega}}{M \cdot r_{\omega}} = \frac{320}{158 \times 0.1524} = 13.4m/s^2 \quad (11)$$

Where  $r_{\omega}=0.1524m$  is the wheel radius. In practice, this acceleration is limited by tyre traction and surface conditions, but the drivetrain configuration demonstrates sufficient capacity for high-performance starts and responsive throttle behaviour [5, 7].

These values affirm that the gearing and motor selection strategy meets or exceeds the required torque and acceleration benchmarks. According to studies such as [3] and [10], this gear ratio and power level are typical for high-performance electric karts intended to match ICE counterparts.

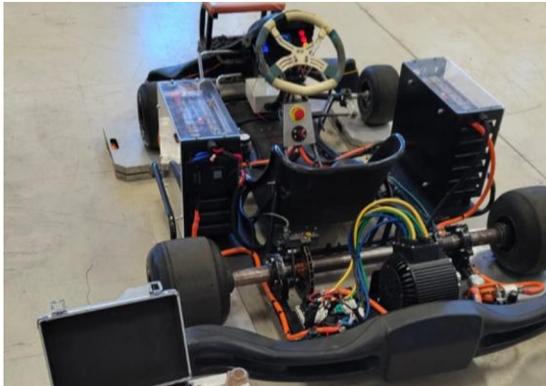
### 3.4 Motor and controller

A 48 V, 10 kW BLDC motor was selected as the propulsion unit, chosen for its high power density, torque delivery, and proven reliability in electric vehicle applications [8, 10]. The motor is rated for 30 N·m continuous torque and supports up to 80 N·m of peak torque. Operating efficiently at 4000 rpm, it provides an ideal combination of speed and torque for a go-kart application [11]. The drivetrain includes a 4:1 gear reduction, translating the motor torque into a higher wheel torque while enabling the motor to operate within its required speed range. With this gear ratio, the motor's continuous and peak torque output is increased to 120 N·m and 320 N·m at the wheels, respectively, both meeting and exceeding the 122 N·m requirement needed for acceleration [3]. The selected controller ensured that the motor remained safe during operation as well as ensuring efficiency. This controller supports programmable current and voltage thresholds and can deliver peak currents up to 300 A. These parameters were tuned to balance performance with battery safety. A mounting

solution was designed for the motor, and finite element analysis (FEA) verified that the structure experienced minimal deflection ( $<0.2$  mm) under load, confirming the mechanical integrity of the system under stress [5].

### 3.5 Battery pack design

A critical aspect of this research was designing a battery pack using second-life lithium-ion cells. These cells were originally part of an EV battery module and were selected based on electrochemical impedance spectroscopy (EIS) testing to ensure consistency in internal resistance and remaining capacity [5- 6]. Only cells that met stringent health metrics were included in the final pack.



**Fig. 1.** Electrified go-kart with battery banks visible.

The pack was configured as 14 series-connected modules (14S) with five cells in parallel per module (5P), resulting in a nominal voltage of 50.4 V and a capacity of 100 Ah, yielding a total energy capacity of approximately 5.04 kWh. The configuration ensures that peak current demands, up to 287 A, are distributed across parallel groups, keeping per-cell current draw within the safe operating limits of under the 3C continuous discharge rating. This configuration balances performance, safety, and longevity [7, 13] and can be seen in Figure 1.

The battery enclosure was designed to address thermal considerations and mechanical protection. Each parallel group was fused individually for overcurrent protection, and the pack structure included shock-absorbing mounts to mitigate the effects of mechanical vibration. Cell temperature was monitored via embedded sensors, with data relayed to the battery management system (BMS). Thermal performance remained within acceptable limits throughout testing [14, 15]. Pack placement was chosen to improve vehicle stability. The battery pack was mounted low and near the chassis centreline, contributing to a low centre of gravity and balanced weight distribution. This strategic placement enhanced cornering performance and reduced the chance of tipping or instability during high-speed manoeuvres [4].

### 3.6 Battery management and safety

A Battery Management System (BMS) is essential when using lithium-ion cells, especially second-life cells, to monitor state-of-charge temperatures and ensure safe operation. The BMS used in this research project monitors each series module's voltage and includes a temperature sensor per pack. It provides cell balancing during charging to keep voltages equal [13].

In the design, the BMS was programmed with conservative thresholds given the unknowns of second-life cells. It will cut off discharge if any cell group falls below 3.0 V or if the pack current exceeds 300 A for more than a few seconds. These safety measures align with recommendations in lithium-ion safety studies. During testing, the pack's temperature remained within safe limits, but the BMS would alarm and cut power if any sensor exceeded 60 °C (which did not occur in the tests) [12].

### **3.7 Motor and controller**

To monitor and record operational data in real-time, a custom telemetry system was developed around an Arduino Giga microcontroller interfaced with the motor controller via CAN bus. This setup enabled real-time communication and allowed continuous speed, current, voltage, temperature, and acceleration tracking.

The telemetry system included a Nextion-based graphical user interface (GUI) mounted on the dashboard. This display provided the driver with live information such as vehicle speed, battery voltage, current draw, and system alerts. This feedback was essential for making on-the-fly adjustments during testing and helped identify anomalies quickly [3].

Captured data were also wirelessly transmitted to a base station for logging and post-processing. This also enabled in-depth analysis of important parameters such as voltage sag under acceleration, thermal trends during operation, and energy consumption per lap. Furthermore, the telemetry allowed comparison between predicted and actual performance, supporting the initial refinement of system models and validating the designs performed [5, 13].

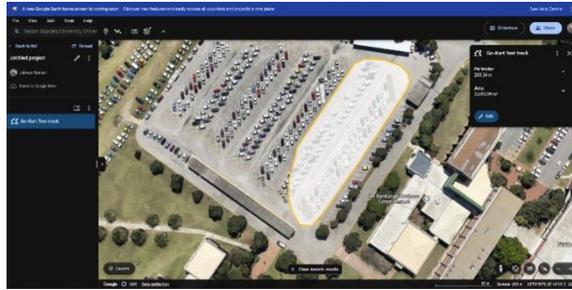
Telemetry systems such as this one play a crucial role in electric vehicle testing and optimisation, as highlighted in [15]. The ability to correlate data like temperature spikes or voltage drops with driver behaviour or track conditions allows for fine-tuning system parameters and improving both performance and reliability [12]. In addition, real-time safety monitoring ensures that dangerous conditions, like overcurrent or thermal runaway, are detected and mitigated immediately.

## **4 Experimental testing procedure**

Once the electric go-kart was built, a series of tests were conducted to evaluate its performance against the design goals and to verify the calculations. Static tests were done first: the kart was secured on a stand to test the drivetrain operation, during which throttle response, motor current draw with wheels free-spinning, and the function of the BMS cutoff were checked. The battery was charged and discharged using a programmable tester to ensure it delivered the expected capacity and to calibrate the state-of-charge estimation, this also replicated the 5-race energy use simulation to confirm the pack could supply 3.3 kWh with some reserve [7, 13].

For dynamic testing, two main types of runs were performed, both a circuit and a straight line test. For the circuit test, the kart was driven on a small test track, shown in Figure 2, with turns and a short straight, laid out to simulate a karting circuit. Data on speed, current, and voltage over time were collected during these runs. This test evaluated how the battery and motor performed under typical driving conditions with frequent acceleration and braking [3, 5]. For the second test, a separate straight road was used to measure the kart's maximum velocity and acceleration on a full-throttle run. An onboard GPS-based speed logger and the accelerometer data were used to determine the top speed achieved and the acceleration profile. The accelerometer data indicated the instantaneous acceleration, though it was

somewhat noisy due to track vibrations. Acceleration was also cross-verified by differentiating GPS speed data for higher accuracy [4].



**Fig. 2.** Dynamic test circuit.

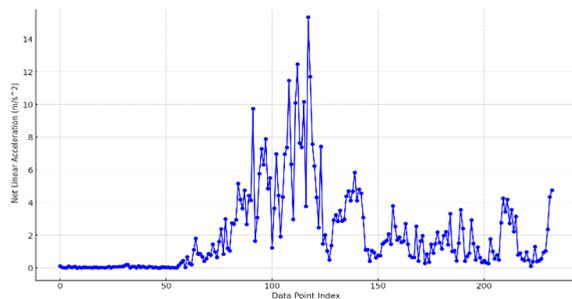
Before each run, the tyre pressures were adjusted to standard values and the battery was fully charged. After each run, the battery pack voltage and temperature of cells and motor were recorded. No active cooling was used on the motor or battery beyond ambient air flow, so the temperature was carefully monitored to ensure safe operation [10].

All test instruments were calibrated – for instance, the shunt resistor for current measurement was verified against a precision meter, and the accelerometer was calibrated for bias. These precautions were taken to ensure that the data collected would be reliable for validating the design calculations and consistent with best practices in EV testing literature [13, 15].

## 5 Results and analysis

### 5.1 Performance metrics achieved

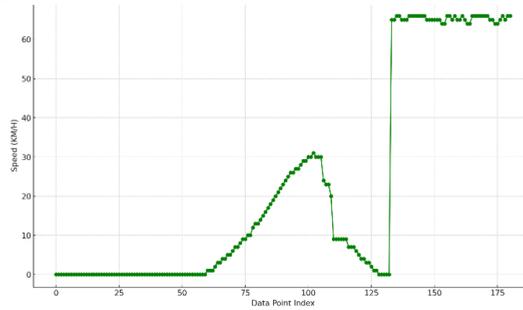
The electric go-kart's performance met or exceeded the initial targets. In repeated straight-line tests, the kart achieved a maximum speed of 67 km/h, slightly above the 60 km/h goal. This top speed was measured at the point of maximum motor rpm (approximately 4400 rpm, slightly above the 4000 rpm rating), made possible as the motor can overspeed under light load once wind resistance balances output [3, 4, 8]. The acceleration was particularly impressive: the kart accelerated from 0 to 50 km/h in 5.5 seconds on average, with an initial



**Fig. 2.** Acceleration measured during the straight-line test.

peak acceleration of 9 m/s<sup>2</sup> was recorded by the accelerometer [4, 5]. Sustained accelerations of 4–5 m/s<sup>2</sup> were observed until nearing top speed. These results validate that the drivetrain

provided more than sufficient torque – traction became the limiting factor, which is consistent with observations in prior electric kart studies [3, 5].

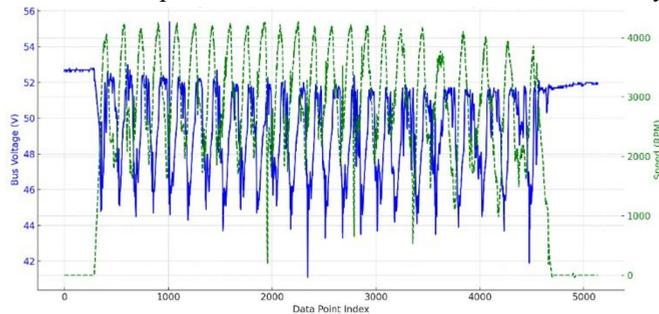


**Fig. 3.** Speed measured during the straight-line test.

Crucially, the performance is on par with or better than typical 125 cc two-stroke racing go-karts, which can reach 0–60 km/h in roughly 4–6 seconds [4]. The electric drivetrain’s immediate torque gave it an edge in acceleration out of corners, a trait widely praised in EV applications [9, 10].

### 5.1.1 Power and current draw

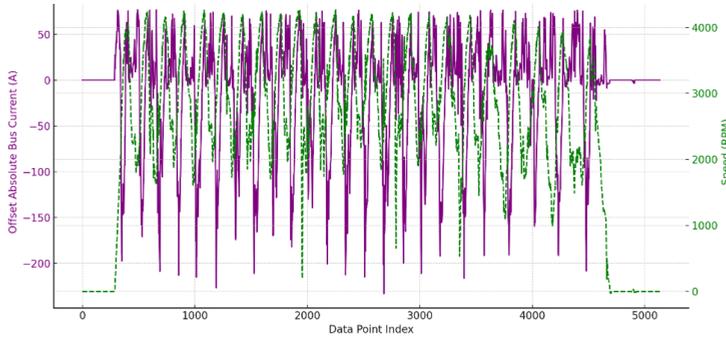
According to the telemetry data from the course illustrated in Figure 2, the peak power drawn from the battery occurred during hard acceleration at low speed. Peak power of up to about 12 kW being drawn from the pack was recorded. At that moment, the battery was supplying



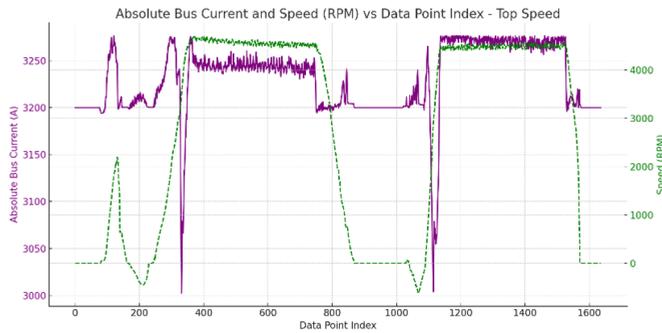
**Fig. 4.** Speed vs bus voltage for the dynamic test circuit.

approximately 287 A, and the pack voltage dipped to around 41 V, as can be seen in Figures 4 and 5. This voltage sag is expected under such a heavy load, corresponding to a temporary reduction of about 20% from the nominal 51–52 V charged voltage. The pack’s internal resistance (aggregate of all cells) can be inferred: a 287 A draw causing an 11 V drop suggests an internal resistance on the order of 40mΩ for the entire pack [5, 6, 13]., which means each cell (or parallel group) has only a few milliohms, a reasonable figure for lithium NMC cells that still have good health. After the acceleration phase, as the current draw fell, the battery voltage recovered to about 52 V. This voltage recovery indicates the cells were not permanently depleted and that their impedance, while noticeable, did not prevent delivering

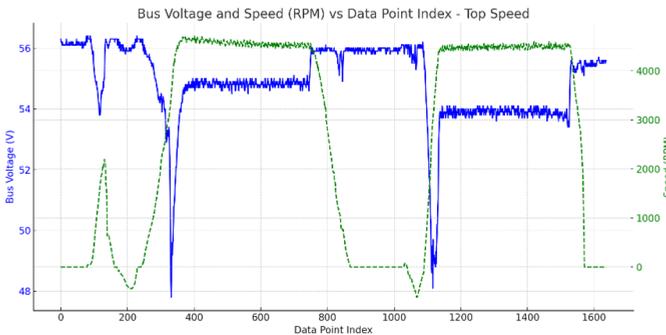
the needed power. It also reflects good pack balancing, no individual series module dropped out prematurely, and strong cell health.[4]



**Fig. 5.** Speed vs bus current draw for the dynamic test circuit.



**Fig. 6.** Speed vs bus current draw for the straight top speed test circuit.



**Fig. 7.** Speed vs bus voltage for the straight top speed test circuit.

The power draw was much lower during steady cruising at top speed (67 km/h), mainly to counteract drag and rolling resistance. The telemetry showed that at high speed on flat ground, the motor drew around 40–50 A (approximately 2–2.5 kW) to maintain velocity.

At this point, the battery voltage was close to nominal. Figure 6 shows the relationship of battery voltage with speed: a sharp dip during acceleration and a plateau during constant high speed, and Figure 7 shows the relationship of battery current draw with speed.

### 5.1.2 Energy consumption and range

In the circuit tests, each 10-lap session, with lap lengths on the order of a few hundred meters each, consumed roughly 12–13% of the battery’s state of charge. This aligns well with the

predicted 0.656 kWh usage, which is 13.1% of a 5 kWh pack from the pre-simulation. For instance, one logged session showed the pack going from 100% down to 87% after 10 laps when accounting for the lack of regenerative braking. Therefore, in practice, the go-kart can complete about five sessions of 10 laps, or approximately 50 laps, before needing a recharge, satisfying the design goal. In more familiar terms, if a lap of 1 km is approximated, the range would be 50 km per charge in a racing scenario. The range would be significantly higher in a less aggressive driving situation or cruising due to lower continuous current draw.

### 5.1.3 Thermal performance

Throughout the testing, neither the motor nor the battery pack exhibited any significant overheating. The batteries did not reach the 60 °C limit after extended runs at an ambient temperature of 25 °C, which is within safe limits. The battery pack temperature increased only slightly, the rise in temperature can be attributed to the moderate ambient conditions and the short duty cycle of high current with bursts of acceleration followed by rests on turns and straights. Longer continuous runs or higher ambient temperatures might lead to higher battery temperatures, but the built-in monitoring system would generate an alert should the temperature exceed the threshold of 60 °C.

### 5.1.4 Vehicle handling and weight

The battery pack weighing 80 kg increased the total weight of the kart to approximately 158 kg and approximately 240 kg with the driver. While this is heavier than a typical petrol kart, often 140 kg with driver for racing classes, the weight distribution and low centre of gravity helped maintain stability. Drivers reported that the kart felt stable through turns, though slightly less agile in quick direction changes compared to lighter karts. The rear-weight bias, approximately 60% on the rear axle without the driver, increasing to 80% with the driver seated due to the driver's weight also near the rear of the kart provided good traction for acceleration, but it also meant care was needed under braking to prevent the rear-wheel locking up. Overall, the handling was acceptable for a recreational kart, but for competitive racing, reducing weight especially un-sprung and rotational mass would be beneficial [2, 4].

## 5.2 Data analysis and comparison with calculations

The measured acceleration curve, despite some sensor noise, clearly shows the kart was able to exceed the design acceleration of 4 m/s<sup>2</sup>, reaching peaks around 9 m/s<sup>2</sup>. When the raw accelerometer data was filtered, the initial spike corresponds well to the theoretical maximum given the tyre friction limits. Using the wheel torque of 320 N·m and the actual mass, the ideal acceleration would be 9.2m/s<sup>2</sup>, which matches the observed peak 9 m/s<sup>2</sup>. This validates both the calculation and the assumption that traction was just sufficient to allow full use of motor torque briefly. Once speed is built up, acceleration drops, which also matches expectations as motor torque falls off after a certain RPM and air drag rises. [3- 5].

The predicted top speed with a 4:1 gear ratio and motor no-load speed around 4500 rpm was 65–70 km/h. The kart achieved a top speed of 67 km/h. This result confirms that the gear ratio choice and motor capability were appropriate for the speed target [3, 8, 9].

An estimated continuous current of approximately 250 A is required during acceleration; accordingly, the pack was specified for 300 A continuous (3C). Telemetry indicates 270 A peak, which remains within this continuous rating. Under this load the pack voltage sagged to 41 V, consistent with an effective pack resistance of 40 mΩ. This magnitude of transient sag is expected for a second-life pack and remained above the BMS low-voltage cutoff. The rapid recovery toward 52 V following the acceleration suggests the state of charge remained

high. In the energy model, voltage sag was treated as negligible; while this introduces a small error during high-current transients, the brevity of these events means the cumulative energy estimate aligns with the measured consumption, consistent with prior lithium-ion degradation observations [5, 13, 15].

Summing the power over time from the recorded data of a 10-lap run gives approximately 0.7 kWh consumed, very close to the 0.656 kWh modelled. The slight difference can be due to variations in driving style or track length. Importantly, this confirms the battery capacity analysis: a 100 Ah pack is indeed sufficient for around five runs ( $5 \times 0.65 = 3.25$  kWh, leaving some reserve). In one continuous run, the kart was run until the BMS indicated 20% remaining charge, this took about 55 laps of the test circuit, demonstrating real-world endurance consistent with calculations. [2, 3, 5].

The Arduino-based telemetry captured the intended dynamic behaviour. While CAN bus raw values required scaling to physical units, these issues were corrected in post-processing. The time-series plots of current versus speed and voltage versus speed exhibit the expected patterns: during corner-exit acceleration, the current trace shows spikes on the order of 200–270 A; during coasting or braking, current trends toward zero and can become slightly negative. Correspondingly, the voltage trace dips under acceleration and rebounds during low-load phases. Taken together, these traces are consistent with the qualitative understanding of the propulsion system and did not reveal unexpected electrical behaviour such as excessive voltage drop in a particular string or controller current oscillations [12, 16].

The results are consistent with the engineering choices made during the design phase: the observed acceleration, top speed, power draw, and energy usage align with the anticipated envelopes, and the behaviour of the second-life pack under load is consistent with expectations for this application. In particular, the pack delivered high current while maintaining stable voltage under the tested conditions, which supports the claim that repurposed batteries can power a go-kart at performance levels comparable to new batteries or ICE engines [3–5]. Table 1 summarises key calculated requirements versus what the design provides.

**Table 1.** Design requirements vs. achieved specifications.

Parameter	Target / Requirement	Achieved (Design Spec)
Top speed	60 km/h (16.7 m/s)	67 km/h (18.6 m/s)
Wheel torque for acceleration	122 N·m (for 4 m/s <sup>2</sup> @ 200 kg)	320 N·m peak, 120 N·m continuous
Total tractive force (flat)	164 N @ 60 km/h	Provided by motor (via gearing)
Total tractive force (6° incline)	335 N @ 60 km/h	Provided (within motor's power)
Motor power	9 kW (est. for targets)	10 kW (continuous), 12 kW peak
Battery capacity (energy)	≥3.3 kWh (for 50 laps)	4.8 kWh (50.4 V, 100 Ah)
Battery discharge C-rate	≥3C (for >250 A)	3C continuous supported (300 A)

As shown, the theoretical design ensured that each component met or exceeded the required performance targets. The 10 kW motor and 4:1 drivetrain were capable of delivering the necessary speed and acceleration, while the battery was sized to supply the energy and current demands with some safety margin.

## 6 Discussion

A central outcome was the validation that second-life lithium-ion batteries are suitable for high-discharge mobile applications. Previously, such batteries were mostly considered for stationary or low-power roles due to concerns about rapid cycling capabilities. However, with careful selection and management, these batteries safely handled discharge rates of 3C and peaks of 12 kW, showing only moderate voltage sag and no dangerous thermal rise. This aligns with findings on second-life battery utility and safety in dynamic environments [5, 6, 13, 15]. Given that end-of-life EV batteries often retain around 75% capacity [5], their repurposing into micro-mobility applications like e-karts offers clear benefits, reducing costs and waste and extending usable service life.

The added 80 kg battery mass increased total vehicle weight beyond that of most racing karts, impacting agility and braking. Nevertheless, the motor's torque capability ensured that acceleration goals were exceeded. This trade-off is acceptable for endurance or recreational use, but competitive applications may benefit from reduced pack sizes or higher energy density cells to improve responsiveness. Design optimisation, especially in terms of weight-to-performance trade-offs, can be explored using simulation tools and performance-based algorithms [9].

Thermal behaviour remained negligible throughout testing, but higher ambient temperatures or fast-charging scenarios could necessitate additional cooling strategies, such as airflow ducting or liquid cooling. The safety systems implemented, which included a BMS, fuses, and containment barriers, ensured fault tolerance and protection against thermal runaway. However, second-life batteries carry some uncertainty due to variable histories, reinforcing the importance of thorough testing and cell matching before deployment. Additionally, improving the mechanical protection of the pack, such as adding crash-absorbing mounts or a safety cage, is recommended for high-risk environments [14].

The telemetry system played a vital role in performance validation and provides a foundation for future optimisation. Real-time data on speed, current, temperature, and state of charge could be used for smart energy management, such as thermal throttling or adaptive torque limiting, to protect the battery and optimise efficiency [10]. Moreover, this data could support advanced modelling or machine learning-based tuning to improve drive profiles, motor parameters, or gearing strategies [8, 11].

When compared to ICE karts, the electric design offered instantaneous torque and smoother driveability, with performance matching or surpassing traditional systems. Though ICE karts are lighter and can refuel faster, the electric variant proved sufficient for multiple sessions and produced zero operational emissions [2, 4, 5, 12]. Unlike ICE engines, which show performance variability as fuel depletes or components heat, the electric drivetrain maintained consistent power output throughout runs.

Reusing second-life batteries contributes meaningfully to sustainability by delaying recycling and extracting more functional value. This supports circular economy principles and reduces the burden on new battery production. However, the manual work of repurposing cells, such as health testing and pack balancing, remains a challenge. Progress in battery module design and standardisation could lower this barrier, as noted in critical reviews of EV battery recyclability and reuse potential [16].

Looking forward, further system-level optimisation could improve performance. Advanced traction control, dynamic field-weakening, and variable gearing could be explored, though these introduce mechanical and control complexity. A more flexible multi-objective design approach, tailored to specific race formats or track profiles, could yield different optimal configurations. In this research, the fixed 4:1 ratio and control setup delivered a robust balance of acceleration, speed, and simplicity.

Overall, the research exemplifies a holistic integration of mechanical, electrical, and embedded system design. Through systematic testing, the team demonstrated that second-life batteries could meet the demands of a high-performance go-kart without sacrificing safety or speed [1, 8, 12]. The findings reinforce the feasibility of second-life battery use in mobility applications and underscore the role of thoughtful engineering in advancing sustainable vehicle platforms [5, 6].

## 7 Conclusion

This work has presented a detailed design, implementation, and analysis of an electric go-kart powered by second-life lithium-ion batteries. The research's findings conclude that it is feasible to retrofit a traditional go-kart with an electric drivetrain and achieve the required performance requirements of 67 km/h top speed and an acceleration of 9 m/s<sup>2</sup> which is in line with those of ICE-based karts. The most critical aspect was the use of a high-torque BLDC motor and a correctly selected gear ratio, which delivered the required acceleration and top speed. Equally important, the second-life NMC battery pack, assembled in a 50.4 V, 100 Ah configuration, proved capable of sustaining the necessary power bursts, validating the hypothesis that second-hand EV batteries can effectively be reused in demanding mobile applications.

## 8 Future research and engineering directions

Future work could explore long-term cycle testing of the second-life battery pack in the go-kart to evaluate how the cells age under high C-rate cycling. It would be valuable to know if any particular degradation modes emerge, for instance, capacity fade vs. internal resistance growth, and how that impacts performance over dozens or hundreds of cycles. Additionally, incorporating active thermal management for the battery would allow testing in more extreme conditions, ensuring the system's reliability in hot climates or during continuous use, such as in an endurance race. On the performance side, implementing traction control and more advanced power management strategies could further improve lap times and energy efficiency – these are software improvements that could be added to the existing platform. From a design perspective, investigating lightweight materials for the chassis or alternative packaging for the battery could help mitigate the weight increase and optimise the weight distribution.

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