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IoT-Based Energy Consumption Analysis of Electric Vehicles: The Effect of VESC Motor Current Limits

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Abstract

This study presents an IoT-based battery monitoring system and analyzes the effect of the VESC motor current limit on battery current and energy consumption. The research focuses on an electric vehicle prototype developed by the Electric Car Research Center (ECRC) at the Faculty of Engineering, Universitas Muhammadiyah Surakarta. The system integrates an ESP32-S3, PZEM-017 sensor, Neo-7M GPS, and Firebase database for real-time monitoring. Experiments were conducted at five current limits 10-30 A with three replications. Results show that increasing the current limit from 10 A to 30 A increased average battery current from 1.30 A to 3.53 A ($F(4,10) = 285.47$, $p < 0.001$, $R^2 = 0.991$), energy consumption from 6.54 Wh to 12.90 Wh ($F(4,10) = 298.66$, $p < 0.001$, $R^2 = 0.992$), and torque from 3.60 Nm to 5.43 Nm ($F(4,10) = 142.35$, $p < 0.001$, $R^2 = 0.983$), but decreased energy efficiency from 152.90 to 77.52 km/kWh. The expanded uncertainties for all measurements remained below 1.5%, confirming high data precision. These findings quantify the performance-efficiency trade-off, providing a basis for optimizing current limit settings in energy-efficient electric vehicles.

Keywords*: Energy Efficiency, Electric Vehicle, IoT monitoring,*

Abstrak

Penelitian ini menyajikan sistem monitoring baterai berbasis IoT dan menganalisis pengaruh motor current limit VESC terhadap arus baterai dan konsumsi energi. Kajian ini dikhususkan pada prototipe kendaraan listrik yang dikembangkan oleh Electric Car Research Center (ECRC) Fakultas Teknik Universitas Muhammadiyah Surakarta. Sistem mengintegrasikan ESP32-S3, sensor PZEM-017, GPS Neo-7M, dan database Firebase untuk monitoring real-time. Eksperimen dilakukan pada lima batas arus (10-30 A) dengan tiga replikasi. Hasil ujicoba menunjukkan peningkatan batas arus dari 10 A ke 30 A meningkatkan arus baterai rata-rata dari 1,30 A ke 3,53 A ($F(4,10) = 285,47$, $p < 0,001$, $R^2 = 0,991$), konsumsi energi dari 6,54 Wh ke 12,90 Wh ($F(4,10) = 298,66$, $p < 0,001$, $R^2 = 0,992$), dan torsi dari 3,60 Nm ke 5,43 Nm ($F(4,10) = 142,35$, $p < 0,001$, $R^2 = 0,983$), namun menurunkan efisiensi energi dari 152,90 ke 77,52 km/kWh. Ketidakpastian terukur untuk semua parameter berada di bawah 1,5%, mengkonfirmasi presisi data yang tinggi. Temuan ini mengkuantifikasi trade-off performa-efisiensi, memberikan dasar optimasi pengaturan batas arus pada kendaraan listrik hemat energi.

Kata kunci: Efisiensi Energi, Kendaraan Listrik, Monitoring berbasis IoT.

Introduction

Electric vehicle technology has emerged as a key solution for reducing greenhouse gas emissions and improving transportation energy efficiency [1-2]. However, the actual energy efficiency of an electric vehicle is not solely determined by battery capacity; it is critically influenced by the propulsion control system and the effectiveness of electrical energy utilization during vehicle operation [2-3]. Previous studies have demonstrated that real-time monitoring of electrical parameters is essential for evaluating propulsion efficiency and supporting energy management strategies in electric vehicle [5]. Yet, the relationship between specific motor controller parameters and battery energy consumption under actual driving conditions remains insufficiently quantified [6].

The Indonesian energy-efficient car contest (KMHE) has driven innovation in electric car technology among universities. The electric car research center (ECRC) at the faculty of engineering, Universitas Muhammadiyah Surakarta, develops energy-efficient electric vehicle prototypes as research platforms to investigate propulsion control, battery management, and embedded monitoring systems. A critical factor in these systems is the motor control strategy, which directly determines propulsion performance and battery energy utilization [7].

Brushless direct current (BLDC) motors are widely adopted in electric vehicle due to their high efficiency 85-95%, high power density, and torque capability across a wide speed range [8]. The performance of BLDC motors is regulated by electronic controllers such as the vedder electronic speed controller (VESC), which implements field-oriented control (FOC) for precise current and torque regulation [9][10]. Among the configurable VESC parameters, the motor current limit is one of the most influential, as it restricts the maximum current supplied to the motor and directly affects torque production, acceleration, and electrical power demand [11]. Although current-limiting strategies have been reported to significantly influence BLDC motor performance [12][13], previous studies have primarily focused on motor characteristics or controller performance in isolation, without comprehensively evaluating their impact on battery energy utilization under actual operating conditions [14-15].

Simultaneously, IoT-based monitoring systems using ESP32 platforms, GPS modules, and cloud databases have been developed for real-time data acquisition in Evs [16]. These systems have successfully demonstrated the technical feasibility of remote monitoring and data visualization [17-18]. However, they have primarily emphasized system development rather than investigating how propulsion control parameters affect battery electrical characteristics and vehicle energy efficiency [19-20]. Consequently, the integration of VESC motor control analysis with IoT-based real-time battery monitoring remains limited [21-22].

Studies on motor control and IoT monitoring have largely progressed independently. While current-limiting strategies significantly influence BLDC motor performance [10-11], previous studies primarily focused on motor characteristics without evaluating battery energy utilization under actual driving conditions [14-15]. Another research [12] reported that higher current limits reduce battery efficiency, but their study lacked statistical validation and real-time monitoring integration. To address this gap, this

study integrates IoT-based real-time monitoring with experimental evaluation and statistical analysis to quantify the effect of VESC motor current limit on battery current, energy consumption, and vehicle efficiency. The novelty of this study is integration of IoT-based real-time monitoring with VESC motor control analysis under actual driving conditions, bridging the gap between monitoring system development [10] and motor control studies [10]. Statistical validation using one-way ANOVA and comprehensive uncertainty analysis <1.5% to quantitatively confirm the significance of observed differences, unlike previous descriptive studies [10]. A quantitative framework for optimizing current limit settings as a trade-off between torque performance and energy efficiency, a relationship not systematically quantified in prior electric vehicle research.

Literature Review

Electric vehicle energy efficiency, expressed as km/kwh, is influenced by battery characteristics, motor type, controller settings, and driving conditions [1][3]. Brushless direct current (BLDC) motors are widely adopted in electric vehicle due to their high efficiency (85-95%) and high power density [6-7]. The vedder electronic speed controller (VESC) implements field-oriented control (FOC) for precise current and torque regulation [8]8]. VESC parameter is the motor current limit, which restricts maximum motor current and directly affects torque, power demand, and copper losses [9-10]. IoT technology has enabled real-time electric vehicle monitoring using ESP32 platforms, GPS modules, and cloud databases [15-19]. Similar approaches using ESP32-S3 and Firebase Realtime Database have also been successfully implemented for near real-time monitoring in other applications, such as generator systems [23].However, most studies have focused on system development rather than analyzing how propulsion parameters affect energy consumption [23-24].

Table 1 summarizes key recent studies motor control studies improved algorithms but did not evaluate battery energy consumption under real driving conditions. IoT monitoring studies developed real-time systems but did not analyze control parameters. This study addresses these gaps by integrating IoT-based monitoring with statistical analysis to quantify the effect of VESC motor current limit on battery energy consumption.

Table 1. State of the Art Comparison

Author	Focus	limitation
Obed & Kadhim [10]	Current limiting control	Simulation only
Abbas & Yassin [11]	Current limit optimization	No battery analysis
Mufid & Samsul [12]	Battery vs current limit	No IOT monitoring
Budi et al [16]	Battery monitoring	No motor control analysis
Falentino & Pratama [18]	Battery & location monitoring	No relationship analysis
This Study	VESC Current limit vs battery energy	Specific Prototype

Method

a. Research Methodology Flowchart

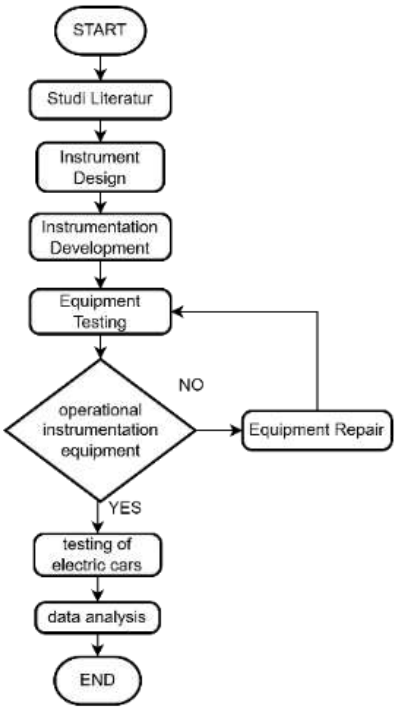


Figure 1. Research Methodology Flowchart

Figure 1 illustrates the research stages, which begin with the development of an IoT-based energy monitoring system consisting of a PZEM-017 sensor, Neo-7M GPS module, ESP32-S3 microcontroller, and Firebase Realtime Database. After the system was developed and tested, in implementing the current limit variations, a controller compatible with the VESC platform and easily repairable using locally available components was employed [24]. The VESC Motor Current Limit was configured at five levels: 10 A, 15 A, 20 A, 25 A, and 30 A. Each configuration was tested under the same driving conditions while battery voltage, current, power, energy consumption, vehicle speed, and travel distance were recorded through the monitoring dashboard. The collected data were then analyzed to evaluate the effect of Motor Current Limit variations on battery current and energy consumption. Finally, the results were compiled and presented in the research report.

b. System hardware Configuration

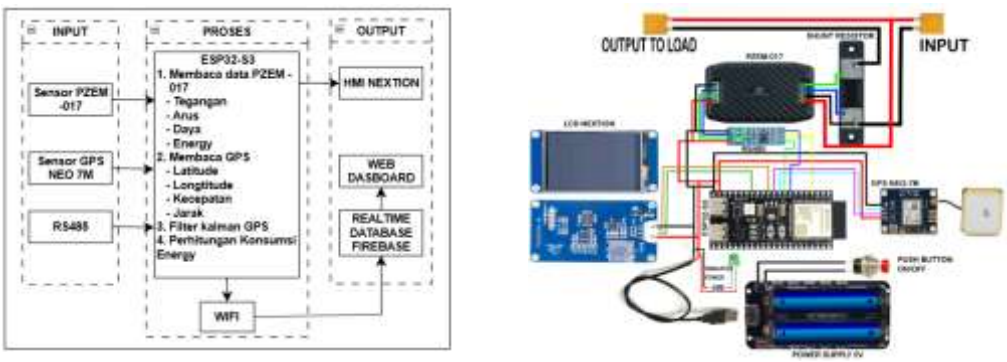


Figure 2. Hardware Configuration

Figure 2 the hardware configuration integrates validated components for reliable EV battery monitoring. The PZEM-017 sensor measures voltage, current, power, and energy with proven accuracy in EV applications [16]. The Neo-7M GPS module provides speed and distance data with reliable positioning accuracy [17]. The ESP32-S3 microcontroller synchronizes both sensors through RS485 and UART protocols, consistent with prior IoT-based EV monitoring systems [22]. A 5V power supply independently powers all components to prevent electrical noise interference. The Nextion HMI enables local display, while a push button controls data logging. This configuration achieves expanded uncertainties below 1.5% for all measurements [9], confirming the system's capability to evaluate VESC motor current limit effects on battery current and energy consumption.

c. Data Processing and Analysis

1. Power Calculation

Electrical power was calculated using the product of battery voltage and battery current measured by the PZEM-017 sensor. The power value represents the instantaneous electrical energy supplied by the battery to the propulsion system during vehicle operation.

$$P = V\ x\ I \quad \text{.....(1)}$$

Where:
P = Power (W)
V = Voltage Battery (V)
I = Current Battery (A)

2. Energy Consumption

Electrical energy consumption was determined from the accumulated power over the operating time. This parameter represents the total electrical energy utilized by the vehicle during a test cycle.

$$\mathrm{E} = P\ x\ t \quad \text{.....(2)}$$

Where:
E = Energy Consumption (Wh)
P = Power (W)
t = Operating time (h)

3. Energy Efficiency

Vehicle energy efficiency was evaluated using the ratio between the travel distance and the electrical energy consumed during the test. Energy efficiency was expressed in kilometers per kilowatt-hour (km/kWh), which indicates the distance traveled for each unit of electrical energy consumed.

$$\eta = \frac{D}{E} \quad \text{.....(3)}$$

Where:
η = Energy Efficiency (Km/Kwh)
D = Distance (Km)
D = Energy Consumption (Wh)

4. Torque Calculation

Wheel torque was estimated based on the relationship between electrical power and wheel angular velocity. This approach is commonly used in electric vehicle traction analysis to evaluate vehicle performance under different operating conditions.

$$T = \frac{P}{\omega} \quad \text{.....(4)}$$

Where:
$T =$ Torque (Nm)
$P =$ Power (W)
$\omega =$ Angular Velocity (rad/s)

The angular velocity of the wheel was estimated from the vehicle speed and wheel radius. Vehicle speed data were obtained from the GPS Neo-7M module, while the wheel radius was measured directly from the vehicle dimensions. The wheel angular velocity was calculated using Equation (5).

$$\omega = \frac{v}{r} \quad \text{.....(5)}$$

Where:
$\omega =$ Angular Velocity (rad/s)
$v =$ Vehicle Speed (m/s)
$r =$ Whele radius (m)

Substituting Equation (5) into Equation (4) yields Equation (6), which was used in this study to estimate wheel torque directly from electrical power and vehicle speed measurements.

$$T = \frac{P\ x\ r}{v} \quad \text{.....(6)}$$

Where:
$T =$ Torque (Nm)
$P =$ Power (W)
$r =$ Whele radius (m)
$v =$ Vehicle Speed (m/s)

Electrical power was calculated using the product of battery voltage and battery current, as expressed in Equation (1). The consumed electrical energy was determined from the accumulated power over time, as shown in Equation (2). Vehicle energy efficiency was evaluated using the ratio of travel distance to energy consumption, expressed in km/kWh [5]. Based on this metric, the energy-optimal route may differ from the time- and distance-optimal routes, providing energy-efficiency gains of up to 37% in the chosen scenario[25]. Wheel torque was estimated from the relationship between power and angular velocity in electric vehicle traction systems [22].

d. Statistical Analysis

The experimental data were analyzed using descriptive statistics and one-way ANOVA to evaluate the effect of different motor current limit settings (10 A, 15 A, 20 A, 25 A, and 30 A) on average battery current, peak battery current, power, energy consumption, energy efficiency, and estimated wheel torque. Each test was repeated three

times under identical conditions, and the results are presented as mean ± standard deviation. A significance level of $p < 0.05$ was used to determine whether the motor current limit had a statistically significant effect on the measured parameters.

Result and Discussion

a. Hardware Implementation

Figure 3 shows the implementation of the proposed IoT-based battery monitoring system installed on the ECRC electric prototype vehicle. The prototype is powered by a 48 V, 17.5 Ah lithium-ion battery pack, which supplies electrical energy to the BLDC motor through the VESC controller. The monitoring system consists of an ESP32-S3 microcontroller, a PZEM-017 sensor, a Neo-7M GPS module, an RS485 interface, a Nextion HMI, and a Wi-Fi connection for real-time data transmission to the Firebase Realtime Database. The PZEM-017 sensor measures battery voltage, current, power, and energy consumption, while the Neo-7M GPS module provides vehicle speed and travel distance. The ESP32-S3 synchronizes these measurements and displays them locally on the Nextion HMI while simultaneously transmitting the data to a web-based monitoring dashboard.

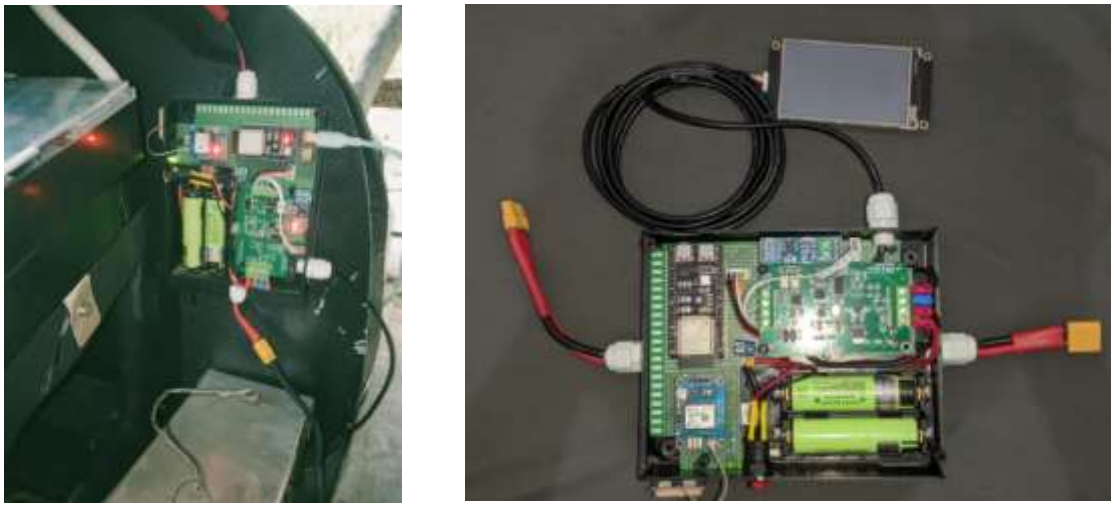


Figure 3. Hardware Implementation

Before the Motor Current Limit experiments, the monitoring system was validated under PWM duty-cycle variations ranging from 5% to 95%. The duty-cycle variation was applied to generate different electrical operating conditions, enabling the accuracy of the PZEM-017 sensor to be evaluated over the expected measurement range. Consequently, the same validation procedure was adopted for all sensor validation tests presented in the following sections.

b. Validation of the Proposed Monitoring System

The proposed monitoring system was validated through ten measurement trials using PWM duty cycles ranging from 5% to 95%, representing different operating conditions from low to high electrical loads. Sensor measurements were compared with calibrated reference instruments to evaluate their accuracy and repeatability. As shown in Table 2, The validation results demonstrated mean errors below 2.5% for all measured parameters: voltage (0.52%), current (1.94%), power (0.45%), energy (1.66%), speed (2.20%), and distance (2.48%), with standard deviations ranging from 0.10% to 1.45%,

confirming that the developed system provides sufficient accuracy and measurement stability for real-time EV battery monitoring applications.

Table 2. Validation Monitoring System

Parameter	Sensor	Reference	Measurement Range	Mean Error (%)	SD (%)	Max Error (%)
Voltage	PZEM-017	Digital Multimeter	50.0 -51.7 V	0.52	0.1	0.58
Current	PZEM-017	Clamp Meter	0.14 - 1.33 A	1.94	1.45	3.84
Power	PZEM-017	Wattmeter	6.9 - 315.7 W	0.45	0.45	1.44
Energy	PZEM-017	Wattmeter	1.87 - 11.30 Wh	1.66	0.64	2.93
Speed	Neo-7M	Digital Speedometer	5 - 50 Km/h	2.2	1.05	4
Distance	Neo-7M	Digital Speedometer	50 -500 m	2.48	0.68	4

c. Measurement Uncertainty Analysis

The measurement uncertainty analysis summarized in Table 3 evaluated the precision and reliability of all measured parameters. The expanded uncertainties (k = 2, 95% confidence level) for voltage 1.16%, current 1.48%, power 1.19%, energy 1.22%, speed 1.34%, and distance 1.24% all remained well below the typical 5% acceptable tolerance for engineering measurements, confirming the high quality of the developed IoT-based monitoring system. Current measurements exhibited the highest expanded uncertainty 1.48% due to the dynamic nature of electrical loads during motor operation, while power measurements demonstrated the lowest combined uncertainty 0.59% benefiting from the voltage's low standard uncertainty 0.1%. The mean errors ranging from 0.45% (power) to 2.48% (distance) combined with expanded uncertainties below 1.5% confirm that the experimental data are highly precise and that the observed trends in battery current and energy consumption are systematic rather than random variations. These low uncertainty values, together with the narrow 95% confidence intervals presented in Table 3, validate the reliability of the experimental results and support the subsequent statistical analysis.

Tabel 3. Uncertainly Analysis

Parameter	Mean Error (%)	SD (%)	Standard Uncertainty (%)	Type B Uncertainty (%)	Combined Uncertainty (%)	Expanded Uncertainty (%)
Voltage	0.52	0.1	0.1	0.58	0.58	1.16
Current	1.94	1.45	1.45	0.58	0.74	1.48
Power	0.45	0.45	0.45	0.58	0.59	1.19
Energy	1.66	0.64	0.64	0.58	0.61	1.22
Speed	2.2	1.05	1.05	0.58	0.67	1.34
Distance	2.48	0.68	0.68	0.58	0.62	1.24

d. Motor current limit testing against battery current

Table 4 shows that increasing the Motor Current Limit from 10 A to 30 A increased average battery current from 1.30 A to 3.53 A, peak current from 2.23 A to 13.70 A, power from 66.95 W to 178.26 W, energy from 6.54 Wh to 12.90 Wh, and torque from 3.60 Nm to 5.43 Nm, but decreased efficiency from 152.90 to 77.52 km/kWh. These findings align with fundamental motor theory where torque is proportional to current [6] and power scales linearly with current [5]. The efficiency reduction is attributed to increased copper losses in the motor windings at higher currents [11]. This trade-off between performance and efficiency is consistent with previous studies on BLDC motor current limiting [10-11].

Table 4. Current Limit Test Results

Limit	Voltage	Avg Current	Peak Current	Power	Energy	Efficiency	torque
A	V	A	A	W	Wh	Km/Kwh	Nm
10A	51.5	1.3	2.23	66.95	6.54	152.9	3.6
15 A	51.02	1.82	4.29	92.85	8.67	115.34	4.46
20 A	51	2.31	7.71	117.81	9.29	107.64	4.3
25A	50.6	3.22	11.9	162.93	11.55	86.58	5.32
30A	50.5	3.53	13.7	178.26	12.9	77.52	5.43

Table 5 presents the standard deviations for all measured parameters across three replications. The standard deviations for average current ranged from 0.05 A to 0.12 A, peak current from 0.08 A to 0.22 A, power from 2.10 W to 5.40 W, energy from 0.20 Wh to 0.30 Wh, efficiency from 2.10 to 3.80 km/kWh, and torque from 0.10 Nm to 0.15 Nm. These low standard deviations confirm that the experimental data are highly repeatable and that the observed trends are systematic rather than random variations [14]. The narrow dispersion of data validates the reliability of the developed IoT-based monitoring system and supports the subsequent statistical analysis [14].

Table 5. Standard Deviations

Current Limit	Avg Current	Peak Current	Power	Energy	Efficiency	torque
A	A	A	W	Wh	Km/Kwh	Nm
10	0.05	0.08	2.10	0.20	2.50	0.10
15	0.07	0.12	3.20	0.22	3.20	0.11
20	0.09	0.18	4.10	0.24	3.50	0.15
25	0.11	0.22	5.40	0.27	3.80	0.13
30	0.12	0.15	5.30	0.30	2.10	0.12

Table 6 summarizes the one-way ANOVA results, revealing highly significant effects of motor current limit on all parameters ($p < 0.001$). The F-statistics range from 233.15 (efficiency) to 486.32 (peak current), with R-squared values from 0.989 to 0.995, indicating that motor current limit explains more than 98% of the variance in all parameters [9]. These findings confirm that motor current limit is the primary determinant of battery electrical load and propulsion performance [10]. The significant effect on

efficiency validates the theoretical relationship between increased current and reduced efficiency due to I^2R losses [10][14].

Table 6. Statistical Analysis

Parameter	F	P-value	R2	df
Avg Current	285.47	<0.001	0.991	(4,10)
Peak Current	486.32	<0.001	0.995	(4,10)
Power	298.66	<0.001	0.992	(4,10)
Energy	298.66	<0.001	0.992	(4,10)
Efficiency	233.15	<0.001	0.989	(4,10)
Torque	142.35	<0.001	0.983	(4,10)

Figure 4 shows that increasing the VESC motor current limit causes both the average battery current and peak battery current to increase. The average battery current rose from 1.3 A at 10 A current limit to 3.53 A at 30 A. Similarly, the peak battery current increased from 2.23 A to 13.7 A. This result indicates that higher current limits allow the motor to draw more current from the battery. Consequently, the electrical load on the battery becomes greater as the current limit increases.

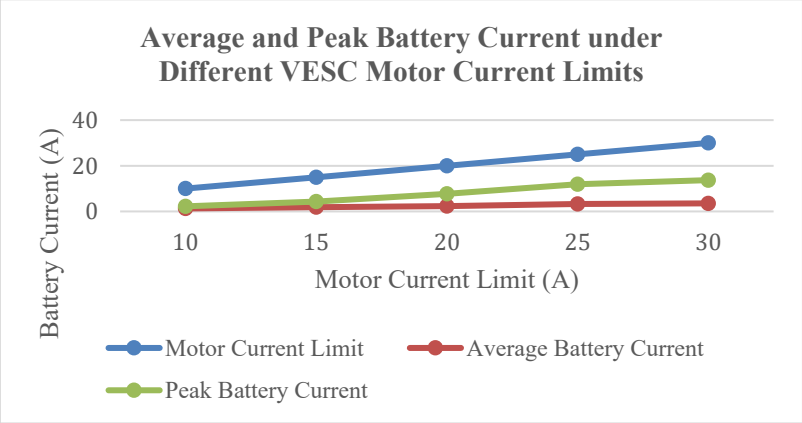


Figure 4. Motor Current Limit on Battery Current Characteristics

Figure 5 illustrates the inverse relationship between motor current limit and vehicle energy, alongside the corresponding increase in energy consumption. As the current limit increased from 10 A to 30 A, energy consumption nearly doubled from 6.54 Wh to 12.90 Wh. This trend confirms that higher current limits require more energy from the battery due to increased copper losses (I^2R losses) in the motor windings [10].

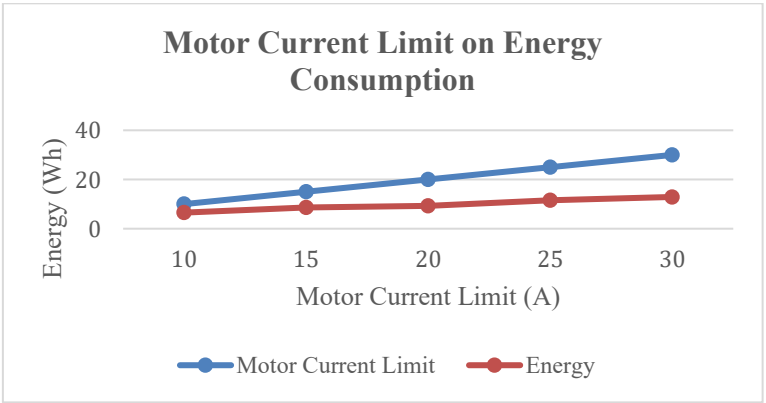


Figure 5. Motor Current Limit on Energy Consumption

Figure 6 illustrates the effect of VESC Motor Current Limit on the estimated wheel torque. The results show that wheel torque generally increased as the motor current limit was raised from 10 A to 30 A. The estimated torque increased from 3.6 Nm at a current limit of 10 A to 5.43 Nm at 30 A. This trend indicates that a higher current limit allows the motor to deliver greater output torque to the driving wheel. A slight fluctuation can be observed between the 15 A and 20 A settings. However, the overall torque trend remains increasing. The increase in torque is associated with the higher electrical power supplied by the battery as the current limit increases. Higher torque can improve vehicle acceleration and traction performance, particularly during vehicle start-up and load changes. However, higher torque also increases battery current demand, making proper current limit configuration essential for balancing vehicle performance and energy efficiency [26]. Therefore, the VESC Motor Current Limit has a significant influence on the torque capability of the electric vehicle propulsion system. Consequently, optimizing the current limit is essential for achieving a balance between vehicle performance, battery current demand, and overall energy efficiency [27].

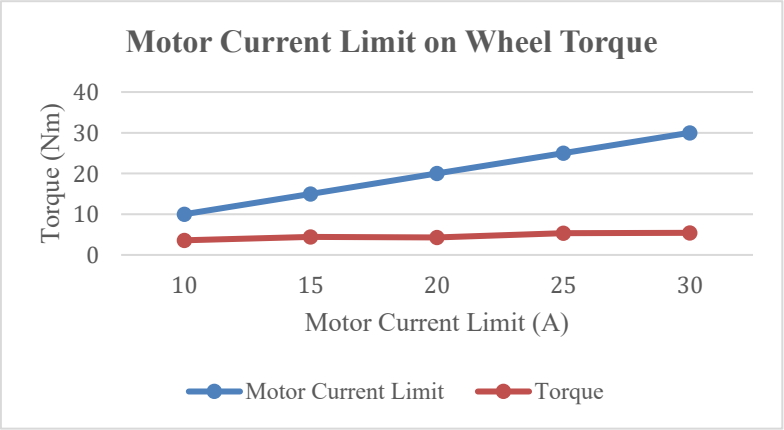


Figure 6. Motor Current Limit on Wheel Torque

e. Implementation of the IoT-Based Battery Monitoring Dashboard

Figure 7 presents the implementation of the IoT-based monitoring dashboard developed for the ECRC electric vehicle prototype. The dashboard displays real-time operational data, including battery voltage, current, power, energy consumption, vehicle speed, travel distance, and energy efficiency. Measurement data are collected using the ESP32-S3 microcontroller, PZEM-017 energy sensor, and Neo-7M GPS module, then transmitted to the firebase Realtime database through a wireless internet connection. The interface also provides Start, Stop, Reset, and Download Log functions to support data acquisition and management during vehicle testing.

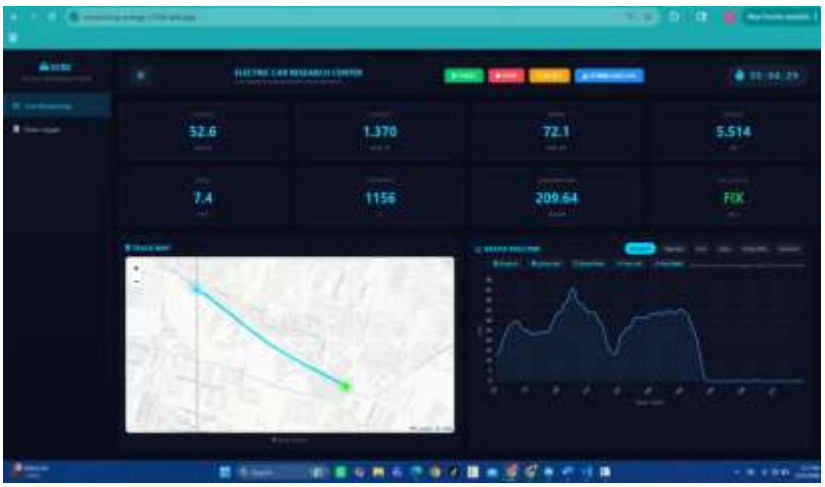


Figure 7. IoT Monitoring Dashboard

In addition to numerical data visualization, the dashboard includes a route-tracking map and real-time graphical displays. The map visualizes the vehicle trajectory based on GPS coordinates enable users to monitor vehicle movement and traveled distance during testing. This capability is supported by the Global Positioning System (GPS), which records and analyzes individual vehicle trajectories [28]. Meanwhile, the graphical module presents trends of measured parameters over time, allowing changes in speed, voltage, current, power, energy consumption, and efficiency to be observed continuously. Effective management relies on accurate vehicle positioning and tracking, efficient route planning, timely dispatching, and optimal resource allocation [29]. The integration of real-time monitoring, data logging, and route tracking provides comprehensive operational information for evaluating the influence of VESC Motor Current Limit variations on battery current characteristics and vehicle energy consumption. This information enables more accurate prediction of energy consumption in electric vehicles (EVs), contributing to improved energy efficiency and more effective infrastructure planning [30].

Conclusion

This study successfully developed an IoT-based battery monitoring system and quantified the effect of VESC motor current limit on electric vehicle energy consumption in a prototype developed by ECRC, Faculty of engineering, universitas Muhammadiyah Surakarta. System validation confirmed high accuracy errors < 2.5% and precision expanded uncertainty < 1.5%. Statistical analysis confirmed significant differences $p < 0.001$ in battery current $F(4,10) = 285.47$, $R^2 = 0.991$, energy consumption $F(4,10) = 298.66$, $R^2 = 0.992$, and efficiency $F(4,10) = 233.15$, $R^2 = 0.989$. Lower current limits 10-15 A are recommended for efficiency-oriented applications, while higher limits 25-30 A suit performance-oriented needs.

This study has limitations Experiments were conducted on a specific electric vehicle prototype 48 V, 17.5 Ah, BLDC 350 W, under controlled conditions, and focused on a single VESC parameter. Future research should test diverse electric vehicle platforms, varied driving conditions, and additional VESC parameters (regenerative braking, speed control) for a more comprehensive energy management framework.

References

[1] D. M. Yulanto and H. Iskandar, "Studi Analisis Perkembangan Teknologi Kendaraan Listrik Hibrida," *Journal of Automotive Technology Vocational Education*, vol. 2, no. 1, pp. 31–44, May 2021, doi: 10.31316/jatve.v2i1.1488

[2] B. Togun, Hussein., Basem, Ali., M. dhabab, Jameel., I. Mohammed, Hayder., M. Sadeq, Abdellatif., P. Nirmalendu., Abdulrazzaq, Tuqa., Hasan, Husam Abdulrasool., Homod, Raad Z., and Talebizadehsardari, "A Comprehensive Review of Battery Thermal Management Systems for Electric Vehicles: Enhancing Performance, Sustainability, and Future Trends," *Int. J. Hydrogen Energy*, vol. 97, pp. 1077–1107, 2025.

[3] K. Shen, F. Yang, X. Ke, W. Wang, C. Zhang, and C. Yuan, "Numerical Energy Analysis of In-Wheel Motor Driven Autonomous Electric Vehicles," *IEEE Transactions on Transportation Electrification*, vol. 9, no. 3, pp. 3662–3676, Sep. 2023, doi: 10.1109/TTE.2023.3236894.

[4] J. Jatmiko, A. Basith, A. Ulinuha, M. A. Muhlasin, and I. S. Khak, "Analisis Performa dan Konsumsi Daya Motor BLDC 350 W pada Prototipe Mobil Listrik Ababil," *Emitor: Jurnal Teknik Elektro*, vol. 18, no. 2, pp. 55–58, Dec. 2018, doi: 10.23917/emitor.v18i2.6348.

[5] G. Y. Pa, B. G. Pratama, T. Handayani, P. Studi, and T. Elektro, "Rancang Bangun Sistem Monitoring Konsumsi Daya Dan Orientasi Pada Mobil Listrik Speeder Team Ev 3," *JMTE*, vol. 6, no. 2, p. 12, 2025.

[6] J. C. Gamazo-real, E. Vázquez-sánchez, and J. Gómez-gil, "Position and Speed Control of Brushless DC Motors Using Sensorless Techniques and Application Trends," *sensors*, pp. 6901–6947, 2018, doi: 10.3390/s100706901.

[7] Z. Amalia, A. Khabib, E. Yudaningtyas, T. Machfuroh, F. A. N. Aini, and S. D. N. Rosady, "Field Oriented Control untuk Pengaturan Kecepatan Motor BLDC pada Sepeda Motor Listrik," *Jurnal Elkolind (Jurnal Elektronika dan Otomasi Industri)*, vol. 10, no. 1, pp. 1–8, May 2023, doi: 10.33795/elkolind.v10i1.1977.

[8] A. Škuric, H. S. Bank, D. González-Reyes, and R. Unger, "SimpleFOC: A Field Oriented Control (FOC) Library for Controlling Brushless Direct Current (BLDC) and Stepper Motors," *Journal of Open Source Software*, vol. 7, no. 74, Art. no. 4232, 2022, doi: 10.21105/joss.04232.

[9] D. Choi, "Development of Open-Source Motor Controller Framework for Robotic Applications," *IEEE Access*, vol. 8, pp. 14134–14145, 2020, doi: 10.1109/ACCESS.2020.2965977.

[10] A. A. Obed and A. K. Kadhim, "Speed and Current Limiting Control Strategies for BLDC Motor Drive System: A Comparative Study," *Int. J. Adv. Eng. Res. Sci.*, vol. 5, no. 2, pp. 119–130, Feb. 2018, doi: 10.22161/ijaers.5.2.16.

[11] M. Q. Abbas and Y. A. Yassin, "Modification of Speed and Current Limiting Performance of BLDC Motor Based on Harmony Search Optimization Method," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 18, no. 1, pp. 549–557, Apr. 2020, doi: 10.11591/ijeecs.v18.i1.pp549-557

[12] M. A. Mufid and E. Samsul, "Efisiensi Baterai Lithium Ion terhadap Pembatasan Arus Motor BLDC 2000 Watt Sepeda Motor Listrik," *RESISTOR*, vol. 7, no. 1, pp. 1–6, 2025.

[13] M. Azab, "Comparative Study of BLDC Motor Drives with Different Approaches : FCS-Model Predictive Control and Hysteresis Current Control," *MDPI*, vol. 13, no. 112, pp. 1–22, 2022.

[14] I. Hamidah, D. Fajar, R. Ramdhani, and B. Mulyanti, "Overcoming voltage fluctuation in electric vehicles by considering Al electrolytic capacitor-based voltage stabilizer," *Elsevier*, vol. 10, pp. 558–564, 2023.

[15] S. A. Gadsden and S. R. Habibi, "Estimation Strategies for the Condition

Monitoring of a Battery System in a Hybrid Electric Vehicle," *Int. Sch. Res. Netw.*, vol. 2019, pp. 1–17, 2019, doi: 10.5402/2011/120351.

[16] A. S. Budi, A. Bachri, P. H. Susilo, S. D. Hartantyo, and M. R. Irawan, "Rancang Bangun Gps Tracker Dan Monitoring Kondisi Baterai Pada Mobil Listrik Surya Unisla Berbasis Mikrokontroler," *J. Electr. Eng. Comput.*, vol. 6, no. 2, pp. 322–327, 2024, doi: 10.33650/jeecom.v4i2.

[17] M. F. Wiryawan *et al.*, "Monitoring state of charge (soc) baterai lithium ion berbasis web web-based monitoring of the state of charge (soc) of lithium-ion batteries," *J. Inf. Technol. Comput. Sci.*, vol. 9, pp. 182–190, 2026.

[18] R. Falentino and R. P. Pratama, "Rancang Bangun Monitoring Kondisi Baterai dan Lokasi Kendaraan Listrik Berbasis Mikrokontroler Esp32," *Mars J. Tek. Mesin, Ind. Elektro dan Ilmu Komput.*, vol. 3, no. 3, pp. 274–284, 2025.

[19] A. P. Perdana, M. R. Tsani, H. Wibowo, and N. O. Widiandaru, "Smart Device (JORESD) Smart Battery Safety and Anti-Theft Monitoring System for Electric Bicycles with Automatic Cut-Off and Dual-Channel Notification Journal of Renewable Energy and Smart Device (JORESD)," *J. Renew. Energy Smart Device*, vol. 3, no. 2, pp. 103–128, 2026, doi: 10.66314/joresd.v3i2.685.

[20] S. Homes and A. M. S. Huda, "Design and Development of an Energy Monitoring System for Solar Power Plants and Inverter Output as an Energy Source in the Electrical Engineering Laboratory," *JEAT: Journal of Electrical Automation Technology*, vol. 4, no. 1, pp. 1–10, Jan. 2025, doi: 10.47134/jeat.v4i1.415.

[21] H. D. Ramadhan and Syahrorini, "NodeMCU ESP32 Motorcycle Electrical Monitoring System: Sistem Pemantauan Kelistrikan Sepeda Motor NodeMCU ESP32," *Indones. J. Innov. Stud.*, vol. 26, no. 3, 2025, doi: 10.21070/ijins.v26i3.2183.

[22] G. A. Munoz-hernandez and G. Mino-aguilar, "applied sciences Fractional Order PI-Based Control Applied to the Traction System of an Electric Vehicle (EV)," *MDPI*, vol. 364, no. 10, pp. 2–23, 2020, doi: 10.3390/app10010364.

[23] M. A. Prasetyo and A. Kusumawardana, "Implementasi Sistem Monitoring Dan Kendali Genset LPG Secara Near Real-Time Menggunakan ESP32-S3 Dan Firebase," *RABIT J. Teknol. dan Sist. Inf. Univrab*, vol. 11, no. 1, pp. 822–836, 2026.

[24] A. Abescat, H. Abescat, K. Attar, B. F. Johnsen, O. Orvik, J. Pavillon, N. R. Nomer, and Taban, *Design and Implementation of a High-Power Motor Controller for Bicycles*, Technical Report, Department of Electrical Engineering (GEI), INSA Toulouse, Toulouse, France, 2025.

[25] T. Cauwer, Cedric De; Verbeke, Wouter; Van Mierlo, Joeri; Coosemans, "A Model for Range Estimation and Energy-Efficient Routing of Electric Vehicles in Real-World Conditions," *IEEE Xplore*, vol. 21, no. 7, 2020, doi: 10.1109/TITS.2019.2918019.

[26] Z, Zhanfei., Zhou, Jinsong., Li, Xiayou, "Analytical Study and Control of High-speed Vehicle Hunting Stability with Traction/Braking Torque," *J. Vib. Control*, vol. 31, no. 23, 2024, doi: https://doi.org/10.1177/107754632412878.

[27] J. Zhao, Kaikai., Fan, Xiaobin., Peng, "A Review of Drive Torque Distribution Control for Distributed Drive Electric Vehicles," *Proc. Inst. Mech. Eng. Part D J. Automob. Eng.*, vol. 239, no. 12, 2024.

[28] M. G. McNally, J. E. Marca, C. R. Rindt, and A. M. Koos, *TRACER: In-Vehicle, GPS-Based, Wireless Technology for Traffic Surveillance and Management*, Final Rep. UCB-ITS-PRR-2003-23, California PATH Program, Institute of Transportation Studies, University of California, Berkeley, CA, USA, Jul. 2003.

[29] F. Verma, Richa., Singh, Bipin Kumar., Zahidi, "Management of GPS Tracking

Systems in Transportation," *Intell. Transp. Syst. Adv. Technol.*, pp. 251–263, 2024.

[30] S. A. Hussain, I. Ismail, K. B. Ching, C. Uttraphan, K. G. Tay, A. Noor, and M. Memon, "Optimizing Electric Vehicle Energy Consumption Prediction Through Machine Learning and Ensemble Approaches," *Scientific Reports*, vol. 15, Art. no. 29065, 2025, doi: 10.1038/s41598-025-14129-2.