International Journal of Engineering Research and Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 22, Issue 4 (April 2026), PP 385-391

Analysis of Power Conversion Efficiency in Electric Vehicle Drive Systems Based on AC-DC Energy Comparison

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ABSTRACT: *This study aims to analyze the power conversion efficiency of an electric vehicle drive system based on the comparison between AC and DC energy. An experimental approach was employed by varying the load conditions at 50 kg, 100 kg, 150 kg, and 200 kg, and operating speeds ranging from 10 to 40 km/h. The measured parameters include AC and DC voltage and current, travel time, and energy consumption. Power and energy were calculated using fundamental electrical equations, while system efficiency was determined based on the ratio of output energy to input energy.The results indicate that both power and current increase with higher speed and load, reflecting greater energy demand in the system. However, the power conversion efficiency shows a significant improvement at higher speeds, reaching a maximum value of 94.44% under a 200 kg load at 40 km/h. This suggests that the system operates more efficiently at medium to high-speed conditions, where the ratio of output power to input power becomes more favorable. Overall, this study demonstrates that the efficiency of electric vehicle drive systems is highly dependent on operating conditions. The findings provide valuable insights for optimizing the design and operational strategies of more efficient electric vehicles.*

Keywords: *electric vehicle, energy consumption, input energy, efficiency, load condition*

Date of Submission: 14-04-2026 Date of acceptance: 25-04-2026

I. INTRODUCTION

The rapid development of electric vehicle (EV) technology has become a strategic solution to address global challenges related to energy sustainability and the reduction of greenhouse gas emissions (Salah et al., 2019). Conventional fossil fuel–based vehicles are known to contribute significantly to environmental pollution and dependence on non-renewable energy resources (Achlison et al., 2024), (Systems et al., 2025). In this context, electric vehicles offer advantages in terms of higher energy efficiency and lower emissions. However, the performance of electric vehicle drive systems still requires in-depth investigation, particularly regarding the efficiency of power conversion from the battery energy source (DC) to the electric motor (AC)(B. A. Kumar et al., 2024).

One of the key aspects of electric vehicle systems is the power conversion process involving the inverter and the electric motor. This process is inevitably associated with various energy losses, such as switching losses in power electronic devices, conduction losses in semiconductor components and conductors, as well as mechanical losses in the motor (Al-Araji et al., 2025). These losses directly affect the overall system efficiency. Therefore, understanding the relationship between operating parameters such as speed and load and the power conversion efficiency is essential to improve the performance of electric vehicle systems (Robles et al., 2022).

Previous studies have investigated electric vehicle efficiency from various perspectives, including motor control strategies (P. S. Kumar & Lavanya, 2025), inverter design (Abualnaeem et al., 2025), and energy management systems (Siddula et al., 2024). Studies on BLDC and PMSM motors indicate that efficiency is highly influenced by operating conditions, particularly torque and speed (Batra et al., 2024). In addition, inverter switching strategies have been shown to reduce harmonic distortion and improve system efficiency (Wiryajati et al., 2021). Other studies on electric vehicle energy consumption demonstrate that speed and load significantly affect power demand (Mara et al., 2025). However, most of these studies are dominated by simulation-based approaches or theoretical models, which may not fully represent real-world operating conditions.

Another limitation of previous research is the lack of integrated analysis that simultaneously evaluates input parameters on the AC side and output parameters on the DC side. Most studies tend to focus on a single subsystem, such as battery performance (Rao et al., 2023) or motor efficiency (Sakti et al., 2025), without considering the interaction between them. This results in a gap in understanding how variations in speed and load influence the overall power conversion process, including energy distribution, current characteristics, and system efficiency.

To address these issues, this study proposes an experimental approach based on direct measurement of electrical parameters on both the AC and DC sides of the electric vehicle drive system. By systematically varying vehicle load and operating speed, this research aims to provide a comprehensive analysis of power, current, energy, and efficiency characteristics under real operating conditions. This approach enables a more accurate identification of the relationship between input energy, output power, and energy losses compared to purely simulation-based methods.

The novelty of this research lies in its integrated approach, combining experimental measurements with comparative analysis of AC and DC parameters under various operating conditions. This study not only evaluates system performance partially but also examines the interrelationship between power, current, and efficiency with respect to variations in speed and load. Thus, it is capable of identifying the optimal operating point of the electric vehicle system that yields maximum efficiency.

Overall, this study presents a comprehensive experimental-based analysis of power conversion efficiency in electric vehicle drive systems. The findings are expected to bridge the gap between theoretical models and practical implementation, while also contributing to the development of more efficient, reliable, and sustainable electric vehicle systems.

II. MATERIAL AND METHODS

This study is designed to analyze the efficiency of power conversion in an electric vehicle drive system through an experimental approach based on a comparison of AC and DC energy. The research stages begin with system preparation, electrical parameter measurement, and proceed to mathematical analysis of power, energy, and efficiency.

The initial stage involves the preparation of tools and materials, which serves as the foundation for ensuring experimental reliability. The electric vehicle system consists of a DC energy source (Li-ion battery), an inverter as a DC-to-AC converter, an electric motor (BLDC or PMSM) as the main drive, and a mechanical system. The fundamental relationship between voltage, current, and power is expressed as:

$$P = V \times I \tag{1}$$

where P is power (Watt), V is voltage (Volt), and I is current (Ampere). This equation forms the basis for all power calculations on both AC and DC sides. Measurement instruments include voltmeters and ammeters for AC and DC, a power meter, and a data logger for continuous recording. Load variations are introduced using additional masses of 50 kg, 100 kg, 150 kg, and 200 kg to simulate operational conditions. Testing is conducted on a flat track to eliminate the influence of gravitational forces.

The next stage is instrument calibration to ensure measurement accuracy. Voltage and current sensors are calibrated using standard reference instruments to minimize systematic errors. The vehicle is then set to optimal conditions, including proper tire pressure, uniform battery state of charge (SoC), and stable ambient temperature. Tests are conducted at constant speeds of 10 km/h, 20 km/h, 30 km/h, and 40 km/h for each load variation.

The core stage of the research is data acquisition. For each combination of load and speed, the vehicle is operated until steady-state conditions are reached. The measured parameters include AC and DC voltage and current, as well as travel time. Electrical power is calculated as:

$$P_{AC} = V_{AC} \times I_{AC}, \quad P_{DC} = V_{DC} \times I_{DC} \tag{2}$$

Energy consumption is then determined using:

$$E_{AC} = P_{AC} \times t, \quad E_{DC} = P_{DC} \times t \tag{3}$$

where E is energy (kWh) and t is time (hours). Efficiency is defined as:

$$\eta = \frac{E_{AC}}{E_{DC}} \times 100\% \tag{4}$$

Additionally, specific energy consumption is expressed as:

$$\text{kWh/km} = \frac{E_{DC}}{d} \tag{5}$$

Where d is the travel distance (km). The collected data are then processed and grouped into three main categories: AC input parameters, DC output parameters, and energy-efficiency comparisons. The data are visualized using graphs to illustrate relationships between power, current, efficiency, and speed. Finally, a comprehensive analysis is conducted to evaluate the relationships between load, speed, power, and efficiency. Energy losses are quantified as:

$$P_{loss} = P_{DC} - P_{AC} \tag{6}$$

These losses may arise from conduction losses, switching losses, and mechanical losses. This analysis enables the identification of key factors affecting system efficiency.

III. RESULTS

This study employs an experimental approach based on direct measurement of an electric vehicle drive system to analyse the characteristics of power conversion between the DC and AC sides. The research model is designed by varying two main parameters, namely vehicle load (50–200 kg) and operating speed (10–40 km/h), allowing for the evaluation of system performance under different operating conditions. The electrical parameters measured include voltage, current, power, and energy on both the AC and DC sides. These parameters are subsequently processed using fundamental electrical equations to determine the power conversion efficiency. This approach enables a comprehensive assessment of the relationship between load, speed, and energy conversion performance within the electric vehicle system.

Table 1 – AC-Side Input Parameters of the System (Inverter Input)

Load (Kg)	Speed (Km/Jam)	Voltage AC (V)	Current AC (A)	Power AC (kWh)	Energy AC (kWh)
50	10	12,95	61,75	0,69	0,29
50	20	14,86	64,91	1,00	0,37
50	30	14,67	67,89	1,21	0,39
50	40	16,05	74,99	1,67	0,48
100	10	14,27	63,65	0,79	0,33
100	20	15,48	66,62	1,07	0,40
100	30	17,93	74,18	1,61	0,52
100	40	19,94	86,05	2,38	0,60
150	10	12,73	61,78	0,68	0,29
150	20	14,42	64,20	0,96	0,36
150	30	18,05	74,73	1,64	0,52
150	40	17,98	93,73	2,34	0,61
200	10	15,93	70,86	0,98	0,41
200	20	16,87	72,56	1,27	0,47
200	30	18,04	80,23	1,75	0,56
200	40	19,88	91,03	2,51	0,68

The measurement results are systematically organized into three main data groups, namely Table 1 representing AC input parameters, Table 2 representing DC output parameters, and Table 3 presenting the comparison of energy and efficiency. To clearly illustrate the relationships among variables, the data are visualized in three main graphs, namely the relationship between power and speed, current and speed, and efficiency and speed. These visual representations serve as the basis for further analysis and interpretation of the system performance.

Table 1 presents the input parameters of the system on the AC side, including voltage, current, power, and energy under various load and speed conditions. In general, it can be observed that the AC power increases significantly with increasing speed and load. This indicates that the energy demand from the inverter rises to meet the operational requirements of the electric motor.

The AC voltage tends to remain relatively stable with only minor variations, whereas the AC current exhibits a more pronounced increase. This phenomenon suggests that the system's power consumption is more strongly influenced by changes in current rather than voltage, indicating a current-driven characteristic in fulfilling the load and speed demands of the vehicle.

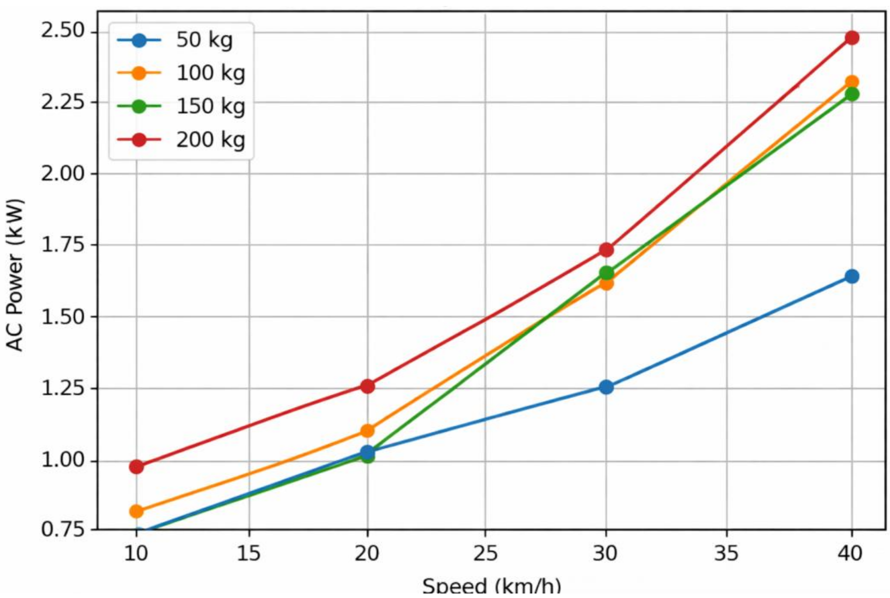

Figure 1: Relationship Between AC Power and Speed for Different Load Conditions.

Figure 1 illustrates the relationship between AC power and speed for various load conditions, showing a significant increase in power as the vehicle speed rises. At each load level, the curve exhibits a non-linear trend, with a steeper increase observed at medium to high speeds. This indicates that the input power demand increases due to the combined effects of higher mechanical load and aerodynamic influences. Furthermore, as the load increases, the required power at each speed also becomes higher. This phenomenon demonstrates that the electric vehicle drive system is highly sensitive to variations in both load and speed in determining the input energy demand.

Table 2 presents the output parameters of the system on the DC side, including voltage, current, power, and energy under various load and speed conditions. In general, the DC voltage remains relatively stable within a certain range, indicating the stability of the battery supply during operation. In contrast, the DC current increases significantly with increasing speed and load, which directly impacts the rise in power and energy delivered to the motor. This indicates that the system's output power demand is strongly influenced by the vehicle's operating conditions. Furthermore, the increase in current reflects the higher workload of the motor, which contributes to system performance while also affecting the overall energy efficiency.

Table 2 – DC-Side Output Parameters of the System (Motor Drive)

Load (Kg)	Speed (Km/Jam)	Voltage DC (V)	Current DC (A)	Power DC (kW)	Energy DC (kWh)
50	10	79,66	13,06	1,04	0,44
50	20	79,43	16,71	1,33	0,49
50	30	79,00	18,77	1,48	0,47
50	40	78,55	23,31	1,83	0,53
100	10	79,89	13,97	1,12	0,47
100	20	79,58	16,91	1,35	0,50
100	30	78,81	23,60	1,86	0,60
100	40	78,54	33,63	2,64	0,66
150	10	79,44	13,10	1,04	0,44
150	20	79,24	15,45	1,22	0,45
150	30	78,79	24,34	1,92	0,61
150	40	78,79	34,15	2,69	0,70
200	10	79,28	19,48	1,54	0,65
200	20	79,17	22,02	1,74	0,64
200	30	78,65	25,93	2,04	0,65
200	40	77,79	34,43	2,68	0,72

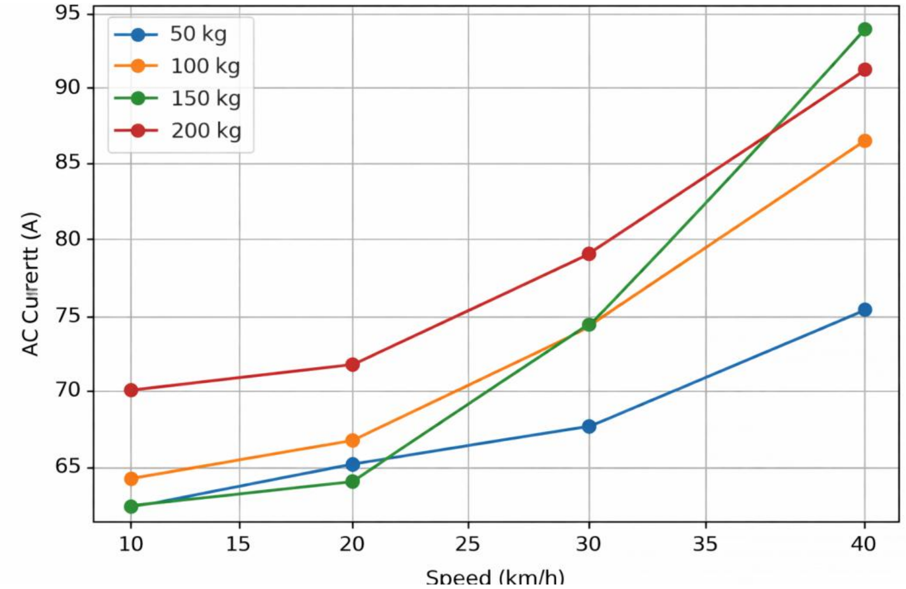

Fig.2 Relationship Between AC Current and Speed for Different Load Conditions

Figure 2 illustrates the relationship between AC current and speed for various load conditions, showing a consistent increase in current as the vehicle speed rises. This increase tends to be non-linear, particularly at speeds above 30 km/h, where a more significant surge in current is observed. In addition, higher loads result in greater current values at each speed, reflecting the increased torque demand of the motor. This phenomenon indicates that the system behavior is predominantly current-driven, where an increase in current directly leads to higher conduction losses, which are proportional to the square of the current. Consequently, this effect has a significant impact on the overall efficiency of the system. Table 3 presents a comparison of energy on the AC and DC sides, along with the power conversion efficiency under various load and speed conditions. In general, it can be observed that the efficiency increases as the vehicle speed rises, although energy consumption also increases.

Table 3 – Comparison of AC–DC Parameters and Energy Conversion Efficiency

Load (Kg)	Speed (Km/Jam)	Energy AC (kWh)	Energy DC (kWh)	Efficiency (%)	kWh/km
50	10	0,29	0,44	65,91	1,05
50	20	0,37	0,49	75,51	1,32
50	30	0,39	0,47	82,98	1,47
50	40	0,48	0,53	90,57	1,83
100	10	0,33	0,47	70,21	1,12
100	20	0,40	0,50	80,00	1,35
100	30	0,52	0,60	86,67	1,88
100	40	0,60	0,66	90,91	2,64
150	10	0,29	0,44	65,91	1,05
150	20	0,36	0,45	80,00	1,22
150	30	0,52	0,61	85,25	1,91
150	40	0,61	0,70	87,14	2,69
200	10	0,41	0,65	63,08	1,55
200	20	0,47	0,64	73,44	1,73
200	30	0,56	0,65	86,15	2,03
200	40	0,68	0,72	94,44	2,67

This indicates that at low speeds, the system does not operate optimally due to the dominance of constant losses, whereas at higher speeds, the ratio of output energy to input energy becomes greater. Furthermore, load variations do not result in a significant decrease in efficiency; in some cases, they even contribute to improved efficiency. These findings suggest the existence of an optimal operating point of the system under specific conditions.

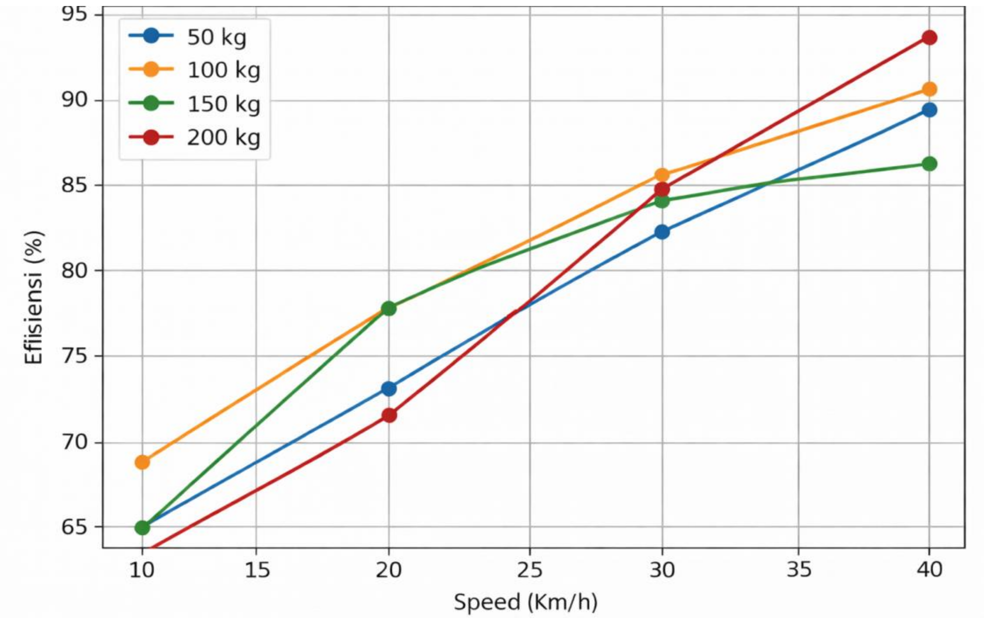

Figure 3 Relationship Between Efficiency and Speed for Different Load Conditions

Figure 3 illustrates the relationship between power conversion efficiency and speed for various load conditions, showing a consistent increase in efficiency as the vehicle speed rises. At low speeds, the efficiency is relatively low due to the dominance of constant losses in the system, such as switching losses and initial mechanical losses.

As the speed increases, the efficiency improves significantly, reaching its maximum value at 40 km/h. Furthermore, higher loads do not necessarily reduce efficiency; in certain conditions, they may even result in higher efficiency values. This phenomenon indicates that the system possesses an optimal operating point at medium to high speeds.

IV. DISCUSSION AND CONCLUSION

Based on the results obtained from the measurements, it can be concluded that the power conversion characteristics of the electric vehicle drive system are significantly influenced by variations in speed and load. The AC-side power and current show a substantial increase as speed and load increase, indicating a higher energy demand to meet the operational requirements. The dominant rise in current also contributes to increased conduction losses, particularly in the inverter and conductive components.Nevertheless, the system's power conversion efficiency exhibits an increasing trend with respect to speed. The highest efficiency value is achieved at a speed of 40 km/h with a load of 200 kg, reaching 94.44%, indicating that the system operates more optimally at medium to high speeds. This behaviour is attributed to the reduced impact of constant losses compared to the transmitted power at higher operating conditions.Overall, this study confirms the existence of an optimal operating point in the electric vehicle system that yields maximum efficiency. These findings provide an important foundation for developing more efficient and reliable operational strategies and system designs for electric vehicles.

Conflict of interest

There is no conflict to disclose.

ACKNOWLEDGEMENT

The author would like to thank the Department of Mechanical Engineering, Faculty of Engineering, University of

Mataram for the support of the facilities provided. Thanks also for expressing to colleagues who have contributed to the completion of this paper.

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