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A COMPREHENSIVE REVIEW OF P0–P5 HYBRID ELECTRIC VEHICLE CONFIGURATIONS

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Abstract. The degree and quality of electrification in a vehicle depend not only on battery size or motor power but also on where the electric motor is physically integrated into the driveline. A widely used way to describe this is the P0–P5 classification, where each position (P0 to P5) corresponds to a typical location of the electric motor between the engine and the wheels. This article presents an overview of P0–P5 architectures, explains their technical characteristics, and discusses their main advantages and limitations.

Keywords: electric motor, HEV, P0-P5 configuration, mild hybrids, PHEV, ICE, battery.

Аннотация. Степень и качество электрификации транспортного средства зависят не только от ёмкости аккумуляторной батареи или мощности электродвигателя, но и от того, где именно электродвигатель физически интегрирован в трансмиссию. Широко используемым способом описания этого является классификация P0–P5, где каждая позиция (от P0 до P5) соответствует типичному расположению электродвигателя между двигателем внутреннего сгорания и ведущими колёсами. В данной статье представлен обзор архитектур P0–P5, разъясняются их технические характеристики, а также рассматриваются основные преимущества и ограничения.

Ключевые слова: электродвигатель, HEV, конфигурация P0–P5, мягкие гибриды, PHEV, ДВС, аккумулятор

Annotatsiya. Transport vositasining elektrlashtirish darajasi va sifati nafaqat akkumulyator batareyasining sig‘imi yoki elektr dvigatel quvvatiga, balki elektr dvigatelning transmissiya tizimida qaysi joyga o‘rnatilganiga ham bog‘liq. Buni tavsiflashning keng qo‘llaniladigan usullaridan biri P0–P5 tasnifi bo‘lib, unda har bir pozitsiya (P0 dan P5 gacha) ichki yonuv dvigateli va yetakchi g‘ildiraklar orasidagi elektr dvigatel joylashuvini ifodalaydi. Mazkur maqolada P0–P5 arxitekturalarining umumiy sharhi keltiriladi, ularning texnik xususiyatlari yoritiladi hamda asosiy afzalliklari va cheklovlari tahlil qilinadi.

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Kalit so‘zlar: elektr dvigatel, HEV, P0–P5 konfiguratsiyasi, yumshoq gibrid, PHEV, ichki yonuv dvigateli, akkumulyator batareyasi.

INTRODUCTION

Electrified vehicles have become a central part of modern transportation strategies to reduce fuel consumption and emissions. Battery electric vehicles completely remove the internal combustion engine, whereas hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs) operate using both an internal combustion engine (ICE) and an electric drive system. In these vehicles, overall performance depends not only on the power ratings of individual components but also on how the powertrain is structurally arranged. According to their powertrain layout, hybrid electric vehicles are typically classified into three main types: series, parallel, and series–parallel architectures. The P0–P5 classification framework primarily refers to parallel hybrid architectures, in which the electric motor supports or complements the mechanical power transmitted from the internal combustion engine (ICE) to the drive wheels. As shown in Figure 1, these positions range from a belt-driven machine at the front of the engine to motors located at or near the wheels. Each position changes how energy flows through the powertrain and what operating modes are feasible. For instance, whether the vehicle can move with the engine completely off depends strongly on whether the motor can be mechanically decoupled from the ICE [1][2]. Therefore, motor positioning is not a minor packaging decision but a core architectural choice.

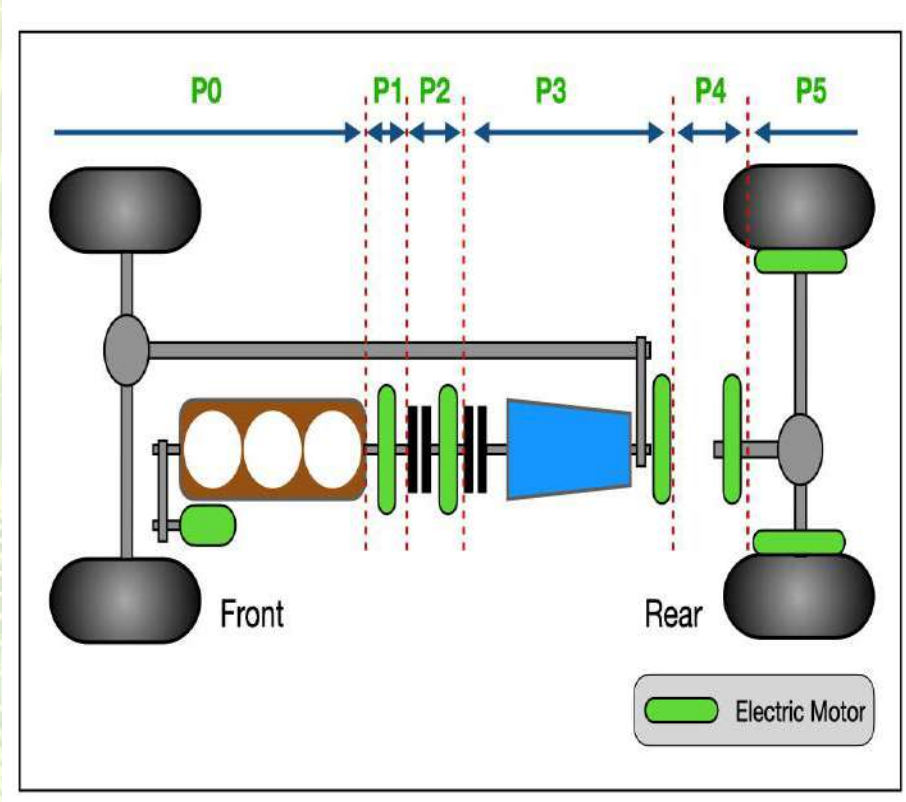


Figure 1. Topology of P0-P5 hybrid electric vehicle configuration

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This paper systematically reviews P0–P5 hybrid configurations and provides a structured comparison to highlight their technical characteristics and application suitability.

METHODOLOGY

This paper is based on a systematic analysis of existing literature related to P0–P5 hybrid electric vehicle architectures. Scientific articles, conference papers, and technical reports were collected from major engineering databases using relevant keywords associated with hybrid powertrain configurations. The selected studies were classified according to motor location, power flow structure, electrification level, and regenerative capability. A comparative evaluation framework was applied to identify the technical differences, advantages, and limitations of each P0–P5 configuration.

RESULTS AND DISCUSSION

In a P0 configuration (Figure 1), the electric machine is connected to the engine via a belt drive, typically acting as a belt-driven starter-generator. From an engineering standpoint, this is one of the simplest forms of electrification. The system can support automatic stop–start, provide small torque assistance, and recuperate a limited amount of braking energy. However, the belt limits torque transmission and efficiency at higher loads. Pure electric propulsion is not feasible because the motor cannot drive the wheels independently. For these reasons, P0 is mainly used in mild hybrid systems, often at 12 V or 48 V, where cost and ease of integration are priorities [3][4].

The P1 position (Figure 1) mounts the electric machine directly on the crankshaft or engine output shaft. This removes belt slip issues and allows higher torque transfer than P0. The motor can assist the engine more effectively and improve transient response. Regeneration capability is also somewhat improved. Nevertheless, the motor is still rigidly coupled to the engine, so engine drag losses remain during regeneration, and electric-only driving is generally not possible without additional decoupling devices. Thus, P1 remains closer to mild hybrid functionality than to full hybrid capability [2][5].

A more capable arrangement is P2, where the motor is located between the engine and the transmission, typically combined with a clutch that can disconnect the engine. As indicated in Figure 1, this location allows the motor to drive the vehicle while the engine is fully decoupled. This enables true electric-only operation at low to medium loads, efficient regenerative braking, and engine-off coasting. Many modern full hybrids and PHEVs use a P2-like layout because it offers a good compromise between functionality and compatibility with existing transmission technologies. The trade-off is higher mechanical complexity,

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additional clutches, and the need for sophisticated control of mode transitions and torsional vibrations [1][6].

In the P3 configuration (Figure 1), the motor is placed on the transmission output side, closer to the differential and wheels. This positioning can be effective for regenerative braking because the motor is directly linked to wheel speed. It also reduces the need to modify the engine–transmission interface. However, since the motor is downstream of the gearbox, it cannot always exploit gear ratios for torque multiplication in the same way as P2. As a result, higher motor torque may be required for the same wheel torque. Electric-only operation depends on whether the engine can be decoupled and on transmission design details. P3 can be attractive in certain integration scenarios but requires careful sizing and control design [7][8].

P4, shown in Figure 1 on a separate axle, represents an electric axle drive. A common example is a rear e-axle added to a front-engine front-wheel-drive vehicle. This enables electric all-wheel drive without a mechanical prop shaft. From a system perspective, P4 allows independent electric propulsion on one axle, strong regenerative braking on that axle, and flexible torque distribution for traction and stability control. The disadvantages include additional cost, mass, and a more demanding control problem because two propulsion sources must be coordinated across axles. Brake blending and thermal management become particularly important in these systems [2][9].

The P5 configuration moves the concept even closer to the wheels, typically with in-wheel motors. As suggested by Figure 1, each wheel can have its own electric machine. This provides maximum flexibility in torque control and enables advanced functions such as precise torque vectoring. It can also reduce mechanical transmission losses. However, placing motors in or near the wheels increases unsprung mass, which can negatively affect ride comfort and handling. The motors must also withstand harsh environmental conditions. Durability, sealing, and cost are major engineering challenges. Consequently, P5 is still more common in research prototypes and specialized vehicles than in large-scale production cars [10][11].

Table 1

The comparitive analysis of the P0-P5 configurations

Configuration	EV mode	Regenerative Efficiency	Complexity	Application level
P0	No	Low	Low	Mild hybrid
P1	No	Medium	Low	Mild hybrid
P2	Yes	High	Medium	Full/PHEV
P3	Yes	High	High	Advanced parallel

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P4	Yes	High	High	AWD hybrid
P5	Yes	Very high	Very high	Advanced EV/Hybrid

The comparative analysis of the P0–P5 configurations is presented in Table 1, considering operating modes, regenerative braking efficiency, system complexity, and application level. When comparing all positions in Figure 1, a general pattern emerges: moving from P0 toward P5 typically increases functional capability and electrification potential, but also raises system complexity and cost. The optimal solution depends on target market, performance goals, and cost constraints rather than on a single technical metric [1][12].

CONCLUSION

The P0–P5 classification provides a clear and practical framework for understanding hybrid and electrified vehicle architectures. As illustrated in Figure 1, each motor position defines a different balance between cost, complexity, and functionality. P0 and P1 are well suited for mild hybridization and incremental efficiency gains. P2 and P3 enable deeper hybrid functions and more effective energy recuperation, with P2 particularly strong due to engine decoupling. P4 supports e-axle concepts and electric all-wheel drive, while P5 offers maximum controllability but faces significant engineering challenges.

In real-world vehicle development, motor position is only one part of a larger system that includes batteries, power electronics, and control strategies. Still, it strongly shapes what the system can achieve. As electric machines and batteries continue to improve, the trade-offs among P0–P5 may shift, but the classification itself will remain a useful conceptual tool for engineers and researchers.

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