The title of project

(A) Bench marking for Belt Starter Generator & Mild Hybrid vehicles

(B) Knowing Nissan methodology and work for project

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1. **Review**

1.1 **Aim of the project**

(A) **BSG** (Belt Starter Generator) system is one of the new technologies to reducing the air pollution. It is mainly installed to Mild Hybrid vehicle and assists the torque by the force of electricity. The feature of this system is included the both alternator and starter. When cars is braking and running by inertia, it is accumulating the electric to the battery. However the technology is the latest one for Nissan Technical Center Europe and there were not so many information. Therefore the aim of this project is to investigate current status and market situation about **BSG**. Forecast, I expect the future trends of this technology.

(B) Nissan Motor Iberica S.A develop a new technology and make manufacture own facility. One of the engine design team which I joined management of engine structure. (Ex. **BSG** system Harness connector issue and the other is starter motor icing contact evaluation test.).

1.2 **Scope of the project**

(A) This bench marking was carried out within the range of European market.

(B) The management about engine structure had been carried out of mainly alliance between NTCE, NTC and Renault.

1.3 **Objective of the project**

(A) The objective this activity is to get the latest information from the other OEM’s and compare to these configuration. It will be helpful for our development and choice the purchasing from supplier.

(B) The purpose of this activity is to participant the management of engine which mainly occur from the validation test. (budget issue, assembling issue)

1.4 **Method of the project**

(A) There are four big BSG supplier in Europa. The way to get information from these BSG supplier is contact the person who are familiar to this technology at each company. After that arranging the opportunity to communicate and the face-to-face discussion was held to get the latest information.
(B) NTCE use high quality management application and it will easy to manage for these design. Contacting some supplier and getting the information can solve various issue. Once or twice per weeks, the Skype meeting is held with Renault or NTC Japan about the progress of management.

1.5 Result
(A) We have had a technical discussion several times with three supplier (Valeo, MELCO, Bosch) by Skype and Face to Face and got each milestone or load maps of mild Hybrid technology.

(B) Through the management of Nissan validation test, several concerns of prototype had solved before starting mass production.

1.6 Conclusions
(A) The items which Nissan had never known at that moment and it could help us determine to next generation Nissan mild Hybrid strategy. On one hands Nissan focus on the 12 V technology. Currently it is cheaper way than other structure to reduce CO2 emission. On the other hands, Nissan need to concentrate E-power and Leaf as well and in the future, internal combustion engine are going to completely change to the ICE which included some electronic functions the HEV and Electronic car to reduce emissions.

(B) It will be able to start mass production the few years later, if all concerns which include this project will have been solved.
2. **Glossary**

1. *NMSIA*: Nissan motor Iberica S.A Factory
2. *NTCE*: Nissan Technical Center Europa
3. *NTC*: Nissan Technical Center (Japan)
4. *OEM*: Original Equipment Manufacturer
5. *mHEV*: Mild Hybrid Vehicle
6. *HEV*: Hybrid vehicle
7. *PHEV*: Plug in hybrid vehicle
8. *FEV*: Full hybrid vehicle
9. *BRM*: Belt recuperation machine
3. **Introduction**

3.1 Some history of vehicle engines

3.1-1 **History of internal combustion engine**

The internal combustion engine is a heat engine in which the burning of a fuel occurs in a confined space called a combustion chamber. This exothermic reaction of a fuel with an oxidizer create gases of high temperature and pressure, which permitted to expand. The defining feature of an internal combustion engine is that useful work is performed by expanding hot gases acting on pistons, rotors, or even by pressing on and moving the entire engine itself.

It all started back in 1506 when no one else than Leonardo da Vinci described a compression-less engine—his description may not imply that idea was original with him or that it was actually build. The same thing was done a century and half latter, in 1673 by Christiaan Huygens. In 1794, Robert Street built compression-less engine whose principle of operation would dominate for nearly a century. One of the inventors Samuel Morland from U.K used gunpowder to drive water pumps in the 17th century.

The first internal combustion engine to be applied industrially was patented by Samuel Brown in 1823. It was based on what Hardenberg calls the Leonardo cycle. As this name implies, was already out of date at that time. The Italians Eugenio Barsanti and Felice Matteucci patented the first working, efficient internal combustion engine in 1854 in London. However it did not get into production.

In 1860, Etienne Lenoir produced a gas-fired internal combustion engine not dissimilar appearance to a steam beam engine. This closely resembled a horizontal double acting steam engine, with cylinders, pistons connecting-rods and fly wheel in which the gas essentially took the place of steam. This was the first internal combustion engine to be produced numbers. The American Samuel Morey received a patent on April 1, 1826 for "Gas or Vapor Engine".

The internal combustion engine was invented by Jean Joseph Etienne Lenoir. Lenoir made the first internal combustion engine that provides a reliable and continuous source of power. Which was the gas engine using coal in 1860 in France.

The first practical internal combustion engine based heavily on experience from the
production of steam engines. The engine had a horizontal cylinder; slide valves were used to draw in the fuel-air mixture; alternately at either end of the piston. Once in cylinder the mixture was ignited by electric sparks generated at spark plugs by a coil and a battery. This ignition system a primitive ancestor of modern electric ignition, was unreliable.

In 1863 Alphonse-Eugene Beau de Rochas designed a four stroke engine that would overcome many problems associated with the gas engine of that time. Two- stroke engines eliminate the intake and exhaust strokes, combining them with the compression and power strokes. This allows for lighter, more powerful engine – relative to the engine’s size – requiring a less complex design. But the two stroke cycle is less efficient method of burning fuel. A residue of unburned fuel remains inside the cylinder, which hinders combustion Two-stroke engines eliminate the intake and exhaust strokes, combining them with the compression and power stroke.

An internal – combustion engine can have anywhere from one to twelve or more cylinders. All acting together in precisely timed sequence to drive the crankshaft

3.1-2 History of Electric vehicle Engine

History of electric vehicle, the demand for electric drive vehicles will continue to climb as prices drop and consumers look for ways to save money at the pump. Currently more than 3 percent of new vehicle sales could grow nearly 7% or 6.6 million per year worldwide by 2020.

In the 1800s that led to the first electric vehicle on the road. An electric vehicle had the vehicular land speed record until around 1900. However it is the high cost, low top speed, and short range of battery electric vehicles, compared to later internal combustion engine vehicles.

In the early part of the 19 century, innovators in Hungary, the Innovators began toying with the concept of a battery-powered vehicle and created some of the first small scale electric cars. Robert Anderson, a British inventor, developed the first crude electric carriage around this same time.

In the U.S. the first successful electric car which made by William Morrison and a
chemist who lived in Des Moines Iowa by 1890. His six passenger vehicle which capability is 14 miles per hour was little more than an electrified wagon.

Fig. 1 Courtesy of the Library of Congress

Over the next few years, electric vehicles from different car company began spreading around the U.S. By 1900, electric cars were at their heyday, occupied for 30% of all vehicles on the road. During the next 10 years, the continued to show strong sales.

Fig. 2 Edison Takes on Electric vehicle Batteries

Car manufacture began to notice and started experimenting with electrical and early hybrid cars.
3.1-3 **History of Nissan vehicle engine**

Masujiro Hashimoto led by establishing Kwaishinsha The factory embarked on domestic automobile production, which became the pioneer of the domestic automobile industry.

In 1914, The DAT car was completed manufacturing. The DAT cars was named by combining the initial of the three men who invested in Kwaishinsha.(Kenjiro Den, Rokuro Aoyama and Aketaro Takeuchi) The DAT cars was entered in the Taisho Exposition held in the same year.

Over the next few years, The Kwaishinsha Motor Car works grew in size to 600 thousand yen in capital, with 60 employees. They completed and released Model 41DAT in the following year, the engine which was mounted on DAT was the first casting 4-cylinder engine in Japan. Kawaishinsha established DAT Jidosha & Co., Ltd. for the purpose of strengthening sales.

One years later, William R. Gorham, an American engineer, developed a three-wheeled vehicle in 1919. This drew attention from a businessman in Osaka, who established Jitsuyo Jidosha Co. was modern automobile factory of the time. In 1926, Jitsuyo Jidosha Seizo Co., Ltd. Become DAT Jidosha Seizo Co. Ltd and merged with DAT jidosha Trading Company.

In 1933 Tobata Casting Co., Ltd establishes Automoblie Division Tobata Casting Co., Ltd. set up an Automobile Division in March 1933 and began automobile production in earnest. In October of the same year, the company purchased more than 66,000m² of reclaimed land in Shinyokoyasu on the coast in Yokohama City (the site where the present Yokohama Plant is located
3-2. Evaluation of ICE/petrol and diesel performance

Pros of diesel
Financial
- Diesel engines are more efficient and use 15-20% less fuel meaning cheaper running costs. The cars historically have tended to have slightly higher resale value too, but this is changing with time.

Environmental
- Lower CO2 emissions means that diesels from before April 2017 get lower tax band than petrol engines car. However latest model diesel cars are usually higher tax than petrol.

Driving experience
- Diesel cars are superior low speed torque which means they have better overtaking power and towing ability.

Cons of diesel
Financial
- Diesel cars usually cost more than petrol. Diesel fuel is more expensive than petrol and servicing or fixing a serious problem on a diesel car might be slightly more expensive. New diesel cars also cost more to tax than petrol cars, and description is now slightly higher. There are a number of new charges, such as the London T-Charge and Ultra Low some diesels in certain cites

Environmental
- Despite lower CO2 emissions diesel fuel produces tiny particles linked to breathing disorders such as asthma

Driving experience
- Diesel engines tend to be slightly noisier, but this problem is improving than past.

Pros of petrol
Financial
- The cost of petrol is cheaper than diesel fuel and the cars tend to be slightly cheaper to purchase and service fee.

Environmental
- While CO2 emissions are higher than diesel, petrol cars produce less of some other dangerous emissions like nitrogen.

Driving experience
- The sound of petrol engines tend to be less noisy than diesel.

Cons of petrol

Financial
- Engines are less efficient and use more fuel than diesel

Environmental
- Petrol engines emit more CO2 than diesel cars.

Driving experience
- Petrol engines need the driver to change gear more regularly, for instance when overtaking, to make the most of engine’s power – but some people will actually prefer this style of driving.
3.3. Mild Hybrid or EV vehicle including Mission & reasons

3.3.1. Emission restriction of each part of the world

Fig. 3 Global Emission Legislation by World Region

Fig. 4 historical evolution of European emission limits for Diesel and Gasoline engines
**Spain and Italy**

In Spain, electric mobility still has not really taken hold. The situation is similar in Italy, where some regions offer tax exemption for five years. The overall number of privately owned electric vehicles remains low due in part to the fact that the 3kW electric supply found in many households hardly enough to charge a car.

**France**

The France government is doing a lot. Customers trading in their diesel for an e-mobile stand to receive up to €10,000. And those who are simply purchasing a vehicle without trading in their old one still qualify for a premium of just over €6,000. Those who install their own charging station at home receive a 30 percent tax rebate in addition.

**USA**

In America, gasoline is so cheap. This is one of the main reasons electric mobility has failed to take off. However, some states are progressive. The trailblazing state of California offers tax rebates and allows electric vehicles to bypass congestion at peak times by using the extra lane provided. Austin, Seattle and San Diego also have exemplary infrastructures for electric vehicles.

On April 2, 2018, the EPA Administrator signed the Mid-term Evaluation Final Determination which finds that the model year 2022-2025 greenhouse gas standards are not appropriate and therefore, should be revised.

NHTSA and the EPA are proposing the Safer Affordable Fuel-Efficient (SAFE) Vehicles Rule for Model Years 2021-2026 Passenger Cars and Light trucks (SAFE Vehicle Rule). The SAFE Vehicle Rule. If finalized will establish new standards for Corporate Average Fuel Economy (CAFE) and tailpipe Green House Gas (GHG) emission standards for passenger cars and light trucks covering model years 2021 through 2026.

**China**

China has an air pollution problem so all hopes are pinned on electric mobility. The state has implemented a program of subsidies. Those opting to go electric benefit from a purchase premium of just over €7,000 provided. The most attractive point is the
advantages to be gained on registration. For electric vehicle owners registration is immediate and free of charge.

The final version of China 6 emission standard for light-duty vehicles was released on December 2016. All sold and registered vehicles should meet the requirements of this standard from 1 July 2020, where for Type I test, 6a limits will apply.

Japan

Japan is also forcing a more stringent emission legislation and officially announced to adopt WLTP and RDE. WLTP will be introduced in October 2018 and RDE will be additionally installed from 2022 on. The test method of WLTP/RDE are based on EU regulation, but as a result of consideration of the real road environment in Japan there some small difference in the test conditions.

South Korea

Korea adopted the WLTP for Small & Mild-size diesel vehicle’s emission test mode effective from 22. March 2018.

India

Government of India determined to move directly from BS-IV to BS-VI from April 2020. Due to that fact a reduction of Diesel passenger cars share is expected, local OEMs focus more and more on gasoline engine development. Government introduced FAME [Faster Adoption & Manufacturing of (Hybrid &) Electric Vehicle] policy to boost & support hybrid/electric vehicle market.

Brazil

End of 2018 Brazilian emissions regulation PROCONVE L7/L8 was announced. PL will be introduced Jan 1st 2022 and PL8 will follow Jan 1st 2025 the new regulation has stricter emission limits as well RED will be introduced with PL8. With the introduction of PL7 and PL8 the OBD requirements OBD-3 must be standardized. Regarding to energy efficiency the innovative program came to an end and new Rota 2030 program followed.
3.3-2 **Current CO2 Emission**

Greenhouse gas emissions are mainly CO₂, but also CH₄ and N₂O. CO₂ is a natural result of combustion processes of carbon-containing fuels.

![Figure 5](image.png)

*Fig. 5: Historical fleet CO2 emissions performance and current standards (in g/km normalized to NEDC) for passenger cars. [5]*

In Europe, the exhaust gas regulation (Euro6D full) which was decided by the global organization will be conducted 2023 (*Fig. 5*). The target value will become more strictly. Many car companies are forced to develop CO₂ reduction systems. If they do not achieve this goal, they have to pay penalty fees depending on the degree of quantity which is not achieved. Therefore, each car company is solving the problem in various ways.

The majority of car companies think that Mild Hybrid vehicle is necessary as a connection technology until expanding more high-efficiency CO₂ reduction vehicles (Full Hybrid and Electric Vehicle). The electric car supply is expected to be increased by 2030. Besides, the most of increasing is Mild Hybrid vehicle. In Nissan, now we focus on the Mild Hybrid Strategy. Mild Hybrid system can be added to the configuration of conventional internal combustion engines. It is cheap and easy to assemble. On the other hand, it is not so much high ability to reduce CO₂.
4. Nucleus of the memory
4.1 Study of current and future Mild Hybrid technology

4.1-1 Current different Electrization types and description

Category of electric vehicle.

![Fig.6: Types of Electric vehicle](image1)

Currently there are many kind of electrical vehicles in the market. These electric vehicles are categorized by the rate of fuel and electric using. As it can be seen the Fig.1, the more rate of electric using, the less emission of exhaust gas.
According to Fig.2, Nissan and Mitsubishi have all types of configuration except 48 mild hybrid vehicle. The three structures above (EV, PHEV, HEV) has already sold in the market but 12V micro hybrid is under developing.

4.1-2 Current European market situation

*Fig.8: Current European passenger car sales*
According to Fig. 8, the majority structure in the European market is Gasoline and Diesel. In recent years, the Diesel sales amount is gradually decreasing because of exhaust emissions regulation.

On the other hand, within the range of electric vehicles, PHEV is decreasing due to UK sales. In contrast, mHEV sales is increasing to 1.8%. It seems to be a little bit change of whole market sales at this moment, but mHEV is predicted to rapidly increase until 2030.

![Fig. 9: Estimation of market penetration of hybrid electric vehicles by 2030](image)

As it can be seen, Fig. 9, the whole future electrification predicted is 10 times from the amount of current value.

The breakdown of future electrification is predicted as in Fig. 9. The most increasing electrification is 48V mHEV and it occupies half of the whole electric supply. All of electrification
4.1-3 Information about mHEV of each topology

Fig. 10: Topology - Segment of Mild Hybrid structure [2]

Fig. 10 shows the kind of Mild Hybrid topology. These categorize are determined by the location of structure which adds electrical torque. The cost and CO₂ reduction is differ from depend on the topology. All segment structure is able to add to the conventional vehicle structure but it become difficult according to the degree of interfering of conventional configuration.
4.1-4 Summarized information about Mild hybrid information

I summarized the information from supplier and each OEM by Table.2 to Table.5 below.

Table.1: Micro and Mild Hybrid P0 topology

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Micro Hybrid</th>
<th>Mild Hybrid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structure</td>
<td>P0</td>
<td>P0</td>
</tr>
<tr>
<td>OEM's</td>
<td>Suzuki: swift, Ignis, Valeno(G)</td>
<td>RSA: Scénic(D), Audi A6/A8/SQ7/Q8(G+D) Mazda3(G/D), Mercedes: C-Class(G), Hyundai: Tucson(D), Volvo: S60/V60 (G+D), Ford: Focus(G/D), KIA Ceed(D)/Sportage(D), PSA: Citroen C3(D), Range rover: Evoque(D), FCA: Renegade(G)</td>
</tr>
<tr>
<td>Supplier</td>
<td>Valeo, (Melco?)</td>
<td>Valeo, Bosch, Melco, Denso, Borg warner, Continental</td>
</tr>
<tr>
<td>Number of components</td>
<td>(1)BSG, (2)Additional 12V battery</td>
<td>(1)BSG, (2)48V battery, (3)DC/DC convertor(48V/12V)</td>
</tr>
<tr>
<td>Battery Voltage [V]</td>
<td>12</td>
<td>48</td>
</tr>
<tr>
<td>Cost</td>
<td>Low (+ 400 - 1.500 €)</td>
<td>Low (+ 1.100 - 2.000 €)</td>
</tr>
<tr>
<td>Electric machine power [kW]</td>
<td>&lt; 5</td>
<td>12 - 14</td>
</tr>
<tr>
<td>Additional engine torque [Nm]</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>CO₂ saving potential [%]</td>
<td>3 - 4</td>
<td>7 - 8</td>
</tr>
</tbody>
</table>
According to these Micro and Mild Hybrid information, Mild Hybrid 48V P0 topology is the most majority structure in current market. The reason why it is most chosen of all topology is because cost-effectiveness of CO2 reduction.

12V P0 structure is the cheapest structure but it CO2 reduction is quite small (3 – 4%). Recent year the conventional devices of car interior replace electronic gradually and if we add the other Electronic devices (E-turbo, E-Cat), 12 V voltage is not enough to cover these structure.

On the other hand, 48V P1 to P4 topology have more potential of CO2 reduction. However, it more interrupts of conventional structure and need to a lot of change and much cost in order to integrated Mild Hybrid functional and conventional structure.

From these result, the most appropriate balance of cost and CO2 reduction is P0 48V topology. It is estimated to continue to dominate majority of Mild Hybrid market in the near future.
### Table 3: HEV, e-Power

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>HEV</th>
<th>e-Power</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structure</strong></td>
<td><img src="image" alt="Conventional Hybrid" /></td>
<td><img src="image" alt="e-Power" /></td>
</tr>
<tr>
<td><strong>Segment</strong></td>
<td>Hybrid (CONV)</td>
<td>e-POWER</td>
</tr>
<tr>
<td><strong>OEM’s</strong></td>
<td>Toyota: Prius/C-HR/Corolla/RAV4, Volkswagen: Golf VII, Volvo: XC60, AWD, Porche: Cayenne e-Hybrid; Ioniq, Kia: Niro, BMW: Active Tourner/530e</td>
<td>Nissan: Note/Qashqai/Serena</td>
</tr>
<tr>
<td><strong>Battery Voltage [V]</strong></td>
<td>200 - 300</td>
<td>200 - 300</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Super High</td>
<td>Super High</td>
</tr>
<tr>
<td><strong>Electric machine power [kW]</strong></td>
<td>20 - 40</td>
<td>20 - 40</td>
</tr>
<tr>
<td><strong>CO₂ saving potential [%]</strong></td>
<td>20 - 30</td>
<td>20 - 30</td>
</tr>
</tbody>
</table>

### Table 4: PHEV, FEV

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>PHEV</th>
<th>FEV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structure</strong></td>
<td><img src="image" alt="Plug in Hybrid" /></td>
<td><img src="image" alt="100% Electric Vehicle" /></td>
</tr>
<tr>
<td><strong>Segment</strong></td>
<td>Plug in Hybrid</td>
<td>100% Electric vehicle</td>
</tr>
<tr>
<td><strong>OEM’s</strong></td>
<td>Mitsubishi: Out lander</td>
<td>Nissan: Leaf/e-NV200, Opel: Ampera, Volkswagen: e-GOLF, Mitsubishi, RSA, BMW, Mercedes, Audi: e-tron, Volvo, Kia, Porche</td>
</tr>
<tr>
<td><strong>Battery Voltage [V]</strong></td>
<td>200 - 300</td>
<td>300 - 400</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Super High</td>
<td>Super High</td>
</tr>
<tr>
<td><strong>Electric machine power [kW]</strong></td>
<td>60 - 120</td>
<td>60 - 120</td>
</tr>
<tr>
<td><strong>CO₂ saving potential [%]</strong></td>
<td>50 - 75</td>
<td>100</td>
</tr>
</tbody>
</table>
As it can be seen Table 3.4 the high voltage electric vehicle is also widely developed by various OEM’s. Particularly Hybrid Vehicle and Full electric vehicle. These types of vehicle are quite high cost compare to mild Hybrid vehicle but the capabilities of CO2 saving is much higher than \( mHEV \).

If all vehicles change directly to PHEV or FEV from ICE not through the \( mHEV \), it will be expected to occur some problem. At first, there are not enough infrastructure to charge the battery in Europe. As it can be seen the figure below, coverage of charging infrastructure in Europe. Northern and Western countries of Europe has enough vehicle charger and 76% of all charging points are located in 4 countries (Netherlands, Germany, France and UK)

![Map of Fast charging sites per 60 km motor way](image)

*Fig.11 Fast charging sites per 60 km motor way* [11]

Hence the part of country especially east and south of European country still have being needed the ICE added some electrification. That is the reason why not to directly change ICE to PHEV and EV.
[P0, P1 topology]

**P0, topology**
The electric machine is connected with internal combustion engine through a belt on the front end accessory drive.

![Fig. 12 P0 topology construction](image)

P0, P1 topology is always connected to Engine. The difference of two topology is location of additional torque. P0 structure add electric torque through a belt, on the front end accessory drive (FEAD). BSG is categorized P0 topology.

![Fig. 13 BSG structure (P0)](image)
Fig. 13 is one of the typical structure of BSG. The component is following.

- 1, Pulley
- 2, Housing
- 3, Rotor
- 4, Stator
- 5, Integrated inverter

12V BSG and 48V BSG are both known as P0 architecture is a cost effective solution which can provide up to a 14% reduction in CO₂. Commonly the boost recuperation systems (reference SEG) of 48V system maximum power rating are around 10 kW for mechanical output in boost mode and 12 kW for electrical output during recuperation. These values are peak power. Besides continuous power can reach up to 5 kW with maximum efficiency of 85%. Renault Scenic Grand 1.5 is one of the Specific vehicles of using 48V P0 topology. The table below is the detail information of this car. As it can be seen, there are two battery. One is 12V Electric Fluid Battery and the other is 48 Li-ion Battery.

**12V and 48V BSG**

In EU, two different volume of battery is used to BSG technology. One is 12V and the other is 48V. It is mentioned by table.1 below that the advantage and disadvantage of these two structure. BSG 12V is conventional technology and European OEM’s is rapidly proceeding for developing 48 bolt recent year.

<table>
<thead>
<tr>
<th></th>
<th>12V</th>
<th>48V</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC/DC converter</td>
<td>no need</td>
<td>need</td>
</tr>
<tr>
<td>48V Li - ion battery</td>
<td>no need</td>
<td>need</td>
</tr>
<tr>
<td>Fuel economy</td>
<td>4%</td>
<td>15%</td>
</tr>
<tr>
<td>cost</td>
<td>cheap 300 €</td>
<td>expensive 1000 €</td>
</tr>
<tr>
<td>Other electronics supply</td>
<td>not enough capacity</td>
<td>enough capacity</td>
</tr>
</tbody>
</table>

The reason why 48V was chosen as new battery is the safety risk of electrical
equipment operation. Higher voltage of an electrical system can achieve the higher efficiency and performance. However higher voltages have some possibility to trigger electric shocks for the human operator. Experts agree with that voltages under 50 V are considered safe from the electric shock and can treat it as well as 12V. It means 48 V is not required additional health and risk requirements. Therefore when the phase of vehicle manufacturing, electric systems operating at 48V can avoid to Health and risk concern. Following these reason 12V P0 replace 48V P0 and other topologies as well.
Comparison initial starting condition: conventional starter and BSG

**Fig. 14 Comparison of initial starting, conventional pinion starter and BSG [1]**

The initial starting or starting after an engine is accelerated to high rotational speed by the BSG with 10 kW and released. For the vehicle passenger, this means comfortable and very fast starting than with a conventional pinion starter. In contrast to a conventional starter

The BSG enables virtually noiseless and vibration-free starting.
**P1, topology**

The electric machine is connected directly with the cranks shaft of the internal combustion engine.

![Fig. 15 P1 topology construction](image)

In contrast, P1 topology is the starter generator mounted directly on the cranks shaft. This provides higher torque than the P0 architecture without no belt losses. There generation is efficiency. The maximum power required is 15 kW but efficiency goes up to 94%.

**[P2 topology on axil]**

The electric machine is side attached (Through a belt) or integrated between the initial combustion engine and crank shaft.
In a P2 topology, it is complex than P0 and P1 but it higher CO2 reduction. The transmission, connected through a belt integrated in the transmission, the main advantage of P2 architecture is the increased energy recuperation potential and the availability of additional hybrid control functions (electric creep/drive or energy recuperation during coasting). The main disadvantage is the higher integration cost to such a system.

[P2 topology off axil]
The electric machine is side-attached or integrated between the internal combustion engine and clank shaft.
Fig. 17 P2 topology off axil construction

The benefit of P2 topology “off axil” is almost same with P2 topology “on axil”. The difference of these two configuration are the location of Damper & Absorber.

[P3 topology]
The electric machine is connected through a gear mesh with the transmission.

P3 mild Hybrid topology is architecture the motor is attached on the transmission clutch, on the output shaft and P3 topology cannot work itself and required additional P0, P1 structure. The main profit of P3 topology is the highest energy recuperation potential of all mild Hybrid architecture. It is because P3 topology does not need to consider belt losses. However the obvious disadvantage of shaft mounted electrical machine is the cost of integration.

[P4 topology]
The electric machine is connected through a gear on the rear axle of the vehicle.

In P4 architecture, the electric motor is mounted on the rear axle drive or wheel hubs. The main advantage of P4 topology is highest energy recuperation same as P3 topology. This topology provides the vehicle with 4-wheel drive capabilities, with the combustion engine at front and electrical machine at the back. P4 architecture can reach up to 21 kW with an efficiency of 95% and it is able to reduce the CO₂ emissions by reach up to 19% in urban driving environment.

[Comparison]

Fig.19 Comparison of CO₂ reduction of each topology

As it can be seen Fig.19, P2 topology is the most CO₂ reduction of these three structure. The CO₂ reduction of P0 structure is around 11%. However when it use together with P3 structure, it improve up to 16%.

There are many predictions about the future Mild hybrid topology segment but these almost expected that P0 topology is highly occupy the market.

[HEV] Hybrid Electric Vehicle
Hybrid electric vehicle combine the benefits of gasoline engines and electric motors.

![Configuration of HEV](image)

*Fig. 20 Configuration of HEV*

The following items are several advanced technologies of most hybrids.

- **Regenerative Braking.**
  Regenerative braking recaptures energy normally lost during coasting or braking. It uses the forward motion of the wheels to turn the motor. This generates electricity and helps slow the vehicle.

- **Electric Motor Drive /Assist.**
  The electric motor provides power to assist the engine in accelerating, passing, or hill climbing. This allows smaller, more-efficient engine to be used. In some hybrids the electric motor alone propels the vehicle at low speeds, where gasoline engines are least efficient.

- **Automatic Start/Stop.**
  Automatically shuts off the engine when the vehicle comes to stop and restarts it when the accelerator is pressed. This reduces wasted energy from idling.

**[PHEV]** Plug in Hybrid Vehicle is a hybrid electric vehicle whose battery can
be recharged by plugging it into an external source of electric power.

Key Components of a Plug in Hybrid Electric Car

- **Battery**
  In an electric drive vehicle, the auxiliary battery provides electricity to start the car before the traction battery is engaged and also powers vehicle accessories.

- **Charge port**
  The charge port allows the vehicle to connect to an external power supply in order to charge the traction battery pack.

- **DC/DC convertor**
  This device converts higher-voltage DC power from the traction battery pack to the lower-voltage DC power needed to run vehicle accessories and recharge the auxiliary battery.

- **Electric generator**
  Generates electricity from the rotating wheels while braking, transferring that energy back to the transaction battery pack. Some vehicles use motor generators that perform both the drive and regeneration functions.

- **Electric traction motor**
  Using power from the traction battery pack, this motor drives the vehicle’s wheels.
Some vehicles use motor generators that perform both drive

- **Exhaust system**
The exhaust system channels the exhaust gases from the engine out through the tailpipe. A three way catalyst is designed to reduce engine out emissions within the exhaust system.

- **Fuel filler**
A nozzle from a high-pressure hydrogen dispenser attaches to the receptacle on the vehicle to fill the tank.

- **Fuel tank (gasoline)**
This tank stores gasoline on board the vehicle until it’s needed by engine

- **Internal combustion engine (spark-ignited)**
In this configuration, fuel is injected into either the intake repeated or the combustion chamber, where it is combined with air, and the air/ fuel mixture is ignited

- **Onboard charger**
Takes the incoming AC electricity supplied via the charge port and converts it to DC power for charging the traction battery. It monitors battery characteristics such as voltage, current, temperature, and state of charge while charging the pack.

- **Power electronics controller**
This unit manages the flows of electrical energy delivered by the traction battery, controlling the speed of the electric traction motor,

- **Thermal system (cooling)**
This system maintains a proper operating temperature range of engine, electric motor power electronics and other components.

- **Traction battery pack**
Stores electricity for use by the electric traction motor

- **Transmission**
The transmission transfers mechanical power from the engine and/or electric traction motor to drive the wheels.
Full Electric Vehicle is running only used the energy, which charged from the external electric.

Fig. 22 Configuration of HEV

Key components of an all-electric car

Battery (all-electric auxiliary)
- In an electric drive vehicle, the auxiliary battery provides electricity to power vehicle accessories.

Charge port
- The charge port allows the vehicle to connect to an external power supply in order to change the traction battery pack.

DC/DC converter
- This device converts higher-voltage DC power from the traction battery pack to the lower-voltage DC power needed to run vehicle accessories and recharge the auxiliary battery.

Electric traction motor
- Using power from the traction battery pack, this motor drives the vehicle’s wheels. Some vehicles use motor generators that perform both the drive and regeneration


functions.

**Onboard charger**
- Takes the incoming AC electricity supplied via the charge port and converts it to DC power for charging the traction battery. It monitors battery characteristics such as voltage, current, temperature, and state of charge while charging the pack.

**Power electronics controller**
- This unit manages the flow of electrical energy delivered by the traction battery, controlling the speed of the electric traction motor and the torque it produces.

**Thermal system (cooling)**
- This system maintains a proper operating temperature range of the engine, electric motor, power electronics, and other components.

**Traction battery pack**
- Stores electricity for use by the electric traction motor

**Transmission (electric)**
- The transmission transfers mechanical power from the electric traction motor to drive the wheels.

[e-Power] e-Power is the structure for Nissan original. Vehicle run only the
power from electric motor and the engine is used for generating electricity. It is categorized for HEV.

Fig. 23 Configuration of e-Power

**e-Power delivers a responsive drive with smooth acceleration like an EV**
- The e-POWER system allows you to enjoy all the benefits of all of an EV without having to worry about charging battery.
- e-Power delivers massive torque almost instantly, which enhance drive response and results in smooth acceleration. Also, the system operates very quietly, much like a full EV.
- Because e-Power can drive engine at most efficient point, its fuel efficiency is comparable to that of leading conventional hybrid, especially during around-the-town commutes.

**Technology Functionality**
e-Power borrows from the EV technology perfected in the Nissan LEAF, adding a gasoline engine to charge the high-output battery when necessary. This eliminates the need for an external charger, while offering the same high output as an EV.

**The Technology of e-POWER**
The e-POWER system offers full electric motor drive, meaning that the wheels are completely driven by the electric motor. e-Power is comprised a high-output battery and the power train.
This system structure generally requires a bigger motor as the only direct source to drive wheels. This has made it hard for the automotive industry to mount the system in compact cars. However, Nissan has cracked the code and learned how to minimize and reduce weight, develop more responsive motor control methods and optimize energy management. As a result e-POWER uses a smaller battery than the LEAF but the LEAF, but delivers the same driving experience as a full EV.

4.1-5 Information about BSG
BSG is the most concentrated structure of all Mild Hybrid technology while my benchmarking activity.

Key component of BSG
The fundamental structure and component of BSG is same as Alternator. Hence, key components is described based on Alternator specification.

![Fig. 24 Key component of Alternator](image)

1. V-belt pulley
   - Directly connected the Belt. It required to
2. Bearing lock bolts
   - Bolts to fasten Front cover and Bearing lock

3. Front cover
   - To cover the main functional component. The role of many slide are to go through
     the wind and heat to avoid the high temperature

4. V-belt pulley spacer
   - Spacer located between Front cover and Front bearing. It help rotate smoothly
     Front bearing.

5. Front bearing
   - It is excellent for durability for rotating a long time.

6. Bearing lock
   - Located outside of Front bearing to keep flatness of the rotation.

7. Rotor
   - It is at very center of the magnetic field creation. It creates amperage flow in the
     stator windings. This is opposite of a DC generator where a field current created
     in the stationary external position of the generator and induces voltage into the
     rotating armature.

   The alternator rotor is constructed a many coils of insulated with vanish copper
   wire wound directionally around a solid iron core. The core is centered and
   balanced on a steel shaft for high speed rotation and affixed by some design of
   bearing on both end. These pole figures are spaced alternately around the outer
   circumference of the rotor.

8. Back bearing
   - Rotating smoothly and supporting the rotor parts

9. Windings
   Field exciter winding is placed in rotor, and the low dc voltage can be transferred
   safely. The armature winding can be braced well, In order to prevent deformation
   caused by the high centrifugal force.
   The frequency of alternator voltage depends upon the speed rotation of the rotor
   and the number of poles. The faster the speed the higher the frequency.
10. Back cover

Covering form back side and radiating the heat from the slide

11. Alternator pins

Fixed front cover and back one.

12 – 18. These configuration only have Alternator.

In case of BSG, more strongly and complex Inverter is located this position.

4.1-6 Logic of BSG

There are four condition of BSG mode.
- NEUTRAL mode
- Generator mode
- Torque assist mode
- Restart mode

Fig.25 BSG condition of each vehicle speed

Functional sequence

Power on sequence
Wake-up BSG is managed thanks to
- CAN network (CAN wake up request)
- Rotation of the machine over a threshold Wake up by self-energy.

Main features
- Selection of the main functional mode via interface communication.

1, NEUTRAL

Neutral mode is typically active before the first crank or during idle stop. This mode is considered as a passive or safe mode because the electrical machine does not apply or provide torque on the crank shaft.

2. Generator mode

During the Generator mode BSG transforms mechanical power (coming from ICE via drive belt) in electrical power (transferred to the electrical on-board network).

3, Torque assist mode

During a Torque Assist mode, BSG transforms electrical power from the battery into mechanical torque transferred to the internal combustion engine via the belt.

4, Restart mode

During a Restart mode, BSG shall transform electrical power from the battery into mechanical power transferred to the engine via the belt.

4.1-7 Over view of some specific suppliers

[Valeo]

- Strategy of Valeo
  Innovation
  Valeo is aimed at reducing CO₂ emissions and developing intuitive operation,

  Growth
  Valeo anticipate new market demands and strength profitable growth momentum.
For instance geographical expansion in high-growth potential regions, especially in Asia and emerging countries.

*Fig.26 Valeo BSG*

Valeo had introduced 48V e4Sports mild Hybrid system, a new solution designed to increase the dynamic performance of a vehicle while reducing the fuel consumption and CO₂. Their 48V electrified powertrain solutions can be applied all vehicle segments, to both gasoline and diesel engine models. Their manufactures are well adjusted to urban car and compact sedans and it is the highest selling on the European market

[SEG]
- SEG company was independent department from Bosch.

48V P0 Boost Recuperation Machine BRM1
Fig. 27 SEG boost recuperation machine (BRM)

- Recuperation of braking energy to save fuel and CO₂ emissions
- 48V power supply enabling new functions with high energy demand
- Extra power via electric boosting
- Comfort start: extremely smooth start/stop operations
- Coasting at high speeds with the engine turned off

[MELCO]
- MELCO is one of the name of Mitsubishi electronic Japan.

Fig. 28 MELCO BSG 12 V

- Inverter-integrated design without interrupt other engine structure
- Belt driven quite start
- Quick restart and high engine speed assist from their Unique control technologies
- Unique motor winding technologies of their latest alternator for high torque, high generation efficiency and low noise
**Borg Warner**

*Fig. 29 Borg Warner HVH146 (48V)*

- **Description**
  Interior permanent magnet electric machine designed for belt drive integration (P0) in HEV applications.

- **Specification**
  - Continuous Power 25 kW
  - Peak Power 35 kW
  - Continuous Torque 50 Nm
  - Peak Torque 65 Nm
  - Nominal Voltage 300 V<sub>DC</sub>
  - Max Phase Current 150 A
  - Cooling WEG
  - Peak efficiency 95%

- **Benefits**
  - Full motoring and generating functionality
  - Water cooled
  - Compact size with 146 mm starter OD
  - High speed operation up to 16,500
  - Environmentally sealed housing-IP6K9K
  - Operational ambient temperature -40 to + 125 °C
  - Quick disconnect high voltage connector
4.1-8 **Comparison of BSG supplier**

**Table.5: Future plan of 12V and 48V BSG of each supplier**

<table>
<thead>
<tr>
<th></th>
<th>12V</th>
<th>48V</th>
</tr>
</thead>
<tbody>
<tr>
<td>Valeo</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Melco</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>SEG</td>
<td>×</td>
<td>○</td>
</tr>
<tr>
<td>Borg Warner</td>
<td>×</td>
<td>○</td>
</tr>
<tr>
<td>Denso</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

As it can be seen the *table.5* above, there are only two 12V BSG supplier in current market. The one is Valeo and the other is Melco. SEG and Borg Warner had decided that it would not supply 12V in the future. Some OEM’s completely shift to 48V technology and other OEM’s gradually instead from 12V to 48V as well.

4.2 **Contributing Nissan methodology and work for project**

4.2-1 **Daily work of NTCE**
Doing Management around engine component evaluation test of the latest Nissan Qashqai.

1, **Starter motor**: Starter motor is the component to add some initial torque when the vehicle start and restart.

**Icing contact evaluation test**
It is conduct durability test to low condition temperature change. The main purpose of my job is examine to necessity of this investigation.

**Engine Assembling**
When the assembling phase, there are some problem to construct the starter motor to engine. It was difficult to assemble by only human forces because not to be able to insert smoothly.
At first it was considered that the cause of this issue comes from the difference between manufacture and blue print. For that reason, it was necessary to requiring measurement to the factory. However the result of the measurement, the diameter is
within the value of tolerance based on blue print.

2, **BSG**: BSG is one of the mild Hybrid technology which add the additional torque via the belt. It is stand for belt starter generator.

**Harness connector**
Harness connector concern is the engine side have some trouble to connect. To clarify this issue, BSG side and Engine side connector was checked by each person in charge.

**Reprograming VC-lot car**
Reprograming Electric control unit was used by OBD (On-Board-Diagnosis). If there are some error around engine function, ECU memorized malfunction and DTC display that situation by the DTC code. There are a lot of types of missing message related voltage, temperature and so on.

**Logic development**
When the some vehicle trouble occur in the market, DTC (Date Trouble Code) transmit to the Engine control unit from the BSG. To correspond quickly and to conducting hearing process, learning of the deeply logic is important. However it is under developing and need to learn the latest mode information
5. Educational Grant by Nissan

To conduct this research assignment, the following Educational support was paid by Nissan. As it can be seen working time table, work time is 6 hours/day and workday was determined based on Nissan Calendar. The price of educational grant is 10,32 euro/hour. As fund the service and cover administration cost, 991,59 euros was paid to UPC. It’s equivalent to 15,70% of the total amount of educational grant. In addition, the total amount of the corresponding invoice was 1,199,82 and it was paid from total amount of educational grant. The total amount of after tax was 4124,44 euros and 800.01 average per month paid monthly.

<table>
<thead>
<tr>
<th>Worktime table</th>
<th>Educational support</th>
<th>Worktime</th>
</tr>
</thead>
<tbody>
<tr>
<td>8:00 - 9:00</td>
<td>10.32 €/hour</td>
<td>6 hour/day</td>
</tr>
<tr>
<td>9:00 - 10:00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10:00 - 11:00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11:00 - 12:00</td>
<td>lunch break</td>
<td></td>
</tr>
<tr>
<td>12:00 - 13:00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13:00 - 14:00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14:00 - 15:00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6 Worktime table and payment

<table>
<thead>
<tr>
<th>Month</th>
<th>Work Day</th>
<th>Support (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>September</td>
<td>4</td>
<td>247,68</td>
</tr>
<tr>
<td>October</td>
<td>23</td>
<td>1424,16</td>
</tr>
<tr>
<td>November</td>
<td>20</td>
<td>1238,4</td>
</tr>
<tr>
<td>December</td>
<td>14</td>
<td>866,88</td>
</tr>
<tr>
<td>January</td>
<td>21</td>
<td>1300,32</td>
</tr>
<tr>
<td>February</td>
<td>20</td>
<td>1238,4</td>
</tr>
<tr>
<td>Total</td>
<td>102</td>
<td>6315,84</td>
</tr>
</tbody>
</table>

Tax

- 15% to UPC: 991,586
- 21% to iva: 1199,82

After tax

Total support - Tax: 4124,43
6. **Conclusions**

6.1 Future market trend in EU

Various *OEM’s* expected that 12 V is replaced 48 V in the future, It because electric surrounding instruments are increasingly and the demand of voltage is increasing also. More over 12V is not enough CO2 benefit to achieve the Euro6d full.

6.2 Demand of 12V in the future market trend

Within the range of *mHEV* P0 topology, the 12V belt starter generator will not completely replace 48V in the future market. However 48V will definitely growing up. Therefore, we need to find out the benefit and situation which is suited 12 V in order to not fall behind 48V technology (cost performance, no need DC/DC converter).

6.3 In the future

In Europe it is not only the mild Hybrid strategy but also High voltage electrical vehicle begin to widely spread to achieve the regulation. Sooner or later the way to add some equipment to conventional technology will come technical limit. Besides *ICE* improvement requires big effort but can get small benefit. Therefore we finally need to completely reform from phase of vehicle production.
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