OKAN UNIVERSITY

INSTITUTE OF SCIENCES AND ENGINEERING

AUTOMOTIVE MECHATRONICS AND INTELLIGENT VEHICLES

ELECTRIC CITY BUSES STEERING SYSTEM ENERGY CONSUMPTION OPTIMISATION

MASTER OF SCIENCE

submitted by

ULUCAN ERGÜL

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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THESIS

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SUPERVISOR: DR. ALPER TEZCAN

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PROGRAM: AUTOMOTIVE MECHATRONICS AND INTELLIGENT VEHICLES

ABSTRACT

ELECTRIC CITY BUSES STEERING SYSTEM

ENERGY CONSUMPTION OPTIMISATION

These days, almost all industries in the world have undergone a change in order to reduce carbon emissions. One of the industries most affected by this change is the automotive industry. In order to obtain more efficiency on production and the products, many transformations are taking place in the automotive industry with the help of technology. Perhaps the most important part of this transformation is the electrification of vehicles. Today, fossil fuel-powered vehicles are gradually being replaced by electric-powered vehicles. This transformation takes place not only at the vehicle level; but also take place in a way that covers the entire ecosystem in order to generate, transfer, store and spend electrical energy in the most efficient way possible. It is possible to define electrification exactly in this way.

The electrification transformation has brought along many changes in vehicle architecture. While the internal combustion engines on the vehicles are replaced by electric motors; In order to provide the necessary electrical energy to the electric motor on the vehicle, batteries have been added to the vehicles. Due to this fundamental change on the power package, all systems that provide their energy from the internal combustion engine have been redesigned. Perhaps the most important of these additional systems is the steering system.

Steering systems are generally supported by the assisted forces in order to the drivers can manage the vehicle in the most comfortable way. This power assistance can be provided by hydraulic energy as well as electrical energy.

The steering system of the vehicle type we will discuss in this thesis is hydraulically assisted in the internal combustion versions. With the electrification of this vehicle, which is used as a passenger bus, the need to assist the steering system with electrical energy and to optimize this energy consumption has arisen.

Within the scope of the thesis; The energy consumption of the steering system of the internal combustion version of the vehicle was calculated, and data collection studies were carried out on the parameters that this energy consumption depends on. Then, taking into account the changing parameters (weight distribution, etc.) due to the electrification of the electrified vehicle, the calculation studies and the algorithm created with the collected data were applied and the results were tested.

As a result of the study, the energy consumption of the steering system of the electric passenger bus decreased by 25% compared to the algorithm first developed for the electric vehicle.

Keywords: Electrification, Steering System, Assist Forces, Algorithm, Energy Consumption

ÖZET

Bu günlerde, karbon emisyonlarını azaltmak adına dünya üzerindeki hemen hemen tüm endüstriler bir değişim içerisine girmiştir. Bu değişimden en çok etkilenen sektörlerden biri de otomotiv sektörüdür. Hem üretim teknolojileri hem de daha verimli bir ürün elde etmek adına, teknolojinin de yardımıyla, otomotiv sektöründe birçok dönüşüm gerçekleşmektedir. Bu dönüşümün belki de en önemli parçası, taşıtların elektrifikasyonudur. Günümüzde fosil yakıtla çalışan taşıtlar, yavaş yavaş yerini elektrik enerjisi ile çalışan taşıtlara bırakmaktadır. Bu dönüşüm sadece araç seviyesinde değil aynı zamanda elektrik enerjisinin üretilmesi, aktarılması, depolanması ve mümkün olan en verimli şekilde harcanması adına tüm ekosistemi kapsayacak şekilde gerçekleşmektedir. Elektrifikasyon tanımını tam olarak bu şekilde yapabilmek mümkündür.

Elektrifikasyon dönüşümü, taşıt mimarisi üzerinde de pek çok değişikliği beraberinde getirmiştir. Araçlar üzerindeki içten yanmalı motorlar, yerini elektrik motorlarına bırakırken; araç üzerindeki elektrik motoruna gerekli elektrik enerjisini sağlayabilmek adına araçlara batarya eklenmesi ihtiyacı oluşmuştur. Güç paketi üzerindeki bu temel değişim, enerjisini içten yanmalı motordan sağlayan tüm sistemlerin tekrardan tasarlanmasını gerektirmiştir. Bu ilave sistemlerden belki de en önemlisi direksiyon sistemidir.

Direksiyon sistemleri genellikle taşıt dinamiğinden kaynaklı kuvvetleri sürücülerin aracı en rahat şekilde yönetebilmesi adına desteklenmiştir. Bu kuvvet yardımı hidrolik enerji ile sağlanabildiği gibi elektrik enerjisi ile de sağlanabilmektedir.

Bu tez kapsamında ele alacağımız araç tipinin direksiyon sistemi, içten yanmalı versiyonlarında, hidrolik olarak desteklemektir. Yolcu otobüsü olarak kullanılan bu aracın

elektrifiye edilmesi ile, direksiyon sisteminin desteklenmesinin elektrik enerjisi ile sağlanması ve bu enerji tüketiminin optimize edilmesi ihtiyacı doğmuştur.

Tez çalışması kapsamında; konu taşıtın içten yanmalı versiyonun direksiyon sistemi enerji tüketimi hesaplanmış, bu enerji tüketiminin bağlı olduğu parametreler üzerinden data toplama çalışmaları gerçekleştirilmiştir. Daha sonra elektrifiye olmuş versiyonu üzerine, aracın elektrifiye olmasından kaynaklı değişen parametreleri de göz önünde bulundurularak (ağırlık dağılımı vs.) yapılan hesaplama çalışmaları ve toplanan datalar ile oluşturulmuş algoritma, araca uygulanmış ve sonuçlar test edilmiştir.

Çalışmanın sonucunda, elektrikli yolcu otobüsünün direksiyon sistemi enerji tüketimi, elektrikli araç için ilk geliştirilen algoritmaya göre %25 azalmıştır.

Anahtar Kelimeler: Elektrifikasyon, Direksiyon Sistemi, Destek Kuvveti, Enerji Tüketimi

To My Family

ACKNOWLEDGMENT

First of all, I would like to express my gratitude to my company Otokar Automotive and Defense Industry, where I have worked for more than 5 years and to Koç Holding.

Especially in this difficult term that our country has been going through for the last few years, my company, which still continues its investments in Turkish Industry and Turkish young engineers, is one of the biggest reasons for the realization of this study.

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SYMBOLS

a	Acceleration
C	Capacitance
J	Inertia
M	Moment
I	Electric current
P	Power
P	Pressure
R	Resistance
T	Torque
U	Voltage
Q	Flow
V	Vehicle speed
ω	Angular velocity

ACRONYMS

ASM	Asynchronous Motor
BLDC	Brushless DC Motor
CAN	Controller Area Network
COG	Center of Gravity
CPU	Central Processing Unit
DC	Direct Current
ECE	Electronics and Communications Engineering
ECU	Electronic Control Unit
EHPS	Electro-Hydrolic Power Steering
EHPAS	Electro-Hydrolic Power Assisted Steering
EM	Electric Motor
EMI	Electromagnetic Interference
EPS	Electric Power Steering
EPAS	Electric Power Assisted Steering
ESP	Electronic Stability Program
GPS	Global Positioning System
GVW	Gross Vehicle Weight

HPS	Hydrolic Power Steering
ISO	International Organization for Standardization
LLS	Lader Logic System
MR	Magneto Resistive
PID	Proportional Integral Derivative
PWM	Pulse Width Modul
UITP	International Association of Public Transport
UN	United Nations

1.INTRODUCTION

Depending on the development of technology, the automotive industry is constantly changing. The systems on the vehicles are constantly changing accordingly. Basically, the steering system is created so that the driver can move in the desired direction. The change in the total load and operating conditions in the vehicle presents various difficulties to the driver. In order to minimize these difficulties, additional units are added to the steering systems. Basically, the following elements are expected from Steering systems.

a. Easy, quick and smooth steering of the wheels

b. Minimum force to be applied to the steering wheel without adverse conditions

c. Ensuring that steering control is not lost as a result of impacts caused by the road in adverse road conditions,

1.1.Steering Systems General Spesifications

The steering system is the system that allows the driver to turn the front wheels by turning the steering wheel. The driveline and connections extending from the steering wheel to the wheels form the steering system. Steering movements created by the driver are transmitted to the wheels with the help of the steering wheel, steering shaft, steering gear box and steering link arm. [1]

The steering movement applied by the driver to the steering wheel is used by the steering system to steer the front wheels. The steering system provides the driver with driving information about the speed of the car, the condition of the road the car is traveling on (Uneven or smooth road) and vehicle Dynamics. [2]

1.2.Steering Systems Components

1.2.1.Steering Wheel

With the help of the steering wheel in the vehicle, the steering shaft is rotated. The driver adjusts the vehicle's direction of rotation with the steering wheel. Generally, the steering wheel is made of light metal alloys. It is designed as a cover so that the driver can easily grasp the steering wheel.

1.2.2.Steering Column

The steering shaft column the power from the steering wheel to the gearbox. The steering column consists of the main steering shaft that transmits the movement of the steering wheel to the steering box and the column tube that connects this shaft to the body.

There is also a shock absorbing mechanism on the steering column in case of an accident. This mechanism prevents impacts that may cause injury to the driver in the event of a collision. The column is attached to the body with a frangible bracket. When a blow comes, this bracket breaks and absorbs the blow. The steering main shaft is connected to the steering gear box by a sliding joint or a joint cross. Thus, vibrations coming from the road through the steering box are transmitted to the steering wheel in a reduced manner.

Figure 1: Steering Column

1.2.3.Steering Damper

The steering damper; dampens the vibrations and road bumps transferred from the wheels to the steering wheel between the chassis and steering connections.

Figure 2: Steering Damper

1.2.4.Pitman Arm

The Pitman Arm transfers the movement of the steering gear to the short course. The larger end of the lever is threaded into the sector shaft of the steering gear with a finely splined thread and is connected with a nut. The small end of the arm is connected with the short track ball joint.

Figure 3: Pitman Arm

1.2.5.Rods

Rod: Allows the distance between the joints to be adjusted.

Joints: The tie rod ends are connected to the ends of the rods, connecting the gooseneck, the long intermediate rod and the rods.

Long intermediate rod: It transfers the movement of the command arm to the rods.

Short tie rod: connects the command arm to the gooseneck. It works like a link that transfers the right and left movement of the command arm back and forth.

Figure 4: Rods

1.2.6.Track Rod Arm

It transfers the movement of the short tie and long intermetdiate rods to the steering knuckle. [3]

1.3.Types of Steering Systems

The steering system is the most important system that the driver interacts with in order to steer the vehicle. The driver must constantly adjust the steering wheel at a certain angle to keep vehicle deviations less than the set course. The relationship between steering wheel and tires is non-linear due to its kinematic structure such as steering wheel, steering column, tie rod joints and tires. The slip angle or side slip angle is the angle between the direction the wheel is

steered and the direction it actually travels. The graph of change according to the steering angle in the time domain of the sideslip angle is shown in figure 5.[4] [5]

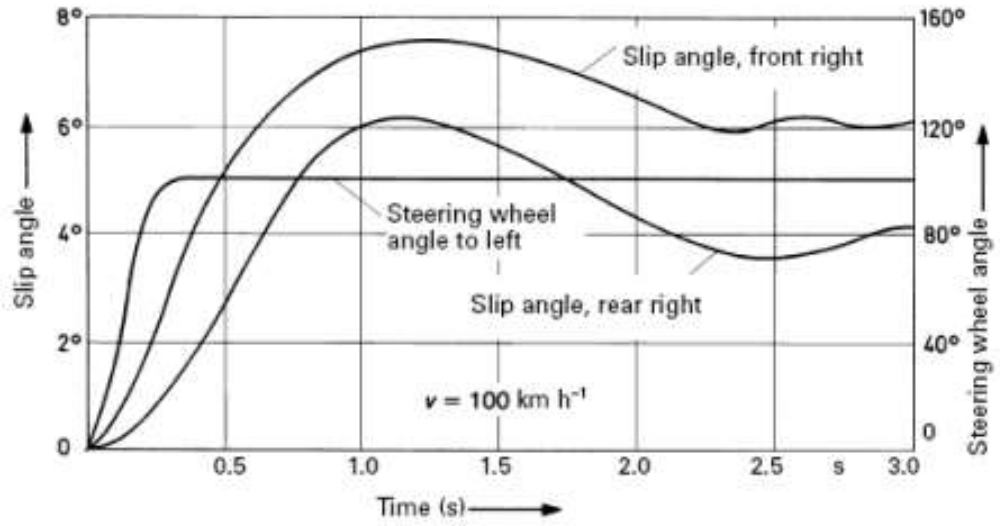


Figure 5: Non-Linear Relationship between Steering Angle and Slip Angle

The driver manages the steering system by monitoring the following variables.

a. Visual deviation from the route

b. Rolling acceleration of the vehicle body

c. Lateral acceleration

d. Steering torque felt by the driver through the steering wheel

There are 4 main types of steering systems:

a. Mechanical Steering Systems

b. Hydrolic Steering Systems

c. Electro-Hydrolic Steering Systems

d. Electric Steering Systems

Information of all these types of steering systems are given in next sections.

The most important variable monitored by the driver is the steering torque felt in the steering wheel. The steering torque informs the driver of the forces acting on the wheels resulting from road interaction.

1.3.1.Mechanical Steering Systems

Mechanical steering systems do not have a hydraulic or electrical mechanism that assists the driver during vehicle maneuvering. The system consists of the steering wheel, steering column, steering gear and connecting rods. The energy consumed by the driver to steer the vehicle is more than other steering systems.

In the rack and pinion steering gear, the lateral translation of the rack is transmitted to the right and left steering arms via the rods. Thus, it produces steering torque that turns the wheels around the steering axes.

It is designed as trapezoidal geometry in accordance with the kinematic geometry of the connecting rods. The Ackerman geometry has a minor influence on the high-speed maneuvering characteristics of vehicles. However, it has an effect on the self-centering torque at low speed maneuvers. During the maneuver of the vehicle, the resistance torque increases continuously according to the angle of the steering wheel .[4],[6]

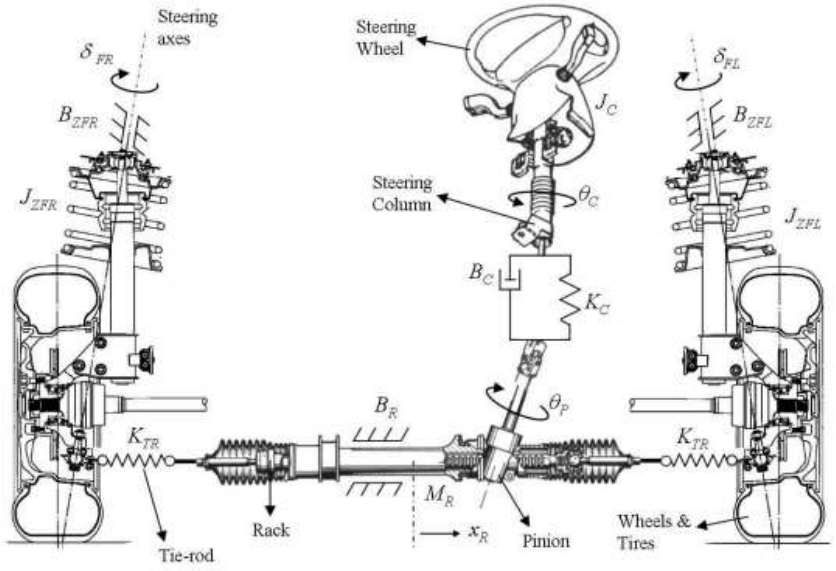


Figure 6: Mechanical Steering System

The mechanical component that changes the angle of the tires depending on the driver is named the steering gear. There are two types of mechanical solutions for the steering gear.

1.3.1.1.Rack and Pinion Steering

The steering column transfers the angular input of the steering wheel to the pinion. The angular movement of the pinion is transferred to the lateral movement of the rack. Connecting rods connect the ends of the rack to the steering arms of the left/right wheels. Via the steering arms and tie rods, the lateral movement of the rack is transferred back to the angular movement of the wheels. It is used in light and medium commercial cars as well as passenger cars. [6]

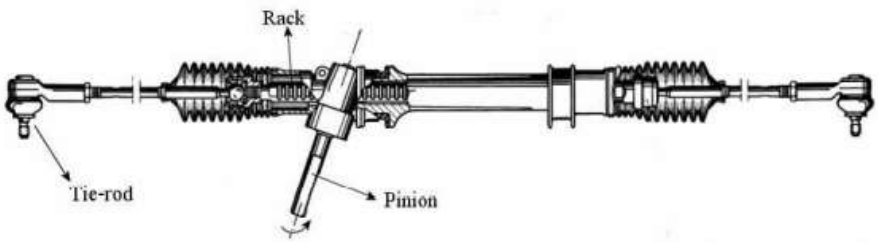


Figure 7: Rack And Pinion Steering Gear

Advantages;

a. Simple and compact structure

b. Economical and uncomplicated to manufacture

c. Easy to use due to good efficiency

d. Contact between steering rack and pinion is free

e. Minimum steering flexibility compatibility

f. It is easy to limit the movement of the steering rack and the steering angle

Disadvantages;

a. Greater sensitivity to influences

b. More sensitive in case of rod angular forces

c. Easier to feel the discomfort of the steering wheel

d. The size of the steering angle depending on the movement of the steering rack

e. Reduction in steering ratio above the steering angle

f. Can not be used on rigid axles

1.3.1.2.Re-circulating Ball Steering

In passenger cars with independent front suspension design, the rotary ball steering system is more complex and more expensive than the rack and pinion steering system. Re-circulating Ball Steering is used in some commercial vehicles since rigid axles are not used in the rack and pinion steering system. [6]

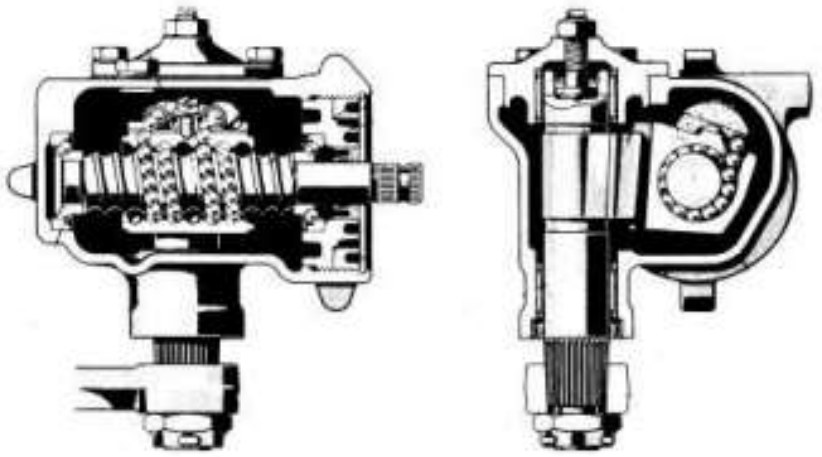


Figure 8: Re-Circulating Ball Steering Gear

Advantages over Rack and Pinion Steering System; [4]

a. It can be used on rigid axles.

b. It can transmit higher forces.

c. A large input wheel angle is possible.

d. It is possible to use long steering arms.

e. It is possible to design connecting rods of any length

1.3.2.Hydrolic Steering Systems

In hydraulic assisted steering systems, hydraulic pressure is used as an assist during the control of the driver's wheels. The hydraulic level is determined based on the torque applied to the driver's steering wheel. Drive torque is not measured via an electronic sensor. In order to create assist force in hydraulic power steering systems, there is a hydraulic cylinder and hydraulic pump built into the rack in the system. The pump is driven directly by the engine,

continuously generating hydraulic power. Hydraulic pressure provides the power to move the wheels. The assist force exerted by the driver on the steering wheel is greatly reduced.

Since the pump is driven by an internal combustion engine, it can operate even at low speeds. However, it causes a pressure increase at high speeds. Even when the steering boost is not required, the pump creates a load on the internal combustion engine, thus negatively affecting fuel consumption. [4],[7]

Hydraulic power assisted steering systems are still widely used. Thanks to the self-damping feature of the hydraulic system, the sensitivity to road movement caused while driving is greatly reduced. There is no need for steering dampers, which may be required in mechanical steering systems. [4]

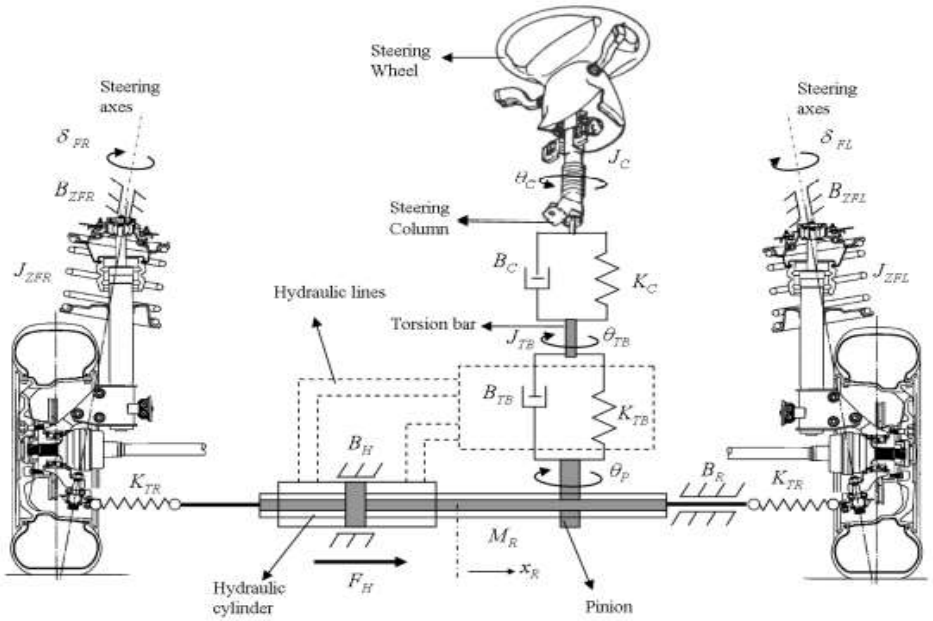


Figure 9: Hydrolic Steering System Model

1.3.3.Electro-Hydrolic Steering Systems

In recent years, the traditional engine belt driven hydraulic power assisted steering (HPS) system has been abandoned because of its less energy efficiency. Instead, fuel-saving electro-hydraulic assisted steering systems (EHPS) which is more efficient relatively to HPS system use more oftenly. [8]

In electro-hydraulic steering systems, a special electric motor drives the hydraulic pump, which provides hydrolic flow to the steering valve. The steering valve provides a differential pressure to the engine to provide the necessary assist power to the connecting rods. The differential pressure is governed by the bending angle of the torsion bar and the steering wheel. Since the pump does not consume engine power, it does not reduce fuel performance. In conventional power steering systems, the pump generates its minimum pressure at low vehicle speeds and during parking maneuvers, especially due to low or idling engine speed. High pressure is achieved at high vehicle speeds for undesirable vehicle stability issues. [4],[9]

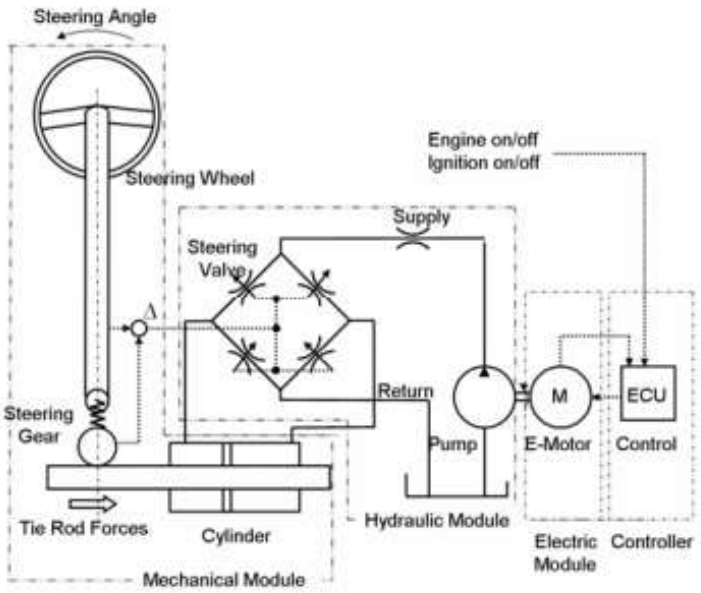


Figure 10: Electro-Hydrolic Steering System Model

The speed of the electric motor can be adjusted according to the vehicle speed and it can create high support forces at low vehicle speeds and low support forces at high speeds. In addition, the electrical control unit (ECU) provides pulse width modulated (PWM) voltage according to the power demand of the electric motor. [9]

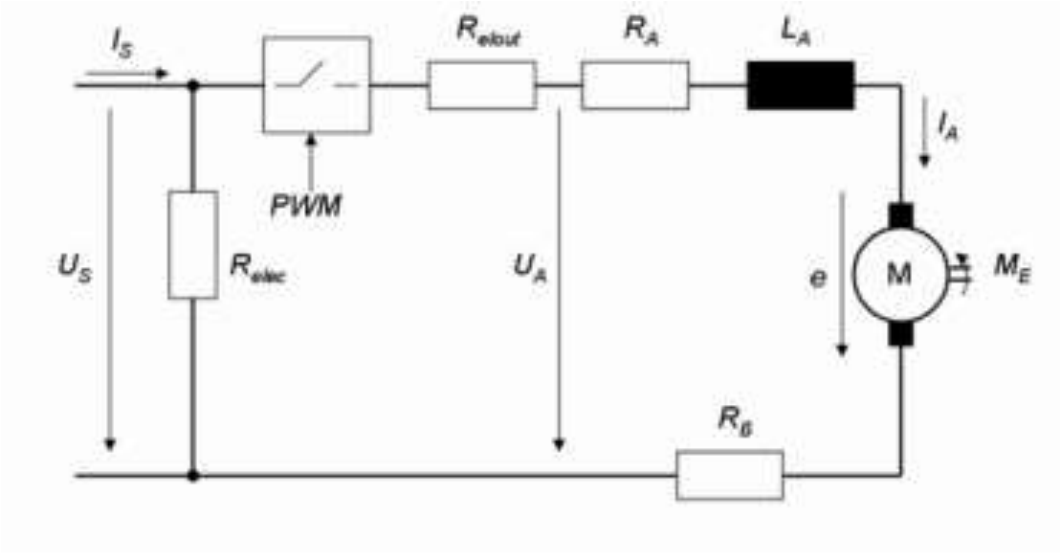


Figure 11: Electro-Hydrolic Steering Electrical Circuit

The EHPS system is used in many passenger cars. Although the three vehicles listed in Table 1; used similar EHPS systems, There are also many differences between them. Using the EHPS system is minimizing variations. [7]

Table 1: EHPS System Spesifications

	Opel astra/Zafira	**VW Polo**	**Audi A2**
Electric Motor	12 V DC	13,5 V DC	12 V DC
Hydraulic Pump	Max. 100 bar	Max. 104 bar	Max. 100 bar
Flow	3.5 L/dak.	2 L/dak.	2 L/dak.
Hydraulic Power	500 W	500 W	500 W

Current	6 A 68 A(max)	2,5 A 68 A(max)	2,5 A 68 A(max)
Gear Ratio	48 mm/rev	49.8 mm/rev	49.8 mm/rev
Vehicle Mass	1035 kg	820 kg	790 kg
Maximum Rack Load	8200 N	6200 N	6200 N
Routing Speed	360°/sn (8200 N) 800°/sn (3100 N)	360°/sn (6200 N) 800°/sn (3100 N)	360°/sn (6200 N) 800°/sn (3100 N)

1.3.4.Electric Steering Systems

Regulative conditions in automotive industry such as high energy efficiency and low exhaust emissions demanded in vehicles push manufacturers to innovate in part design. Recently, electric assisted steering (EPS) system has been adopted in passenger cars, the applicability of which is passenger cars. EPS systems replace traditional hydraulic systems used in vehicles. Compared with the hydraulic power steering (HPS) system, the EPS system is better in many aspects, including safety, cost, energy efficiency, environmental protection and installation. EPS systems represent last level of power assisted steering technology. In the schematic diagram of an EPS system mounted on the steering column, it consists of a motor, a torque sensor, a reduction gear and a rack and pinion structure. The schematic structure is shown in the Figure 12.

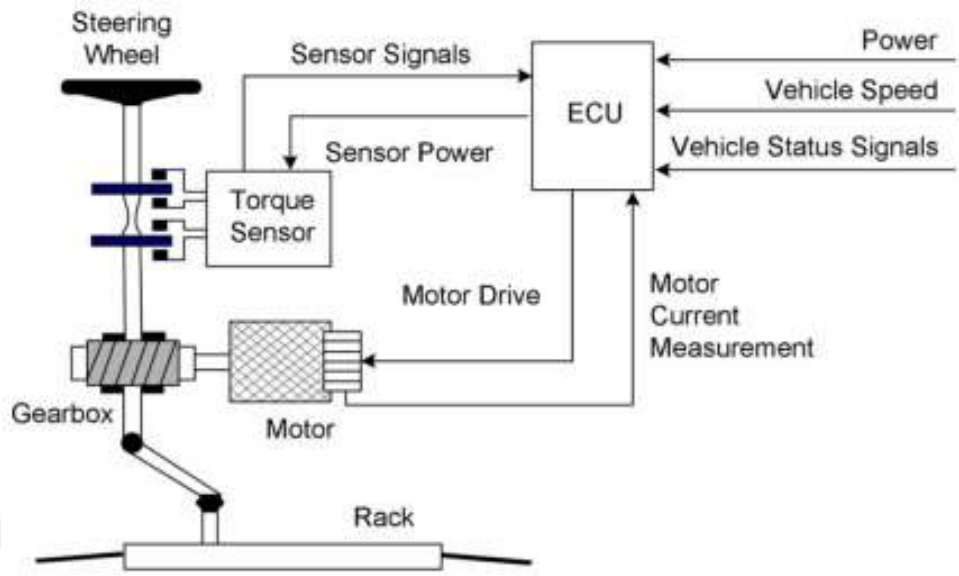


Figure 12: EPS System Diagram

Knowing the mathematical equations of the electric steering system, which consists of electrical and mechanical components, helps to model the system. Equations are derived according to characteristics and behavior.

Newton's linear Force and Moment laws are used while deriving the mathematical model of the mechanical elements of the system. [2]

$$\sum \boldsymbol{F} = \boldsymbol{M}.\ddot{\boldsymbol{X}}$$

$$\sum \boldsymbol{T} = \boldsymbol{J}.\ddot{\boldsymbol{\theta}}$$

$\boldsymbol{M}$: Mass

$\ddot{\boldsymbol{X}}$: Acceleration

J : Inertia

$\ddot{\boldsymbol{\theta}}$: Angular Acceleration

According to the working principle of the system; The torque sensor communicates with an electrical control module by estimating the input torque of the drive via the torsion bar mechanism. The electrical control module must steer the engine in order to properly transmit the auxiliary steering torque. The reduction gear increases the rotational force coming from the engine and transfers it to the steering shaft.

The control of the EPS system is carried out in 2 ways: [10]

a. With torque control, the required assist force is provided.

b. With the steering wheel control, it gives the driver a sense of security during steering in different environments and conditions.

The features of different EPS designs are as follows; [11]

a. Ability to work safely in different driving conditions

b. Dynamic response feature in different driving conditions

c. Adequate steering assist for the driver hard harsh conditions such as parking maneuvers.

d. Minimal noise during steering maneuvers

e. High quality and standard steering features

f. Steering functions are integrated into EPS systems for driver safety and comfort

2.STEERING SYSTEMS CONTROL

2.1.Steering Systems Control Methods

Steering systems were described under 4 main headings in the previous sections.

a. Mechanical Steering Systems
b. Hydrolic Steering Systems
c. Electro-Hydrolic Steering Systems
d. Electric Steering Systems

Steering system controls can also be grouped under similar headings. With the development of technology, the development of users' needs, safety issues and the advancement of regulations; control infrastructures have begun to be created in steering systems.

These electronic infrastructures added to the steering systems, which have a mechanical structure in their basis, are controlled according to various purposes; steering systems have become both more functional and safer.

Due to its electronic infrastructure and control requirements; We can collect steering system control types; under 2 main headings as:

a. Electro-Hydraulic Steering Assisted System (EHPAS) Control
b. Electric Steering Assisted System (EPAS) Control

2.1.1.Electro-Hydraulic Assisted Steering System (EHPAS) Control

Electro hydraulic steering systems; It carries the advantages of hydraulic and electric steering systems together. [12]

The fuel consumption of the system increases as the hydraulic pump in Hydralic Power Assisted Steering (HPAS) Systems is constantly working with the engine. At low vehicle speeds and when parked, the driver must apply less steering wheel torque, however power assist is high. [13]

In electric steering systems, the assist power in the system is provided by the electric motor. This servo motor; The steering system is operated in accordance with the information from the torque and vehicle speed variables. All power during the operation of the steering system is determined by the operating system. In this case, the reactive torque required for steering feel is artificially generated on the steering system. [13]

Electronic control unit and electric actuators are applied to the EHPS to overcome the shortcomings of HPS in terms of fuel economy. This brings the effect of speed into the system, which creates the speed sensitive type power steering system. These systems are called Electro-Hydraulic steering system (EHPS). [14],[8]

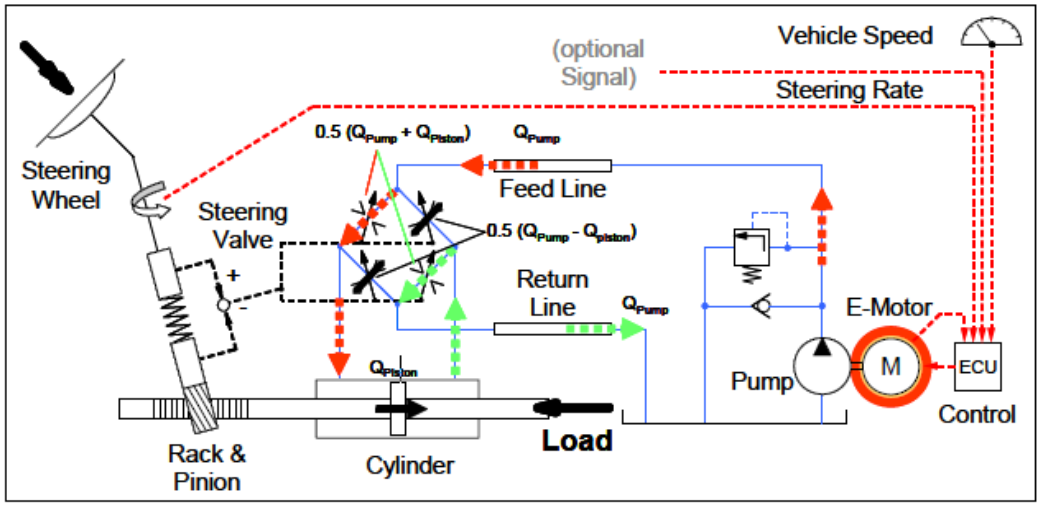


Figure 13: EHPAS System Diagram

In EHPS systems, steering wheel force varies with vehicle speed and driving conditions. This is basically dependent on the steering speed. At low speeds the assist force is greater than at high speeds. At high speed the auxiliary force is less than at low speeds to ensure good road feel and safety. The power ratio of the EHPS changes as the speed changes. At high speed, the power ratio is lower, so steering stability can be improved.

The characteristic curve of the EHPAS system is given in the figure below. [15]

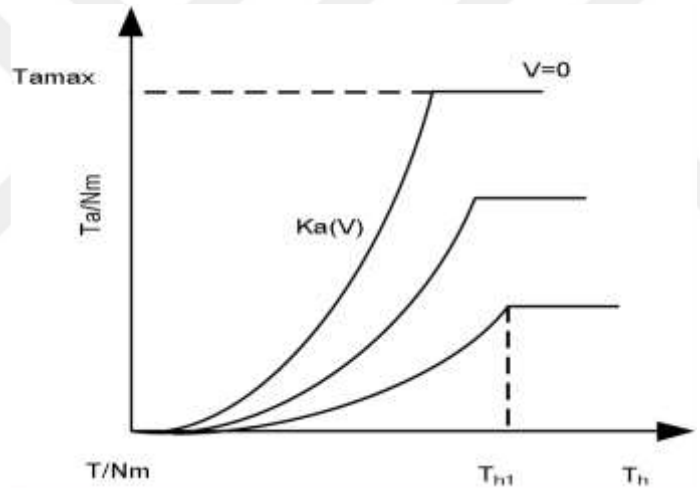


Figure 14: EHPAS System Characteristic Curve

These EHPAS systems consist of three subsystems. [23]

a. Mechanical steering subsystem;
    i. Wheel,
    ii. Steering Column
    iii. Torsion Bar

iv. Recirculation Ball Steering

v. Gear and Steering Links

b. Hydraulic subsystem:

i. E-motor

ii. Pump

iii. Open/Close Center Rotary Valve,

iv. Helper Roller

c. Electronic control subsystem

i. Electronic Control Unit (ECU)

ii. Vehicle Speed Sensor

iii. Steering Ratio Sensor

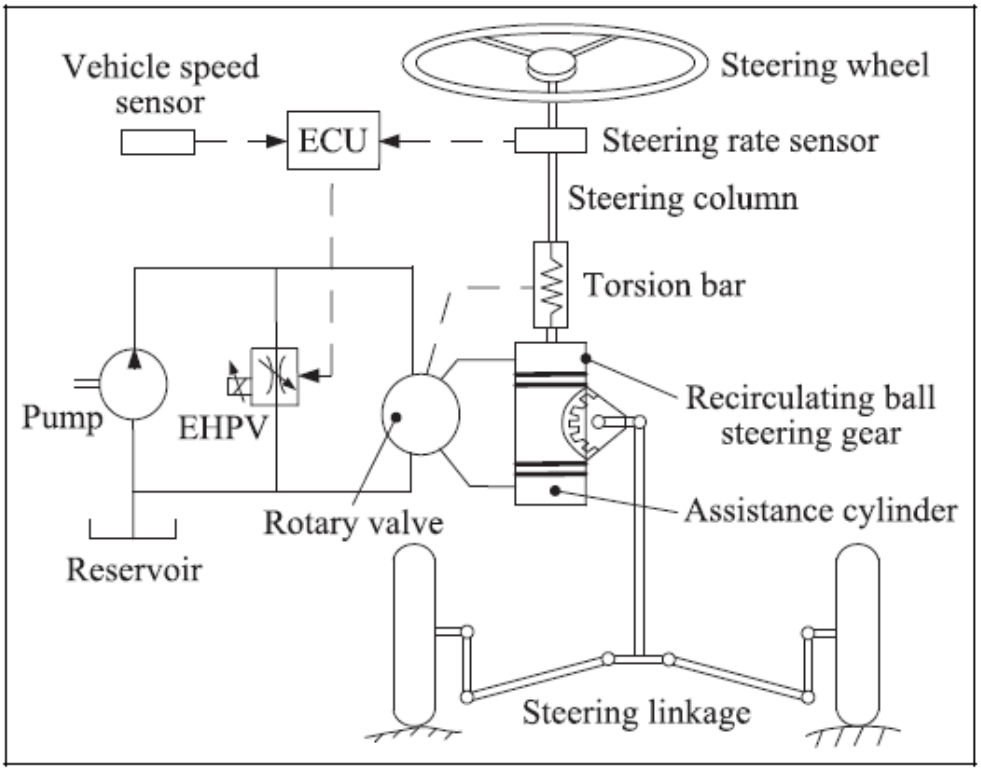


Figure 15: EPHAS System Diagram

Mathematical model of EHPAS; The steering resistance torque consists of the tire alignment torque produced by the cornering force, the alignment torque generated by the gravity of the steering system structure, the internal friction torque of the steering system, and the friction torque between the tire and the road. In order to create the mathematical model of this control system, the following 3 main mathematical models should be examined separately. [17]

a. Steering System Geometric Model
b. Vehicle Model
c. Tire Model

In addition, we can collect EHPAS systems under other 2 main headings:

a. Open Loop Hydraulic Steering System

The conventional power steering system consists of a flow pump driven by a stationary motor.

b. Close Loop Hyraulic Steering System

Contrary to the open-centered hydraulic system; It consists of electronically controlled closed-centre valves that separately control the pressure in each chamber of the slave cylinder.

Open Center and closed Center electro hydraulic steering systems are shown in the graphic below. [18]

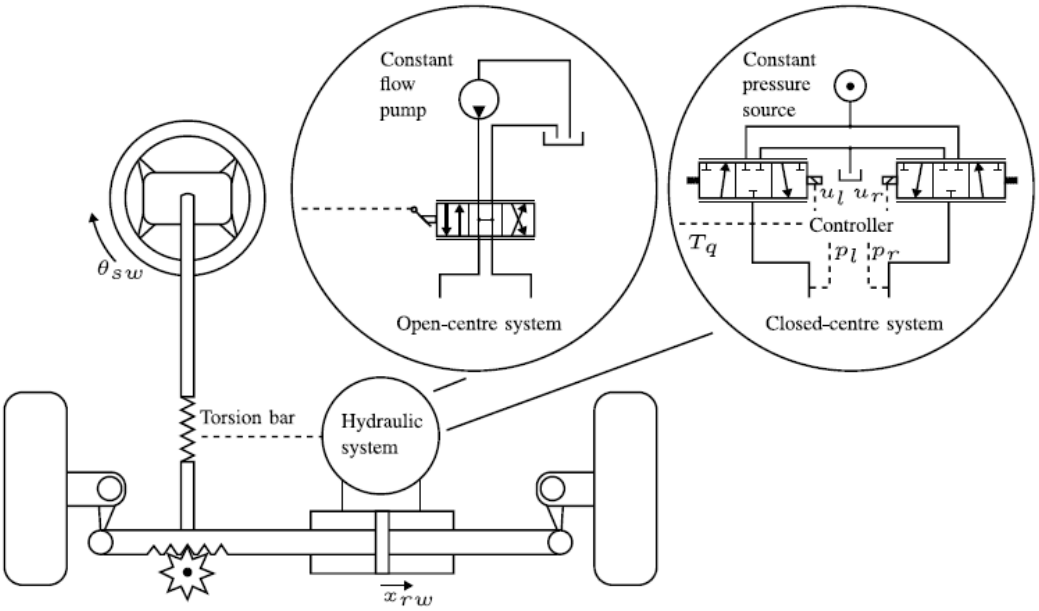


Figure 16: EPHAS Open/Close Loop System

2.1.2.Electric Assisted Steering System (EPAS) Control

Electric Power Assisted Steering (EPAS) System is one of the biggest advancements in the steering system development. Main advantages over conventional HPS systems are: [19]

a. Engine Independence / Fuel Economy

b. Tunability of Steering Feel

c. Modularity / Quick Assembly

d. Compact Size

e. Environmental Friendliness

Although the EPAS system varies according to the application methods of the manufacturers, it consists of the following 6 basic components: [20]

a. Torque Sensor

b. Electric Motor

c. Rotational Angle Sensor

d. Controller

e. Vehicle Speed Sensor

f. Coupling Between Motor and Steering Mechanism

The structure of a basic EPAS system is given in the graph below: [21]

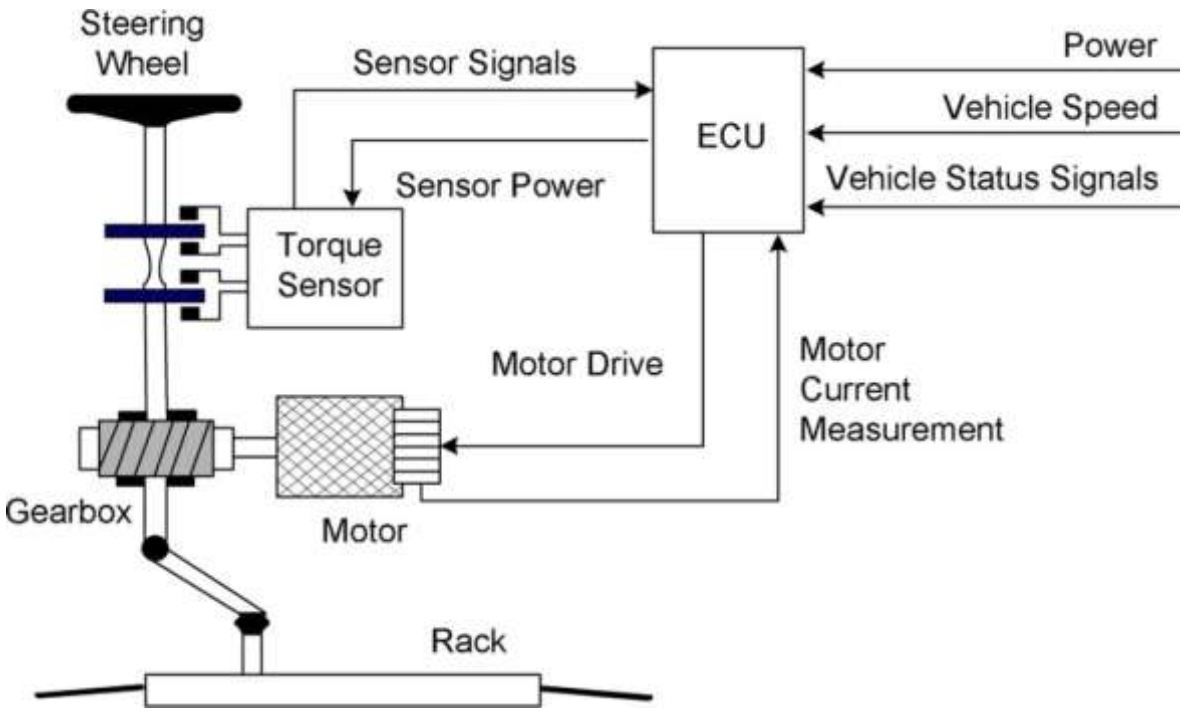


Figure 137: EPAS System Diagram

The torque sensor is one of the most important components on the EPAS system. It measures the effort on the steering wheel and forms the basic input of the algorithm on the system. In addition, vehicle speed is one of the important inputs in this algorithm. [20]

We can basically examine the mathematical model of the EPAS system with 5 ingredient. Before creating the model of the system, the inputs and outputs of the dynamic model should be determined. [22]

Inputs:

a. Steering Torque
b. The Disturbance Torque (comes from the road),

Outputs:

c. Steering Wheel Angle
d. Road Feeling (reaction torque)
e. Tire Angle.

Basic System Block diagram Shown in below figure. [23]

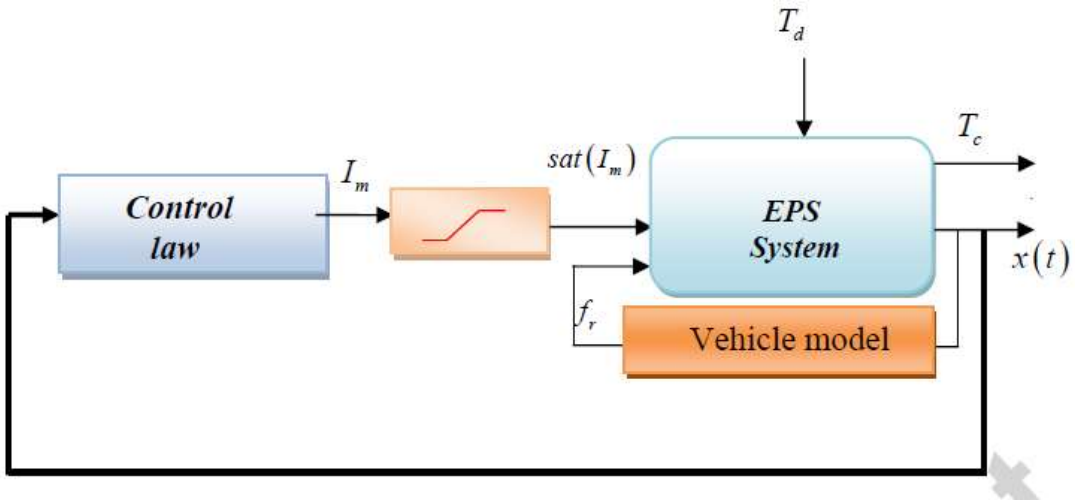


Figure 148: EPAS System Basic Diagram

2.2.Steering Systems ECUs

The information distribution center of the steering system is the ECU. All signals come to the ECU. Auxiliary torques and power flows are calculated for the respective driving situation and sent to the electric motor. The status of the system and the process are monitored by the ECU and necessary measures are taken in the detection of malfunctions.

The torque sensor signals coming to the vehicle's power supply and the angle position of the engine are converted by the input circuits into electrical signals that the ECU can process. [24],[25]

The information coming to the central processing unit (CPU) is used to calculate the current required for the motor phases when the appropriate steering support is created. The CPU must be monitored for the safety of EPS systems. [26]

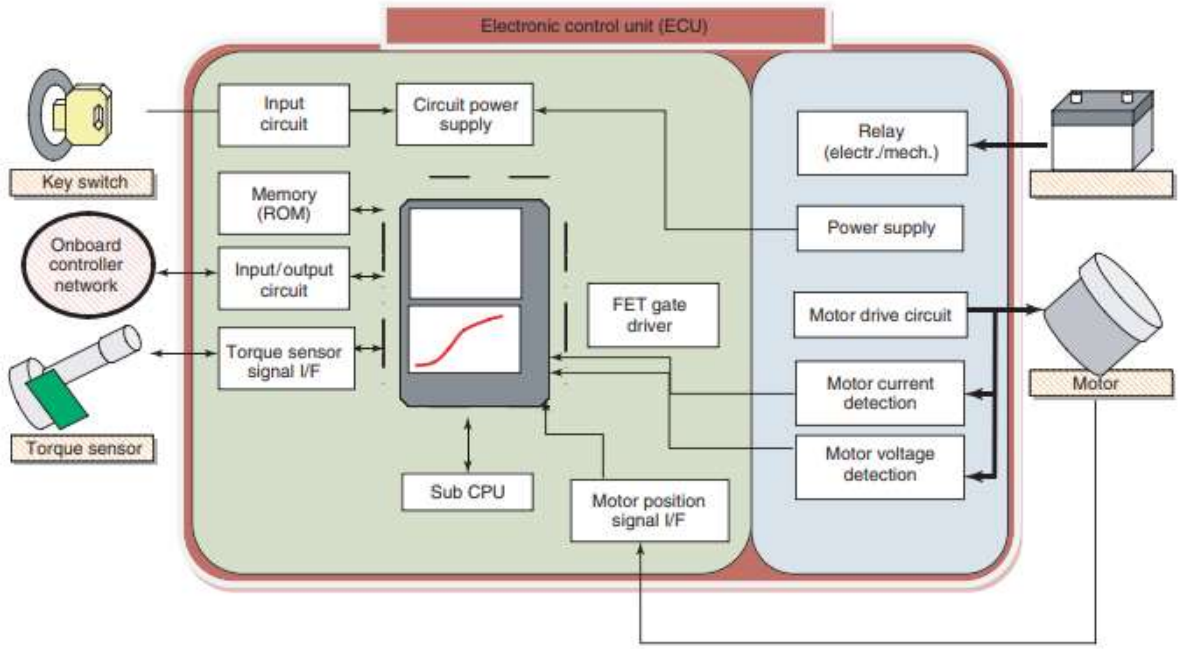


Figure 159: ECU Diagram

2.3. Sensor Technologies

2.3.1.Torque Sensors

In EPS systems, the input variable, the steering torque applied by the driver, is important for calculating the electric steering assistance. There are some features for torque sensors of EPS systems that reach high demands.

a. In order to find the required assisted torque, torque sensors with high angular speeds of 2500°/s -3200°/s and high signal quality are used.
b. The direction of the steering movement and its ability to transmit correct signals are important for the safety of the steering system. Incorrect operation of the control unit can cause incorrect steering assistance. Safety critical topics should be detected and precautions should be taken.
c. It should have low failure rates when exposed to influences such as vibrations, high temperature etc.
d. Low friction or contactless systems are used for subsystems such as the torque sensor.

2.3.2.Electric Motors Angle Sensors

For asynchronous and brushless motors, the motor angle and motor angular speed information is required as the basis of the control algorithm. The task of the angle sensor is to convert the angle position into an electrical signal and transmit it to the ECU. In EPS systems, non-contact solutions such as magnetoresistive (MR) technologies are used to prevent friction.

2.3.3.Steering Angle Sensors

The ECU calculates the steering angle, taking into account the resolution, mechanical gear ratio and mechanical tolerance provided by the engine angle sensor. Engine angle sensors with limited rotation determine the position for only one revolution (360°). It is not possible to determine the absolute position of the engine and steering shaft. To determine the absolute steering angle without electrical equipment, an algorithm is used that can calculate straight-line feed using the rotational speeds of the wheels. Thanks to the elecric motor (EM) angular speed signal, the absolute steering angle can be calculated in EPS systems. When the engine is started, in high-precision and fast EPS systems, the control unit is activated and the position of the absolute steering angle is determined. [11]

2.3.4.Electric Motors

In Electro-Mechanical steering systems, the electric motor converts the electrical energy into the required mechanical support torque. Performance, dynamics, efficiency, acoustics, safety, resistance to environmental factors, cost are important features for an electric motor.

EPS systems use DC motors or brushed DC motors for 500W power, asynchronous motors (ASM) for 300W-500W power,and brushless motors (BLDC) for 900W power. [8]

While the use of brushed DC motor in EPS systems provides the advantage of low cost and simple control, low total power, maintenance of the brushes and electromagnetic interference (EMI) in the commutator are disadvantages. Due to some disadvantages, manufacturers use brushless DC motor (BLDC) in EPS systems. [27]

BLDC motors are preferred in EPS systems due to their low inertia, long life, high efficiency and high power density. To achieve high power density in BLDC motors, high-energy magnets made of neodymium iron boron (NeFeB) are used. [11]

In [9] study, energy optimization is achieved by using the electric motor to assist the steering wheel. In order to provide this, the PID controller produces assisted torque according to the desired energy saving. Two different EPS systems were used in the study, namely EPS with brushed DC motor and EPS with brushless DC motor (BLDC). According to Matlab simulation results, the control methods applied for two different EPS systems provide higher energy optimization.

2.4. Algorithms

The automotive sector is becoming more integrated with technology day by day in line with technological developments. Steering systems contain many different themes in terms of safety, functionality and comfort on the vehicle. As steering systems began to become electronic, many different control methods had to be developed. although these control methods are based on different foundations; It receives input and creates output through conventional systems on the steering system. Although very different algorithms have been developed for these control methods; It is basically based on 3 different control methods. [28],[29]

2.4.1.Vehicle Speed Based Algorithms

In the vehicle speed based algorithms, the highest steering forces are needed when the vehicle speed is the lowest. When the speed of the vehicle is low, it moves at the maximum

torque value (maximum torque speed value). As the vehicle accelerates, the required assisted torque gradually decreases.

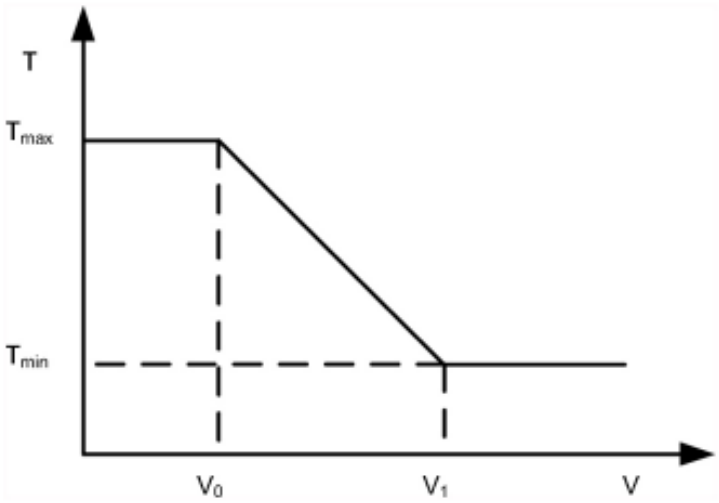


Figure 16: Vehicle Speed Assist Torque Graphic

Mathematical expression of Vehicle Speed Assist Toruqe Graphic;

$$T=\begin{cases} \text{Tmax}: & (0 \leq V < V0) \\ \text{f1}(V): & (V0 \leq V \leq V1) \\ \text{Tmin}: & (V > V1) \end{cases}$$

Tmax represents the highest torque, while Tmin represents the lowest torque. There are different torque values for each different vehicle type. f1(V) is a decreasing function as V increases and expresses a linear function. [30]

2.4.2.Steering Angel Based Algorithms

Steering angle is one of the most important factors affecting the assist torque of the steering system.After a certain angle, the assisted torque starts to increase as the steering angle increases.

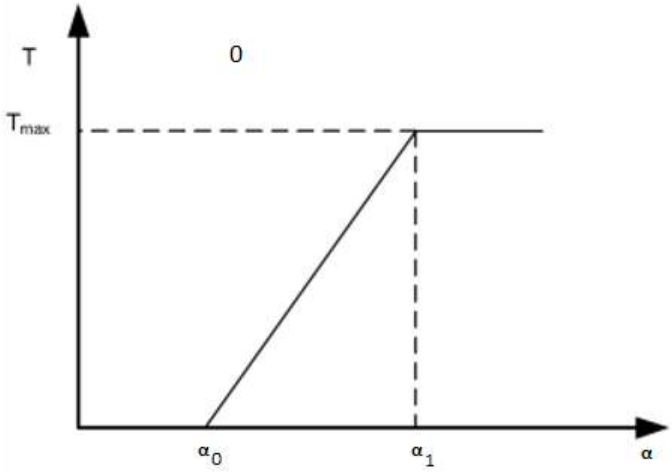


Figure 217: Steering Angle and Torque Graphic

Mathematical expression of Steering Angle and Torque Graphic;

$$T=\begin{cases} 0 & (\alpha \le \alpha 0) \\ f2(\alpha) & (\alpha 0 \le \alpha \le \alpha 1) \\ Tmax & (\alpha \ge \alpha 1) \end{cases}$$

Steering wheel angular velocity consists of three parts. Low angular velocity, medium angular velocity, high angular velocity segment. In the low angular velocity segment, the torque value is zero. In the medium angular velocity segment, the torque increases with the angular velocity. Torque is constant in the high angular velocity segment. Tmax is the maximum torque that the system can reach. f2(ω), is a linear function varying with ω. [31]

After a certain angular speed, the assisted torque starts to increase as the steering angular speed increases. Thus, it can meet the power requirement under emergency steering conditions.

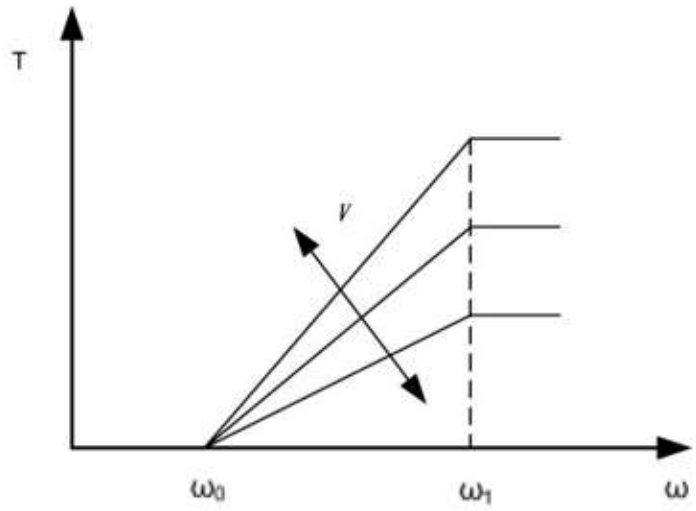


Figure 22: Steering Wheel Angular Velocity and Torque Graphic

Mathematical expression of Steering Angle Velocity and Torque Graphic;

$$T=\begin{cases} 0 & (\omega \leq \omega 0) \\ f2(\omega) & (\omega 0 \leq \omega \leq \omega 1) \\ Tmax & (\omega \geq \omega 1) \end{cases}$$

In driving systems, the torque based algorithm has 2 inputs. The first of these is the angle sensor and the other is the torque sensor. There should be a system that detects the power when the steering wheel is turned. When a slight power is used while turning the steering wheel, the steering pump does not increase its power for nothing, the power given to the steering wheel is sufficient. The steering pump increases its power as the steering becomes difficult while turning the steering wheel. It is not an easy system since 2 sensors are needed. Most vehicles

also have an angle sensor ESP. However, there is no torque sensor. A separate torque sensor needs to be added.

When comparing the two algorithms, the force dependent algorithm can be better. In the speed-dependent algorithm, the steering becomes stiffer as the vehicle accelerates. In force-dependent systems, when the steering wheel is turned with a sudden movement in any sudden situation, the steering wheel is softened according to the power requested by the driver. In the speed dependent algorithm, the pump rotates at the lowest speed when the steering wheel becomes the hardest. If the pump speed is below a certain value, it causes the pump to work inefficiently. The noise of the pump increases as the speed of the pump decreases. The lower limit for the pump speed must be determined and fixed to that value.

2.4.3.Steering Torque Based Algorithms

The main objective of the steering control system is to reduce the driver's steering effort by produce assist torque using an electric motor. The torque required to be produced by the e-motor relate on the demanded torque and vehicle speed. The torque assistance is high at low vehicle speeds; as the vehicle speed increases, the amount of assistance decreases. The control systems must ensure the generation of the desired assist torque, a stable system with assistance, and the motor's quick response to the driver torque command. [32]

When the steering wheel is rotated while driving, the self-aligning torque returns the steering wheel natural position. This situation provides assist to the driver when turning the steering wheel to the middle position, but not too much overshoot; it will have detrimental effects on stable driving. A traditional hydraulic the power steering systems can produce some damping effects with its inertia and friction force. [33]

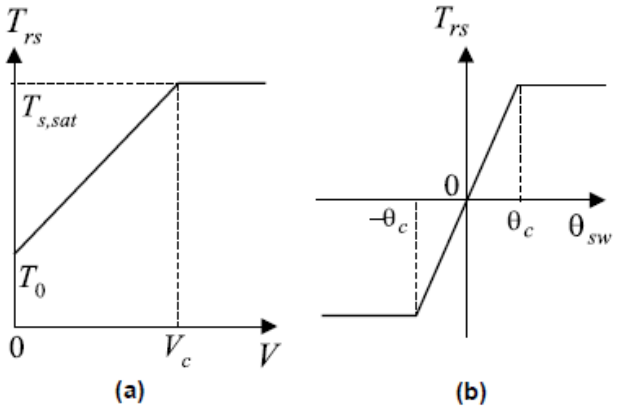


Figure 23: Steering Wheel Angle and Vehicle Speed Torque Graphics

The power assistance is for reducing the steering effort, active damping is to improve the steering stability, and the active return function helps steering wheel returns to center when a driver releases the steering wheel. [34]

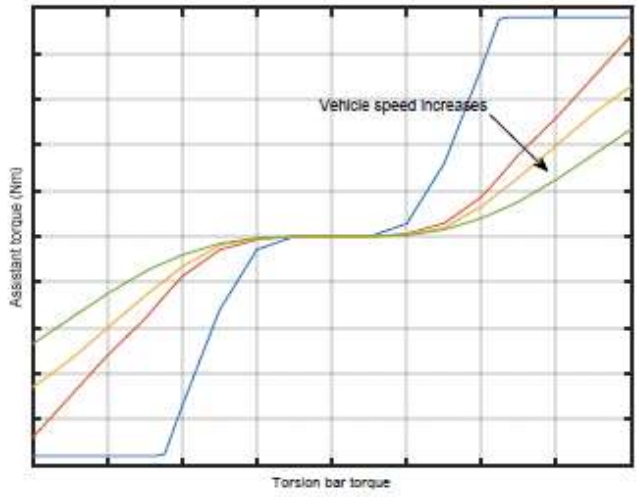


Figure 24: Assistant Torque Vehicle Speed Graphics

3.CITY BUSES STEERING SYSTEM (KENT C / E-KENT)

Commercial vehicle architectures are often built on functionality, payload, or special capability needs. The basic and auxiliary systems on the vehicle are designed in a modular structure to meet at least one of these 3 basic features. For example, specific off-road capabilities are important in a construction machine, while carrying capacity is often the focus of design on a truck. The passenger bus platform, which is the subject of the thesis, is a commercial vehicle type with a length of 12 meters in low floor structure, which is classified as Class I in the regulations, and capable of carrying passengers both standing and sitting. These vehicles generally work all day long between many stops on the lines determined in urban passenger transportation and meet the passenger transportation service. They are of the type that make a lot of stop and go during the day, have a high maneuvering capacity in the city, and are not focused on top speed.

The feature tables of the base electric and diesel versions of the Otokar Kent platform, (Figure 25, Figure 26) the vehicle that we will be subject to in the thesis, are as follows. [35]

TEKNİK ÖZELLİKLER		Kent LF
BOYUTLAR		
Uzunluk	(mm)	: 12000
Genişlik	(mm)	: 2540
Yükseklik	(mm)	: 3145 [maksimum]
İç Yükseklik	(mm)	: 2438
Ön İz Genişliği	(mm)	: 2166
Arka İz Genişliği	(mm)	: 1874
YÜK VE YOLCU TAŞIMA KAPASİTELERİ		
Yerleşim Düzeni		: 26 oturan + 76 ayakta
Alternatif Yerleşim Düzeni		: 26 oturan + 72 ayakta + 1 (tekerlekli sandalye)
MOTOR		
Motor Tipi		: Cummins Turbo şarjlı, Euro 6
Silindir Sayısı		: 6 / Sıralı
Motor Hacmi		: 6,7 lt
Maksimum Güç		: 220 kW @ 2100 d/d
Maksimum Tork		: 1182 Nm @ 1150-1400 d/d
ŞANZIMAN		
Tipi		: Otomatik 6 ileri, 1 geri (standart) Otomatik 4 ileri, 1 geri (opsiyonel)
AKSLAR		
Ön Aks		: Bağımsız tip, 6,5 ton kapasiteli
Arka Aks		: Rijit tip, 11,5 ton kapasiteli
SÜSPANSİYON		
Ön		: 2 Hava Körüğü, 2 Hidrolik Amortisör, 1 Seviye Sensörü
Arka		: 4 Hava Körüğü, 4 Hidrolik Amortisör, 2 Seviye Sensörü
FRENLER		
Servis Freni		: Tam kuru havalı, Çift devreli ABS, ASR, EBS
Ön Fren		: Disk
Arka Fren		: Disk
Park Freni		: Pnömatik, Arka tekerlere etkili
DİREKSİYON		
Direksiyon Tanımı		: Hidrolik
LASTİKLER		
Lastik		: 275/70 R22,5
KAPILAR		
Ön Kapı		: Çift kanat içe açılır, Hava tahrikli
Orta Kapı		: Çift kanat içe açılır, Hava tahrikli
Arka Kapı		: Çift kanat içe açılır, Hava tahrikli
ELEKTRİK EKİPMANLARI		
Aküler		: 2x12 V 225 Ah
Alternatörler		: 24 V, 2x120 A

Figure 25: Kent C Spesifications

TEKNİK ÖZELLİKLER			*Kent Electra*
BOYUTLAR			
Araç Uzunluğu	(mm)	:	12.000
Araç Genişliği	(mm)	:	2.540
Araç Yüksekliği Klimalı	(mm)	:	3.220 [Maksimum]
İç Yükseklik (Koridor)	(mm)	:	2.358
Ön İz Genişliği	(mm)	:	2.158
Arka İz Genişliği	(mm)	:	1.911
YOLCU KAPASİTESİ *			
Yerleşim Düzeni		:	27 oturan + 52 ayakta
Alternatif Yerleşim Düzeni		:	27 oturan + 47 ayakta + 1 tekerlekli sandalye
AĞIRLIK			
Azami Yüklü Ağırlık	(kg)	:	18.000
MOTOR			
Motor		:	Voith Elektrikli Motor
Maksimum Güç		:	410 kW
Maksimum Tork		:	3100 Nm
BATARYA			
Batarya Tip		:	Lityum İyon / NMC
Batarya Kapasitesi		:	210 kWh
Batarya Voltajı		:	800 VDC [Maksimum]
Şarj Süresi */**		:	<2 saat
Şarj Fişleri		:	Combo2
AKSLAR			
Ön Aks		:	Bağımsız tip, 6.5 ton kapasiteli
Arka Aks		:	Rijit tip, 11.5 ton kapasiteli
SÜSPANSİYON			
Ön		:	2 Hava Körüğü, 2 Hidrolik Amortisör
		:	1 Seviye Sensörü, Viraj Denge Çubuğu
Arka		:	4 Hava Körüğü, 4 Hidrolik Amortisör
		:	2 Seviye Sensörü, Viraj Denge Çubuğu
FREN SİSTEMİ			
		:	EBS, ABS, ASR
Ön Fren		:	Disk
Arka Fren		:	Disk
Park Freni		:	Pnömatik Arka Tekere Etkili
Yardımcı Frenler		:	Rejenerasyon
KAPILAR			
Ön Kapı		:	Çift kanat içe açılır, Hava tahrikli, Uzaktan kumandalı, Yolcu sıkışmasını önleyen emniyet sistemi - Çift yönlü
Orta Kapı		:	Çift kanat içe açılır, Hava tahrikli, Yolcu sıkışmasını önleyen emniyet sistemi - Çift yönlü
Arka Kapı		:	Çift kanat içe açılır, Hava tahrikli, Yolcu sıkışmasını önleyen emniyet sistemi - Çift yönlü
LASTİKLER			
Lastik		:	275/70 R22,5"
Jant		:	Çelik Jant

Figure 26: E-Kent Spesifications

As can be seen in the specification tables, both the electric E-Kent vehicle and the Diesel Kent C vehicle basically share a common chassis systems infrastructure:

The basic spesifications of both vehicles such as front and rear axles, heights, gross vehicle weights (GWV), hydrolic-powered steering systems are same. In other words, the electric E-Kent vehicle is the electrified version of the Diesel Kent C vehicle. A simple definition; In the Diesel City C vehicle, the systems operated with the energy obtained from the diesel engine are operated over the battery and electrical systems in the Electric E-Kent vehicle. These systems are the air system, the traction system, the general electrical system of the vehicle, and the steering system etc.

As it is the subject of this thesis, during the electrification of the diesel vehicle to an electric vehicle, the need to drive the hydraulic steering system in the electric vehicle with an electric motor (EM) and a gear pump instead of a mechanical pump. In the next sections of thesis, the steering systems of both the electric E-Kent and diesel Kent C vehicles will be explained.

3.1.Kent C Steering System

Kent C; has 12m vehicle length, 5900 mm wheelbase, 2158 mm front and 1911 mm rear track width, 8 Tons front axle load, 275/70/R22,5 tires (2 on the front axle and 4 on the rear axle, totally of 6 tires are used), a Class I Low Floor type City Bus.

3.1.1.Front Axle Structure

In Front chassis system layout of the Kent C, an independent front axle which has a hub-to-hub width of 2446 mm, 2,5° caster, 8° kingpin angles, double wishbone structure, and a carrying capacity of 8,2 tons is used. R22,5 155mm offset rims and 275/70 size tires attached to these wheels are used on these axles.

There are 2 air suspension bellows and 2 shock absorbers on front the axle. For the steering geometry of the vehicle, 2 tie rods which are also supported on the knuckle arms on the hub, are connected to the L and I arms. There is also an intermediate rod for the continuity of the kinematics between the L and I arms. In addition, the L arm is also connected to the pitman arm with rod for the roll stability of the bus, there is an anti-roll bar on the front axle.

The 3D data image of the front axle assembly is given in Figure 27.

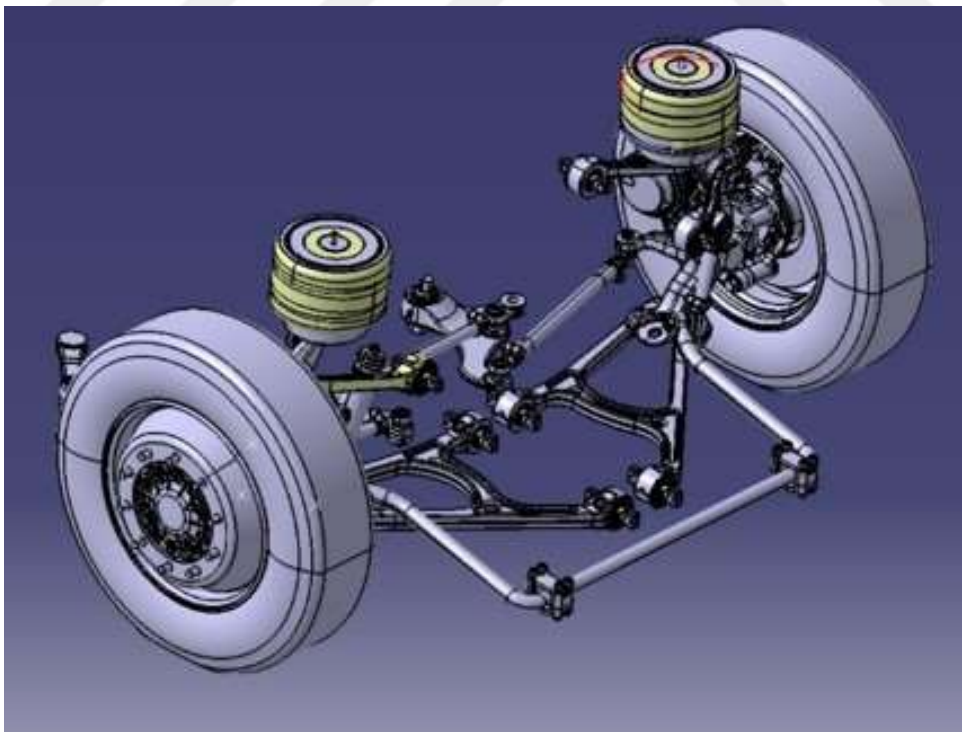


Figure 27: Steering Wheel Angular Velocity and Torque Graphic

3.1.2.Components

3.1.2.1.Steering Gear Box

The assisting force in the Diesel City C vehicle's steering system is created by a hydraulic steering box. This steering box has a variable gear ratio of 22.2:1 – 26.2:1 and has a ±3,1 turning capacity. The flow requirement of the steering gear box is between 12-25 l/min. There is a pressure release valve at the level of 180 bar as a precaution in case of excessive pressure that may occur on the steering system.

The 3D data image of the steering gear box is given in Figure 28.

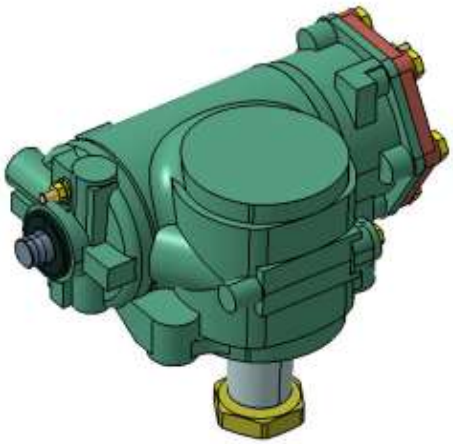


Figure 28: Kent C Steering Box

3.1.2.2.Steering Pump

On the Diesel City C Vehicle steering system, the steering box is flown through a vane pump located on the diesel engine which has 10 kW theoritical power. Due to its design, this pump has a variator working principle; In case of pressure increase on the steering box, it can manage the flow and pressure control with the physical movement of the pallets without changing the demanded flow. The steering pump is driven by the engine crank.

The 3D data image of the steering pump is given in Figure 29.

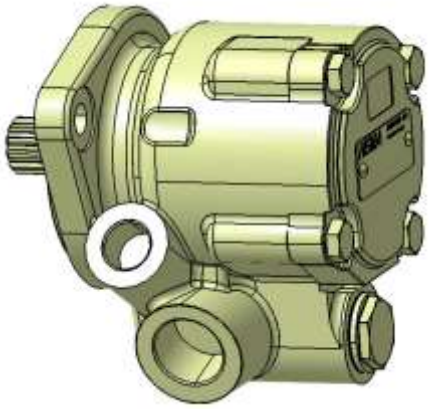


Figure 29: Kent C Steering Pump

3.1.2.3.Hydrolic Line and Reservoir

There is a 30 m long hydraulic line on the Diesel City C Vehicle's steering system to transmit the flow between the steering box and the steering pump. This line consists of 3 parts: pressure line, return line and suction line. The maximum pressure that can occur on the steering system; Although it is limited to 180 bar by the release valve on the steering box, the pressure burst levels of the pipes forming the hydraulic line are determined as 250 bar. In addition, a 2.5 liters reservoir was used to create a control volume on the line. Hydraulic volume level control can also be done from this reservoir. Total of 6 liters of API Class II type hydraulic fluid is used in the 12m Diesel Kent C vehicle.

The 3D data image of the hyrolic line is given in Figure 30.

Figure 30: Kent C Hydrolic Line

3.1.2.4.Pitman Arm

Diesel City C Vehicle's steering system has a forged metal pitman arm with a 210mm force arm length that transmits the rotational movement created by the steering box to the front axle arrangement via rods. This pitman arm is designed to withstand a moment of 880 N/mm2 that may occur in the steering force.

3.1.2.5.Steering Columns

On the steering system of the Diesel City C Vehicle, the shafts that transmit the movement of the steering wheel to the steering box and the cardan shafts joints between the columns are used to provide the axial direction changes of these shafts. In addition, the idler shaft under the steering wheel; It has variable stroke capability. Thus, with the adjustable steering mechanism, the driver can adjust the steering system according to the desired position.

The 3D data image of the steering Columns is given in Figure 31.

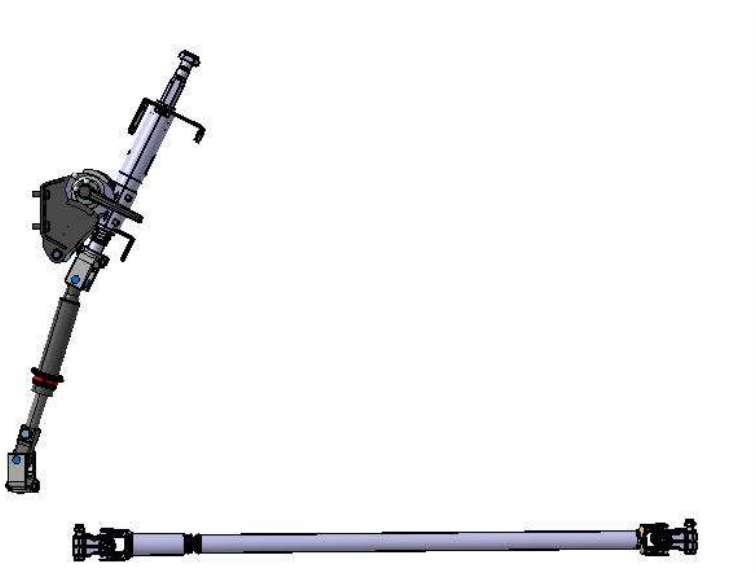


Figure 31: Kent C Steering Columns

3.1.2.6.Steering Link Box

On Diesel City C Vehicle's steering system, 1:1 ratio converter gear box is used for motion transmission at an angle of 90°. Due to the design of the 12m LF city bus, the driver sits in front of the front axle and in the front overhang area. Therefore, the use of this part was needed to transfer the steering movement to front axle.

The 3D data image of the steering Steering Link Box is given in Figure 32.

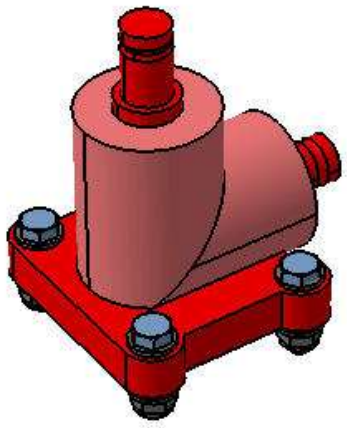


Figure 32: Kent C Steering Link Box

3.1.2.7.Steering Wheel

A steering wheel which has 450 mm of diameter is used on the steering system of the Diesel City C Vehicle. This steering wheel is designed to provide the driver with the highest comfort and maneuverability, taking into account the steering system forces, the number of steering turns and UN ECE/R79 regulations of the commercial vehicles steering system. [36]

The 3D data image of the steering Steering wheel is given in Figure 33.

Figure 33: Kent C Steering Wheel

3.1.3.Assist System

Diesel City C Vehicle steering system is basically a closed-loop hydraulic system. The hydraulics which are flown by the vane pump on the diesel engine are rotated along the line. According to the working principle of the steering box; when operated according to the demandss, it creates a pressure field. This pressure created appears as assist force or assisted torque between the sector shafts.

The 3D data image of Diesel Kent C Steering System is given in Figure 34 and 35.

Figure 18: Kent C Steering System

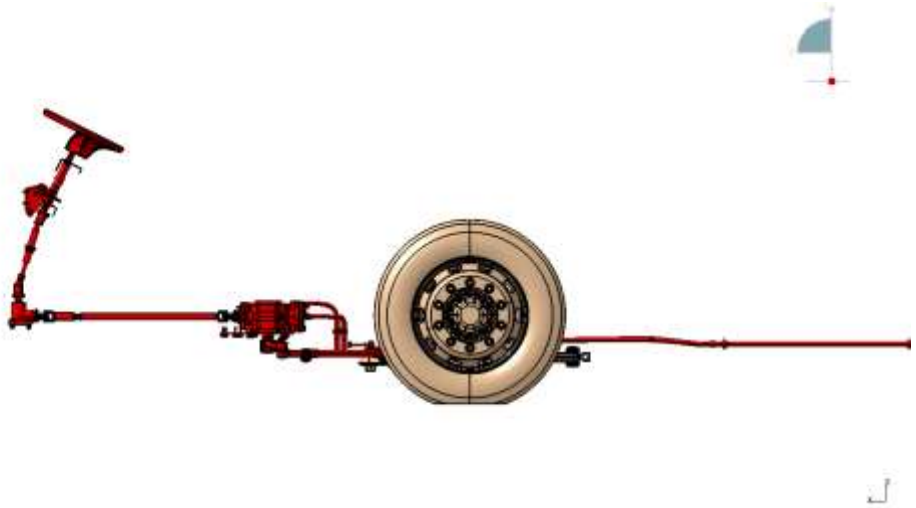


Figure 35: Kent C Steering System

3.2.E- Kent Steering System

E- Kent has 12m vehicle length, 5900 mm wheelbase, 2158 mm front and 1911 mm rear track width, 8 Tons front axle load, 275/70/R22,5 tires (2 on the front axle and 4 on the rear axle, totally of 6 tires are used), a Class I Low Floor type City Bus.

As a base, it is indistinguishable from the Diesel Kent C vehicle. However, due to its packaging and layout, there are weight distribution differences according to the diesel Kent vehicle.

3.2.1.Front Axle Structure

The front layout of the E-Kent vehicle is the same as in the diesel Kent C vehicle. on Front chassis system layout of the E-Kent, an independent front axle which has a hub-to-hub width of 2446 mm, 2,5° caster, 8° kingpin angles, double wishbone structure, and a carrying capacity of 8,2 tons is used. R22,5 155mm offset rims and 275/70 size tires attached to these wheels are used on these axles.

There are 2 air suspension bellows and 2 shock absorbers on front the axle. For the steering geometry of the vehicle, 2 tie rods which are also supported on the knuckle arms on the hub, are connected to the L and I arms. There is also an intermediate rod for the continuity of the kinematics between the L and I arms. In addition, the L arm is also connected to the pitman arm with a rod. For the roll stability of the vehicle, there is an anti-roll bar on the front axle.

The 3D data image of the front axle assembly is given in Figure 36.

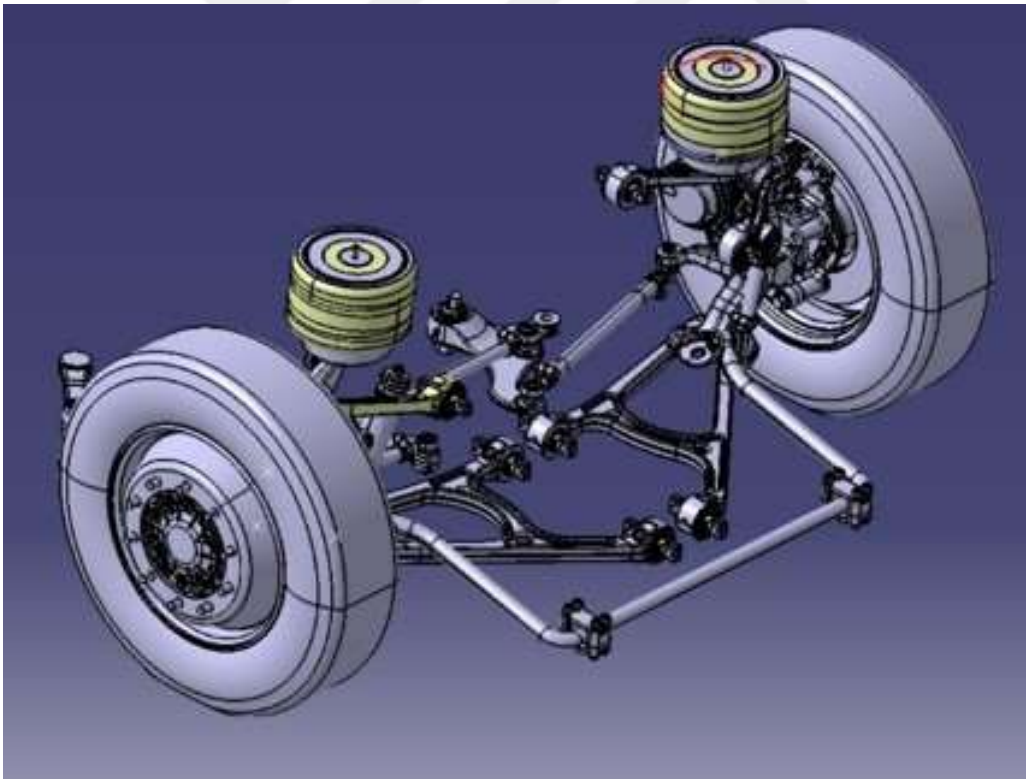


Figure 36: E-Kent Front Axle

3.2.2.Components

3.2.2.1.Steering Box

The assisting force in the electric E-Kent vehicle's steering system is created by same hydraulic steering box on diesel Kent C. This steering box has a variable gear ratio of 22.2:1 – 26.2:1 and has a ±3,1 turning capacity. The flow requirement of the steering gear box is between 12-25 l/min. There is a pressure release valve at the level of 180 bar as a precaution in case of excessive pressure that may occur on the steering system.

The 3D data image of the steering gear box is given in Figure 37.

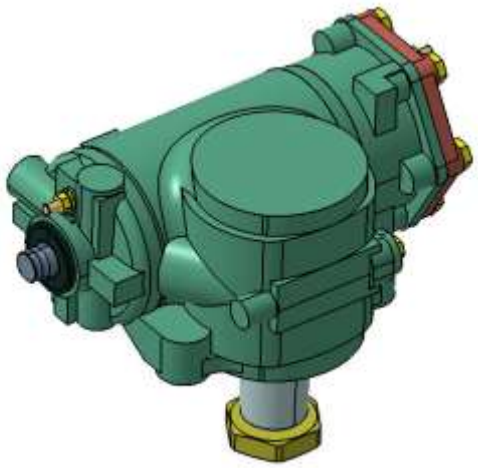


Figure 37: E-Kent Steering Box

3.2.2.2.Steering Pump

On the steering system of the E-Kent vehicle, the steering box is different from the diesel Kent C vehicle. An electric motor is coupled to a gear pump. Due to its structure, this pump produces constant flow under constant speed. In order to change the demanded flow in case of pressure increase on the steering box, the flow and pressure control can be managed by

changing the electric motor speed. The steering pump has a displacement of 8cc. The electric motor used behind the pump has a continuous power of 4 kW and a peak power of 8.5 kW.

The 3D data image of the steering pump is given in Figure 38.

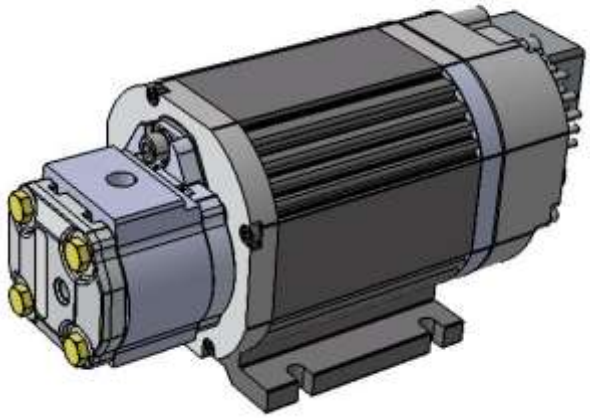


Figure 38: E-Kent Steering Pump

3.2.2.3.Hydrolic Line and Reservoir

On the steering system of the E-City Vehicle, there is 4 meters length hydraulic line to transmit the flow between the steering box and the steering pump. The reason for keeping this line so short is to minimize the flow energy loss that may occur along the hydraulic line. This line consists of 3 parts: pressure line, return line and suction line. The maximum pressure that can occur on the steering system; Although it is limited to 180 bar by the release valve on the steering box, the pressure burst levels of the pipes forming the hydraulic line are determined as 250 bar. In addition, a 2,5 liters reservoir was used to create a control volume on the line. Hydraulic volume level control can also be done from this reservoir.

On the E-Kent Bus, 3,5 liters of API Class III type hydraulic fluid is used in the line.

The 3D data image of the steering pump is given in Figure 39.

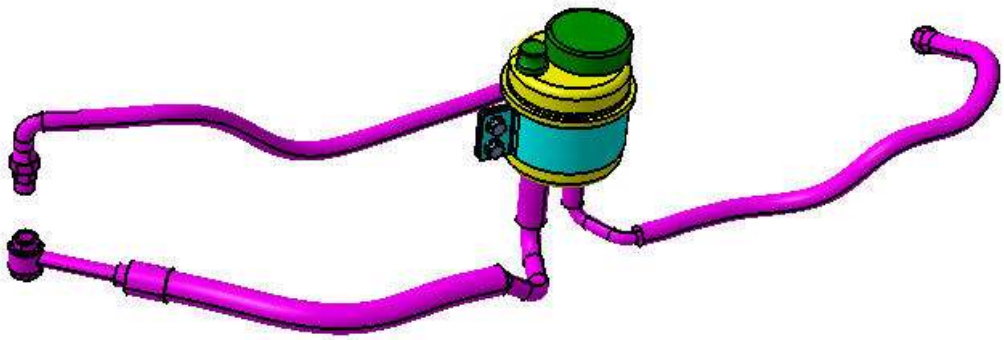


Figure 39: E-Kent Steering System Hydrolic Line

3.2.2.4.Pitman Arm

Electric E-Kent Vehicle's steering system has a forged metal pitman arm with a 210mm force arm length that transmits the rotational movement created by the steering box to the front axle arrangement via rods. This pitman arm is designed to withstand a moment of 880 N/mm2 that may occur in the steering force.

The 3D data image of the pitman arm is given in Figure 40.

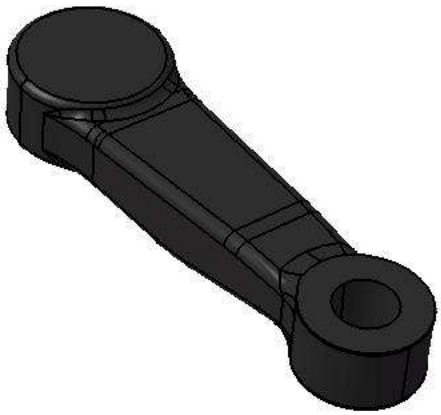


Figure 40: E-Kent Pitman Arm

3.2.2.5.Steering Columns

On the steering system of the E-Kent Bus, the shafts that transmit the movement of the steering wheel to the steering box and the cardan shafts joints between the columns are used to provide the axial direction changes of these columns. These components and their placement are exactly the same as the diesel diesel Kent C vehicle. Due to the fact that all basic structures of both vehicles such as seating position, front axle placements, steering box placements are the same. Again, as in the Diesel Kent C vehicle, the idler shaft under the steering wheel in the E-Kent vehicle; It has variable stroke capability. Thus, with the adjustable steering mechanism, the driver can adjust the steering system according to the desired position.

The 3D data image of the steering columns is given in Figure 41.

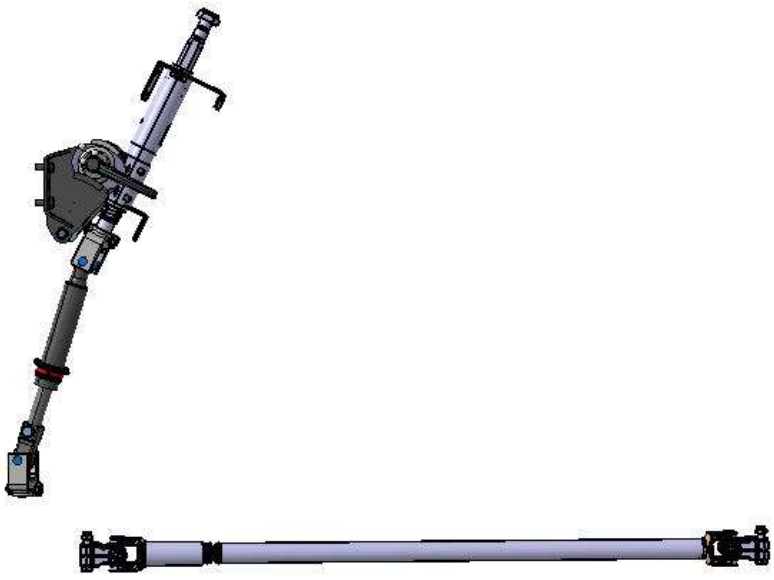


Figure 41: E-Kent Steering Columns

3.2.2.6.Steering Link Box

On the steering system of the E-Kent Bus, 1:1 ratio converter gear box is used for motion transmission at an angle of 90°. Due to the design of the 12m LF city bus, the driver sits in front of the front axle and in the front overhang area. Therefore, the use of this part was needed to transfer the steering movement to front axle.

Again, these components and the placement of these components are exactly the same as the diesel Kent C vehicle due to the fact that all basic structures of both vehicles such as seating position, front axle placements, steering box placements are the same.

The 3D data image of the steering link box is given in Figure 42.

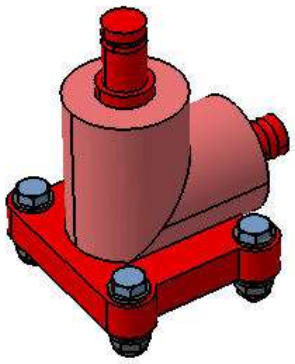


Figure 42: E-Kent Steering Link Box

3.2.2.7.Steering Wheel

A steering wheel which has 450 mm of diameter is used on the steering system of the E-Kent Bus. This steering wheel is designed to provide the driver with the highest comfort and maneuverability, taking into account the steering system forces, the number of steering turns and UN ECE/R79 regulations of the commercial vehicles steering system. [36]

Again, these components and the placement of these components are exactly the same as the diesel Kent C vehicle due to the fact that all basic structures of both vehicles such as seating position, front axle placements, steering box placements are the same.

3.2.3.Assist System

E-Kent Vehicle steering system is basically a closed-loop hydraulic system. The hydraulics which are flown by electric pump are rotated along the line. According to the working principle of the steering box; when operated according to the demands, it creates a pressure field. This pressure created appears as assist force or assisted torque between the sector shafts. Flow and pressure control in this system is carried out by electric motor speed management.

The 3D data image of E- Kent Steering System is given in Figure 43 and Figure 44.

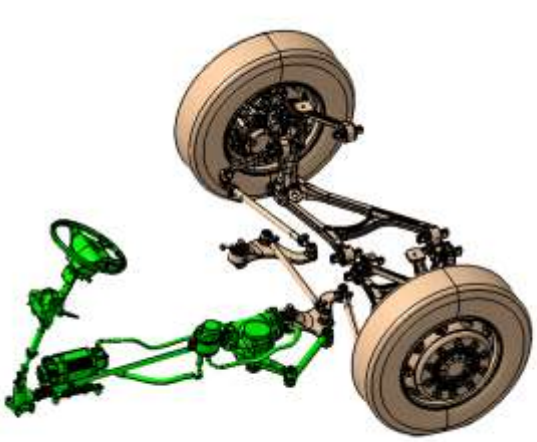


Figure 43: E-Kent Steering System

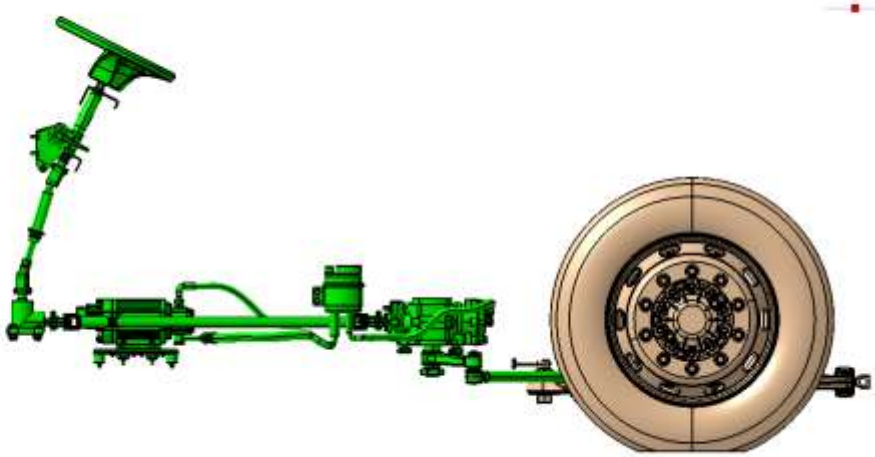


Figure 44: E-Kent Steering System

4.STEERING SYSTEM ENERGY CONSUMPTION STUDY

The steering system of the Kent city bus, which is the subject of the thesis, was explained under the title of Commercial Vehicles Steering Systems in Chapter 3. We mentioned that the capacity of the steering box and steering pump used in the current vehicle has also been selected to meet the forces that occur as a result of vehicle dynamics.

The current vehicle has a steering box with a flow rate of 12-25 l/min and a 180 Bar pressure release valve. A steering box of this capacity can assist the steering system of a 12m Low Floor city bus with 275/70/R22,5 tires, 8 tons of front axle load, 80km/h maximum speed, within the framework of regulative rules.

4.1.Reguiatons and Vehicle Spesifications

Steering systems of vehicles are within the scope of UN ECE/R79. Within this scope, many development, test and safety criteria related to the steering systems of the vehicles have been standardized. [36]

Steering system requirements for vehicles in this class are given in Table 2. Kent Buses, which we have discussed in the thesis, are accepted in the M3 class. As can be seen from the table, the forces that must be regulated in the active and passive positions for the steering system are standardized by the regulations. In addition, the turning diameters and action time limits of the vehicles are standardized by the regulation. All development activities of the vehicle were carried out within the scope of these regulations. The result to be obtained in the thesis study will also be tested and approved again within the framework of this regulation.

Table 2: Steering Control Effort Requirements

VEHİCLE CATAGORY	INACT			WITH FAILURE		
	Maximum Effort (daN)	Time(s)	Turnin Radius (m)	Maximum Effort (daN)	Time(s)	Turning Radius (m)
M1	15	4	12	30	4	20
M2	15	4	12	30	4	20
M3	20	4	12	45	6	20
N1	20	4	12	30	4	20
N2	25	4	12	40	4	20
N3	20	4	12	45	6	20

The power of the steering box used in the Kent vehicles, which is the subject of the thesis, operates between the flow and pressure values in the specified ranges can be calculated with the following formula:

P = (p X Q) / 540

P : Power (kiloWatt ; kW)

p : Pressure (bar)

Q : Flow (lt / min)

On the diesel vehicle configuration, this demand is met by a 10 kW variable displacement mechanical pump on the internal combustion engine. The pressure and flow values formed on the box in line with the current steering system forces of the vehicle determine the power that the steering pump will demand over the internal combustion engine. This variable situation occurs within the framework of mechanical principles and the steering pump works like a variator, providing the necessary flow and pressure for the steering box.

The flow values specified in the box specifications should never fall below 12 l/min. This value is the main factor that creates the necessary assisting force by keeping the volume on the steering box permanently full.

In line with the excessive force demand that will occur in the steering system, this power cannot be provided by the pump and if the flow rate falls below this figure, the volume in the steering box cannot be filled completely and there will be momentary interruptions in the assisting force. This phenomenon is called 'stabbing'.

Stabbing is a situation that should definitely not be encountered in line with security criteria. During a steering maneuver performed by the driver at a constant speed, this situation, which will be encountered with the momentary interruption of the assist force, may cause serious safety risks by causing the maneuver to be interrupted or completed late. The precaution to be taken in this situation is even more critical, especially in commercial vehicles with a large number of steering turns.

The power capacity of the steering pump to be used on the vehicle is determined in line with the maximum power demanded by the steering box in the case of maximum pressure and flow.

If this power is calculated according to the formula given above;

P = (p X Q) / 540

P = (180 X 25) / 540 = 8,34 kW

The maximum power demanded by the box for the Diesel Kent C is around 8.5 kW.

Although the maximum power to be drawn is 8.5 kW, these levels can be reached under some harsh conditions. These conditions are; low speeds, high speed sudden maneuvers,

parking maneuvers etc. However, when the total duty cycle of a vehicle is considered, the situations requiring peak power above are rarely encountered and the average energy consumption will be well below the maximum pump power. These situations and the average pressure and energy consumption values are more clearly expressed in the collected data.

As explained in Chapter 3, Diesel Kent and electric E-Kent vehicles share all systems that will affect the basic vehicle dynamics, such as front axle systems, steering boxes, vehicle wheelbases, and front axle loads. The steering box of the electric E-Kent vehicle, which is also powered by hydraulic assistance, had to be driven by an electrically driven pump in this vehicle due to electrification.

Since the steering boxes of electric and diesel vehicles are the same, the boundary conditions of the demands of steering boxes will be also same. The existing steering box has been chosen in such a way that it can cover the forces caused by the vehicle dynamics of both vehicles. In both vehicles with a common steering box, it is expected that the same forces that the steering box will demand from the steering pumps that powers (paddle mechanical pump for diesel vehicle, electric drive pump for electric vehicle) are expected to be the same.

In this case, there was a need to select an electric pump of at least 8.5 kW in the existing E-Kent Bus. Considering the cumulative energy consumption of electric vehicles, it is not possible to continuously operate the pump feeding the steering box to the maximum. Therefore, it is necessary to drive the electric vehicle steering pump continuously to provide optimum energy needs and to operate in a setup that can provide peak power in cases where the pressure and flow rate increase. The basis of this thesis is to produce a solution to this problem.

On diesel Kent C vehicle, a pump that meets the need for extra maximum power can demand power from the engine with a mechanical infrastructure, according to the energy need

arising from the power demand, while this operating characteristic for electric vehicles should be designed algorithmically and managed by the vehicle energy management system.

In this thesis study; It is aimed to solve this algorithmic problem with the data already generated on the vehicle and to catch the optimum energy consumption of the steering system in a diesel vehicle.

In the previous sections of this thesis, it has been mentioned that the basic steering system components (such as front axle, tire sizes, wheelbase, front axle geometry, steering box) in the steering systems of the diesel Kent C vehicle and the electric E-Kent vehicle are the same. In addition, due to electrification, the electric E-Kent vehicle has differences from the diesel Kent C vehicle in terms of packaging. In the electric E-Kent bus, unlike the diesel Kent C vehicle, there are systems such as 2400 kg battery pack on the roof, 150 kg VIB unit and 350 kg pantograph etc. On the other hand, in the electric E-Kent vehicle, an engine weighing 800 kg and a gearbox of around 450 kg have been reduced from the engine room. In addition, considering the downforce axle weights of these vehicles to the extent permitted by the highway regulations, the interior layouts of the vehicles have been designed differently from each other in order to achieve the optimum level.

As can be seen in Table 3, the COGs, curb weights and heights of electric E-Kent Bus and Diesel Kent C Bus are different from each other. As a result, as can be seen in Table 4, the vehicle dynamic behaviors of these vehicles under the same effects are also different from each other. On Table 4; the roll limits, body tilt angles and Iso lane change statistics of both buses under static and dynamic conditions are shared.

Table 3: Vehicle Spesifications

Vehicle	Height	Load Condition	Weight	z-COG
Kent C	3245	Laden	12510	1060mm
	3245	Unladen	17957	1109mm
E-Kent	3410	Laden	12510	1743mm
	3410	Unladen	18962	1562mm

Table 4: Vehicle Dynamic Characteristics

	Lift-Off Limit			Roll Angle	ISO Lane Change	Tilt Table
Vehicle	G Limit	Angle Limit	Steering Angle			
Kent C	0.58G	2.36°	210°/4s	0.4°/0.1G	1.7°/0.43G	36°
	0.52G	2.1°	190°/4s			N/A
E-Kent	0.33G	1.74°	150°/4s	0.53°/0.1G	3.44°/0.43G	23.7°
	0.39G	2.75°	150°/4s		3.9°/0.43G	N/A

4.2.Modifications

At the beginning of the study, in order to ensure that the vehicle dynamics behavior of the diesel Kent C Bus is similar to the electric E-Kent Bus, the Diesel Kent C vehicle was modified and the vehicle scale weight, front axle and rear axle weight distributions, vehicle layouts were made similar to each other. In order to make the weight distribution of the vehicles similar, many welded constructions were carried out on the diesel vehicle and dummy weights were added. As a result of the modifications, the COG values of the vehicles are brought to the same level and when the same inputs such as vehicle speed, steering maneuver, acceleration or braking are given; It is aimed to get similar outputs from roll, pitch, yaw moments as output.

In this context, the images of the modification steps can be seen in the Figure 45 and 46.

Figure 45: Kent C Modification Process

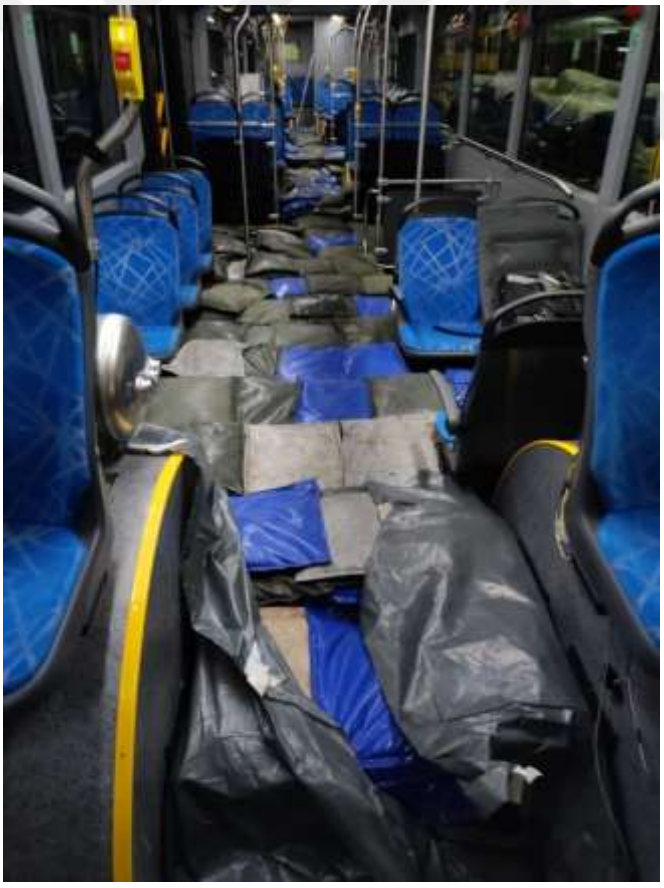


Figure 46: Kent C Modification Process

4.3 Validation Tests

After the modifications were completed, a number of static, dynamic and simulation tests were carried out to understand whether the vehicle dynamic characteristics of the vehicles were the same.

4.3.1.Static Tests

In order to compare the similarities of vehicle static characteristics, the modified diesel vehicle was lifted to the tilt table within the scope of static tests and lift-off values were calculated.

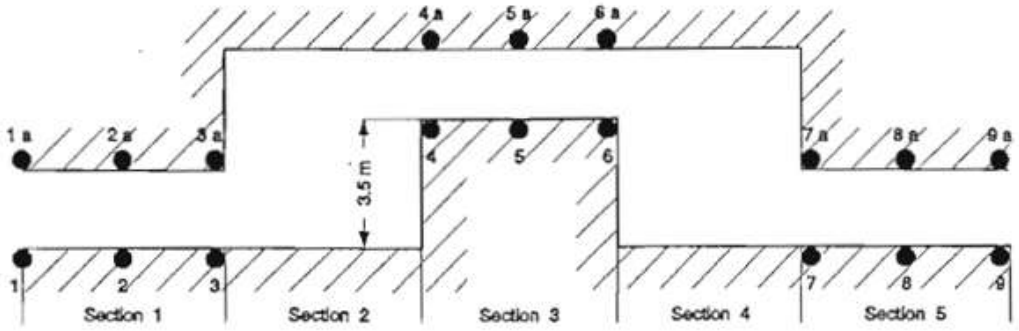
The images of the static tests can be seen in the Figure 47 and Figure 48.

Figure 47: Modified Kent C Static Tests

Figure 48: Modified Kent C Static Tests

4.3.2.Dynamic Tests

Within the scope of dynamic tests, diesel Kent C and electric E-Kent vehicles were tested in accordance with ISO lane change standards. [37] The features of the track prepared in accordance with ISO lane change standards are shown in Fig 41.



Lane – change track dimensions

Section 1 : Length = 15 m
Width = 1.1 . vehicle width + 0.25 m

Section 2 : Length = Overall length of vehicle*) + 24 m

Section 3 : Length = 25 m
Width = 1.2 vehicle width + 0.25 m

Section 4 : Length = Overall length of vehicle + 24 m

Section 5 : Length = 15 m
Width = 1.1 . vehicle width + 0.25 m

*) Overall length of vehicle, measured at 0.50 m from the ground.

Figure 49: ISO Lane Change Track Diagram

Images obtained from vehicle Dynamics behavior tests performed by professional drivers at the ISO lane change track created in the test center of Otokar Otomotiv ve Savunma Sanayi A.Ş.'s Arifiye campus are shown on Figure 50 and Figure 51.

Figure 50: ISO Lane Change Dynamic Tests

Figure 51: ISO Lane Change Dynamic Tests

4.3.3. Simulation Tests

In addition to the physical tests, the ISO Lane change, vehicle dynamics performances of the modified Diesel Kent C and Electric E-Kent buses were also carried out in a simulation environment.

Modeling images related to simulation preparations are given in Figure 52,53 and 54.

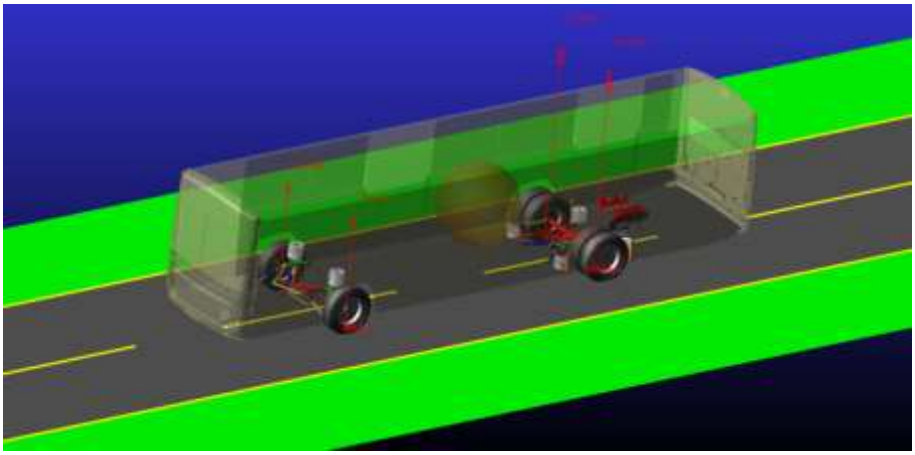


Figure 52: Simulation Preparations

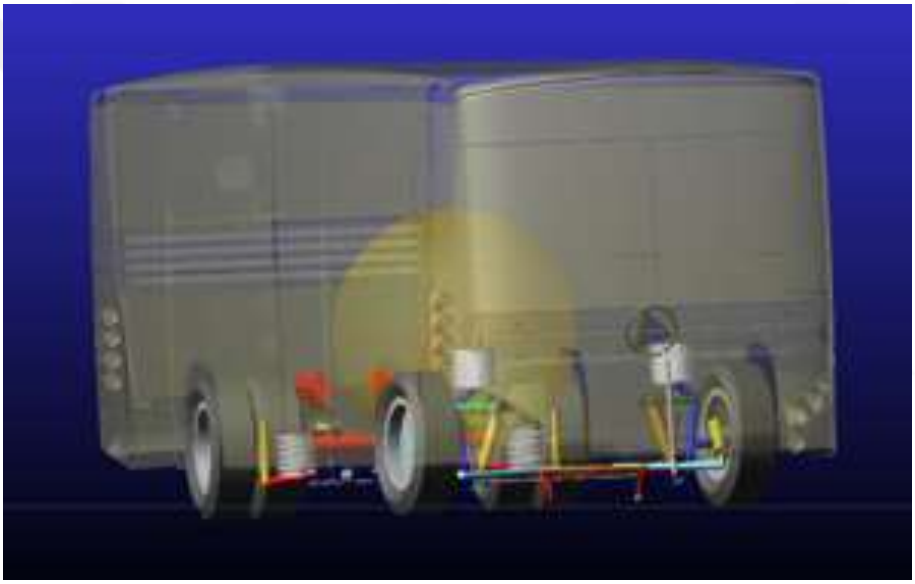


Figure 53: Simulation Preparations

Figure 54: Simulation Preparations

As can be seen in the simulation results in the Figure 55, Figure 56, Figure 57, Figure 58, Figure 59 and Figure 60; the vehicle dynamic performance of the modified diesel Kent C versions of vehicle gave similar results to the electric E-Kent vehicle.

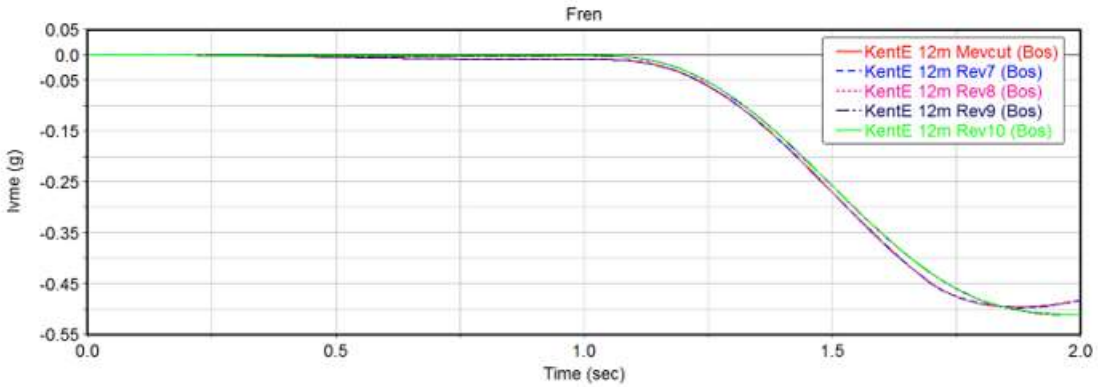


Figure 55: Simulation Results

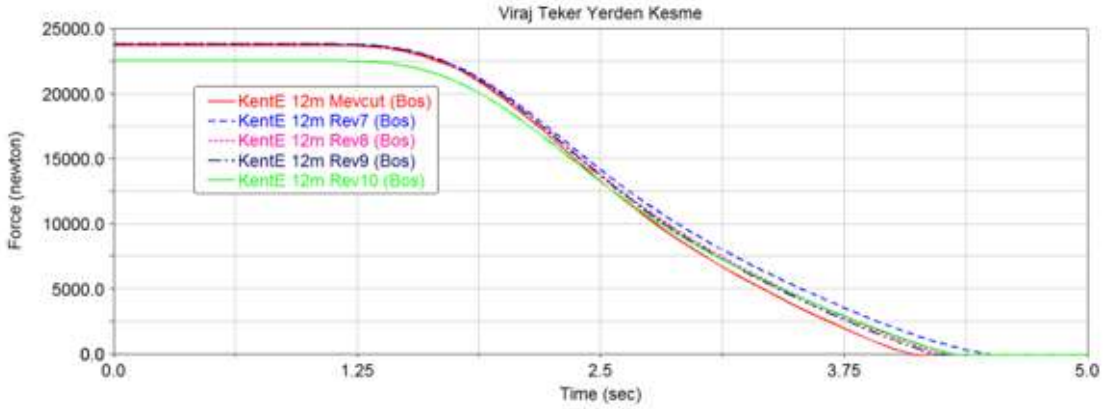


Figure 56: Simulation Results

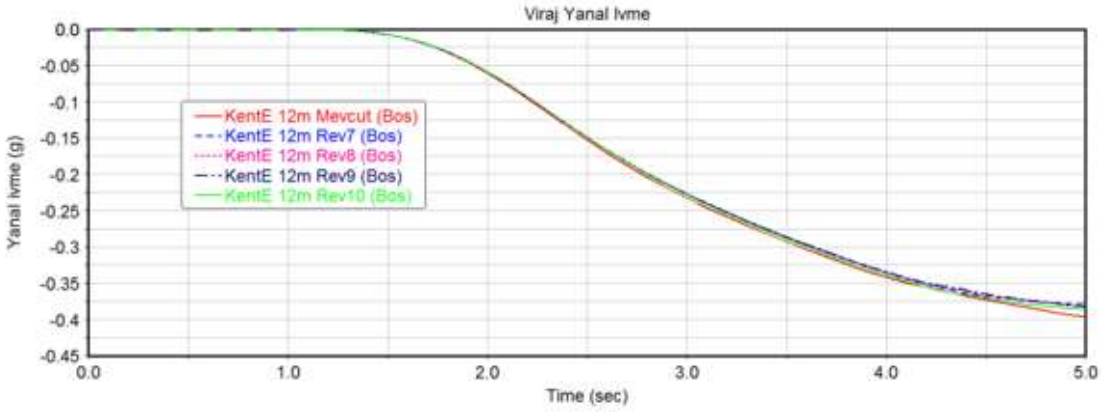


Figure 57: Simulation Results

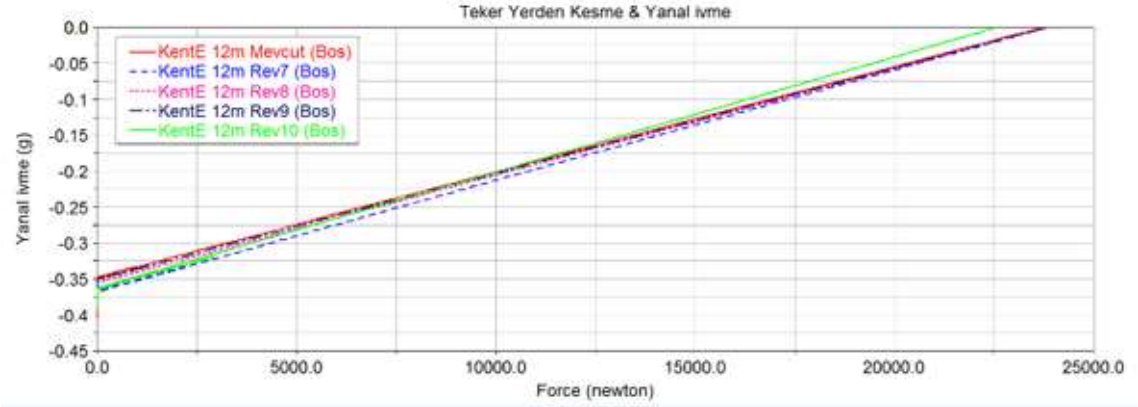


Figure 58: Simulation Results

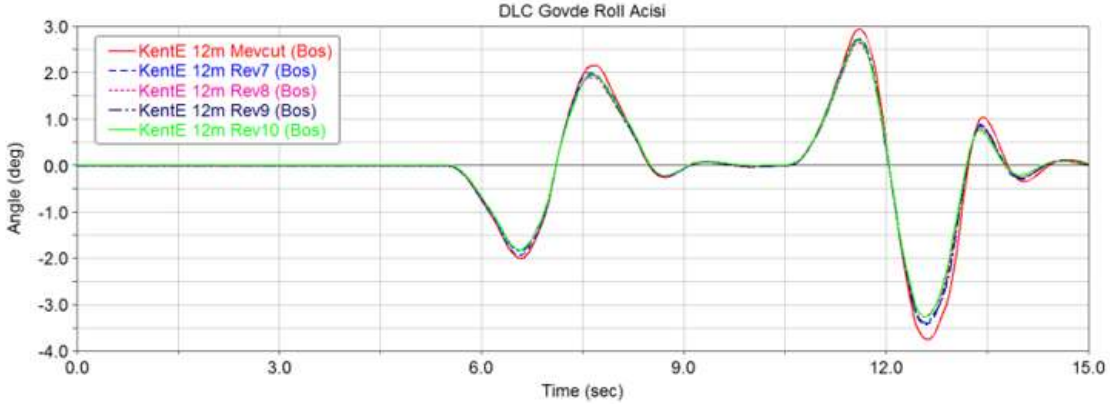


Figure 59: Simulation Results

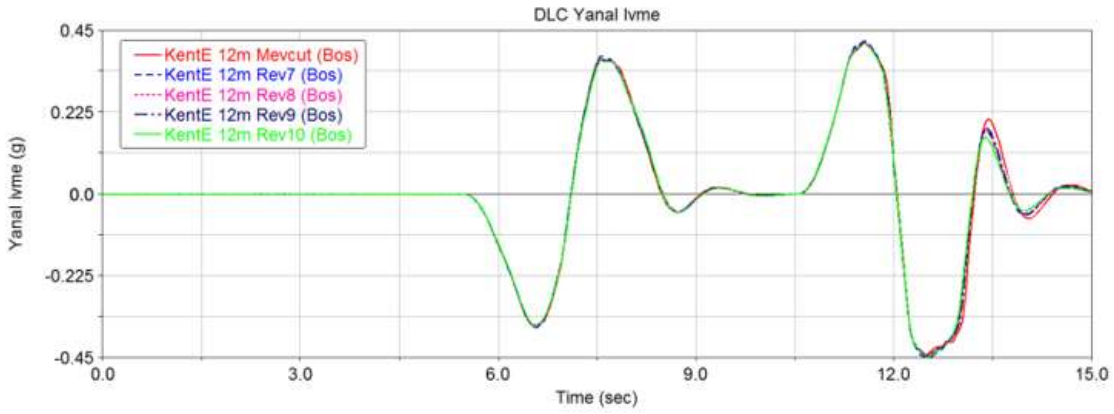


Figure 60: Simulation Results

4.4.Data Collection Study

Now, the physical effects on the steering system are equalized for both vehicles to be tested under the same duty cycle. For example; In a same lane change movement made during deceleration from 60 km/h to 0 km/h, it can be read from both vehicles; The data we need to have about the bus steering system, such as steering wheel force, instantaneous steering box flow rate, instant steering box pressure, will be common.

Thus, the behavior of the pump can be determined as a result of these effects on the diesel Kent C bus. If these data can be collected simultaneously; each steering angle value, front axle load value, vehicle speed value corresponds to a steering flow value. This value is actually produced by the steering pump on the diesel engine on the Diesel Kent C bus, according to demand. In the light of these data, this value will again be the value that will be used to drive the electric steering pump of the electric E-Kent vehicle steering system.

With the 3D input lookup table that will be consisted with front axle load, steering angle, vehicle speed data; Steering pump flow will be obtained as output.

In order to collect this data, the vehicles were run on the routes shown in the Figure 61 and 62, with the specified duty cyle. Both routes are real usage routes for the urban vehicle group that is the subject of the thesis. On these routes, the most realistic energy consumption results have been obtained, taking into account the topographical conditions in big metropolises such as Istanbul and Izmir, which comply with UITP standards. [38],[39]

Figure 61: Arnavutkoy Route

Figure 19: Izmır Route

The modified diesel vehicle was tested under different load conditions for 8 hours a day for a total of 14 days on the specified routes. The reason why data collection tests are kept so long is to ensure that the data to be collected from the vehicle covers all the usage conditions of the vehicle. On the basis of the test is to obtain steering pump flow rate (Q) steering pump pressure (p), vehicle speed (v), steering angle(°), front axle load (kg).

In addition to all these tests, the fuel consumption data on the vehicle was collected and the ratio of the energy consumed by the steering system to the total energy consumed by the vehicle was determined. This data will then be used to compare the total energy consumption of the electric vehicle with the energy consumption of the steering system.

Cleaning and refining the raw data collected from the tool is very important for the simple and smooth operation of the algorithm. Purpose of this; It is to prepare the simplest lookup table that can cover all the terms of use of the vehicle. During this process, certain resolution values were determined and each row of each lookup table was created.The following values are taken as a basis while determining the resolution of the data.

a. Flow (lt/dk) : 0,1 l/dk
b. Vehicle Speed (km/h) : 5 km/h
c. Front Axle Load (kg) : 340 kg
d. Steering Angle (°) : 1°
e. Steering Pressure (p) : 1 Bar

It has been observed that the steering pump flow rate varies between 12.8 and 24.9 l/min. Although the flow rate generally works in the region of 14 -17 l/min continuous conditions, it has been observed to increase to 24 l/min in some extra-maximal conditions. The resolution value for the pump flow rate was chosen as 0.1 l/min.

Vehicle speed varied between 0 and 80 km/h. During the table refining, all other data were kept constant, and the effect of vehicle speed on the steering system flow and pressure was examined, and as a result, a speed row was created in the table for each 5 km/h value.

Vehicle front axle load varies between approximately 2.5 tons and 8 tons. In addition, there have been cases where these values were measured outside the static limits in line with the pitch and roll movements of the vehicle. The resolution value for the front axle load is determined as 340 kg. According to UN ECE R107, the weight of 1 passenger is accepted as 68 kg for class 1 vehicles.[40] Passenger weight acceptance table according to vehicle classes is shown in table 5. Therefore, the effect of the weight change on the front axle on the pressure and flow rate of the vehicle steering system is taken as 5 passengers.

Table 5: Q and Ssp values laid down in the following table

Vehicle class	**Q (kg) mass of one passenger**	**Ssp (m2 /passenger) conventional space for one standing passenger**
Classes I and A	68	0,125
Class II	71	0,15
Classes III and B	71	None

The steering angle value is one of the most important factors affecting the pressure and flow rate changes due to the steering system kinematics. It is an extremely difficult engineering problem to establish the relationship between the angular change of the vehicle steering wheel and the energy consumption of the steering system. Many factors such as the variable ratio of the steering box, the independence of the front axle, the vehicle side slip characteristics, the behavior of the suspension system caused by the vehicle dynamics, the variable flow of the steering pump made it impossible to solve this engineering problem. Although it is possible to

overcome this problem by making some assumptions, these assumptions cause many cases not to be covered in real driving conditions. In this case, there is no real optimization process.

Thanks to the approach used in the thesis, the actual behavior of the steering system can be revealed much more clearly with the simultaneous data collected as a result of the physical tests. As can be seen in Figure 63, although the effect of steering angle value on steering system pressure was not very high in the first turns of the steering movement, it increases parabolicly as the number of steering turns increase. In order to cover the conditions created by all these variables at the maximum level, the resolution value of the steering system angle value was determined as 1°.

Steering system pressure value was collected from the vehicle (mbar) resolution and it was observed that it changed between 2.5 and 167 bar while the vehicle was running. Since the steering system is directly effective in energy consumption, its resolution is taken as 1 bar.

In addition, in order to better examine the data collected on the vehicle; A test was carried out in which the number of steering laps, instantaneous steering system pressure and steering wheel effort information were collected on the vehicle. As can be seen in Figure 63, momentary change in the torque on the steering wheel of the vehicle can be seen. In order to perform this test; The converted diesel vehicle was subjected to a test called the '8' maneuver in a sufficiently large area. The basis of this test is an industrial know-how; found to see all the behavior between the extramums of the steering system.

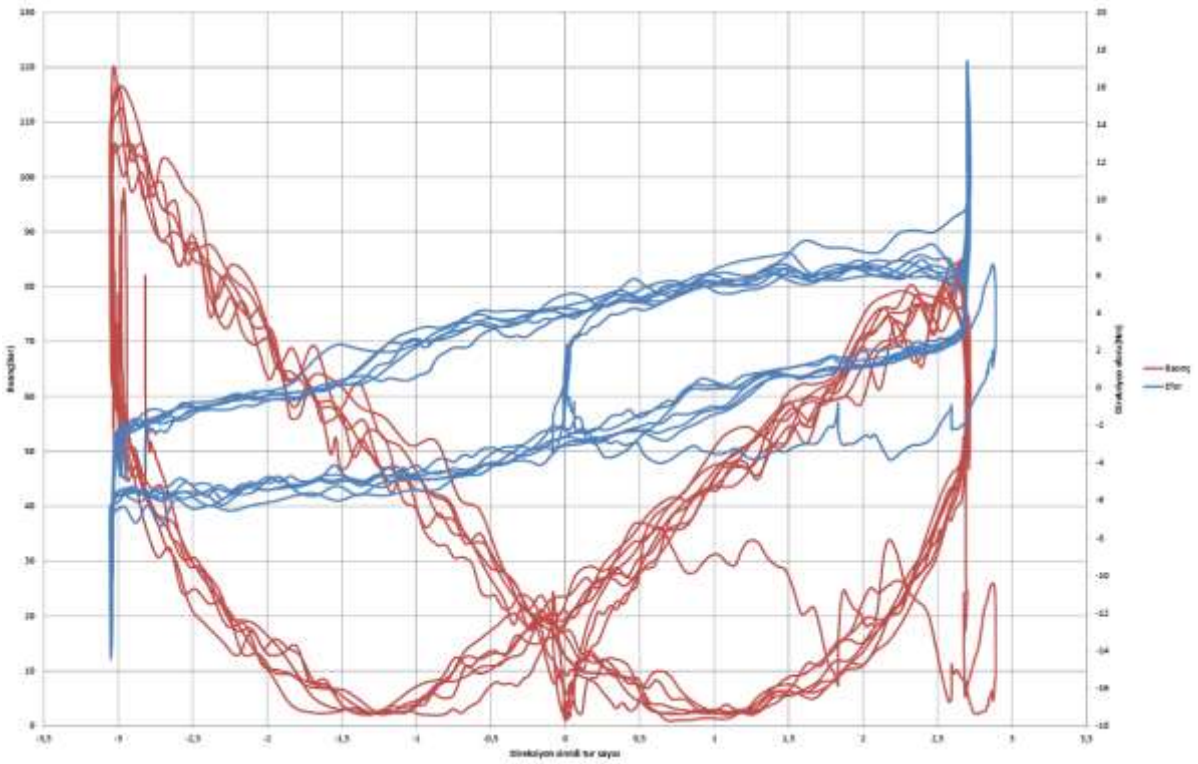


Figure 63: Steering System Pressure Graph

On the Table 7, some of the data collected from the vehicle can be seen. These data were collected in the same frequency range and simultaneously. In order to run these data in a healthy way; The data before the look up table to be created has been refined.

Table 6: Can Datas Collected from Routes

Time (s)	Steering Angle (°)	Front Axle Load (kg)	Vehicle Speed (km/h)	Steering System Pressure (mBar)	Steering System Flow (lt/min)
1	2	4030	18	7963,516	16,098
2	-19	4030	18	32715,12	16,016
2487	-89	7345	57	46495,628	24,220
165	211	5125	3	113617,22	16,112
30671	64	2990	24	51831,34	19,176
1854	-17	6500	64	13641,130	21,173
6944	3	4543	81	7622,479	22,042

17012	188	6997	11	119323,14	18,065
911	-72	3315	41	8616,263	19,817
615	-113	3274	21	93419,10	19,074
21214	-4	5111	86	8305,431	20,003
36017	-90	6917	32	38230,831	22,919
17189	24	3542	74	13075,416	18,091
5345	-17	4498	10	27932,433	21,648
416	-39	5667	22	37856,750	19,616

Refined look up table has not been shared due to industrial information confidentiality.

4.5.Algorithm Design

The 3D look up table created as a result of the current filtering is as in the graphic above. On the input side of this look up table, there are steering angle (°), vehicle speed (km/h), front axle load (kg) data. As an output; Flow rate (l/min) value is included. After the flow value, since the pump displacement volume (cc) is certain, the electric motor will be switched to the speed and the steering pump electric motor will be driven in line with this speed information.

The generated block diagram is shown in Figure 64 below as a representation. As explained in the previous sections; The data already produced on the vehicle will be used as input. As a process; In return for the data line containing the value read from each data, there is a flow value as output. This flow value is the flow that the vehicle's electric power steering pump should produce. The vehicle's steering pump is a fixed displacement gear pump. The ratio of the flow rate to the displacement of the pump will give the speed of the pump.

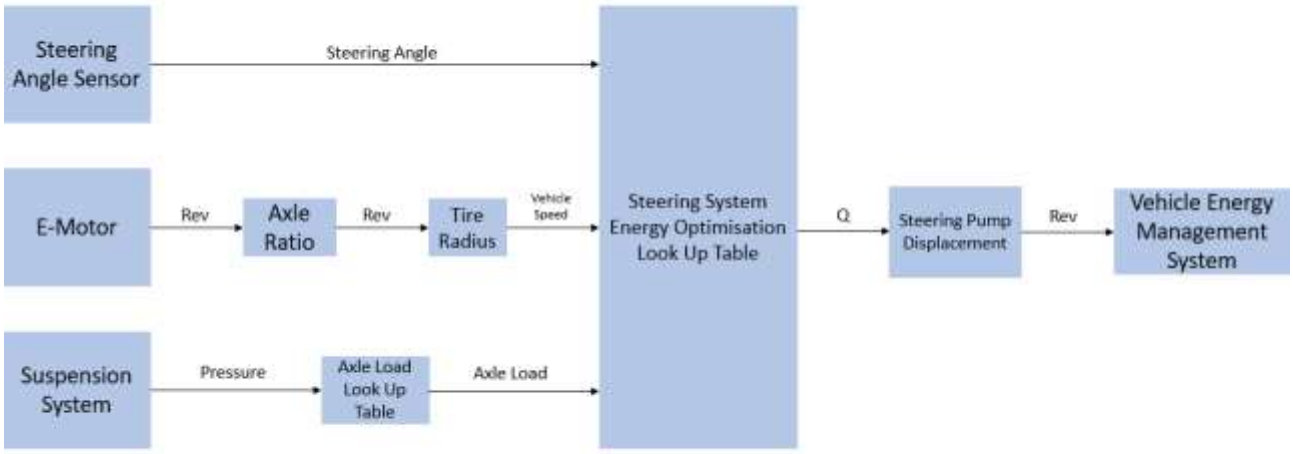


Figure 64: Steering Control System Block Diagram

In addition, the block diagram of the first algorithm prepared for the electric vehicle is also shared in figure 65. This algorithm was used in the prototype phase of the vehicle and is dependent only on the vehicle speed variable.

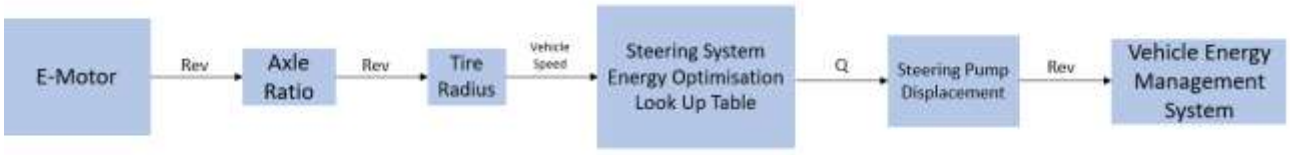


Figure 65: Steering Control System Block Diagram of First Algorithm

4.6.Application and Tests

In order to run the designed algorithms on the vehicle, multiplexers available on the vehicles were used. Multiplexers multiply, change, command or stop the information produced on the CAN Communication Line on the vehicles; are the units that control the flow of

information. Functions such as the door, wiper motor, air conditioner motor, automatic window on the vehicle are controlled via this system. Multiplex systems used in Otokar vehicles have their own embedded software interfaces called LSS (Lader Logic System). By creating designed algorithms and diagrams in this interface, package files with .vmm extension can be produced. These generated files can be uploaded to multiplexers via the vehicle's life line. [41]

The algorithm was loaded on the multiplexers of the E-Kent vehicle and the steering pump of the electric vehicle was started. The steering pump was first tested within the scope of safety at the test center of Otokar Otomotiv ve Savunma Sanayi A.Ş.'s During these tests, scope controls were made for the active force values of the vehicle's steering system within the scope of UN ECE R79 regulations.[36] During the regulation tests, the force coming from the steering wheel of the vehicle was monitored. Within the scope of the regulation, this value should not be over 20 daN while the vehicle is running. This value was measured with a torquemeter attached to the vehicle's steering column.

After making sure the software security and meeting the regulation conditions, the vehicles were tested in the same route, scope and time period as they were tested during the data collection phase. During the test, vehicle energy consumption data, steering system energy consumption data, steering system pressure and steering pump speed information were also collected from the vehicle via the vehicle CAN Line.

In addition, the same tests were repeated for a standard diesel Kent C vehicle for the same route, scope and time. Since data such as vehicle energy consumption or steering pump energy consumption information is not produced on the Diesel Kent C CAN line; steering

system energy consumption, steering system pressure and steering pump flow rate information is calculated with the help of the formula metioned in section 4.

The graphs created with the data collected from Diesel Kent C and E-Kent vehicles during the tests are shown in Figure 66, Figure 67, Figure 68, Figure 69, Figure, 70, Figure 71.

Firstly, the electric E-KENT was tested only with the speed based algorithm. The steering system average energy consumption of the vehicle which was tested on Arnavutköy and Izmir routes, was around 0.02 kWh/km. This value is approximately 3% of the vehicle's total energy consumption

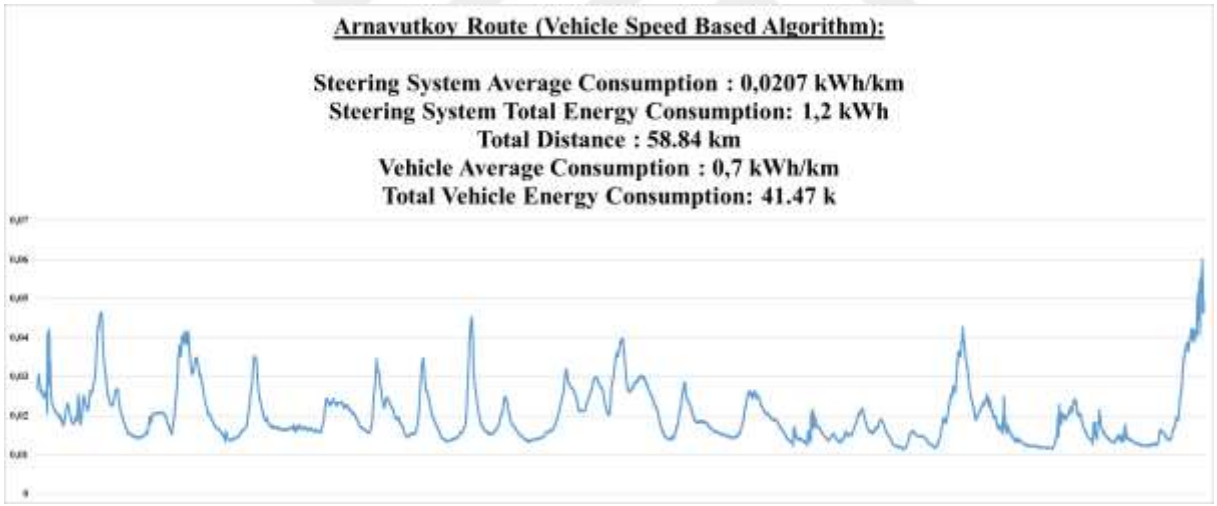


Figure 66: Arnavutkoy Route Consumptions (Vehicle Speed Based Algorithm)

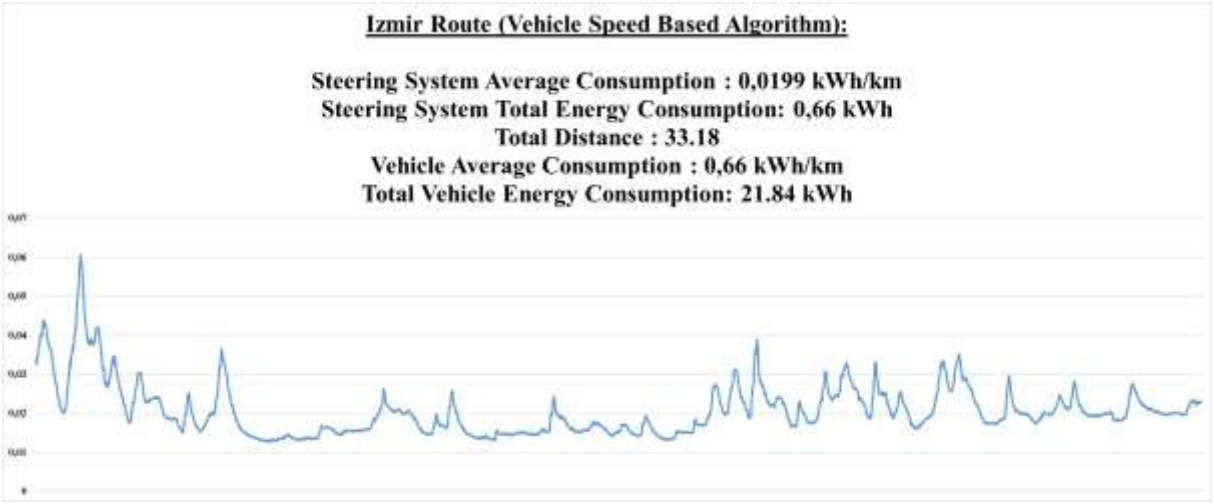


Figure 67: Izmir Route Consumptions (Vehicle Speed Based Algorithm)

In the next tests, the algorithm developed within the scope of the thesis was loaded on the E-Kent and the vehicle were tested on the same routes. As can be seen in the graphics, the average energy consumption of the steering system can be reduced to 0.015 kWh/km with the newly designed algorithm. This value is approximately 2% of the vehicle's total energy consumption.

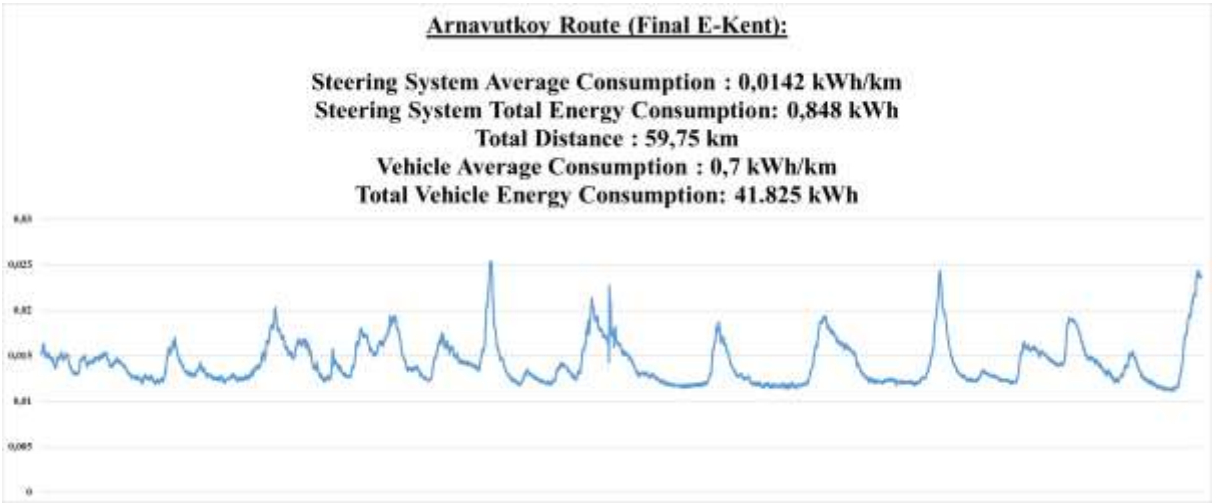


Figure 68: Arnavutkoy Route Consumptions (Final E-Kent)

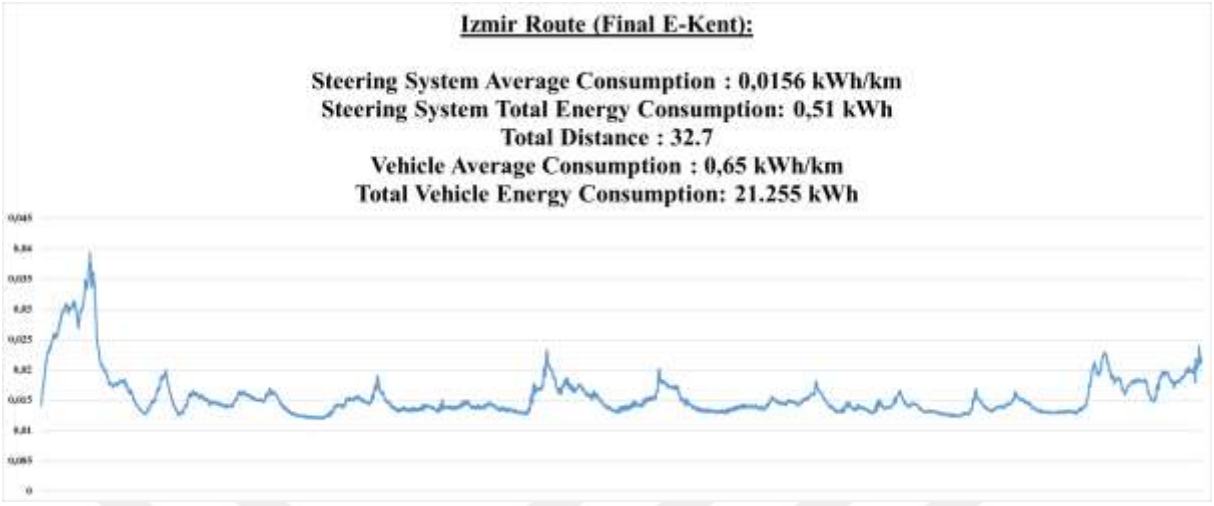


Figure 69: Izmir Route Consumptions (Final E-Kent)

Finally, the diesel Kent C was tested on the same routes. The energy consumption values in the diesel vehicle were calculated with the help of the steering pump flow rate and steering system pressure collected from the vehicle. As a result of the tests, it has been observed that the energy consumption of the diesel Kent C varies in a wider range. This is due to the variable operation of the vane pump on the vehicle and the high losses on the system. The average energy consumption of the Kent C steering system is approximately 0.017 kWh/km.

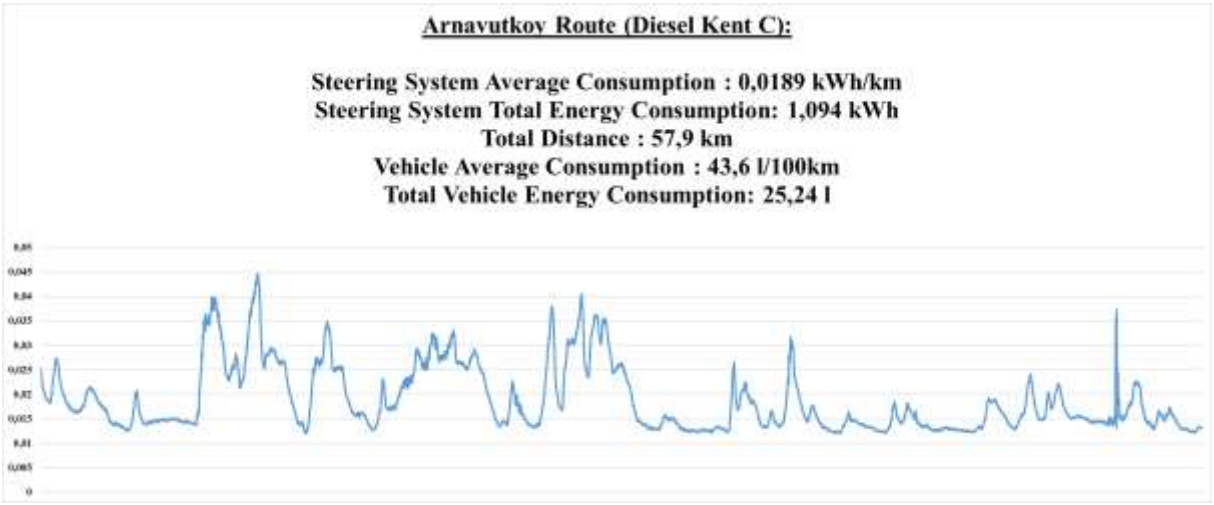


Figure 70: Arnavutkoy Route Consumptions (Diesel Kent C)

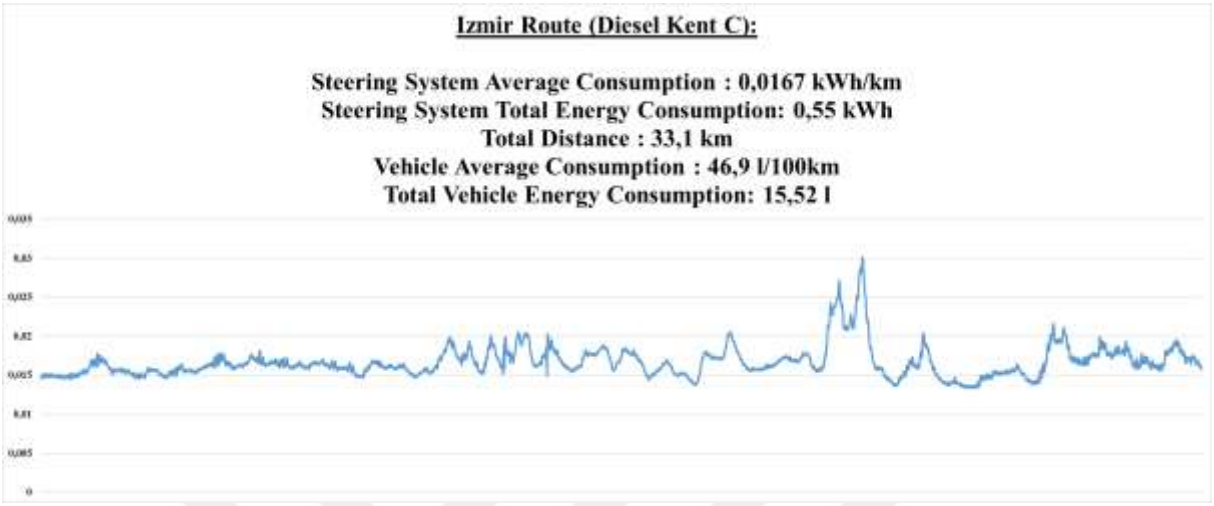


Figure 71: Izmir Route Consumptions (Diesel Kent C)

A summary of all collected data is shown in table 7 as a single table. In addition, by adding a last column to the summary table, the ratio of the energy consumption of the steering system of the vehicles to the energy consumption of the whole vehicle is calculated.

Table 7: Simulation Results Summary Table

		Total Distance (km)	Steering System Average Consumption (kWh/km)	Steering System Total Energy Consumption (kWh)	Vehicle Average Energy Consumption (kWh/km)	Vehicle Total Energy Consumption (kWh)	The ratio of the energy consumption of the steering system to the energy consumption of the all vehicle
Vehicle Speed based algorithm	**Arnavutköy**	58,84	0,0207	1,20	0,70	41,47	2,96%
	İzmir	33,18	0,0199	0,660	0,66	21,84	3,02%
Final Algorithm	**Arnavutköy**	59,75	0,0142	0,848	0,70	41,83	2,03%
	İzmir	32,70	0,0156	0,510	0,65	21,26	2,40%
Diesel Kent C	**Arnavutköy**	57,90	0,0189	1,094	43,6 lt/100km	25,24 lt	NA
	İzmir	33,10	0,0167	0,550	46,9 lt/100km	15,52 lt	NA

5. CONCLUSION

Steering systems of vehicles are one of the most important systems in terms of safety, comfort and functionality. Considering the development of the automotive industry in recent years, the design of the steering system, like many systems on the vehicle, is taken again with a different perspective and engineering approach. Systems on existing conventional vehicles are the output of the Automotive foundation of nearly 100 years of development. The systems and regulations currently used today have been configured simultaneously to this day. Within the scope of the electrification transformation we are in today, the engineering problem in this transition needs to be solved very quickly.

This thesis focuses on solving the mentioned engineering problem with the fastest, most profitable and optimum method from an industrial point of view.

Vehicle steering systems are extremely complex. At the same time, since it is one of the most safety critical elements on the vehicle, it is controlled by many regulations. As there are many cases that need to be solved on the functionality side of the vehicles, there are also many engineering problems that need to be overcome in safety issues. Only the design and adaptation of the steering box on the vehicle requires a great deal of engineering work.

As mentioned in the literature research section, there are many control methods related to steering systems. All of these developed algorithms was created as a result of the analysis of the vehicle model, tire model and steering system models. These methods not only bring along a very complex engineering problem, but also do not cover all conditions on the vehicle. Basically, all of these problems are nonlinear, and many real conditions are ignored for their solution.

With the study, which is the subject of the thesis, a solution to an engineering problem, which is very complex to be solved, has been produced thanks to the algorithm that is run through the data obtained from the vehicle. This algorithm was created with real-time data obtained as a result of tests performed on another vehicle.

As a result of the tests, The steering system energy consumption of the algorithm-loaded electric vehicle consumed 32% less energy than a vehicle whose vehicle speed base controlled steering system.

Table 8: Initial and Final Algorithm Based System Energy Consumption Comparison

	Arnavutköy Route Steering System Average Consumption (kWh/km)	İzmir Route Steering System Average Consumption (kWh/km)
Vehicle Speed based	0,0207	0,0199
Final Algorithm	0,0142 -%32	0,0156 -%22

With the currently developed algorithm, the steering system of the electric E-Kent vehicle consumes 17% less energy than the diesel Kent C vehicle.

Table 9: Diesel and Electric Vehicle Energy Consumption Comparison

	Arnavutköy Route Steering System Average Consumption (kWh/km)	İzmir Route Steering System Average Consumption (kWh/km)
Diesel Bus	0,0189	0,0167
Electric Bus	0,0142 -%25	0,0156 -%7

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