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DEVELOPMENT OF ALTERNATIVE STEERING MODELS FOR EV BUS: A PRELIMINARY STUDY ON THE CONVERSION OF HYDRAULIC TO ELECTRIC POWER STEERING

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This study aims to develop alternative steering models for the EV bus. The EV bus uses its energy source from the main 384 VDC 300 Ah battery and the secondary battery with a capacity of 25.8 VDC 100 Ah. The use of energy in this electric bus is divided into the main components, namely the BLDC motor as the main drive of 200 kW, 15 kW of air conditioning, 7.5 kW of hydraulic power steering, a compressor for the air braking system of 4 kW, and accessory components. The other is 2.4 kW. It is expected that this 7.5 kW electric power can be reduced by an electric system by up to 20 %. This research will study the steering system with an electric power system (EPS) to convert the hydraulic steering system (HPS). With this EPS system, it is hoped that controlling the vehicle's motion towards the steer by wire will be easier. Initially, data were collected from the types of large vehicles from various well-known brands about the steering system used. A large commercial vehicle that purely uses EPS is not yet found. The model developed for EPS on this electric bus is through the reverse engineering method by redrawing all the components involved in the previous steering system. Because this type of EV bus is included in the upper mid-size class, this paper proposes two new EPS models, namely the addition of an assist motor on the drag link and on the steering rack. The links involved in this system are wheel drive, steering column, lower steering column, rack and pinion gear, assist motor, drop link, drag link, drop link extension, drag link extension, tie rod, knuckle, kingpin, tire, axle beam and several others. The values of stiffness, inertia, and damping of each link will affect the driver's torque and the assist motor as a wheel speed function on this electric bus. The steering structure of the EV bus consists of a truss structure and a frame structure with a kinematic structure consisting of two four-bar linkages joined together.

Keywords: assist motor, wheel drive, steering column, pinion, rack, vehicle speed, torsion motor, truss structure, frame structure, four-bar linkage

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1. Introduction

This research is part of a vehicle conversion program from internal combustion engine (ICE) to electric vehicle (EV). The electric cars are Electric Vehicle Bus (EV bus), Makara Electric Vehicle (MEV) 01, City Car MEV 02, and City Car MEV 03. The electric bus (EV bus) has an energy source from the main 384 VDC 300 Ah battery and a 25.8 VDC 100 Ah secondary battery. The energy is continued for a prime mover of 200 kW with a BLDC motor, 15 kW air conditioning, 7.5 kW hydraulic power steering, 4 kW compressor for braking systems, each with an induction motor, and 2.4 kW for other accessories.

The steering system is also part of the current research of the EV bus research team. The current steering system for buses is still a hydraulic power system, and this study proposed to develop it into electric power steering. A preliminary investigation has been conducted for this steering research, including a review of several models of electric power steering [1] and possible parameters that will be involved in its dynamic equations. All models reviewed in this paper are generally used for small cars or city cars. The EV bus is a large vehicle, where the distance between the steering column and the front axle is almost 2–3 times larger than that usually used in city cars. Therefore, the studies are devoted to outlining several models by putting the assist motor on the drag link or the steering rack so that the loss of energy to turn the wheel can be minimized.

2. Literature review and problem statement

The paper [2] presents a hydraulic power-assisted steering system known as hydraulic power steering (HPS). The difference in pressure (P) in and out of the cylinder will help reduce the thrust on the drag link, which is concentrically mounted on the rack bar (Fig. 1). The force F on the rack bar is used to move the left and right wheels based on the amount of torque T on the drive wheel, while the angle Θ depends on the stiffness of the torsion bar and the stiffness of the rack and pinion gear K_r.

For reasons of energy savings and easier control of the steer by the wire system, hydraulic power steering was developed to motor-assisted steering system known as electric power steering (EPS). The EPS generally has three types depending on the position of the assist motor used. The position of the assist motor depends on the value of the force required on the steering rack [3].

A steering rack force is defined as the amount of force needed to guide the assist motor. For example, a steering rack force below 8 kN means the assist motor is placed on the steering column. If the value is greater than 8 kN but smaller than 12 kN, it means that the assist motor is attached to the pinion, and the value greater than 12 kN indicates that it is mounted on the rack. These settings are illustrated in Fig. 2, *a*, while the classification is presented in Fig. 2, *b*.

To find out the mechanical parameters that will be involved in the steering system to be converted into EPS, a review of the existing EPS systems is first conducted. The first model we'll look at is a steering system that includes a wheel drive and a steering column. The EPS schematic [4] shows how this is connected to a pair of gears that link it to the assist motor. The control structure has three big loops. To dampen the steering shaft flexibility, an inner-loop force with quick dynamics is used first. As a result, an outer location loop is created to ensure accurate monitoring and good disturbance rejection. The feedback and feed-forward loops make up the location regulation. The parameter that characterizes the device equation is model 1 in Table 1.

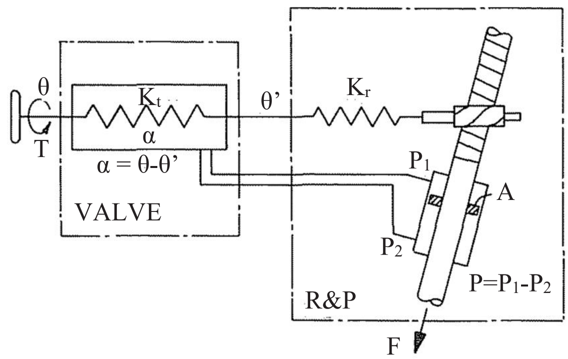
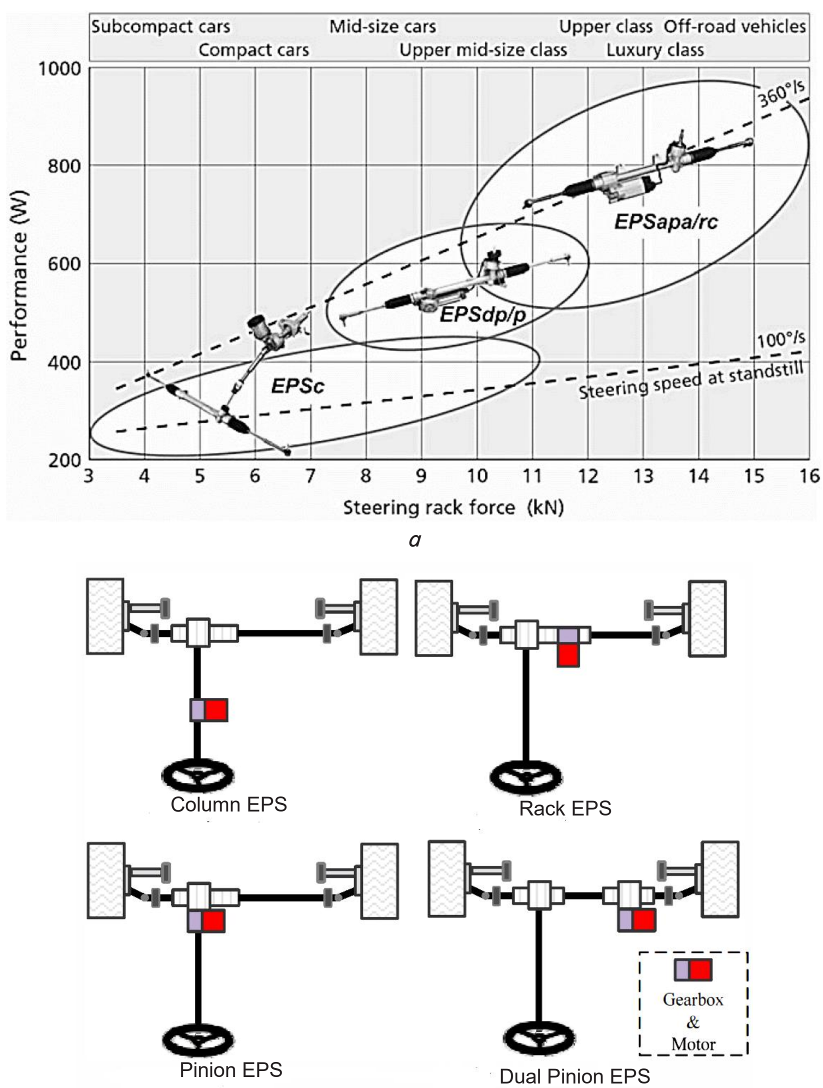


Fig. 1. Hydraulic power steering model [2]



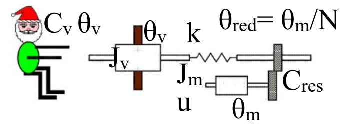
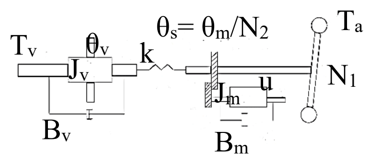
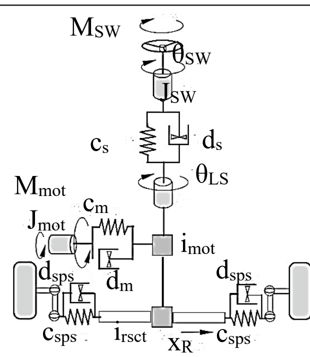
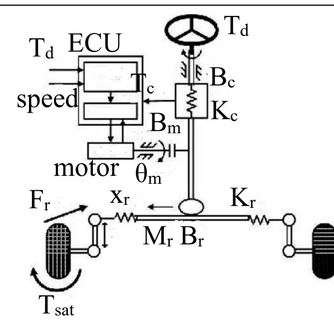
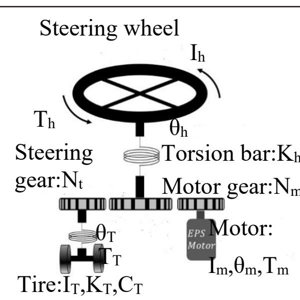
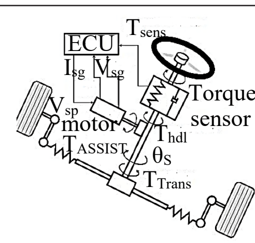
a

b

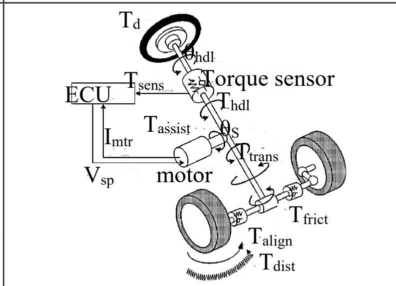
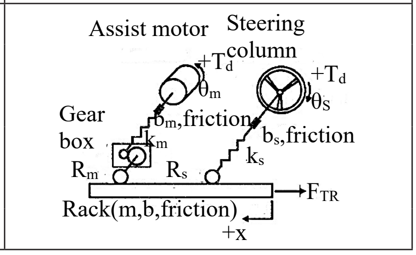
Fig. 2. Electric power steering (EPS) [3]: *a* — classification of EPS systems depending on rack force; *b* — position of motor assist

Table 1

Results of model review [1]

Model [Reference]	EPS Components	Mechanical Parameter				Position of Assist Motor	Figure of The Model
		A	*B*	*C*	*D*		
1	2	3	4	5	6	7	8
Model 1 [4]	Steering Wheel	✔	×	×	✔	Steering Column	
	Steering Column	×	✔	×	×		
	Rack and Pinion	×	×	×	✔		
	Assist Motor Shaft	✔	×	×	✔		
	Motor	×	×	×	×		
	Tire	×	×	×	×		
Model 2 [5]	Steering Wheel	✔	×	✔	✔	Steering Column	
	Steering Column	×	✔	×	×		
	Rack and Pinion	×	×	×	✔		
	Assist Motor Shaft	✔	×	✔	✔		
	Motor	×	×	×	×		
	Tire	×	×	×	×		
Model 3 [6]	Steering Wheel	✔	×	✔	✔	Steering Column	
	Steering Column	✔	✔	✔	×		
	Rack and Pinion	×	✔	✔	✔		
	Assist Motor Shaft	✔	✔	✔	✔		
	Motor	✔	×	×	×		
	Tire	×	×	×	×		
Model 4 [7]	Steering Wheel	×	×	×	×	Steering Column	
	Steering Column	✔	✔	✔	✔		
	Rack and Pinion	×	✔	✔	✔		
	Assist Motor Shaft	✔	✔	✔	✔		
	Motor	✔	×	×	×		
	Tire	×	×	×	×		
Model 5 [8]	Steering Wheel	✔	×	×	✔	Steering Column	
	Steering Column	×	✔	×	✔		
	Rack and Pinion	×	×	×	✔		
	Assist Motor Shaft	×	×	×	✔		
	Motor	✔	×	×	✔		
	Tire	✔	✔	×	✔		
Model 6 [9]	Steering Wheel	×	×	×	✔	Steering Column	
	Steering Column	×	×	×	✔		
	Rack and Pinion	×	×	×	✔		
	Assist Motor Shaft	×	×	×	✔		
	Motor	✔	✔	×	✔		
	Tire	×	×	×	×		

Continuation of Table 1

1	2	3	4	5	6	7	8
Model 7 [10]	Steering Wheel	×	×	×	✔	Steering Column	
	Steering Column	×	✔	×	✔		
	Rack and Pinion	×	✔	×	×		
	Assist Motor Shaft	×	×	×	×		
	Motor	✔	×	×	✔		
	Tire	✔	×	×	×		
Model 8 [11]	Steering Wheel	×	×	×	✔	Steering Rack	
	Steering Column	×	✔	×	✔		
	Rack and Pinion	×	✔	×	×		
	Assist Motor Shaft	×	×	×	×		
	Motor	✔	×	×	✔		
	Tire	×	×	×	×		

Note: mechanical parameters (A=Inertia, B=Stiffness, C=Damping, D=Angle); ✔ *– including the mechanical parameters;* × *– not including the mechanical parameters*

The second model in the paper [4] is electric power steering (EPS), which should be able to provide torque assistance. The model could be modified for a variety of driver groups, including young drivers, the elderly, the disabled, and so on. The control system should also include observers that allow for the recovery of signals that were not sensed, as well as a control law that compensates for column stiffness. The parameter that characterizes the EPS equation is model 2 in Table 1.

The EPS's next mechanical model is built on a single-pinion architecture that is suitable for simple vehicles and consists of the following components: a steering rack, a steering column connected to the steering rack by a pinion gear, and the assist motor. The steering rack is connected to the tires by tie rods [5]. The steering wheel's motion is defined by the parameter as model 3 in Table 1. The electric power steering system is the next model in the other paper [6], which involves the equation of the electric motor, as well as the force on the wheel from the road. The EPAS dynamic model establishes the relationship between the steering mechanism, motor electric dynamics, and tire/road contact forces. The schematic of EPS depicts a brushed DC motor-driven steering mechanism model. The parameters of motion can be seen as model 4 in Table 1.

In the field of small steering-wheel angles, the area of contact between the front tires and the road surface does not change during static steering. Since the torsion of the tires functions as a spring, the steering angle and reaction torque have a nearly constant gain proportional relationship [7]. This model's linearization aims to perform frequency analysis and describe the vibration mechanism during static steering. The motor inertia, the steering torque applied by the driver T_{hdl}, the assist torque provided by the assist motor, and the reaction torque of the steering mechanism T_{tran} can all be expressed as a balance in this model. The parameter that characterizes the EPS is model 5 in Table 1. The final electric power steering model is an EPS control technique for reducing steering vibration caused by road wheel disturbance [8]. The steering torque at the steering shaft is denoted by «*Thdl*», the steering torque at the steering wheel is denoted by «*Td*», and the reaction torque at the steering shaft is denoted by «*Ttran*». Ttran is the amount of the road wheels' alignment torque «*Talign*», the road wheels' disruption torque «*Tdist*», and the rack & pinion's frictional failure torque «*Tfric*».

The mechanical parameters that work on several previous EPS systems that have been reviewed in previous studies and rearranged are presented in Table 1.

Models 1 to 7 put the assist motor on the steering column. Only on model 8, the assist motor is placed on the rack. The input parameters of this system are mass inertia, stiffness, damping, and turning angle. The steering system components that will be involved in this system are the steering wheel, steering column, rack and pinion, assist motor, and tire.

3. The aim and objectives of the study

This study aims to investigate the conversion of the hydraulic power steering system to electric power steering as part of ICE bus conversion to EV bus. To achieve this aim, the following objectives were accomplished:

– to collect some data on the same type of heavy vehicle about the steering system it uses;

– to redesign the steering mechanism on this EV bus with the reverse-engineering method;

– to determine alternative assist motor positions as part of research on the conversion of ICE bus to EV bus and what parameters are involved in this EPS system.

4. Materials and methods of research

This research is in the context of an internal combustion engine (ICE) bus conversion program to an electric vehicle (EV) bus. One of the parts that will be converted is the steering system. The steering system currently installed is hydraulic power steering. This HPS will be converted into electric power steering. Initially, data will be collected about the current steering system on the upper mid-size class bus to get an electric power steering model that matches some of the current references. After that, the electric power steering model was built by the reverse engineering method. The model developed is still based on the current hydraulic system by considering the possibility of adding a suitable assist motor. From the model created, what links build this system and possible mechanical parameters for it will be seen, in full it can be explained as follows.

4. 1. Steering type data for some heavy vehicles

The collection of data on the steering system currently installed on the upper mid-size class bus is carried out by searching for open source data from various well-known brands. The data on well-known brands from various countries include Scania, Hino, Mercedes-Benz, Isuzu, Volvo, King Long, Volvo and Green Power Bus. This data collection method is to search from various open sources of these brands, such as websites, brochures or leaflets.

4. 2. Redesigning the steering mechanism on the EV bus by the reverse-engineering method

Hydraulic power steering (HPS) on the EV bus shown in Fig. 3, *a* was replaced with electric power steering (EPS) as indicated in Fig. 3, *b* for further development. This system is expected to reduce energy use since not many valves cause energy losses in the hydraulic system. The EPS involves using energy from the battery for torsion motors to directly assist in the steering rod's movement, as observed from the reviewed literature. Moreover, it is 25 % cheaper to maintain in comparison with the hydraulic system.

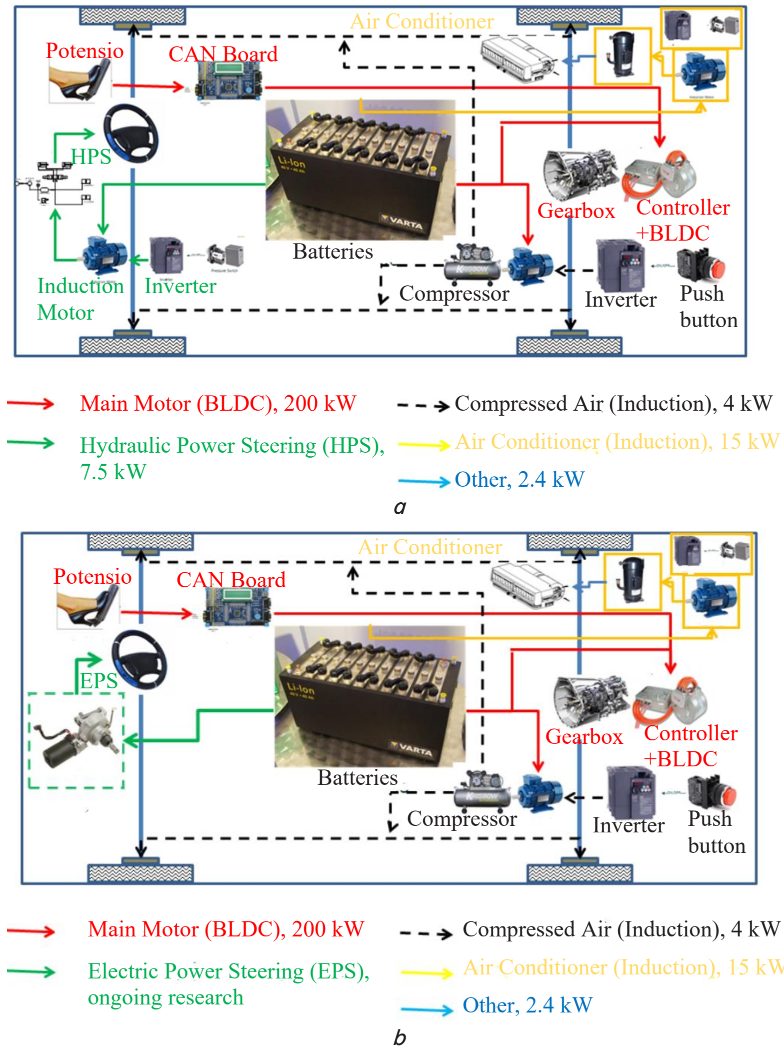


Fig. 3. Energy layout of the EV bus with: *a* — HPS; *b* — EPS [5]

Reverse engineering was conducted to obtain the dimensions of each steering component. The steps were implemented on the parts of the EV bus hydraulic power steering shown in Fig. 3, *a*. The hydraulic power steering will be converted into an electric power steering system, with the energy use scheme shown in Fig. 3, *b*.

Fig. 4. EV bus Molina UI [5]

The bus uses the Hino R260 chassis presented in Fig. 4, with the fundamental difference observed in the distance of the front overhang, which is approximately 2,380 mm and averagely twice the distance in a city car.

The links on the steering system's dimensions in Fig. 4 are obtained by measuring these components. The components being measured are drop link, drag link, drop arm, axle beam, drag link extension, and drop link shown in Fig. 5. After all dimensions are obtained, the CAD software is redrawn.

Fig. 5. Existing components of HPS in the EV bus

The steering system components currently installed on the EV bus chassis in Fig. 4 are as shown in Fig. 5. To obtain a complete steering system, these components are subjected to reverse engineering. There are several components to this steering system, namely wheel drive, column steering, lower column steering, drop link, drag link, drop link extension, drag link extension, kingpin, axle beam and tire. These links will be carried out, as well as a reverse engineering process. This reverse engineering produces a collection of links that build the steering system using CAD modeling.

4. 3. Assist motor positions of the EV bus and the parameters involved in the system

After obtaining the complete components of the steering system on the EV bus, the next step is to determine the composing mechanical parameters. The parameters that will be involved are a combination of parameters as reviewed in Table 1.

5. Results of research on the development of an alternative steering model of the EV bus

The development of the steering model of the EV bus is to determine an alternative model for the placement of the assist motor for the EPS system. Some of the steps taken are to look at the current model of the EPS system on large-scale buses. The EPS system on the EV bus this time is a conversion of the existing HPS system on the previous ICE bus. Therefore, reverse engineering is used for modeling. The special characteristics of the structure that builds this steering system are also reviewed, as well as differentiating it from the previous EPS system that is currently available.

5. 1. Data on the steering system of heavy vehicles

The results of the steering types of various brands with certain types of chassis can be seen in Table 2.

Based on Table 2, it can be seen that almost 90 % of these famous brands of heavy vehicles still use the hydraulic steering system. The type of hydraulic steering is mostly ZF8098. Only a Volvo type 7900 bus already uses an electric hydraulic power steering system.

5. 2. Reverse engineering result of redesigning the steering mechanism

The results of this three-dimensional redraw are as shown in Fig. 6. An electric power steering model will be developed from the three-dimensional model of the hydraulic steering system on the EV bus. One model that has been proposed is the addition of an assist motor on the steering column [1].

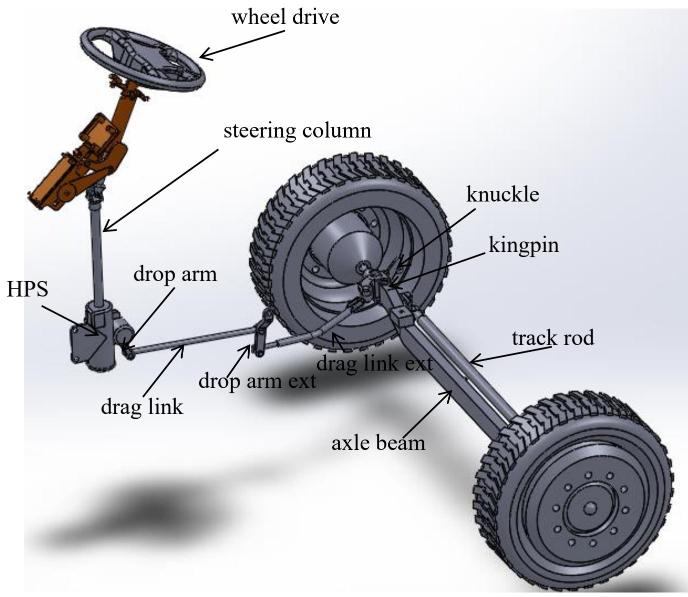


Fig. 6. CAD modeling result of the steering system

The eight models reviewed are presented in Table 1, and the main components were the steering wheel, steering column, rack and pinion, assist motor shaft, motor, and tire. On the other hand, the parameters reviewed include inertia, stiffness, damping, and angle. These parameters of the components will affect as long as the system performs a movement. Therefore, model 3 was reasonably good and used as a reference for the new EV bus model. Alternatively, models 5 and 7 were added when the tire was used as the parameter. Meanwhile, the drag link mechanism was quite distinguished because it was specifically reviewed later with matrix methods to form the stiffness in the bus's structural analysis.

5. 3. Alternative assist motor positions and parameters involved in the EPS system

So, based on the components involved in this steering system as in Fig. 6, a parameter model has been proposed [1] by adding an assist motor to the steering column as in Fig. 7.

Table 2

Steering type data for large buses [1]

Type of Vehicle	Bus Brand	Chassis Type	Steering Type
Internal Combustion Engine (ICE)	Scania Sweden	K3601B4X2	Power Steering with 4 spoke safety hydraulic, tilt angle 25–45° Right-hand steering
	Hino Japan	RK8J	Telescopic and tilt column with locking device, Recirculating ball with Integral Power Steering
	Mercedes-Benz German	OC 500 RF 2542	Power Steering ZF – Servocom 8098
	Isuzu Japan	6 HK1-TC EURO-III	Power Steering Re-Circulating Ball Type with Hydraulic Assist
	Volvo Sweden	Volvo B7R	Power Steering ZF – Servocom 8098
	King Long China	XMQ6127	Power Steering ZF – Servocom 8098
Electric Vehicle (EV)	Green Power Bus Canadian	EV250	Imported ZF power steering gear
	Green Power Bus Canadian	SYNAPSE SHUTTLE	ZF8098
	Green Power Bus Canadian	EV550	ZF8098
	Green Power Bus Canadian	EV350	ZF8098
	Volvo Sweden	Volvo 7900	Electrically powered hydraulic steering

Note: Data were taken from various open sources

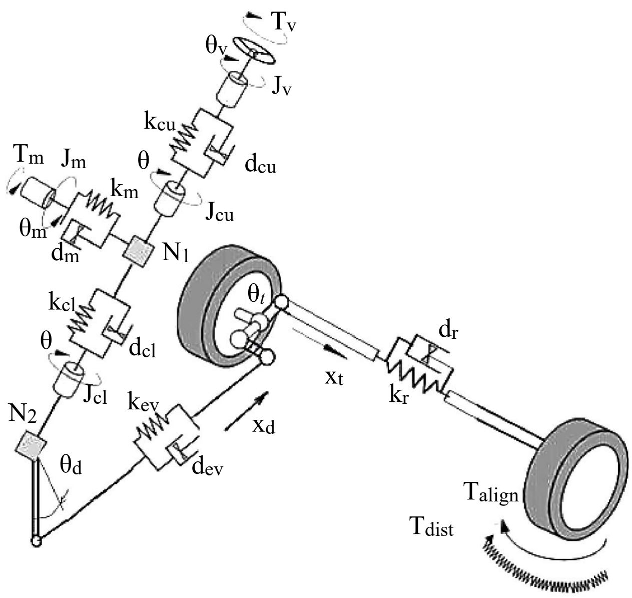


Fig. 7. EPS for the EV bus with assist motor at the steering column [1]

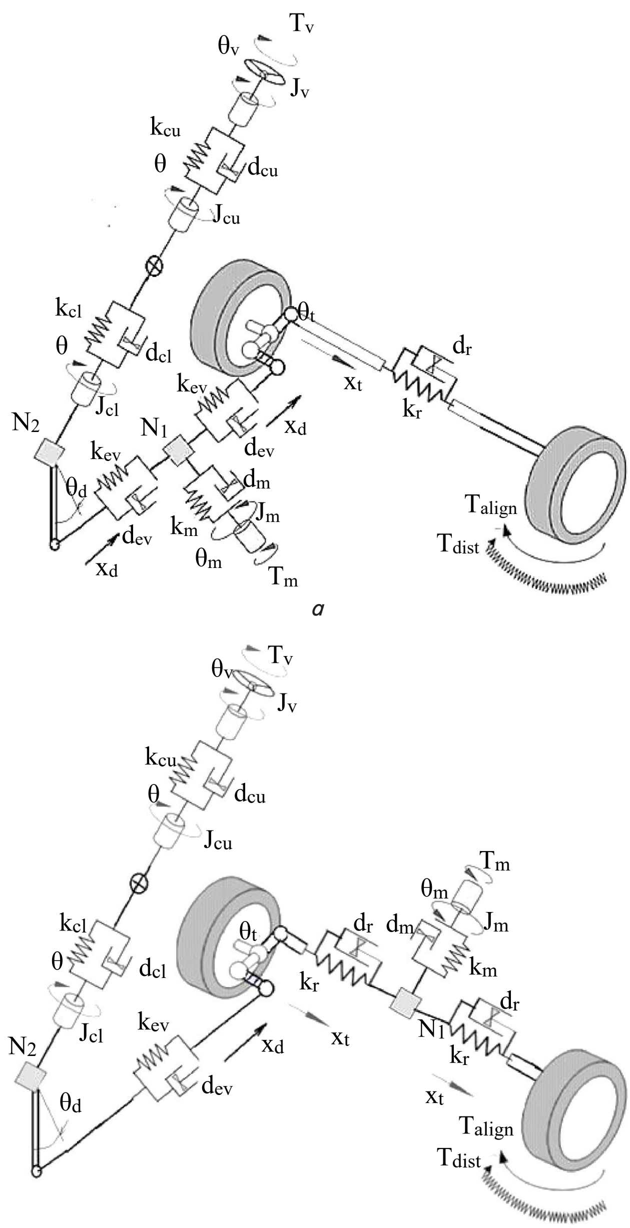


Fig. 8. New proposed EPS model for the EV bus: *a* — assist motor at the drag link; *b* — assist motor at the steering rack

The parameters in the models of Fig. 7, *a* are presented as follows:

– T_v – torque on the steering wheel;
– T_m – torque of the motor;
– T – torque of the steering column;
– θ_v – angle of the steering wheel;
– θ_m – angle of the motor;
– θ – angle of the steering column;
– θ_d – angle of the drop link;
– θ_t – angle of the tire;
– J_v – inertia of the steering wheel;
– J_m – inertia of the motor;
– J_{cu} – inertia of the steering column (upper);
– J_{cl} – inertia of the steering column (lower);
– d_{cu} – damping coefficient of the steering column (upper);
– d_{cl} – damping coefficient of the steering column (lower);
– d_m – damping coefficient of the motor shaft;
– d_{ev} – damping coefficient of the drag link mechanism;
– d_r – damping coefficient of the tie rod;
– k_{cu} – spring constant of the steering column (upper);
– k_{cl} – spring constant of the steering column (lower);
– k_m – spring constant of the motor shaft;
– k_{ev} – spring constant of the drag link mechanism;
– k_r – spring constant of the tie rod;
– N_1 – gear ratio (the rack to the steering column);
– N_2 – gear ratio (the motor to the steering column).

The EPS model with the assist motor in the steering column has been explained in the previous study. Rack type assist motor power steering is a system mounting the electric motor to the rack gear. This model is heavier and more expensive than the column assist motor power steering and is applied to medium and large vehicles over 2000 cc class [12]. The EV bus is the conversion result of the internal combustion engine (ICE) with an engine capacity of 7,684 cm^3. Therefore, the steering rack force from the EV bus was found to be quite large. Hence, an alternative was proposed on the EV bus, as shown in Fig. 8. The EPS involved installing the assist motor on the drag link mechanism, where the parts are sufficient to differentiate the steering system from the city car model. Fig. 8, *b* proposes the installation of the assist motor on the rack.

It is important to note that none of the eight models reviewed was the same with the steering construct in the Molina EV bus UI (Indonesia) since electric power steering is currently being used in small vehicles. Large vehicles like this bus have quite immense power in the steering rack, requiring an AC motor to be used as the assist motor. However, the control system of electric power steering with an AC motor also has some challenges. Therefore, it is necessary to model the EPS further to determine the motor-assisted precise torque to help the steering column movement. Moreover, the kinematic model produced showed the need for an analysis to ensure the wheel drive and tire movement. Simultaneously, the dynamic equation indicates it is also necessary to make the rigidity equivalent to the kinematic structure, which certainly requires other quantities such as the dimensions and elasticity of each link. It means that kinematic analysis is further necessary to determine the stiffness matrix of the drag link structure.

The drag link structure as Fig. 6 consists of truss and frame structures; the local and global stiffness matrix form and the transformation matrix of each of these structures must first be known. The structure of the kinematic mechanism system is the truss and frame structure as in Fig. 9, so to form the equivalent stiffness matrix of the truss matrix and frame as follows. The local stiffness matrix truss structure is as follows:

$$k=\frac{EA}{L}\begin{bmatrix}1 & -1\\ -1 & 1\end{bmatrix}. \quad (1)$$

The transformation matrix for the truss structure is:

$$\begin{Bmatrix}u_1'\\ u_2'\end{Bmatrix}=\begin{bmatrix}l & m & 0 & 0\\ 0 & 0 & l & m\end{bmatrix}\begin{Bmatrix}u_1\\ v_1\\ u_2\\ v_2\end{Bmatrix}, \quad (2)$$

where

$$l=\cos\theta=\frac{x_2-x_1}{L};\ \ m=\sin\theta=\frac{y_2-y_1}{L};$$

$L=\sqrt{(x_2-x_1)^2+(y_2-y_1)^2}$ so the global stiffness matrix for the truss structure is:

$$k=\frac{EA}{L}\begin{bmatrix}l^2 & lm & -l^2 & -lm\\ lm & l^2 & -lm & -l^2\\ -l^2 & -lm & l^2 & lm\\ -lm & -l^2 & lm & l^2\end{bmatrix} \quad (3)$$

and the stiffness matrix in the frame structure is as follows:

$$\begin{Bmatrix}f_1\\ f_2\\ f_3\\ f_4\\ f_5\\ f_6\end{Bmatrix}=\begin{bmatrix}\frac{EA}{L} & 0 & 0 & -\frac{EA}{L} & 0 & 0\\ 0 & \frac{12EI}{L^3} & \frac{6EI}{L^2} & 0 & -\frac{12EI}{L^3} & -\frac{6EI}{L^2}\\ 0 & \frac{6EI}{L^2} & \frac{4EI}{L} & 0 & -\frac{6EI}{L^2} & -\frac{4EI}{L}\\ -\frac{EA}{L} & 0 & 0 & \frac{EA}{L} & 0 & 0\\ 0 & -\frac{12EI}{L^3} & -\frac{6EI}{L^2} & 0 & \frac{12EI}{L^3} & \frac{6EI}{L^2}\\ 0 & -\frac{6EI}{L^2} & -\frac{4EI}{L} & 0 & \frac{6EI}{L^2} & \frac{4EI}{L}\end{bmatrix}\begin{Bmatrix}u_1\\ u_2\\ u_3\\ u_4\\ u_5\\ u_6\end{Bmatrix}. \quad (4)$$

From equations (1)–(4), a local stiffness matrix for each link can be made. By entering the boundary conditions of each link, the global stiffness matrix of this mechanism system can be formed.

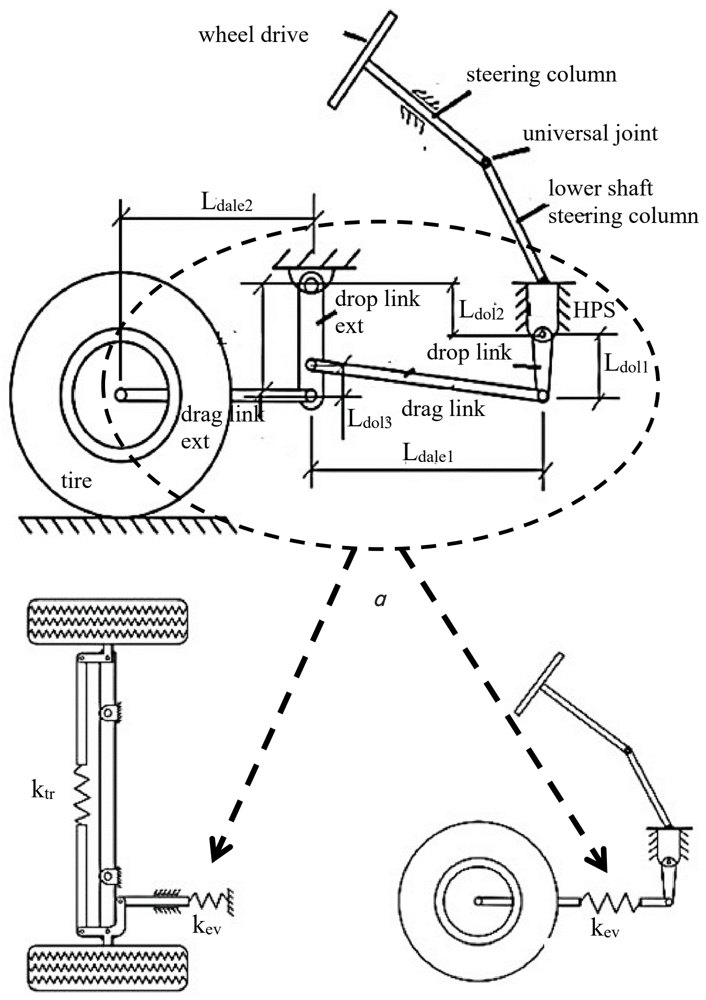


Fig. 9. Steering mechanism of the EV bus:
a — steering structure will be made an equivalent stiffness matrix; *b* — top view; *c* — side view

These boundary conditions can ensure the input and output movements of this mechanism. This equivalent stiffness matrix is conducive in making overall dynamic movements in large-sized vehicles. It can help in estimating the amount of torque required by a motorist to change hydraulic power steering to electric power steering in large-sized cars.

Further research from the model that has been made is to create a dynamic equation for the motion of these two systems. To see the characteristics of the dynamic equation, refer to the research application of the rack type motor driven power steering control system for heavy vehicles. One that is quite helpful is the bond graph model for with or without derivative causality for drag link and rack type electric power steering as in Fig. 10.

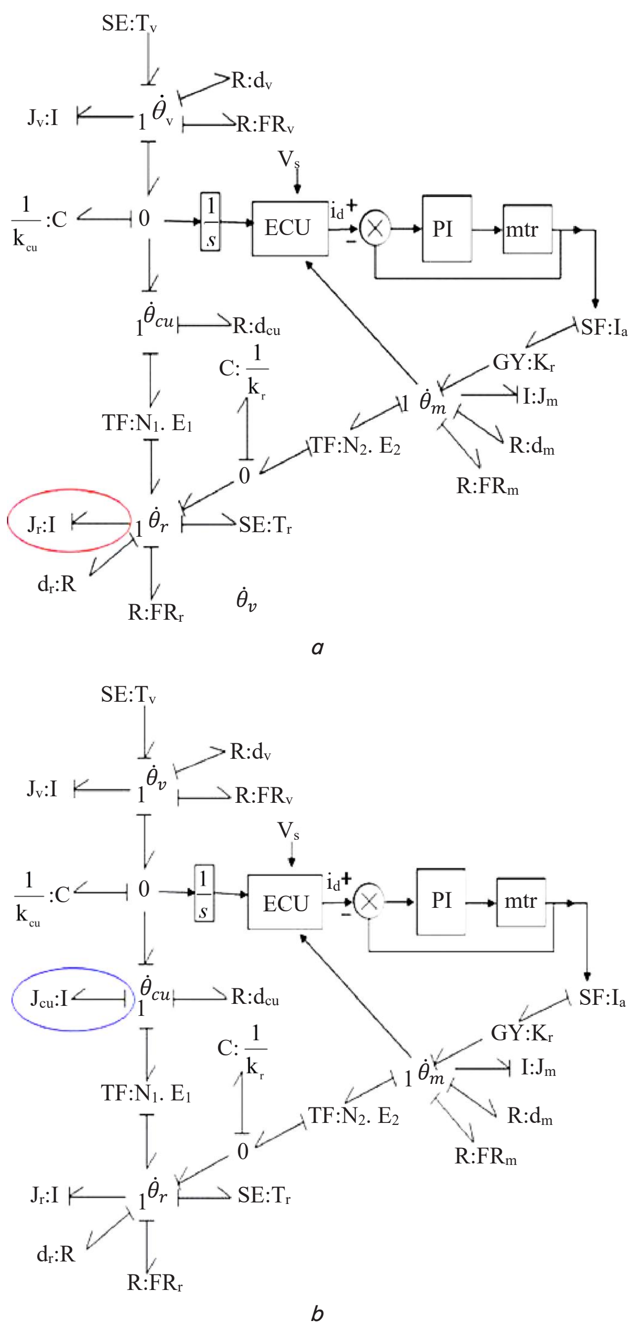


Fig. 10. Bond graph model for drag link and rack type electric power steering [12]: *a* – with derivative causality; *b* – without derivative causality

6. Discussion of modelling results

A review of several models of the electric power steering system has been carried out as in Table 1. From this table, it can be seen that most of the assist motors are still placed on the steering column. The application of the EPS system with an assist motor in column steering is generally in small cars such as city cars and the like. Table 2 presents the use of the steering system on the heavy vehicle for the ICE bus and EV bus. Data were collected from various open sources from brochures and leaflets for certain brands. Only the new Volvo type 7900 (Sweden) car applies electric-hydraulic power steering.

According to the reverse engineering method, the hydraulic power steering model of the EV bus has been successfully assembled as shown in Fig. 5. The components directly involved were the wheel drive, steering column, HPS, drop arm, drag link, drop link extension, drag link extension, knuckle, king pin, axle beam, track rod and tire. The base on the steering system will be developed into electric power steering by adding an assist motor. The first model has been presented in the previous paper [1], where the assist motor is placed on the steering column.

The two models presented in this paper are the drag link and the steering rack. This is based on the distance between the column steering and the axle beam, which is relatively far 2,380 mm, almost three times that of an ordinary car. Another cause is the amount of hydraulic motor power currently used, namely 7.5 kW (Fig. 3). If from several studies, the energy saving from the hydraulic system to the electric power system is only about 20 %, then based on Fig. 2, *a* [3] it is recommended to install the assist motor on the steering rack.

The parameters involved in the dynamic model of the electric power steering system are the relationship between steering wheel torque and wheel torque. The stiffness and damping of each component that connects the two are also parameters that determine how much torque the assist motor must provide later. Components such as a steering column, lower steering column, drag link, drop link, stiffness and damping parameters are strongly influenced by the shape and dimensions as well as the material of each.

This research has a specificity that distinguishes it from the previous system, which is that it has a structure between the steering column and the axle beam. This structure occurs because of the long distance between the steering column and the axle beam. To facilitate the analysis and prepare the equations of motion for this steering system, it is necessary to construct an equivalent stiffness matrix of this structure. This structure is constructed from several truss rods and frame rods. Truss rods, namely drop link, drag link, drag link extension and knuckle. Meanwhile, the frame rods is a drop link extension. This structure is actually a combination of two four-bar linkage mechanisms.

The direction of this study is to determine the amount of torque required for each proposed model. The dynamic equations for each model will be studied further, but considering that the model is more complex than the previous models of the steering system. Therefore, it is necessary to validate the model with vehicle modeling software that has been developed at this time, before laboratory scale testing is carried out. The next difficulty may be the assist motor. Look at the motor power for a hydraulic system of 7.5 kW assuming a reduction of only about 20 % in this electrical system. Then the size of the assist motor will be large enough if later attached to the steering column or on the drag link. So for the size of the assist motor, you might see research in the electric motor from the electro team researchers later.

7. Conclusions

1. The data collected on large vehicles showed that almost none uses electric power steering, including the ICE bus and EV bus.

2. Two models were proposed, and these include the EPS with the assist motor mounted at two positions: one on the drag link, the other on the rack. The components directly involved were the wheel drive, steering column, rack and pinion gear, assist motor, drag link, tie rod, knuckle, kingpin, tire, and several others. Moreover, the mechanical magnitudes involved include the torque, angle, inertia, damping, spring stiffness, gear ratio, torque on the steering wheel, torque of the motor, torque of the steering column, angle of the steering wheel, angle of the motor, angle of the steering column, angle of the drop link, angle of the tire, and inertia of the steering wheel.

3. The new parameters discovered for the EV bus steering system include motor inertia, upper and lower steering columns inertia, damping coefficient of upper and lower steering columns, damping coefficient of the motor shaft, damping coefficient of the mechanical drag link, damping coefficient of the tie rod, spring constant of upper and lower steering columns, spring constant of the motor shaft, spring constant of the mechanical drag link, spring constant of the tie rod, gear ratio of the rack to the steering column, and gear ratio of the motor to the steering column. The EV bus steering system is characterized by a connecting structure between the steering column and the axle beam. The structure consists of two mechanisms of four-bar linkage, which are joined to form one linkage structure. This structure also consists of truss structure and frame structure.

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