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(54) **Title**: METHOD AND SYSTEM FOR CONTROLLING AN ELECTRIC MOTOR IN A HYBRID VEHICLE

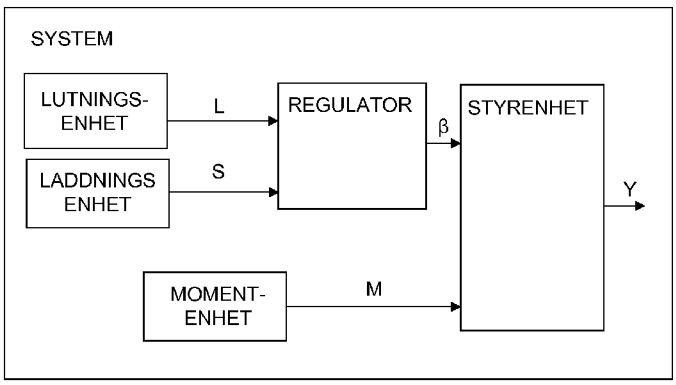

FIG. 4

(57) **Abstract**: The invention comprises a system and a method for controlling an electrical machine in a hybrid vehicle in which the power train comprises a combustion engine and a battery which is connected to said electrical machine, which system comprises: a gradient unit for determining the road gradient α when the vehicle is in motion and for generating a gradient signal on that basis; a charge unit for determining the battery's state of charge (SOC) and generating an SOC signal S on that basis; a regulator adapted to using the gradient signal and the SOC signal as input signals for calculating a weighting factor and generating a weighting signal β on that basis; a torque unit adapted to determining a torque desired by the driver and to generating a torque signal M on that basis; a control unit adapted to calculating for the electrical machine a control signal based on the weighting signal β and the torque signal M, whereupon the electrical machine is controlled according to the control signal.

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Title

Method and system for controlling an electric motor in a hybrid vehicle

Field of the invention

The present invention relates to a method and a system for controlling an electrical machine in a hybrid vehicle according to the introduction to the independent claims.

Background to the invention

One of the greatest challenges in the heavy vehicle industry is to reduce fuel consumption. Fuel costs represent about 30% of a heavy truck's life cycle cost. Average distance travelled is about 150,000 km per annum and average fuel consumption is about 32.5 litres per 100 km. A small decrease in fuel consumption therefore results in large decreases in fuel costs. A good way of saving fuel is to regenerate brake energy and pass it back to the wheels when needed, instead of merely converting the kinetic energy to heat by using conventional brakes. This is possible by using a hybrid vehicle instead of a conventional vehicle.

A hybrid vehicle is a conventional vehicle with at least two energy sources. For example, an internal combustion engine may be backed up by an electrical machine. The electrical machine may be used as both motor and generator, making it possible for the vehicle to treat the electrical machine as a means of reducing the vehicle's speed by using the machine as a generator, in which case the kinetic energy is used to induce a current which is then used to charge the battery, making it possible for energy to be saved and used later instead of the kinetic energy being converted to heat by using the conventional brake equipment. In driving situations which involve high fuel consumption, fuel consumption can be greatly reduced by using the electric motor to back up the combustion engine. Such situations typically occur during acceleration and on upgrades.

There are various kinds of electric hybrid systems, e.g. series hybrid, parallel hybrid and the combination of them known as power split system or series-parallel hybrid. In a series hybrid system, as illustrated in Figure 1, the combustion engine drives an electrical generator instead of directly driving the vehicle's wheels. The generator not only charges a battery but also provides energy for an electric motor which propels the vehicle. When large amounts of energy are needed, the electric motor takes energy from both battery and generator. The combustion engine is therefore not integrated in the vehicle's drive system, since the propulsion is entirely by means of the electric motor. In parallel hybrid vehicles, the combustion engine and an electrical machine which is used as both generator and motor are mechanically connected via engine shafts. An example of a parallel hybrid system is depicted in Figure 2. The connection may be situated between the combustion engine and the electrical machine, making it possible to run the vehicle purely electrically. As the combustion engine and the electrical machine rotate at exactly the same speed (when the connection is made), they complement one another and run in parallel. Series-parallel hybrid systems are common in passenger car technology but usually too complicated for heavy vehicles.

The latest addition to the hybrid vehicle family, charge hybrids (also known as cord hybrids or plug-in hybrids) are suited to charging from the electricity network when the vehicle is parked. Charge hybrids have larger electric motors and powerful battery packages which in a few hours become fully charged from an electric socket outlet via a cord.

Patent application US 2005/0274553 describes a predictive energy management system for electric hybrid vehicles. The system uses various kinds of information such as current location and 3D maps and generates optimum engine instructions based on minisation of a cost function which is limited by restrictions for a battery.

Patent application DE 100 35 027 describes a method for controlling a hybrid vehicle's operating state and uses inter alia a road profile to determine the various states.

Patent application US 2005/0274553 describes a predictive energy management system for a hybrid vehicle. Using a predictive regulating strategy makes it possible to generate engine commands which optimise the hybrid vehicle's current and future operation, but the regulating strategy applied is complex and involves a relatively large amount of computing capacity.

The object of the present invention is to propose a better way of reducing a hybrid vehicle's energy consumption.

Summary of the invention

The object described above is achieved according to an aspect of the invention by a system for controlling an electrical machine in a hybrid vehicle where the power train comprises a combustion engine and a battery which is connected to said electrical machine. The system comprises:

-a gradient unit for determining the road gradient α when the vehicle is in motion and for generating a gradient signal on that basis,

- a charge unit for determining the battery's state of charge (SOC) and generating an SOC signal S on that basis;

- a regulator adapted to using the gradient signal and the SOC signal as input signals for calculating a weighting factor and generating a weighting signal β on that basis;

- a torque unit adapted to determining a torque desired by the driver, and to generating a torque signal M on that basis;

- a control unit adapted to calculating for the electrical machine a control signal based on the weighting signal β and the torque signal M, whereupon the electrical machine is controlled according to the control signal.

The object is achieved according to another aspect by a method for controlling an electrical machine in a hybrid vehicle where the power train comprises a combustion engine and a battery which is connected to said electrical machine. The method comprises:

A) determining the road gradient α when the vehicle is in motion;

B) determining the battery's state of charge (SOC);

C) using the road gradient α and the battery's SOC as input signals to a regulator to calculate a weighting factor;

D) determining a torque desired by the driver;

E) calculating for the electrical machine a control signal based on said weighting factor and driver-desired torque, whereupon the electrical machine is controlled according to the control signal.

Intelligent choices for improving the way the vehicle operates can be made on the basis of the gradient of the road where the vehicle is at the particular time, the battery's SOC and the torque desired by the driver. In this way the vehicle can reduce its energy use by using the battery's energy on upgrades and thereafter charging up the battery on downgrades. The vehicle may thus also have more power when it is most needed, e.g. on steep upgrades.

Fuzzy logic is an example of a regulating strategy which may be used in the present invention and which in a usable way charts an input signal region to an output signal region. This is done, for example, by using a list of "if .... then" sentences called rules, which relate to variables and the adjectives describing them. The veracity of each sentence remains a question of degree. Member functions are used which may be described as taking the form of a curve which defines how each point in the input signal region is charted to a member value, or degree of membership, between 0 and 1. However, other regulating strategies are also usable in conjunction with the invention.

Preferred embodiments are described in the dependent claims and the detailed description.

Brief description of the attached drawings

The invention is described below with reference to the attached drawings, in which:

Figure 1 illustrates the power train in a series hybrid vehicle.

Figure 2 illustrates the power train in a parallel hybrid vehicle.

Figure 3 illustrates a power train used in the present invention.

Figure 4 illustrates the road gradient α.

Figure 5 illustrates the system according to an embodiment of the invention.

Figure 6 illustrates a rule base for use of fuzzy logic according to an embodiment of the invention.

Figure 7 illustrates the relationship between input and output signals in a fuzzy logic regulator according to an embodiment of the invention.

Figure 8 illustrates the relationship between input and output signals in a fuzzy logic regulator according to another embodiment of the invention.

Figure 9 depicts a flowchart for the method according to an embodiment of the invention.

Detailed description of preferred embodiments of the invention

The invention is described below in conjunction with a parallel hybrid system but may also be used in conjunction with other kinds of hybrid system. The power train in a parallel hybrid vehicle illustrated in Figure 3 is the system in the vehicle which transmits energy from the combustion engine and the electrical machine to the road surface via the clutch, the gearbox, driveshafts and wheels. The combustion engine may be run on diesel fuel or petrol or some other suitable liquid or gas. The clutch comprises a series of friction discs which can jointly disconnect the combustion engine from the rest of the power train. The clutch may be operated by the driver by a pedal or be automatic, in which case a control system conducts gear changes and clutch operation. The second energy source in a parallel hybrid vehicle is the electrical machine. The electrical machine comprises two elements, viz. a rotor and a stator. The rotor is the rotating element of the electrical machine and has a shaft which may be equipped with permanent magnets or windings which become electromagnetic when they are connected to an electrical energy source. In the latter case, the degree of magnetisation can be controlled. The stator is the outer shell which encloses the electrical machine and has windings in it to which the energy cables are connected. When the electrical machine is used as a motor, the energy from the cables induces a magnetic field in the stator. When the electrical machine is used as a generator, the rotor induces in the stator windings a current which is then stored as electrical energy in the battery. By way of example, the electrical machine may be a 36 kW permanent magnet synchronous machine, which is a three-phase machine in which the rotor rotates synchronously with the rotating magnetic field in the stator.

A converter (not depicted) is connected to the electrical machine to convert AC to DC when the machine is used as a generator and is charging the battery, and DC to AC when the battery delivers energy to the electrical machine, which is then used as a motor. For the sake of long service life, the power electronics need cooling, which may for example be water-based. An external cooling circuit may therefore need to be installed.

The battery is connected to the electrical machine and comprises a number of cells connected in series to increase the voltage. The series-connected cells are thereafter connected in parallel to increase the capacity of the whole battery package. By way of example, the batteries may be NiMH batteries in which each cell has a nominal voltage of 1.2 V. Another example is lithium ion (Li-ion) batteries, which have better W/kg and Wh/kg values, rendering them smaller and lighter than corresponding NiMH batteries.

The purpose of the gearbox and the final gear is to match the speed of the power train at the input shaft of the gearbox with the speed at the wheels. The transmission ratio in the gearbox can be varied by changing gear, whereas the dynamics of the final gear are constant.

Figure 4 depicts a system for controlling an electrical machine in a hybrid vehicle according to an embodiment of the invention. The hybrid vehicle's power train comprises a combustion engine and a battery which is connected to said electrical machine, as illustrated in Figure 3. The system according to the invention comprises a gradient unit to determine the road gradient α when the vehicle is in motion, and generate a gradient signal L on that basis, a charging unit to determine the battery's state of charge SOC and generate an SOC signal S on that basis, and a reading unit adapted to determining a torque desired by the driver and to generating a torque signal M on that basis. The system further comprises a regulator adapted to using the gradient signal and the SOC signal as input signals for calculating a weighting factor and generating a weighting signal β on that basis; and a control unit adapted to calculating for the electrical machine a control signal Y based on the weighting signal β and the torque signal M. The electrical machine is thereafter controlled according to the control signal Y. The result is a system for controlling the electrical machine so that the battery's stored energy can be used when most needed, i.e. when the road gradients upwards.

The weighting signal β therefore describes how much energy should be drawn from the battery, depending on the current road gradient and current SOC. The control unit thereafter generates for the electrical machine a control signal Y which indicates how much energy should be drawn from the battery when the driver desires a certain torque M. The regulator is preferably adapted to calculating a weighting signal β which is a standardised scale factor. The weighting factor is then standardised to a value of between, for example, [0 1]. According to an embodiment, the scale factor β is multiplied by a predetermined value for the maximum torque which the electrical machine can deliver. If for example the maximum torque is 300 Nm and the scale factor 0.6, the control signal Y will indicate that the electrical machine should deliver 300x0.6=180 Nm to the power train. The control unit ensures that the torque M desired by the driver is not exceeded. Any remaining torque required to provide the power train with the torque desired by the driver is thereafter drawn from the combustion engine.

The road gradient α is illustrated in Figure 5 and the gradient unit comprises according to an embodiment sensors in the vehicle for determining the gradient α. Thus the momentary gradient of the road can be determined continuously. According to a further embodiment, derivatives of the gradient are analysed and the results are used to predict the nature of the gradient ahead, which is incorporated in the calculations in the regulator and/or the control unit in order to produce a control signal for the electrical machine.

Signals used in the system are preferably sent via CAN in the vehicle. CAN (controller area network) is a serial bus system specially developed for use in vehicles. The CAN data bus makes digital data exchange possible between sensors, regulating components, actuators, control devices etc. and provides assurance that two or more control devices can have access to the signals from a given sensor in order to use them to control components connected to them.

The state of charge SOC is a ratio between current charge level and maximum charge and is calculated by the formula

$$SOC = SOC_{init} - \frac{1}{Q_{\max}} \int i(t)dt \qquad (1)$$

where Q_{max} is the battery's maximum charge capacity, SOC_{init} the initial state of charge value and i(t) the current through the battery. The battery's full capacity is never used, since too much circulation of energy in the battery might cause it serious damage. There is therefore an upper limit SOC_u and a lower limit SOC_l for the state of charge. The range between these two limits is known as the SOC window.

The state of charge is preferably scaled when used as input signal to the regulator, in order to simplify the configuration on the basis of knowing that the state of charge is always within the range [0 1]. The scaling is done by using the equation

$$\frac{SOC - SOC_l}{SOC_u - SOC_l} \qquad (2)$$

The charge unit is preferably adapted to measuring the signals needed for the above calculations and to performing the calculations for producing an SOC signal S.

The energy circulating in the battery is the total flow through the battery, calculated as

$$E_{tot} = \int \left| i_{bat}(t) \cdot u_{bat}(t) \right| dt \qquad (3)$$

where i_{bat} and u_{bat} are the battery's current and voltage.

According to an embodiment of the invention, the regulator is a rule-based regulator, e.g. a fuzzy logic regulator. Fuzzy logic involves using a list of "if .... then" sentences called rules. Member functions can be used to provide answers which are matter of degree, not simply "yes" or "no". A member function (MF) is a curve which defines how each point in the input signal region is charted to a member value (or degree of membership) between 0 and 1. Two or more member values are provided as input signals to a fuzzy operator which produces as output signal a true value. A fuzzy operator may be a logic operator such as AND, OR or NOT. Figure 6 depicts an example of a rule base for the fuzzy logic regulator. In this example there are two member functions for gradient input signals L, viz. "High" and "Low". For the SOC input signal S there are two member functions, likewise called "High" and "Low". The output signal from the fuzzy regulator also has the two member functions "High" and "Low". Figures 7 and 8 depict two examples of fuzzy regulators illustrated graphically in which the input signals and output signals appear on the various axes. The surface shows clearly how the regulators work. The first regulator in Figure 7 has almost only one state, which means a strong weighting signal β. The strength of the weighting signal decreases somewhat when SOC decreases and when the gradient is less steep. In the system with the second regulator illustrated in Figure 7, the regulator is adapted to calculating for the control unit a weighting signal β which gradually increases with rising gradient signal L and rising SOC signal S in order to receive a uniform supply of energy from the battery. The regulator illustrated in Figure 8 is significantly more gentle than that in Figure 7 in that when SOC is high and the road gradient large the output signal β is close to maximum value. However, support from the electrical machine comes when the road gradient is relatively steep. On smaller gradients, SOC has to be relatively high for the regulator to react. Fuel consumption can be reduced significantly by regulating the electric motor in this way.

The system is therefore preferably adapted to calculating a control signal for the electrical machine to use energy from the battery when the battery's SOC is between SOC_{min} and SOC_{max} and the road gradient α indicates an upgrade. The vehicle thus receives extra energy when most needed, particularly on upgrades. A requirement for using energy from the battery is that SOC is between the limit values described above.

However, other regulating strategies are also conceivable and fuzzy logic is only described as an example.

The system is preferably adapted to regenerating brake energy to the battery when the road gradient α indicates a downgrade. The vehicle will then be running downhill and the battery can be charged up by taking advantage of the kinetic energy provided by the vehicle. When the speed needs to be reduced, this is usually done by a hydraulic retarder unit, the exhaust brake and/or the wheel brakes in combination with the electrical machine. So long as the battery is allowed to be charged, i.e. so long as SOC_u is not exceeded and the vehicle needs to be braked, the electrical machine is used as a generator as much as possible.

The invention relates also to a method for controlling an electrical machine in a heavy vehicle in which the power train comprises a combustion engine and a battery which is connected to said electrical machine. The method will now be described with reference to the flowchart in Figure 9.

Accordingly, the method comprises: A) determining the road gradient α when the vehicle is in motion; B) determining the battery's state of charge (SOC); C) using the road gradient α and the battery's SOC as input signals to a regulator to calculate a weighting factor; D) determining a torque desired by the driver; and E) calculating for the electrical machine a control signal based on said weighting factor and driver-desired torque, whereupon the electrical machine is controlled according to the control signal. The method described enables the combustion engine to receive more energy from the battery when the road is steep and SOC is sufficient.

According to an embodiment, a rule-based regulator, e.g. a fuzzy logic regulator, may be used in step C). This makes it possible for control values for reducing fuel consumption to be calculated for the electrical machine in a way which does not take up so much computing capacity. Using a regulator by which the control signal in step D) is calculated to increase gradually makes it possible for a uniform supply of energy from the battery to be used to power the vehicle.

In step C) the weighting factor is preferably calculated as a standardised scale factor, making it possible to arrive at a value between [0 1] which can easily be used for calculating how large a contribution should be taken from the batteries.

The road gradient α is determined according to an embodiment by means of sensors in the vehicle. The current gradient can thus be determined continually.

In step D) the control signal is preferably calculated so that energy is provided from the battery when its SOC is between SOC_{min} and SOC_{max} and the road gradient α indicates an upgrade. Energy is thus drawn from the battery when it is available and the vehicle needs extra on upgrades.

According to an embodiment, the weighting factor for the control unit is calculated in step D) to gradually increase when the gradient increases and SOC rises, in order to provide a uniform supply of energy from the battery. The result is a more uniform offtake of energy from the battery, causing less wear of the battery, which in many cases is one of the vehicle's most expensive components.

Brake energy is preferably regenerated to the battery when the road gradient α indicates a downgrade. The kinetic energy which the vehicle acquires downhill is thus utilised instead of being merely braked away.

The present invention comprises also a computer programme product comprising computer programme instructions for enabling a computer system in a vehicle to perform the steps according to the method described above when the computer programme instructions are run on said computer system. According to an embodiment, the computer programme instructions are stored on a medium which is readable by a computer system.

The present invention is not limited to the embodiments described above. Various alternatives, modifications and equivalents may be used. The embodiments mentioned above therefore do not limit the scope of the invention, which is defined by the attached claims.

Claims

1. A system for controlling an electrical machine in a hybrid vehicle in which the power train comprises a combustion engine and a battery which is connected to said electrical machine, c h a r a c t e r i s e d in that the system comprises:

-a gradient unit for determining the road gradient α when the vehicle is in motion and for generating a gradient signal (L) on that basis,

- a charge unit for determining the battery's state of charge (SOC) and to generating an SOC signal (S) on that basis;

- a regulator adapted to using the gradient signal and the SOC signal as input signals for calculating a weighting factor and generating a weighting signal (β) on that basis;

- a reading unit adapted to determining a torque desired by the driver, and to generating a torque signal (M) on that basis;

- a control unit adapted to calculating for the electrical machine a control signal (Y) based on the weighting signal (β) and the torque signal (M), whereupon the electrical machine is controlled according to the control signal (Y).

2. A system according to claim 1, in which the regulator is adapted to calculating a weighting signal (β) which is a standardised scale factor.

3. A system according to claim 1 or 2, in which the regulator is a rule-based regulator, e.g. a fuzzy logic regulator.

4. A system according to any one of claims 1 to 3, which system is adapted to calculating a control signal for the electrical machine to use energy from the battery when the battery's SOC is between SOC_{min} and SOC_{max} and the road gradient α indicates an upgrade.

5. A system according to any one of claims 1 to 4, in which the regulator is adapted to calculating for the control unit a weighting signal (β) which gradually increases with rising gradient signal (L) and rising SOC signal (S), in order to achieve a uniform supply of energy from the battery.

6. A system according to any one of claims 1 to 4, in which the gradient unit comprises sensors in the vehicle for determining the road gradient α.

7. A system according to any one of claims 1 to 6, which system is adapted to regenerating brake energy to the battery when the road gradient α indicates a downgrade.

8. A method for controlling an electrical machine in a hybrid vehicle in which the power train comprises a combustion engine and a battery which is connected to said electrical machine, c h a r a c t e r i s e d in that the method comprises:

A) determining the road gradient (α) when the vehicle is in motion;

B) determining the battery's state of charge (SOC);

C) using the road gradient (α) and the battery's SOC as input signals to a regulator for calculating a weighting factor;

D) determining a torque desired by the driver;

E) calculating for the electrical machine a control signal based on said weighting factor and driver-desired torque, whereupon the electrical machine is controlled according to the control signal.

9. A method according to claim 8, in which a weighting factor which is a standardised scale factor is calculated in step C).

10. A method according to claim 8 or 9, in which a rule-based regulator, e.g. a fuzzy logic regulator, is used in step C).

11. A method according to any one of claims 8 to 10, which the control signal at D) is calculated so that energy from the battery is used when the battery's SOC is between SOC_{min} and SOC_{max} and the road gradient α indicates an upgrade.

12. A method according to any one of claims 8 to 11, in which the weighting factor for the control unit in step D) is calculated to gradually increase with increasing gradient and rising SOC in order to achieve a uniform supply of energy from the battery.

13. A method according to any one of claims 8 to 12, in which the road gradient (α) is determined by means of sensors in the vehicle.

14. A method according to any one of claims 8 to 13, in which brake energy is regenerated to the battery when the road gradient α indicates a downgrade.

15. A computer programme product comprising computer programme instructions for enabling a computer system in a vehicle to perform the steps according to the method according to any one of claims 8 to 14 when the computer programme instructions are run on said computer system.

16. A computer programme product according to claim 15, in which the computer programme instructions are stored on a medium which is readable by a computer system.

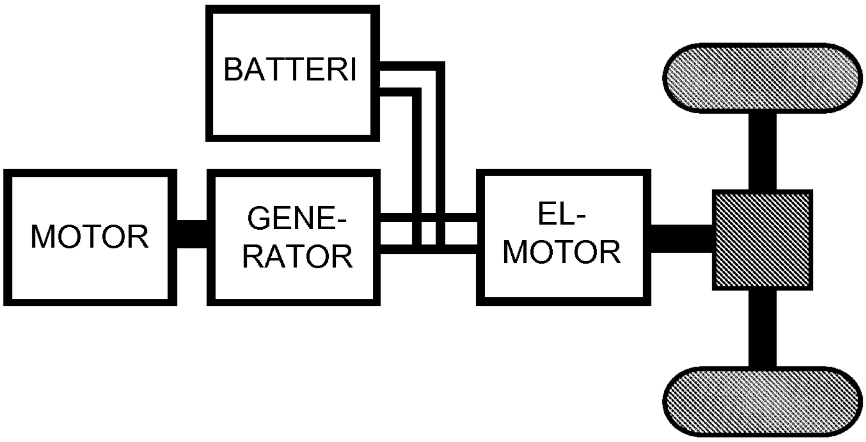


FIG. 1

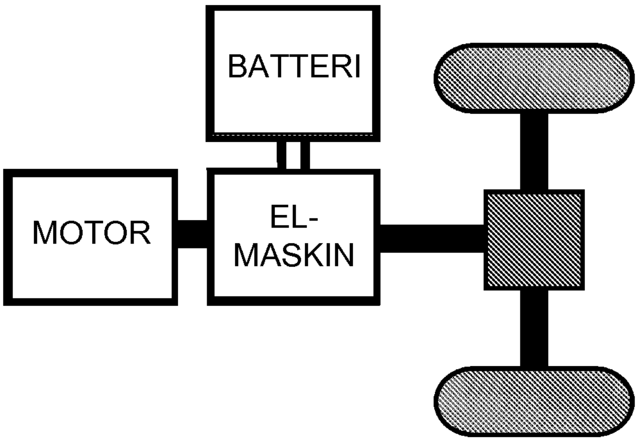
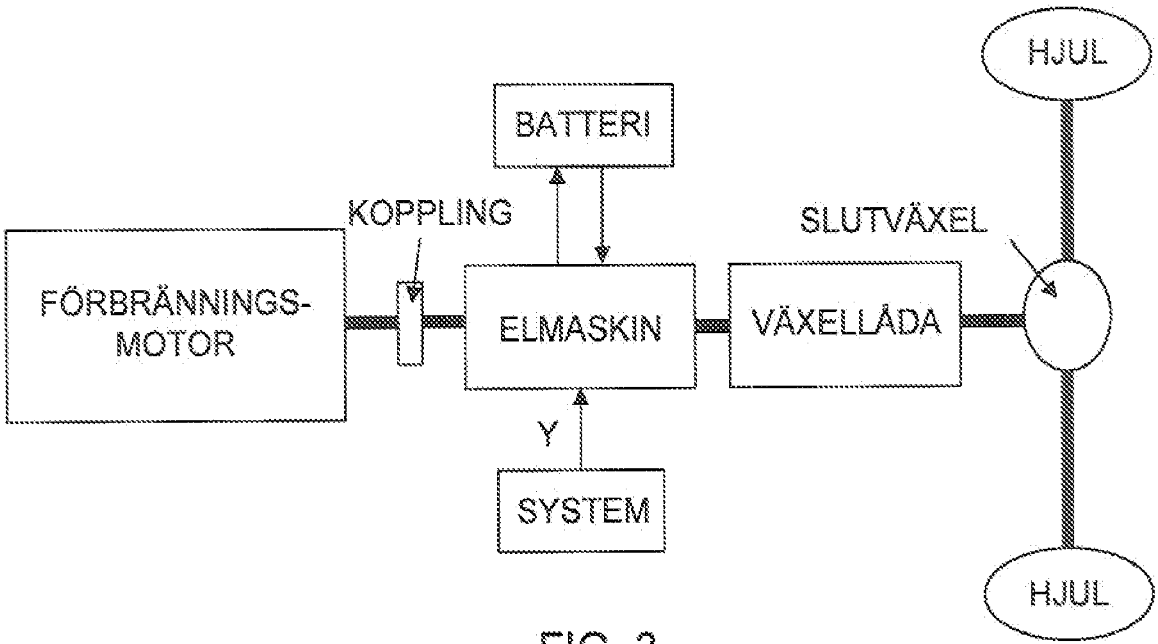


FIG. 2


HJUL
BATTERI
KOPPLING
SLUTVÄXEL
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ELMASKIN
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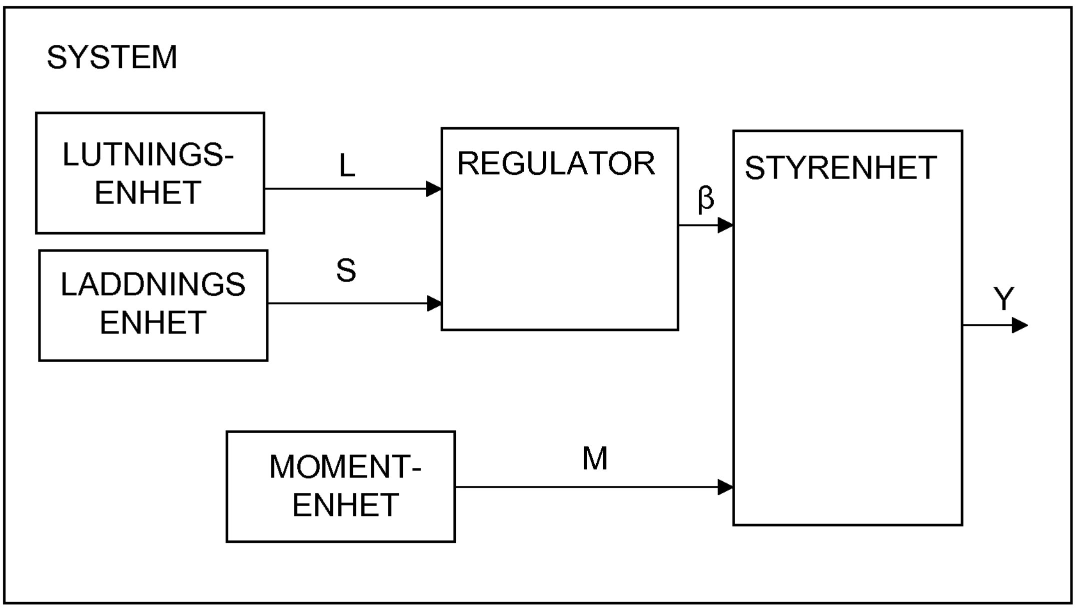
FIG. 3


SYSTEM
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REGULATOR
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FIG. 4

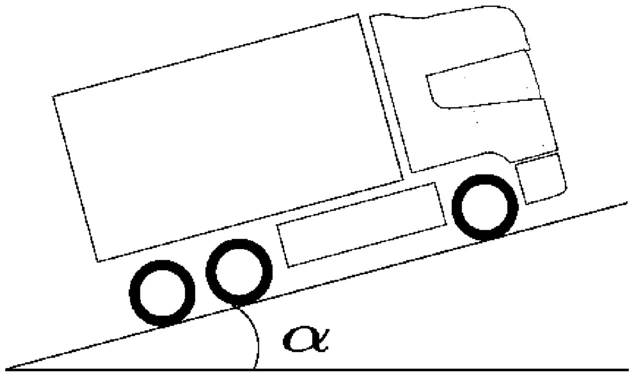
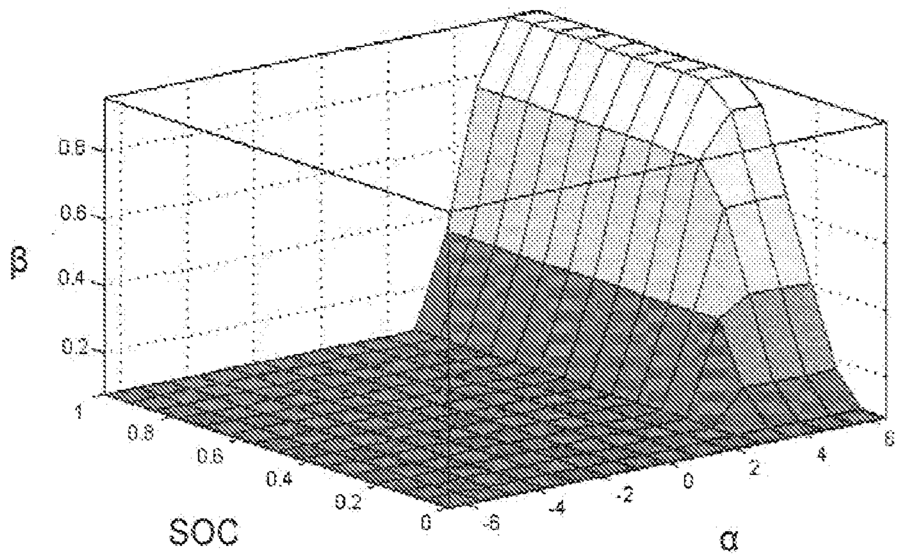


FIG. 5

S

		HÖG	LÅG
L	HÖG	HÖG	LÅG
	LÅG	LÅG	---

FIG. 6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0.8
0.6
0.4
0.2
SOC
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0.8
0.6
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α
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2
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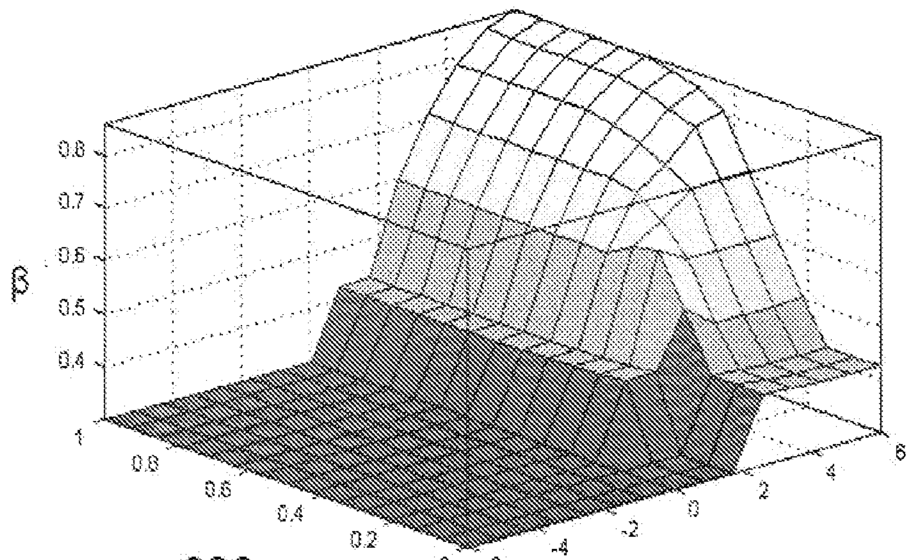
6

FIG. 7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0.7
0.6
0.5
0.4
SOC
1
0.8
0.6
0.4
0.2
0
α
-6
-4
-2
0
2
4
6

FIG. 8

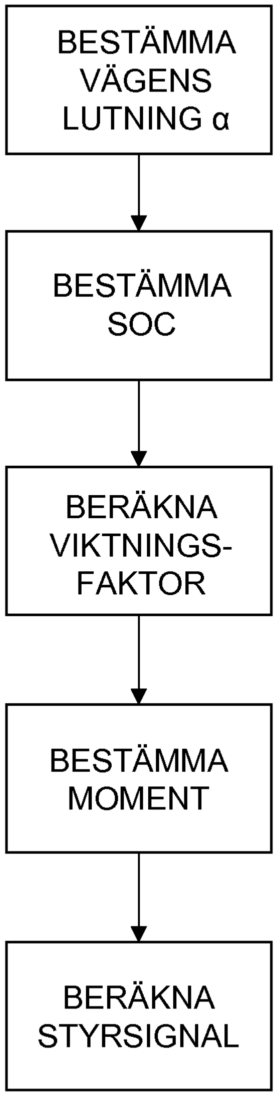
BESTÄMMA VÄGENS LUTNING α
BESTÄMMA SOC
BERÄKNA VIKTNINGS-FAKTOR
BESTÄMMA MOMENT
BERÄKNA STYRSIGNAL

FIG. 9