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MAXIMIZING ENERGY RECOVERY OF REGENERATIVE BRAKING IN ELECTRIC VEHICLES

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ABSTRACT:

Under raising pressure of global energy and environmental issues in recent years, electric efficiency, low noise, and zero emission. Energy recovery is an important technology to ameliorate efficiency and prolong driving range of EVs. The dynamic programming is employed to optimise the motor braking torque under the condition of braking regulation. The control approach is based on real-time sensing of the motor controller dc link current and disabling regenerative braking when current changes direction while the motor is operating as a generator. The vehicle braking system model including mechanic and regenerative braking system is inbuilt. A multi-objective optimization controller with variable switch angles is designed and combined with vehicle braking system. Based on the results obtained from the simulation studies, a dynamic low-speed cut-off point detection method is proposed. It is shown that in juxtaposition with the traditional co-ordinated control strategy, the braking energy recovery efficiency of the proposed braking control strategy is improved by 15% to 25%. Therefore, this paper offers a useful theoretical reference to the design of regenerative braking system coordinated control strategies for Electrified Vehicles.

INDEX TERMS: *Brake controller, Electric vehicle (EV), Braking force distribution, Multi -objective optimization, Recaptured energy, Regenerative braking.*

I. INTRODUCTION:

Regenerative braking plays an important role in improving energy efficiency and increasing driving range of EVs, When EV is in braking, the regenerative braking system (RBS) can convert the kinetic energy or potential energy into electric energy to charge the power battery, and to provide motor braking torque to reinforce braking and lower the brake temperature rise. the automotive companies are resisting the challenge of reducing fuel usage and emission caused by transportation sector. In fact, the transportation sectors alone account roughly 21% of the total energy related to emission. In recent years, growing scales of electric vehicles (EVs) have gained impetus to the global shift toward transportation electrification, making the automotive industry invest more excessive in the transportation electrification technology. However, one important problem in the largescale taking in of EVs is their restricted driving range. Hence, extensive research in both industry and academia is carried out with the aim of increasing the efficiency and driving range of these vehicles. To improve the braking system performance of EVs, a host of research has been carried out in the fields of energy management of EVs, emergency braking control strategies, and anti-lock braking system (ABS). A new regenerative braking system scheme was put forward to ensure the maximum regenerative braking force. Correspondingly to recover more braking energy, a braking torque distribution control algorithm, which consign the available maximum braking torque for the motor output to the braking process and augmented the remaining required braking torque by the hydraulic system. A brake torque distribution strategy fostering damages control to increase the efficiency of energy recovery by examining the difference between the dynamic characteristics of the hydraulic brake system & the regenerative braking system was introduced. In the above studies, the RBS & ABS were synchronized to maximize the ratio of the motor braking torque & output braking torque under normal conditions to retrieve more braking energy. Moreover, this low-speed threshold, under which regenerative braking is no longer implicit, depends on a variety of factors and varies under different operating conditions

[[regenerative braking system of electric vehicle driven by brushless dc motor], [optimum low-speed control of RB for electric vehicle]. Therefore, a dynamically changing low-speed threshold should be considered in designing the brake controller [optimum low-speed control of RB for electric vehicle]. The factors affecting a change in low-speed regenerative braking performance of EVs and proposes a novel method that can precisely identify the instance where regenerative braking is no longer effective.

II. REGENERATIVE BRAKING SYSTEM OF EVs.

1. Vehicle dynamic model

The vehicle driving forces can be enumerated by means of external forces under driving conditions, which is shown below

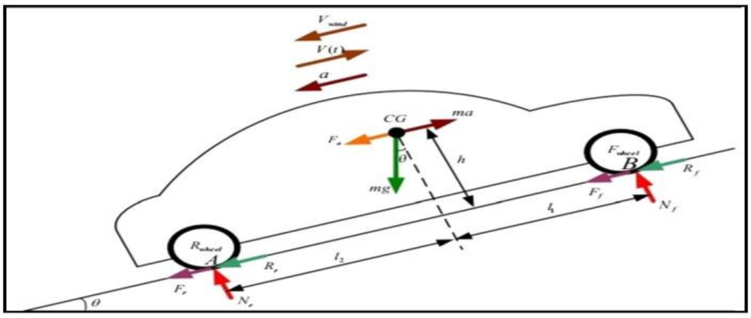
$$F_t = F_f + F_w + F_i + F_j \, (1)$$

Where, F_f is rolling resistance, F_w is air resistance, F_i is gradient resistance and F_j is acceleration resistance respectively.

Force compelling on vehicle and several forces compelling on the land during braking is illustrated in the below figure. Usually, these forces can be categorized into four such as rolling resistance, aerodynamic force, gravitational force and braking force. The total braking force acting on the vehicle parallel to the road surface, demonstrated as a composition of force

$$Fres = (Ff + Fr + Rf + Rr + Fa + mg.) = m.a$$

During the braking process, the vehicle will be annihilated to air resistance, rolling resistance, gradient resistance & braking force from front and rear wheel. The balance equation can be expressed as



M du/dt = mg f cosα + ½ CDApu^2 + mg sinα + F_b (2)

Where, m vehicle mass, u refers to speed of the vehicle, F_b is the braking force of the vehicle.

The braking force F_b can be divided into two components based on front and rear axles, which can be expressed as

$F_b = F_{bf} + F_{br}$ (3)

Where, F_{bf} and F_{br} are the braking forces of the front and rear axles respectively.

2. Braking force distribution:

When it comes to the design of braking system for EVs, the braking energy recovery should be highly considered. The braking force distribution can make sure the best stability of the vehicle braking condition but the recovered braking energy for front drive EVs under 1-curve is not satisfied. The control of braking system under 1-curve could be rather complicated. The maximum recovered braking energy for front drive EVs because of the maximum front braking force

Tabular column:

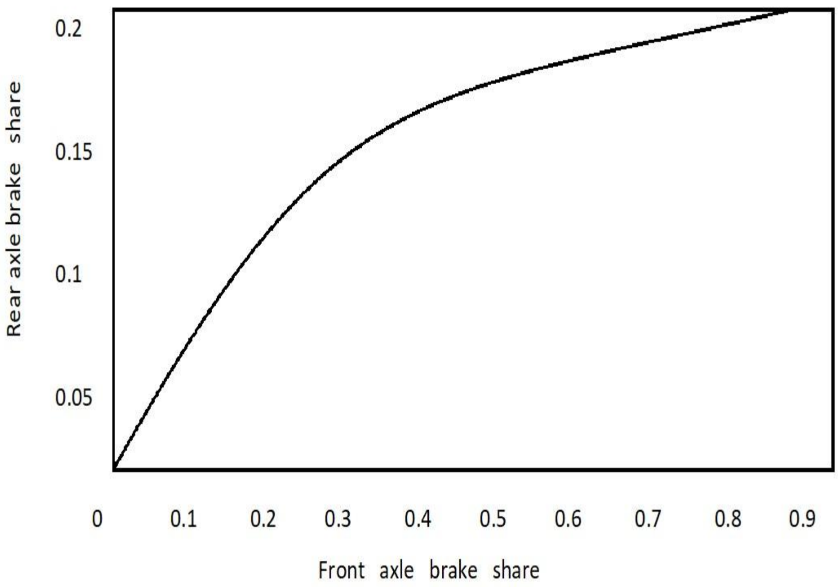
PARAMETERS	SYMBOL	VALUES
ROLLING CO-EFFICIENT	F	0.014
AIR RESISTANCE CO-EFFICIENT	C_0	0.4
GROUND ADHESSION CO-EFFICIENT	ϕ	0.7
RAMP ANGLE	α	0 DEG
WINDWARD AREA	A	1.4M^2
RATED MOTOR VOLTAGE	U	72volts
RATED MOTOR TORQUE	T	25N-M
RATED MOTOR POWER	P	4KW
DISTANCE OF REAL AXLE TO CENTRE	b	0.86m
TRANSMISSION RATIO	i	4.5
WHEEL RADIUS	R	0.25m
WHEEL BASE	L	1.62m
VEHICLE MASS	m	660kg
MASS CENTRE HEIGHT	h_e	0.58m

3. Low -speed limitation:

In order to acquire maximum energy recovery during braking cite while maintaining vehicle stability, both regenerative and frictional braking have to co-exist. Taking into account that friction-based brakes predominantly have delays which can be problematic in vehicle slip control, exploiting regenerative braking contemporaneously can significantly can improve braking performance due to its quick response.

In practical experience, the distribution of brake force between rear and front axle should affirm good braking performance as well as vehicle stability. Hence, brake force distribution follows a normalized nonlinear hyperbolic curve, known as the ideal braking force distribution or I-curve as depicted. This force is set by the load transfer from the near rear axle to the front axle while the vehicle is deaccelerating. If the brake force distribution between front and rear axle follows this curve, the front and rear wheels will lock to maximum brake enactment and stability of the vehicles.

One of the most important constraints to consider about regenerative braking is the inability of the traction motor to operate as a generator and recharge the battery below assured speed threshold. In most of the studies in the literature, LSCP is considered a constant valve; however, LSCP varies dynamically as the operating conditions of the vehicle changes. Thus, a dynamic LSCP should be considered. In this paper, a dynamic LSCP is used to dynamically identifying LSCP. It corresponds to the instant when motor controller DC link current changes direction while the TM is still operating as a generator.

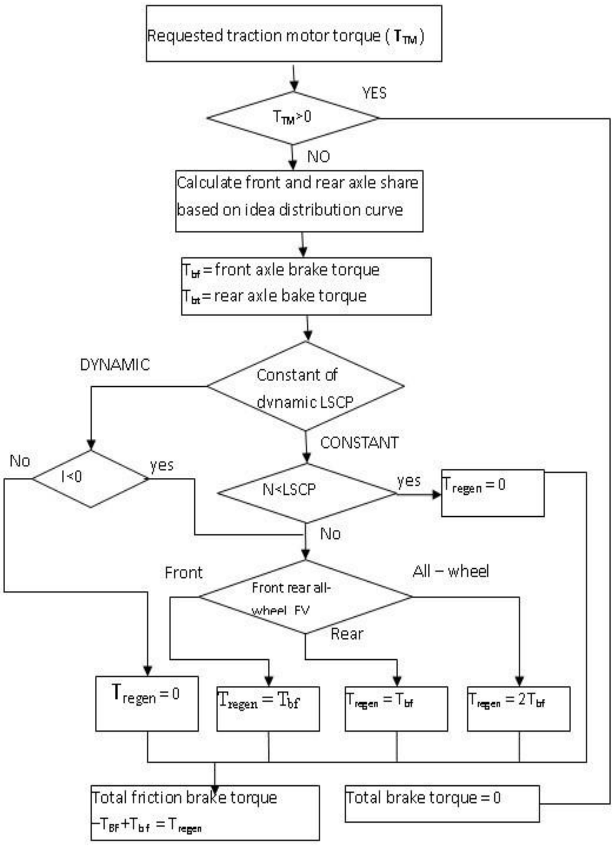


HOW TO MODEL AND IMPLEMENT:

To compare and analyze variable LSCP and LSCP operating modes that do not change in a different EV configuration, the benchmark simulation model is used to mimic EV performance in a variety of contexts. The simulation platform is shown in Fig. 3 and contains a 400V Li-ion battery model as the primary power source, two Permanent Magnet Synchronous Motor (PMSM) drivers connected together using a mechanical shaft that mimics both TM and Dynamometer (Dyno).), and the control block. TM mimics an EV drive motor while

Dyno mimics different road load conditions by mimicking the same opposing forces acting on EV each time.

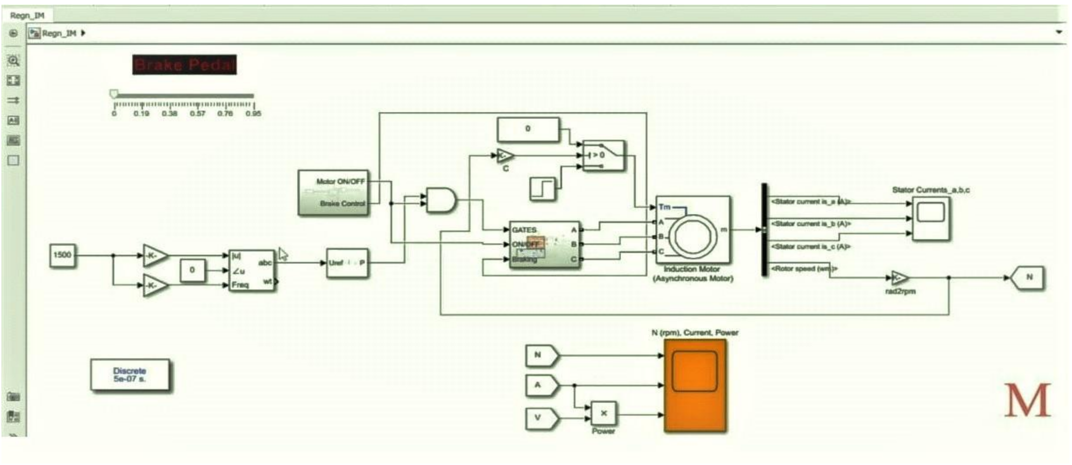
The control block is responsible for calculating speed and strict torque commands at all times while processing the brake control algorithm, EV parameters, and operating conditions; thus, providing an accurate model of a real car in the study. In other words, the control block calculates the speed and torque commands for each TM and Dyno workspace, respectively. In this setting, the reference speed is obtained from a predetermined driving cycle and translated into the required rotational speed, which is provided by a TM drive that operates in speed control mode and ensures accurate speed tracking. In addition, the torque commands representing the opposing force operating in the vehicle are calculated within the controller and directed to the Dyno drive, which operates in a torque control mode, to mimic road load conditions [6]. It should be noted that in order to provide an accurate comparison, all incident studies were conducted in the pre-determined Urban Dynamometer Driving (UDDS) driving schedule as shown in Fig. 4, when the speed in each case is known and given. The parameters of the vehicle used for these simulations are presented in Table I.



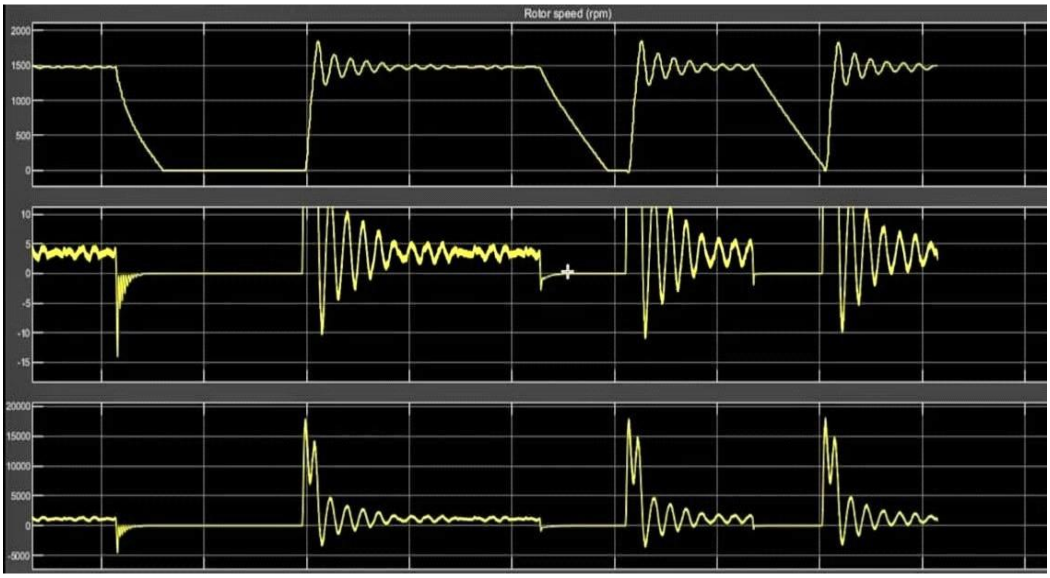
The simulation is made for a different EV configuration (front wheel, rear wheel, and all-wheel drive) taking into account two methods of controlling the brakes, the fixed LSCP and the flexible LSCP. The amount of energy released using regenerative brakes and the power required to complete the drive

cycle is calculated and compared in each configuration of the two configurations of the powerful LSCP and the fixed LSCP. Results are shown in Table II during a single driving cycle. Moreover, the power to harvest.

MATLAB SIMULATION:



OUTPUT WAVEFORM:



FACTS ABOUT THE POINTS OF CONTINUED CONTINUATION:

Considering that the low-speed regenerative power of TM is influenced by the speed and the resistance required during the deceleration, it is important to analyze the operating force in the vehicle at this time. According to Newton's second law of motion, the force operating on a car can be expressed in the following equation [29]:

FD = mgfr cos (α) + 1 2 ραCD A f (v + v W) 2 + mg sin (α) + ma (1).

where FD refers to the driving force at N, m is the total car weight in kg, fr is the coefficient of rolling resistance, α is the slope angle of the road, ρα the air pressure at kg / m3, the CD is the air pulse i -coefficient, indicating EV position, A f front motor area in m2, v car speed in m / s, vW wind speed in m / s, and a speed acceleration or deceleration vehicle in m / s2

The grip strength of a normal car is shown in Figure 4. Depending on (1), variables such as vehicle weight (m), road slope angle (α), vehicle speed (v), wind speed (vW), and acceleration / deceleration (a) are the main factors. which can affect the motor dynamic network (FD) [30]. To investigate the impact of each factor in LSCP removal, a test bench simulation model is used in MATLAB / SIMULINK to mimic EV performance during braking. The simulation model is shown in Fig. 5 and contains a 400-V Li-ion battery model, control block, and two permanent magnetic synchronous motor (PMSM) drivers.

CONCLUSIONS:

In this paper, the importance of processing LSCP flexibility during re-braking was discussed in terms of increasing resilience during low-speed braking. The strategy is tested on single-axle EVs and all-wheel drive. Different scenarios were investigated and the simulation results revealed that the recurrence capacity was enhanced by considering the robust LSCP in all EV preparations under study. In addition, it was concluded that this increase in energy collection was significantly lower for all-wheel drive EVs compared to all-wheel drive and front-wheel drive EVs. The use of flexible LSCP does not require the conversion of computer hardware to existing EV bases that already have the ability to regenerate and may be used with the modification of brake control strategy. This research could be useful to EV car companies looking to improve the ability to regenerate their existing products or to plan to invest in various EV systems with a view to maximizing the performance of renewable brakes.

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