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Design and Analysis of Energy Transition in Hybrid Electric Vehicle Power Train Systems

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The electrified powertrain is the essential component of all these electric car systems. With the help of our power semiconductor products and intelligent control ICs, it is possible to optimize many targets simultaneously for lower system costs, higher power densities, more effective applications, and modular systems. A hybrid electric vehicle (HEV) is modeled and simulated using the MATLAB – Simulink environment in current research. A discussion of the most popular structures for realizing HEVs is suggested. An electric power motor, electronic power converters, and devices for energy storage are routinely given as part of several modeling processes. The most significant electrical and mechanical modeling results that defined the HEVs are given. This modeling approach is highly beneficial and appropriate for explaining power and automotive electronics. In this research article, the design goal is to offer efficient throttle movement, 0 % steady-state speed error, and to maintain a Selected Vehicle (SV) speed. Comparison research is conducted to determine the superiority of the optimal control approach to enhance fuel economy, decrease pollution, maximize driving safety, and lower manufacturing costs. The maximum power proposed in the hybrid electric vehicle train is 35,000 Watts, higher compared to the existing system of 32,000 Watts.

Keywords: Electric vehicle, Converter, Controller.

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1. INTRODUCTION

Significant environmental challenges are starting to arise because of the fast advancement of humankind over the past 200 years. Despite the positive economic trends in business and society, the ecosystem is negatively impacted by them. Those factors include global climate change and ozone depletion, which cause glaciers to melt and sea levels to rise. The fast escalation of gases like carbon dioxide (CO_2), methane, water vapor, and others is one of the primary drivers of these issues. The root causes of the issues may impede the emergence of our planet's life. Automobiles including such internal-combustion engines, buses, vehicles, ships, trains, aircraft, and so on are used all over the world, etc., and come in second to thermal power plants. The depletion of oil reserves is another significant issue driving the development and improvement of hybrid electric cars. There is no way to offset the rising global oil demand. As a result, its price rises, and it becomes significantly more dependent on the nations where it is mined. Finding a new technical approach to lessen this usage is crucial for these reasons [1].

The broadest overview of the problem's content and nature can be provided by descriptive models. This makes it simple to analyze the processes taking place within them. Mathematical models may explain actual physical things using basic or complicated mathematical representations and methods. Because of their undeniable advantages and benefits of implementation in contemporary strategies for the analyzation of system applications with such a significant no. of various kinds of space-time requirements, elements, financial economic productivity, necessities for a short span of computational execution time, the lack of powerful computational energy required, the simplicity that includes results can be displayed, and so on, they are currently the most widely used. For these reasons, a mathematical model of a hybrid electric vehicle is provided in this study along with simulation results [2].

In this paper, the MATLAB/Simulink software is analyzed and designed in different stages of variation in parameters. The paper is organized in the form of a section as follows. Section II describes a brief study of hybrid electric vehicles. Section III explains the bidirectional DC-DC converter with the circuit diagram representation. Section IV explains the modes of operation of the controllers. Section V describes the block representation of the traction motor. Section VI explains the detailed study of the Simulation and Experimental Results of the various traction motor HEV of the proposed system is explained in detail. Finally, section VII provides a conclusion and future work.

2. HYBRID ELECTRIC VEHICLE

Different mechanical converters can be connected using various architectures. The two that are most frequently used for both parallel as well as parallel architecture are depicted. Supercapacitors and fuel cells, which are reversible energy sources, aid in energy recovery during the HEV's regenerative start and stop braking. One benefit is the employment of a combustion powertrain engine coupled to that of an electric engine motor. [3-8].

An electric traction motor powers HEVs. It is dependent on a rechargeable battery and/or a power train generator/motor unit, which aids the whole system whenever it must handle a larger load or charge. It is controlled by the traction motor control system to

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provide the HEV with the necessary power. The dimension size and properties of the traction unit are determined by acceleration, the vehicle's climb ability, and the maximum speed [9].

Parallel drive transmission, as opposed to series hybrid drive transmission, provides various benefits that allow the internal-combustion engine to operate more efficiently, and the drive wheels will get mechanical power straight from the traction motor. In this scenario a generator is not needed, the energy transfer from either the internal-combustion engine or the motor to the pathway of driving wheels is less and the traction motor is not required. Thus, the HEV is more effective as result. Finally, is parallel processing control. Because of the mechanical connections between both the engine and the driving wheels, driving is more complicated [5-10]. Figure 2 shows the architectural layout diagram of a parallel HEV [10-15].

A block diagram representation of the layout diagram of the structure under investigation is shown in Figure 3. It consists of an engine, electric generator, DC-DC converter, traction motor, battery stack, as well as control system-equipped variant of a HEV. Figure 1 shows the structural diagram of a HEV.

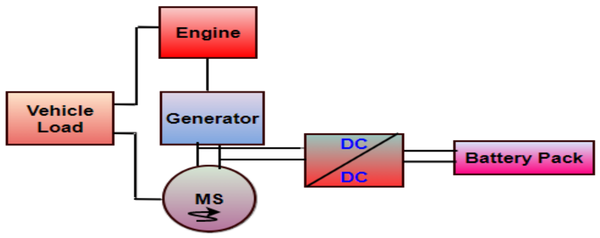

Fig. 1 – Structural Diagram of a hybrid electric vehicle (HEV)

3. BIDIRECTIONAL DC-DC CONVERTER

Non-isolated converter – Without the need for an electrical barrier, a bidirectional DC-DC converter can operate. This type of version has an inductor type, 2 capacitors, as well as 2 switches of a similar device type. This option is the default blocking type facility.

Isolated converter – An electrical obstacle is used in a bidirectional type of DC-DC converter. This model version has four more switches that combine to make a full bridge. Thus, the entire bridge is located on the converter's input type voltage or high-voltage (HV) side. On the side of the converter's output, or low-voltage (LV) side, are the additional two more switches. Various kinds of semiconductors are available for HV as well as LV switching devices. You can, for instance, utilize a GTO for HV switching power devices and an IGBT for LV switching power devices. The method incorporates an HF (high frequency) transformer to separate both the input and output voltages as well as.

Two-level with four quadrant converters.

The operation modes of the converter are defined by the equations that follow (1-4),

$$\frac{d}{dt}i_{L1}(t)=\frac{1}{L1}\left(v(t)-R_{L1}i_{L1}(t)-v_{c1}(t)\cdot\left(1-d(t)\right)\right) \quad (1)$$

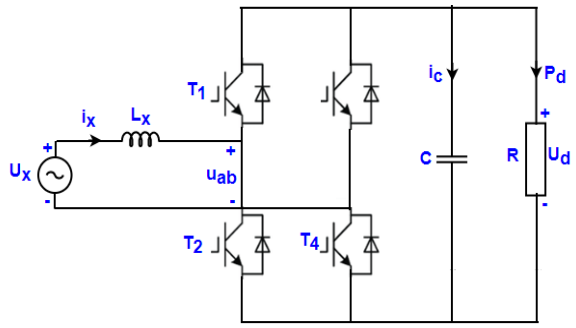

Fig. 2 – Circuit Diagram of a two-level with four quadrant converters

$$\frac{d}{dt}i_{L2}(t)=\frac{1}{L2}\left(v_{c1}(t)-R_{L2}i_{L2}(t)-v_{c2}(t)\right) \quad (2)$$

$$\frac{d}{dt}v_{c1}(t)=\frac{1}{C1}\left(i_{L1}(t)\cdot\left(1-d(t)\right)-i_{L2}(t)\right) \quad (3)$$

$$\frac{d}{dt}v_{c2}(t)=\frac{1}{C2}\left(i_{L2}(t)-\frac{V_{C2}(t)}{R}-I_{load}\right) \quad (4)$$

When R denotes the corresponding load considered in the current flow direction mostly from the source of power to the device for energy storage, $L1$, $L2$, $C1$, $C2$, $RL1$, $RL2$, and $C2$ are the capacitors. The switching function $d(t)$ is equal to 1 in the second quarter time period and 0 in the first quarter time period. A two-half quadrant type DC-DC converter is employed in the current investigation.

4. CONTROLLERS

4.1 Modes of Operation

It is made up of a regeneration controller, discharging controller, as well as charge controller. The following describes their modes of operation roles. Each input quantity and output quantity have a genuine value.

(i) Control of charge

- Input control: V_{batt} – voltage at the battery's side
- I_{batt}: – Flow of current within the battery
- Output control: V_m – Modulation of a PWM generator's signal

Battery charging with a fixed voltage and fixed current is implemented via this block. Constant current-controlled charging happens whenever the battery voltage level is less than the battery float voltage. The inner current loop continuously charges the batteries while the outer voltage loop is deactivated. It is continuous voltage charging once the battery voltage level hits the floating voltage. The outer adjustable voltage loop produces the reference current for such an inner current loop.

(ii) Control of Discharge

- Input control: V_{DC} – Bus voltage in DC
- I_{batt} – Flow of current within the battery
- Output control: V_m – Modulation of a PWM generator's signal

Battery discharge at a constant voltage or current is implemented using this block. The converter manages the DC bus voltage when such control mode of the

DC/DC converter is adjusted to Voltage Mode ($V\_ I\_$ mode = 1). Whenever the control mode is switched to Current Mode, I_ HV_ REF is used. ($V\_ I\_$ mode = 0).

(iii) Control of Regeneration

- Input: V_{DC} – Bus voltage feedback in DC
- T_{es} – approximate torque of the traction motor
- W_m – Speed of the vehicle
- Output: R_{gn} – Flag present in the regeneration (1: regeneration present; 0: no presence of regeneration)

The regenerative flag is generated by this block using the motor power. The regeneration flag is set whenever the power of the motor is found negative, and it crosses the threshold level of regeneration power, as well as the dc bus system voltage being higher than the maximum voltage.

4.2 Block Representation of a Traction Motor

It is made up of a traction motor controller, a linear PMSM traction motor, and a three-phase PWM inverter. The motor is equipped with a PWM space vector, speed control regulation, torque control regulation, dynamic torque limit control, maximum torque per amp control, current control, and torque control. Figure 3 shows the traction motor simulation model.

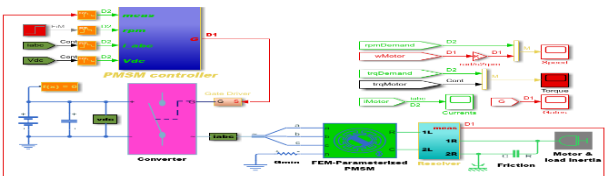

Fig. 3 – Simulation Model description of a traction motor

Below are descriptions of the primary control blocks' functions. Keep in mind that the input and output amounts are all given in per unit.

(i) Current Control:

- Input: I_d, Iq – Currents namely i_d and i_q feedback. I_{dref}, I_{qref} – i_d and i_q current MTPA Controlling block references, I_{dref_fw}, I_{qref_fw} – i_d and i_q current Field Weakening references

(ii) Control block

- F_fw – Flag for Dynamical Torque constraint Control block ('1' while in the field reducing control; '0' Otherwise).
- Output Control: V_d, V_q – d-axis and q-axis voltage references. Table 1 defines the parameter specification of the traction motor to produce the torque.

5. SIMULATION RESULT ANALYSIS

Figure 4-8 illustrates the produced torque for the traction motor in its basic operating mode.

The conducting coils are looped around the armature, causing it to rotate inside a magnetic field when voltage is created.

When a train begins to descend a gradient, its speed rises because the torque is greater than the (lower) drag. As speed climbs, internally produced back-EMF voltage decreases, lowering torque level unless the torque control and drag are once again equal. A single series winding DC type traction motor could not provide dynamic or else regenerative braking by itself due to the back-EMF in a series motor winding that reduces the field current and prevents it from rising over the supply voltage at any speed. However, traction motors are used in a variety of ways to create a retarding force.

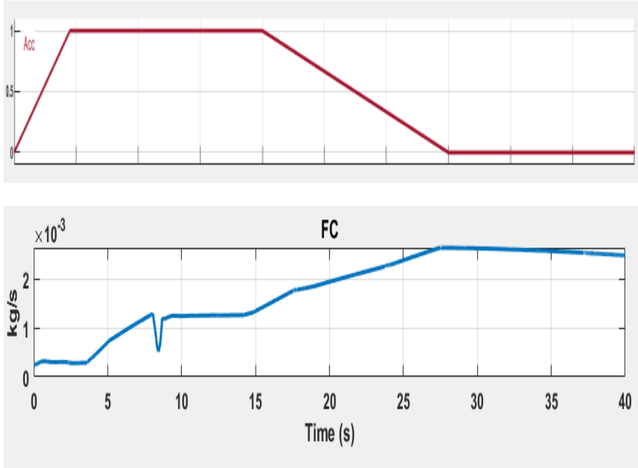

Fig. 4 – Armature winding of the Traction motor

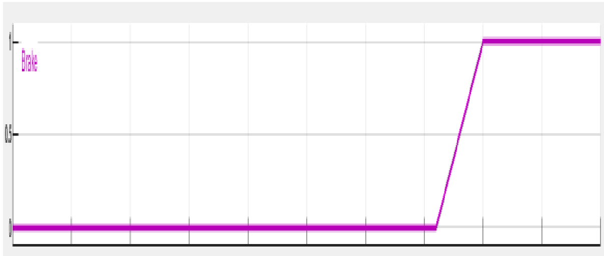

Fig. 5 – Torque produced in the dynamic braking

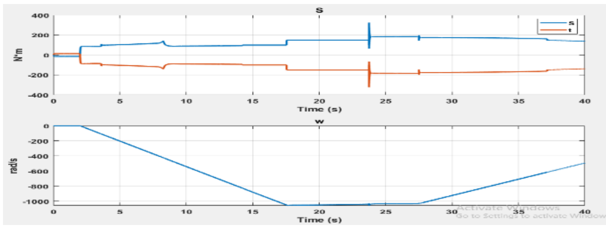

Fig. 6 – Speed, Torque, Power produced in the dynamic braking

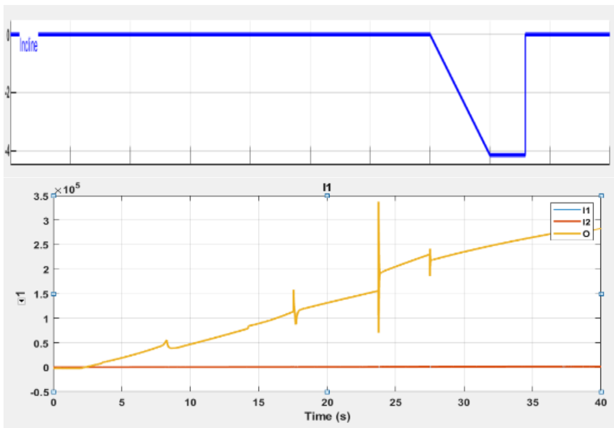

Fig. 7 – Inclination of the traction motor

Series resistors are eventually misplaced to maintain the train's pace. Each and every replacement boosts the efficient and consistent voltage as a result, the current level and the torque level for such a short period of time until either the power motor starts to catch. Therefore, if there is a sudden surge in current, earlier DC trains may feel a series of clunking noises under the floorboards and jerking of acceleration. When there are no additional electrical resistors present in the circuit, the motor is fed with both the full line voltage. Whenever the motor's torque, which is regulated by the effective voltage, equals the drag, a condition known as balancing speed occurs, and the speed of the train remains unchanged. Whenever a train begins to mount an inclination, its speed decreases because drag is greater than torque. As a result, the CEMF decreases and the appropriate and efficient voltage rises till the torque generated by the motor and the current flowing through it equals the new drag. Because a significant amount of energy was wasted as heat, the usage of series resistance was inefficient. Before the invention of power electronics, electric locomotives, and trains were typically fitted with series-parallel control as well to minimize these losses. Table 1 shows the statistical analysis of the proposed system and existing system.

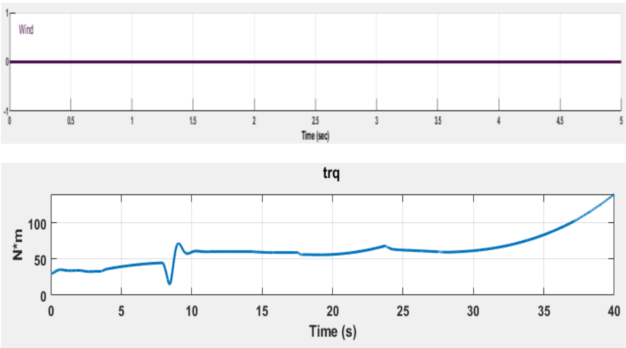

Fig. 8 – Torque Winding produced in the Generator traction motor

Table 1 – Statistical Analysis of proposed system and existing system

Parameter	**Proposed System**	**Existing System**
Maximum power[W]	35000	32000
Maximum torque [N×m]	200	250
Inductance of the Stator *d*-axis [H]	0.00024368	0.00021368
Inductance of the Stator *q*-axis [H]	0.00029758	0.00027756
Stator zero-sequence inductance [H]	0.00012184	0.00010177
Stator resistance per phase [Ohm]	0.010087	0.090074
Permanent magnet linkage [Wb]	0.044	0.020
Number of pole pairs	8	8
Rotor inertia [Kg×m²]	0.1234	0.1

Operational speed is a crucial consideration in the design or specification of traction motors. The windings will remain securely in place at or below the maximum safe rotational speed of the motor armature. Above this top speed, the windings on the armature will be forced outward by centrifugal force. In extreme circumstances, the windings may encounter the motor casing, "bird nest," and finally get completely detached from the armature and uncoil. Because when armature component assembly, wound supports, as well as retainers have also been affected by previous usage, deterioration from overloading and overheating can however be resulting in bird-nesting at speeds lower than the specified speeds. Table 1 gives a comparative analysis of the proposed and existing system. The computational tool created using MATLAB software is a significant benefit because it enables the design of the best traction motors for hybrid/electric vehicle applications for a specific load cycle.

CONCLUSION

The suggested paradigm offers major advantages and benefits to engineers and students, including that can assist system network engineers in assessing system needs and comprehending the interconnections between key subsystems such as batteries, DC/DC converters, traction motors, generators, engines, and vehicle loads. Then, it can assist subsystem network engineers in determining comprehensive software as well as software parameter specifications of subsystems and improve their understanding of how the subsystems function. It may also assist hardware engineers with the selection of components and designs as well as software and control engineers with the creation of DSP control software and control algorithms. Thus, the statistical analysis of the proposed system is obtained with a maximum power of 35,000 watts for using the electric train. This research will serve as the foundation for the future development of novel motors for traction applications, which will be important for our work constructing a hybrid power train.

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Розробка та аналіз процесів перетворення енергії в гібридних системах трансмісії електромобілів

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Електрифікований силовий агрегат є важливим компонентом усіх цих систем електромобіля. За допомогою силових напівпровідникових продуктів і інтелектуальних мікросхем управління можна оптимізувати багато цілей одночасно для зниження системних витрат, більшої щільності потужності, більш ефективних програм і модульних систем. У поточних дослідженнях гібридний електричний транспортний засіб (HEV) моделюється та моделюється за допомогою середовища MATLAB - Simulink. Пропонується обговорення найпопулярніших структур для реалізації ГЕВ. Електричний силовий двигун, електронні перетворювачі енергії та пристрої для накопичення енергії зазвичай наводяться як частина кількох процесів моделювання. Наведено найбільш важливі результати електричного та механічного моделювання, які визначили HEV. Мета даної статті полягала в запропонуванні ефективного руху дросельної заслінки, 0% похибки стабільної швидкості та підтримування швидкості транспортного засобу. Порівняльні дослідження проводяться для визначення переваг оптимального підходу до керування для підвищення економії палива, зменшення забруднення та зниження витрат на виробництво.

Ключові слова: Електромобіль, Перетворювач, Контролер.

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