Neural Network based Direct Torque Controller of SRM for EV Application

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Abstract: the control aspects of the elecytric vehicle are presented in this paper. The electric car which is driven by a 6/4 Switched Reluctance Motor (SRM) powered by four battery banks is presented in this paper. The new topology of converter is proposed to drive SRM effectively for application of electric car. The direct torque controller is implemented with the help of neural network for effective speed controller with minimum ripples in torque. The required pulses are generated with space vector Pulse Width Modulation (PWM) technique. The electromagnetic torque generated by SRM needs to be maintained at ripples free for smooth operation of electric car. The mathematical validation is implemented to achieve the required power rating of SRM for Toyota Car. The proposed topology of converter has a facility of using four battery banks; hence the charging time of batteries will be minimized. The proposed model is designed on the platform of the MATLAB/Simulink package which is dumped into OPAL-RT modules to establish Hardware – in the – Loop (HIL) for presentation of various results. Various results are discussed with validate explanations of the proposed method.

Keywords: Direct Torque Control, ANN, Electric Car, SRM, SVPWM.

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1. INTRODUCTION

Electric Vehicles (EVs) are playing major role in transportation without producing any toxic gases which harms the nature. Day by day, usage of EVs is increasing gradually due to its numerous benefits [1-3]. Market for EVs is demanding for new technology for achieving a better response of the vehicle. A motor must be used in EVs which required an efficient drive system to control the speed of the vehicle. The motor is fed by battery bank as a power source. Both the DC and AC operated motors are using in electric vehicles [3-5]. Based on the performance, size and cost of the vehicle will be decided the motor. AC motors are flexible, less expensive, and compact in size and light-weight for higher power ratings, as compared with DC motor. However, switched reluctance motors (SRMs) are having superior performance compared to all other motors and having significant priority to use in electric vehicles especially in cars. Conventional electric vehicles are having induction motors, permanent magnet synchronous motor (PMSM), brushless DC motor, and permanent magnet DC motors. However, SRMs will replace all these motors in near future. The major control objective in electric vehicle is to control the torque of the drive motor. For this the response of control system should be fast and ripple free. EV requires that the driving electric motor has a wide range of speed regulation. However, the main drawback in electric cars is battery capacity. The availability power in the car can decide the distance traveled by the car.

In order to obtain accurate and precious response of control the motor, artificial neural network (ANN) controllers are used in place of conventional PI controllers. Further paper is organized by including selection of motor rating in Section-2. System description and Control of the motor are described in Section-3 and Section-4 respectively. Results are collected through hardware – in the – loop (HIL) and presented in Section-5. Conclusions are listed in Section-6.

2. SELECTION OF MOTOR RATING

Electric motor is the main part of the electric vehicle. Hence, the rating of motor should be selected perfectly which can drive the vehicle at our requirements. As compared with other motors, Switched Reluctance Motors (SRMs) are more suitable for the application of electric motors. But in recent years, SRMs are becoming developing for electric vehicles since it having superior performance than AC motors. In this project, we considered 6/4 pole 20 kW SRM to run the electric car. Parameters of electric motor are given in Table-1:

Table-1: Details of the motor.

S. NO	PARAMETERS	VALUES
1	Rated Power.	20.0KW
2	Nominal line to line Voltage.	400V
3	Resistance of stator.	0.7384OHM
4	Inductance of stator.	0.003045H
5	Inertia.	0.03431
6	Pole Pairs.	6/4

3. DESCRIPTION OF THE SYSTEM

The layout of the electric vehicle control block is depicted in Fig. 1. The batteries can be charged through charging stations or 1-phase home supply which is not shown in Fig. 3. The new topology of converter is implemented to run the vehicle. So, the vehicle speed is regulated through only SRM. Hence, the speed of the vehicle can be regulated through SRM drive only. Apart from many controllers, Direct Torque Controller (DTC) is having high priority to operate motor under fewer ripples in torque. Therefore, DTC is employed along with Space Vector Pulse Width Modulation (SVPWM) for effective control of SRM. To reduce ripples in torque and smooth operation of speed, the artificial neural network (ANN) is developed.

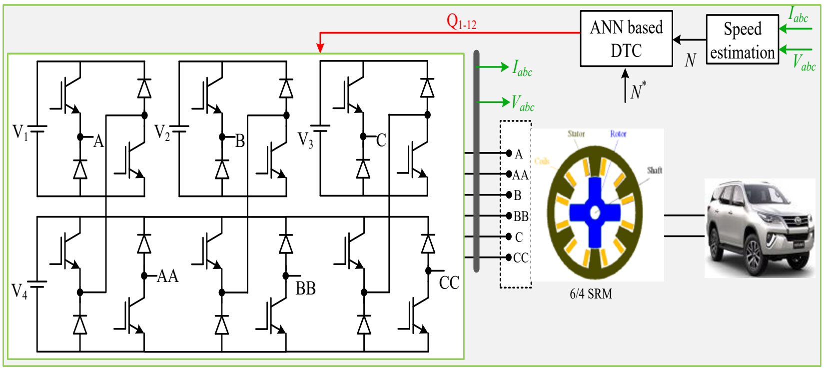

Fig. 1: Proposed System in Electric Car with SRM.

4. Control of SRM

The 6/4 pole 20kW SRM is connected through proposed converter. The motor can able to drive the vehicle. The control unit using in the vehicle will be decided the smooth operation of the vehicle. Hence, characteristics between speed and torque must be identical. Hence, considered that by using DTC, the motor can run with minimum ripples in torque with smooth speed characteristics. Current in the field and armature windings are decoupled in nature. Therefore, the speed and torque can be able to regulate independently [11-12] by using direct torque control (DTC) method. The SRM with the proposed converter and DTC in the front end is shown with two control currents, i_{ds}^* and i_{qs}^*. With DTC, i_{ds} is represented the field current I_f and i_{qs} represents armature current I_a of a dc machine.

The design of DTC heavily relies on the significance of both the position and magnitude of the rotor flux space vector. The rotor magnetic flux space vector can be utilized to easily design the rotational d-q coordinated system. This paper has successfully implemented the flux model using monitored rotor speed, stator voltages, and currents, among various other methods. Essentially, it is derived from a fundamental stationary reference frame (α, β) that is linked to the stator. The α and β components are used to resolve (1) and (2) in order to achieve the rotor flux space vector:

$$\begin{aligned}[(1-\sigma)T_s + T_r]\frac{d}{dt}\psi_{r\alpha} &= \frac{L_m}{R_s}u_{s\alpha} - \psi_{r\alpha} \\ &\quad - \omega T_r \psi_{r\beta} - \sigma L_m T_s \frac{d}{dt} i_{s\alpha}\end{aligned} \tag{1}$$

$$\left[(1-\sigma)T_s + T_r\right]\frac{d}{dt}\psi_{r\beta} = \frac{L_m}{R_s}u_{s\beta} - \psi_{r\beta} + \omega T_r \psi_{r\alpha} - \sigma L_m T_s \frac{d}{dt} i_{s\beta} \tag{2}$$

Where:
$L_{s,r}$ represents self-inductances of stator and rotor [in H] respectively
$R_{r,s}$ represents resistances of rotor and stator [in Ohm] respectively
L_m = motor magnetizing inductance [in H]
ω = Angular rotor speed [in rad.s-1]
P_p = pole pairs in motor

$T_r = \frac{L_r}{R_r}$ = Rotor time constant [s]

$T_s = \frac{L_s}{R_s}$ = Stator time constant [s]

$\sigma = 1 - \frac{L_m^2}{L_s L_r}$ = used for leakage constant [-]

The purpose of designing DTC is to control independently the direct-axis stator current i_{sd} and the quadrature-axis stator current i_{sq}. But unfortunately, the stator voltage components are in decoupled in nature. That means, the direct axis component u_{sd} and i_{sq} as well as quadrature axis component u_{sq} and i_{sd} are in coupled by depending on each other. Further, the i_{sd} and i_{sq} should be controlled independently.

The generalized block model of MRAC is shown in Fig. 2(a) and speed estimation system is depicted in Fig. 2(b) of SRM motor. MRAC block output signal is compared with its actual system. The PI controller is used to estimate the accurate signal during sudden changes happen in the system. The figure 3 illustrates the block diagram for the implementation of SMC in the proposed system. The SPVWM strategy is depicted in Fig. 4 which is used to generate pulses.

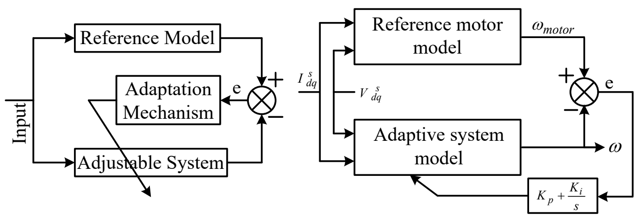

Fig. 2: Estimation of speed using MRAC model of SRM.

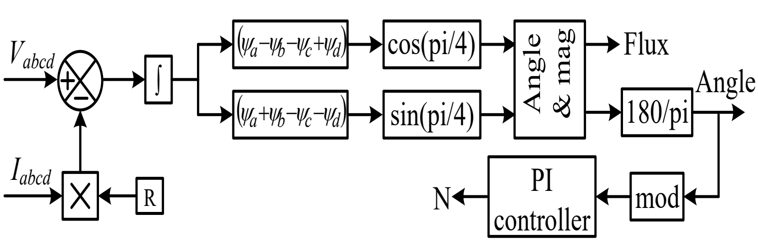

Fig. 3: implementation of SMC of proposed system.

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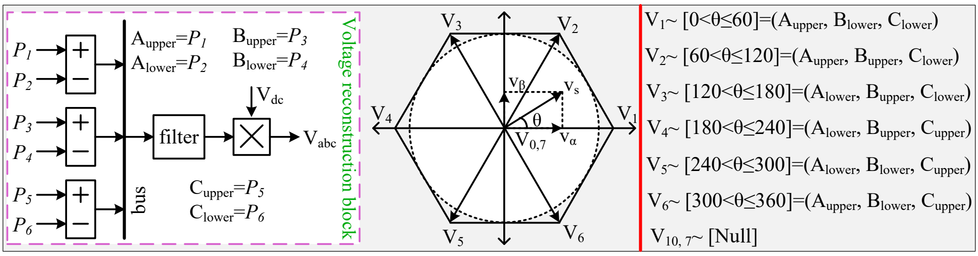

Fig. 4: Space Vector PWM strategy

Implementation of ANN: generally artificial intelligent (AI) strategies are a simple computer oriented programming applications to think and act brilliantly for taking decisions very sharply. To accomplish this objective, the Artificial Neural Networks(ANN), Genetic Algorithms(GA), Fuzzy Logic and reinforcement learning[18] can be used. Due to not dependent on rule based programming, an ANN will give precious response under fast tracking. In present scenario, the information mining can be utilized a neural network to examine the bulk information systems [18, 21]. Essentially the basic computers are great in the process of computations that fundamentally takes inputs process [22]. The targeted output or results are always generated on the basis of arrangements of weight factors accordingly neurons and its input neurons for every cycle in training process. The basic process of learning is depicted in Fig. 5 and the corresponding ANN implementation has been considered in this paper.

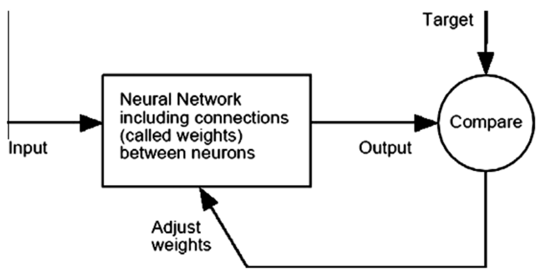

Fig. 5. ANN –Training Structure.

The basic learning process of the ANN system can be patterns subsequent based on response as classified into two general standards: Associative mapping and Hetero-association[16]. Feed-forward ANNs are a very frontward- customary technique, The multilayer of ANN is depicted in Fig. 6.

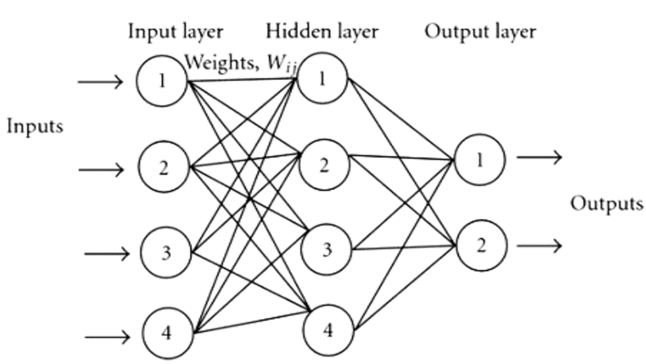

Fig. 6: Feed forward ANN.

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5. Results and Discussions

The real-time test system (RTS) is an automated testing system designed to execute various tasks such as logical operations [1, 4, 25]. Comprehensive results are being analyzed on an additional computer to extract key findings. Figure 7 presents an illustrated depiction of the HIL model setup, utilizing two OPAL-RT devices. The suggested model is divided into two parts: the plant and the regulator. Figure 7 illustrates a visual representation of the HIL cycle of the proposed framework, incorporating appropriate diversity coding. The results are then presented in the subsequent case studies.

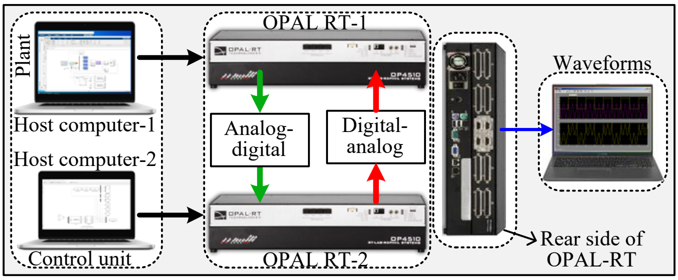

Fig. 7: Configuration of an OPAL-RT setup.

Case-1: Change in Load Torque:

The adjustment of burden force is considered at t=1.5 sec. prior to that ostensible burden force (TL=5Nm) is considered on SRM and its increment to Nm at t=3.0sec. Subsequently, the battery must be supplied the expected ability to SRM or will diminished the charging capacity relies upon accessibility of force and consumed by engine. The vector control will assists with creating the electromagnetic force to driven the heap force (reference force) with practically no progressions in speed (under consistent state). The comparing force and speed reactions are displayed in Figures 8 & 9 separately. According to the data presented in Figure 9, there is no variation in speed under constant conditions, regardless of the substantial increase in force exerted on the engine. Be that as it may, the speed has diminished during transient time because of activity on defeat the electromagnetic force over the heap force. In any case, the vector control assists with running the engine at its reference speed as for changes in force.

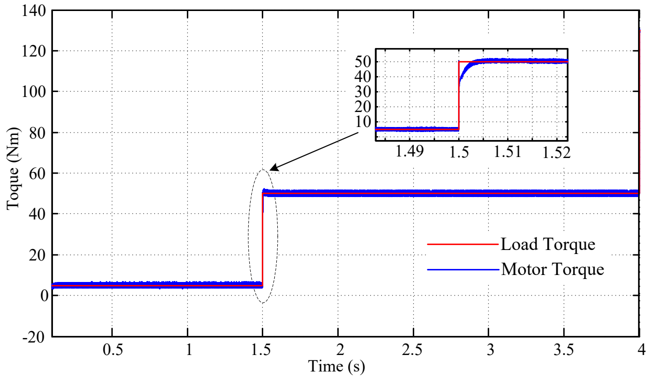

Fig. 8: Electromagnetic and Load torque of the SRM.

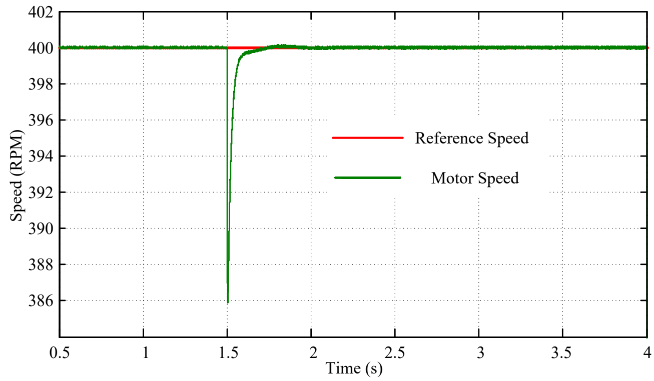

Fig. 9: Speed response during changing in Torque.

Case-2: Change in speed of motor:

In electric vehicle, the quick variations are expected in speed of the motor. Thus, the reaction must be concentrated on under the progressions alongside varieties in the speed. The speed reference on the motor is changed from 40kmph to 50kmph which is equivalents to 320RPM to 400RPM on the motor is assumed. In this way, the speed has changed from 320RPM to 400RPM at t=5.0sec. The DTC assists with working the motor at its reference speed even changes which are referenced previously. The speed reaction of the engine is displayed in Fig. 10. The speed should be expanded; consequently, the electromagnetic force delivered by engine will increment during the transient time span. The produced force by the engine will follows the heap force (reference) which isn't changed in that frame of mind as displayed in Fig. 11. The dc connect voltage will fall and ascend in reasonable worth because of abrupt changes in speed. The comparing voltage on dc side as portrayed in Fig. 12.

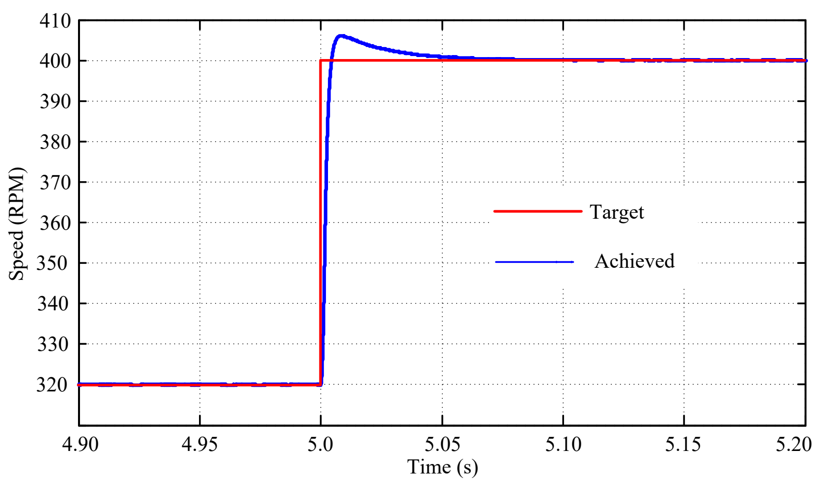

Fig. 10: Response of the motor speed.

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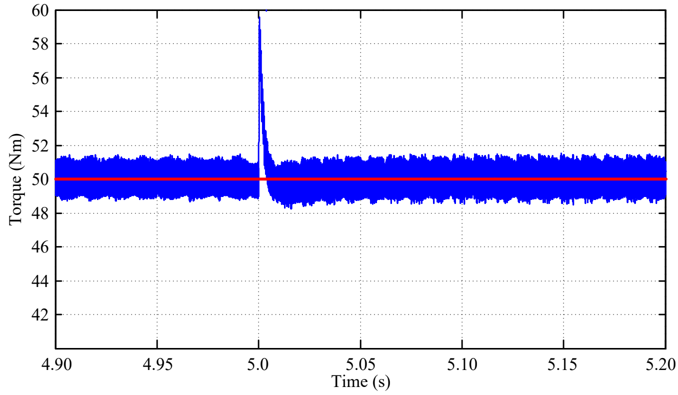

Fig. 11: Response of torque.

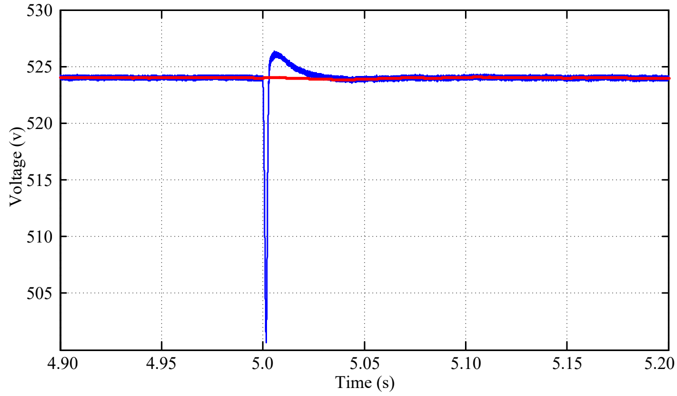

Fig. 12: dc link voltage.

Case-3: Reverse operation of the motor:

For the most part in any four wheeler vehicle the opposite driving assumes an imperative part. Deliberately driving the 4 wheelers in reverse course through physically like 2 wheelers is troublesome. The converse driving is conceivable in electrical vehicle by working the engine in switch motoring mode. Generally the beats of any two stages will be exchanged consequently by vector control strategy to run the engine in turn around heading. Allow us to consider the vehicle to run backward bearing with 10kmph which is equivalents to 80RPM of the engine. It is finished by changing the reference speed of the engine from 80RPM to -80RPM at t=4sec. The vector control makes the speed heading as converse in engine naturally. It is displayed in Fig. 13. Because of unexpected shift in the course, the dc connect voltage will change for few moments and keeps up with at its reference esteem. This is addressed in Fig. 14. Notwithstanding, to run engine in switch heading, the electromagnetic force needs to diminish unexpectedly and DTC will assists with keeping up with electromagnetic force at its reference esteem during consistent state time span as soon in Fig. 15. Be that as it may, little aggravation is happened because of progress in dc connect voltage because of abrupt shifts in course of the speed.

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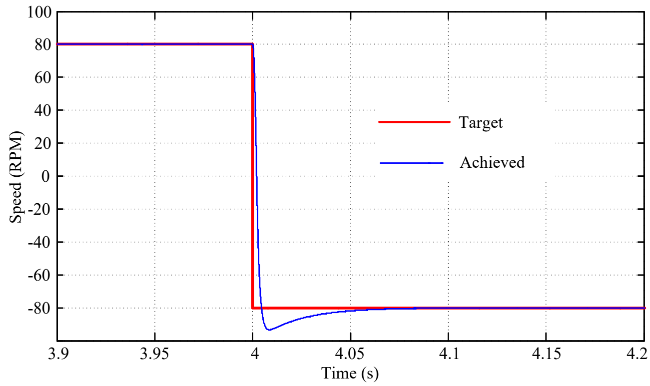

Fig. 13: Reference and motor speed in reverse direction

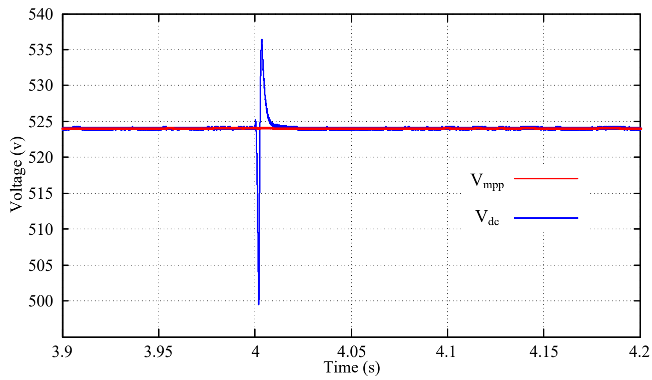

Fig. 14: dc link voltage under change in direction

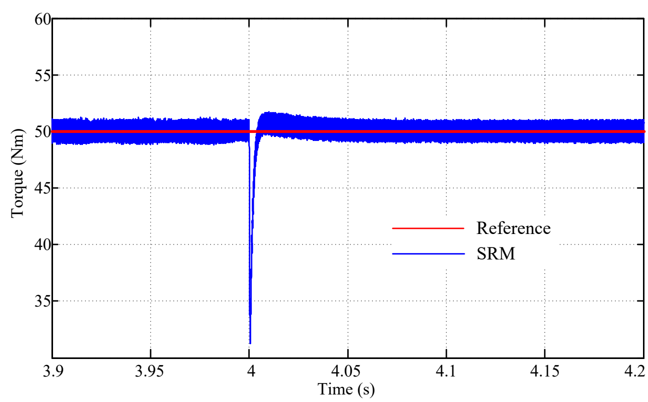

Fig. 15: Torque responses of the motor under change in speed.

6. Conclusions

The novel method of speed sensorless control of SRM motor with DTC is presented in this paper for electric vehicle with the help of ANN. The analysis along with design aspects of the electric car is presented in this paper. Selection of motor, and control method is also presented for a Toyota car. The extensive results are proven the significance of proposed energy management system. The proposed controller and converter help to minimize ripples in torque. ANN controllers are adopted in the proposed control method to obtain precious responses during sudden changes in the system. HIL is developed by using two OPAL-RT units for presentation of various results. The proposed control method with help of ANN is delivering significant responses during sudden changes occurred in the system.

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