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THE EXPERIMENTAL POWER MANAGEMENT CONTROLLER IN PHEV

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Abstract

The purpose of the power management controller subsystem in the Parallel Hybrid Electric Vehicle (PHEV) is to optimally arrange the engine and electric motor for load sharing providing the desired vehicle power while increasing the overall efficiency. This work adopts a PMSM as an electric drive for the HEV system. An experimental electric driving system is implemented in the Laboratory. The Borland C Language was used to implement the control algorithm during experimental work. The algorithm was executed via a data acquisition card. The experimental work in this paper handles the power management controller and torque sharing between the electric driving system and the Internal Combustion Engine (ICE) driving system. The experimental results showing the Direct Torque Control (DTC) behavior of the adopted PMSM and the experimental results at different loading and speed conditions are recorded.

1 INTRODUCTION

Electrical Vehicles (EVs) are vehicles that are powered by an Electric Motor (EM) instead of an ICE. EVs are more efficient than ICE vehicles [1]. However, the major drawbacks in EVs are their limited range and high charging time. In order to overcome these drawbacks, HEVs are used. HEVs combine two or more power sources.

For EVs and HEVs, the output characteristics of electric motors differ from those of ICEs. Typically, the electric motor eliminates the necessity to be idle at a stop, it is allowed to produce large torque at low speed, and it offers a wide range of speed variations. It may be possible to develop lighter, more compact, more efficient systems by taking advantage of the characteristics of electric motors.

Many types of motor drives have been applied to EVs and HEVs. They are brushed DC motor drives, induction motor (IM) drives, permanent magnet synchronous motor (PMSM) drives, and switched reluctance motor (SRM) drives. The advantages of PMSM over the other types are their low inertia, high efficiency, power density, reliability, and less maintenance. Therefore, PMSMs are ideal for HEVs applications where accurate torque control is required [2].

As mentioned previously, the HEV system uses an electric motor and an ICE for traction. Hence the control strategy for optimization of the load sharing between the two power sources is very important. The control strategy is programmed in the power management controller. The power management controller determines the operation mode of both the electric motor and the ICE and the required torque from each driving system. The power management controller depends greatly on the state of charge (SOC) of the battery. The controller notice the battery SOC instantaneously to make sure that the battery has sufficient energy to run the electric motor. SOC estimation for batteries is discussed in many literatures [3-6]. Traction drives used in EVs and HEVs must be configured to provide a good steady state and dynamic performance for the driving motor systems, the direct torque control (DTC) technique permits the achievement of these requirements for traction systems in HEVs applications. The reference torque input to the DTC is determined from the power management controller. So, the DTC technique is adopted in this study for driving the PMSM used in the HEVs. Many literatures handled the study of DTC, as modeling, simulation, and implementation of that driving technique in PMSM electrical vehicle systems, such as [7-11]

In this paper the system is described in Section 2, and in Section 3 the system is implemented. Section 4 describes the power management controller and the experimental results are presented and discussed in Section 5.

2 SYSTEM DESCRIPTION

The system block diagram is shown in figure (1) which presents the system components and their connection in the lab. In the actual lab system setup and system integration, the system emulates an electric vehicle system, which consists of, an electric motor; a driver (inverter) for the motor which is ready made inverter with open inputs (as reference torque, reference speed, and position), the loop controllers can be adapted according to the required performance. A DC generator with a programmable DC electronic load represents a load system for the PMSM. A battery in a temperature controlled chamber, which represents the actual environment of the battery in the vehicle, is emulated at a lab scale, the State Of Charge (SOC) and Battery Available Capacity (BAC) are modeled using fuzzy modeling system. The inputs for the fuzzy model are the discharging current of the battery and the temperature.

The input signals are read by data acquisition system (DAS); also the control signals to the servo amplifier are fed via DAS through buffering circuits. The programming language is the Borland C.

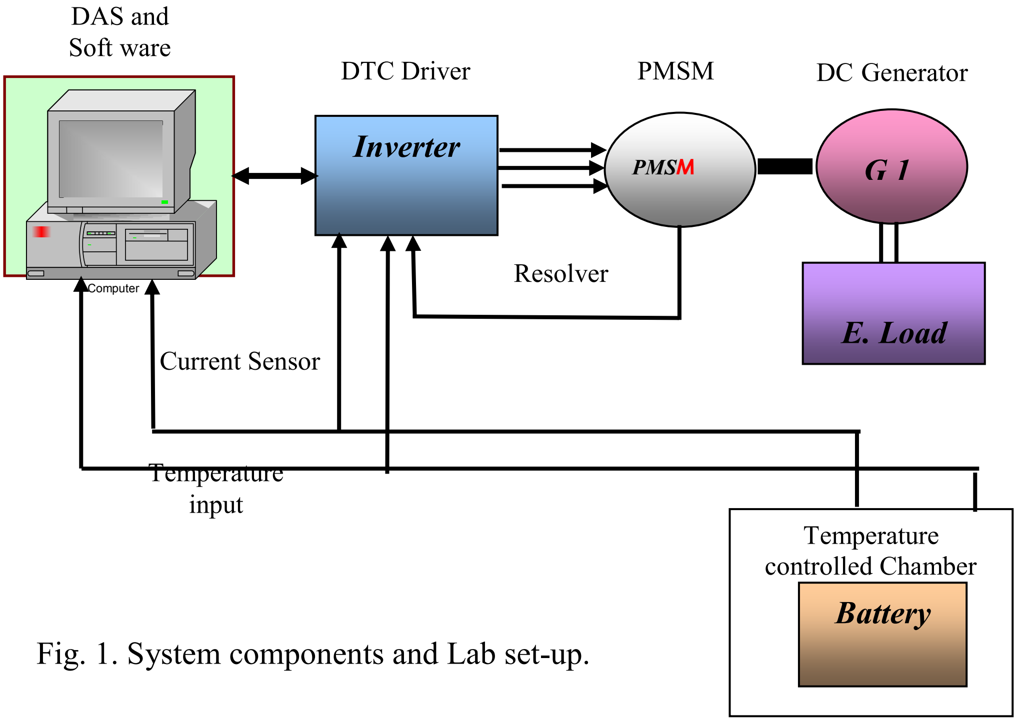

Fig. 1. System components and Lab set-up.

3 SYSTEM IMPLEMENTATION

The experimental work in this paper is divided into two phases. The first phase handles the power management controller and torque sharing between the electric driving system and the ICE driving system. The second phase handles the motion control system including the torque and speed control. The SOC estimated is implemented using the fuzzy modeling technique [6]. The power management software includes the torque sharing between the PMSM and ICE for driving the vehicle. The power management controller determines the torque contribution of both the PMSM and the ICE according to the battery SOC, and the vehicle speed. The generated signals from the power management controller are fed to the servo amplifier and the ICE.

In this paper, a propulsion system implemented as a lab scale is proposed. The system consists of a PMSM with direct torque control (DTC) inverter, which is a ready-made inverter with open inputs while its internal control loops such as current loop (torque loop), speed loop and the position controller outer loop were accessed.

This work deals with the generated signal fed to the servo amplifier, which is considered as a reference signal to the servo amplifier. The servo amplifier has three feedback control loops which are the position feedback, speed feedback, and torque (DTC) feedback. The DTC Driver (servo amplifier) is referenced by the torque output signal generated from the power management controller. The flowchart showing the connection between the DTC and the power management controller is presented in Fig. 2.

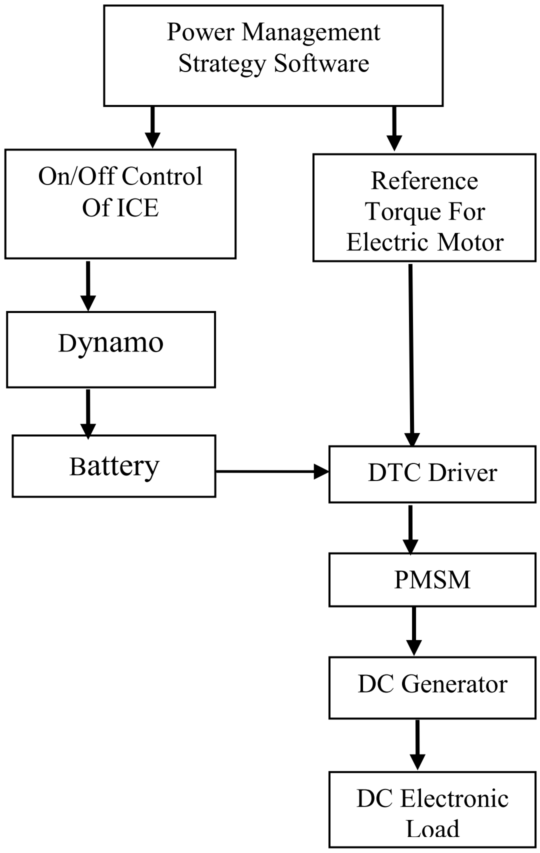

Fig.2. Flow chart of experimental work.

4 POWER MANAGEMENT CONTROLLER

The purpose of the power management controller subsystem in the parallel hybrid electric vehicle is to optimally arrange the engine and electric motor for load sharing providing the desired vehicle power while increasing the overall efficiency. When the vehicle runs at low speed such as in urban areas, the electric motor is more efficient to provide the required power and is considered the primary power source. When the vehicle runs at high speed such as highways, the engine is more efficient and considered as the primary power source. When the vehicle needs hard acceleration, both the electric motor and the engine provide power to accelerate the vehicle. In the case of deceleration, the electric motor acts as a generator to provide electric power to recharge the battery pack. Therefore, the power management controller becomes the key issue of the whole HEV system.

The power management controller is responsible for generating command signals for both the motor and the ICE operation and calculates the torque required from the motor which is fed to the motor driver. The torque required from the motor which is fed to the servo amplifier is calculated. The sharing strategy of the power management illustrating the motor operation mode is shown in Fig. 3, while, the ICE operation mode is shown in Fig. 4.

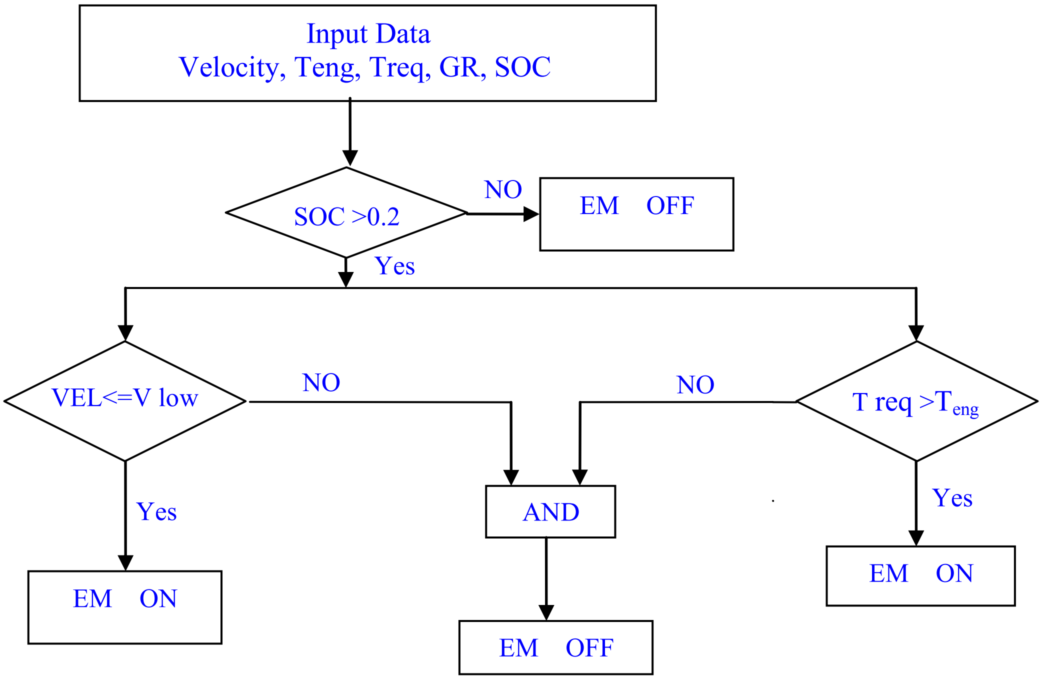

Fig.3. Flow chart of EM control logic

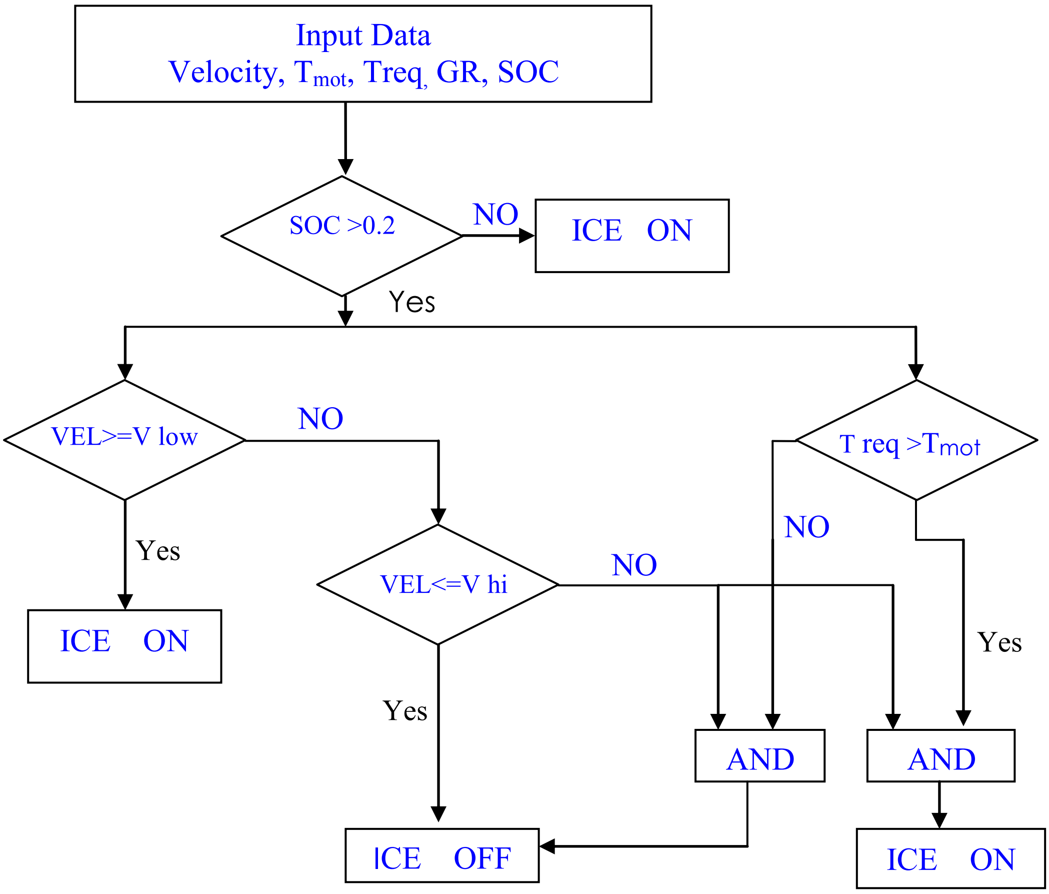

Fig.4. Flow chart of ICE Control Logic

The power management controller is implemented with the SOC estimation in order to control the operation of both electric motor and ICE. The fuzzy model for SOC is executed by BORLAND-C programming language and combined with the power management controller. Fig.5 shows the results for discharging the battery at 15A and at temperature 40^{O}C. Fig.5a shows the estimated SOC, Fig.5b shows the EM operation mode and Fig.5c shows the ICE operation mode. It is shown that when the SOC reaches its minimum value of 20%, the EM shuts down and the ICE turns on.

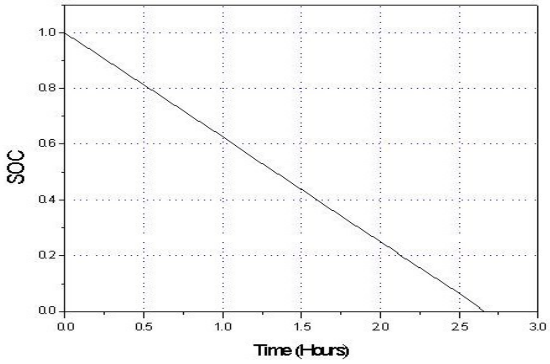

Fig.5a. Estimated SOC using fuzzy logic.

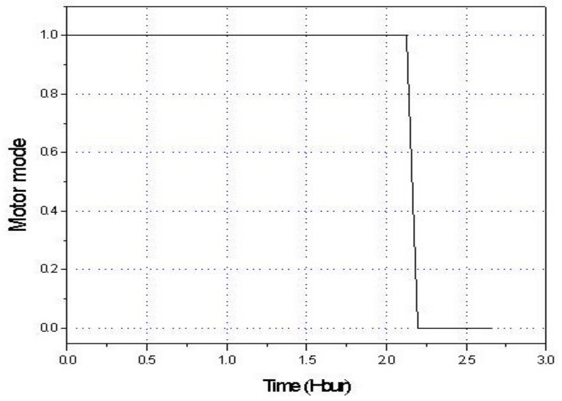

Fig.5b. EM operation mode.

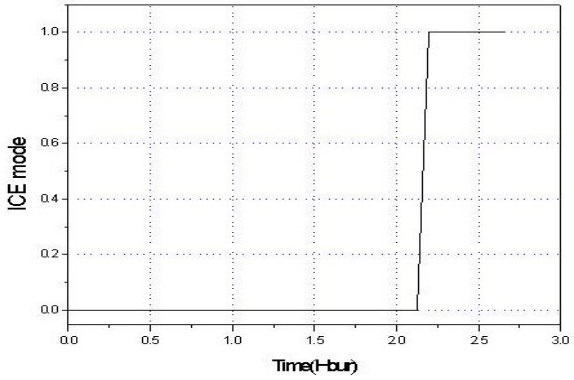

Fig.5c. ICE operation mode.

In this work, we used the servo amplifier to verify the direct torque control. This is obtained by applying an analogue torque signal as a reference input signal to the servo amplifier and selecting the service function to the torque function maintaining the load torque same to the reference torque. The analogue reference torque is the output of the power management controller after passing through the digital to analogue converter (DAC) in the data acquisition system. The input analogue signal enters the servo amplifier as a difference between two signals. Each signal is isolated before entering the servo amplifier through a 741 operational amplifier chip. The output voltage pattern from the servo amplifier is used to feed the PMSM. This control procedure is summarized in Fig. 6.

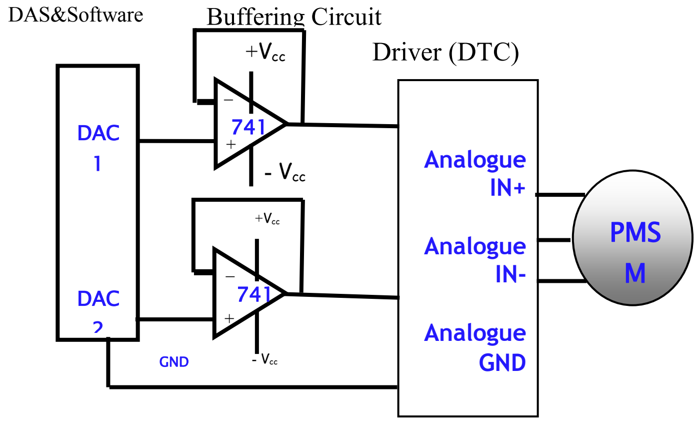

Fig 6. Control signals for motor driver with buffering circuit.

5 EXPERIMENTAL RESULTS:

The serial communication software of the motor servo amplifier includes an oscilloscope that records different signals such as speed, torque, and voltages. So the following signals are recorded through that oscilloscope. The parameters of PMSM are: 470w, 2A, 11Ω, 25mh, 1.6 kg.cm^2, 6pole and 3000rpm.

Fig.7 shows the actual speed response of the motor when the reference speed is set to 1500 rpm., while Fig.8 shows the reference and actual speed response of the motor when the reference speed is set to 300 rpm. It has a small overshoot and oscillations, which gives a good transient behavior. Fig.9 shows the motor actual speed response and current of the motor when the reference speed changes from 500rpm to -500rpm (operation in the reversing mode). The reference and actual torque of the motor when the reference torque is 0.7N.m which is corresponding to current of 0.5A represented in Fig.10. Fig.11 shows the reference and actual torque of the motor when the reference torque is 1.4 N.m which is corresponding to current of 1A.

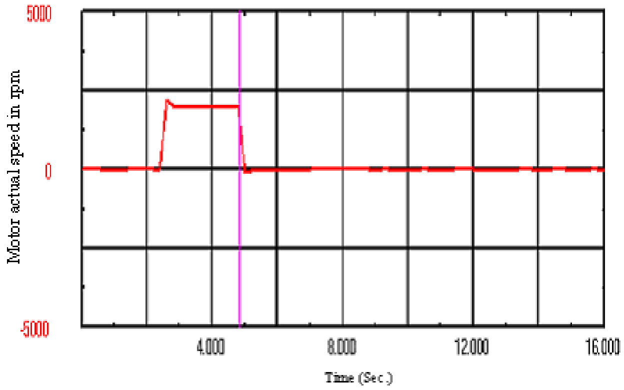

Fig.7. Actual Speed of the PMSM at reference speed 1500 rpm .

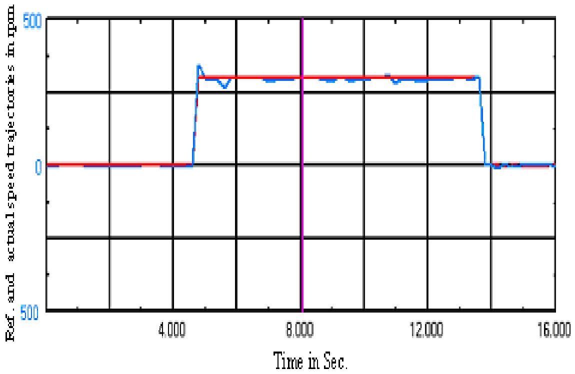

Fig. 8. Reference and actual Speeds of the PMSM at 300 rpm.

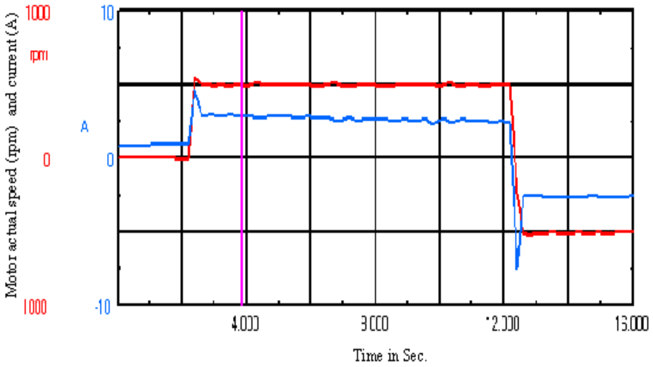

Fig. 9. Motor actual speed response and motor current at reference speed changes from 500rpm to -500rpm.

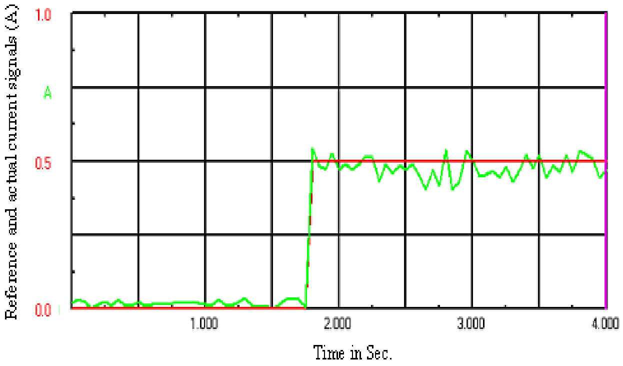

Fig. 10. Reference and actual current signals at 0.7N.m

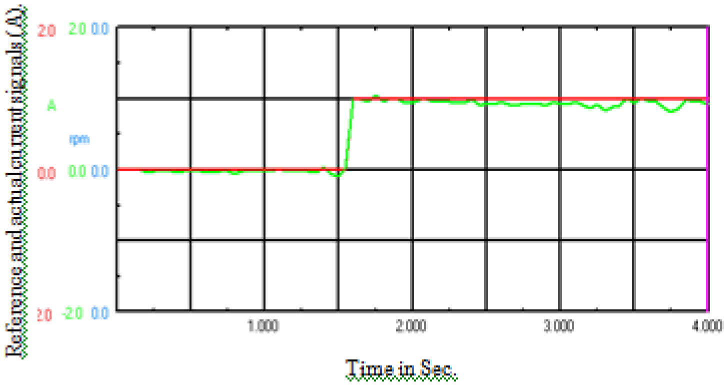

Fig. 11. Reference and actual current signals at 1.4N.m.

6 CONCLUSIONS

An electric propulsion system for HEV application has been implemented at a lab scale. The experimental results have been recorded at different operating conditions including SOC estimation in a real environment using fuzzy modeling system. A motion control system for PMSM has been implemented including torque and speed control. The recorded results show a good agreement between the reference and actual control systems.

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