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Investigation of Chopper Operation of New Series Motor Four Quadrants Drive DC Chopper for DC Drive Electric Car

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ABSTRACT

Electric Car (EC) is an alternative solution in reducing the air pollution resulted from burning of fossil fuel by conventional combustion engine vehicle. However, the EC cost is unaffordable especially for developing and third world countries. DC drive in EC offers better price, nevertheless it requires special research attention to improve DC motors and the converters' performances. The widespread adoption of series DC motors in EC has been hampered by the failure of the conventional Four Quadrants DC Chopper (FQDC) to provide important modes of operation such as field weakening, reversing, resistive braking and generator mode. To overcome these limitations, a new FQDC chopper is proposed to allow the EC to effectively maneuver in challenging conditions such as driving on a flat surface, climbing a steep hill, cruising downhill and driving at high or low battery State Of Charge (SOC). The EC is expected to be able to tolerate different loads due to the weight of the passenger and luggage while operating. Hence, this paper describes the operation of the proposed FQDC while undergoing predetermined simulated driving conditions designed using MATLAB/Simulink. The simulation results revealed the expected EC speed, distance traversed and battery SOC while the chopper is running on several operation modes in response to different types of driving conditions and load levels. The motor torque, field current, armature current and voltage were presented. Such parameters were also used to test the EC performance in three different modes; normal, power and economy modes.

KEYWORDS: DC Drive, EV, Chopper Operation, Series Motor, Four Quadrant Chopper.

INTRODUCTION

In the future, electric motor propulsion might replace the internal combustion engine in vehicles to improve efficiency and reduce carbon emission [1]. But today, electric cars (EC) are still expensive and thus not yet affordable for many people. Separately excited motor with Direct Current (DC) drives was onceregarded as a suitable choicefor ECs as the combination would offer the needed modes of operation and longest distance traversed as depicted in Table 1. Such a system was installed in the early prototypes of EVs like Peugeot 106, Citroen Saxo, GM EV and Lada [2-3].

Table 1: Production of electric cars [2]

Manufacturer	Renault	Peugeot	Nissan
Model Name	Clio Electric	106 Electric	Hypermini
Driving type	AC Induction	Separately excited	PM Synch
Battery Type	NiCd	NiCD	Li-ion
Max Power O/P(kW)	22	20	24
Voltage (V)	114	120	288
Battery energy capacity (kWh)	11.4	12	-
Top Speed (km/h)	95	90	100
Claimed max range (km)	80	150	115
Charge time(h)	7	7-8	4
Price	$27400	$27000	$36,000

Separately excited motors require two sets of batteries for EV application. The batteries would inflate the total cost of the EC by 10 to 25% and complicate its operation and maintenance. A recent study undertaken at Oak Ridge National Laboratory [4-5] reports that DC motors are suitable for EV/HEV applications. Series motors are efficient, smaller, lighter, durableand easier to maintain [4]. Besides, a series motor can operate on a single set of batteries. However, the motor tends to overrrun when unloaded and lose speed drastically when loaded. To ovecome these problems, a new FQDC is proposed. Since the proposed chopper has several working operations, it requires four main controllers such as data distribution, chopper operation, subsequent and delay

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and IGBT firing. The chopper operation controller is the one who picks the most appropriate mode in response to processing several input signals such as speed, accelerator pedal, brake pedal, rate of speed, battery SOC and more [5-7]. Several control algorithms can be used and implemented such as self-tuning fuzzy, expert system, fuzzy logic, neural network and adaptive neuro fuzzy inference system [6-7]. In order to implement and tune the chopper operation control algorithms, it requires understanding on the EC driving patterns.

METHODOLOGY

For EV application withseries motor, the common half-bridge DC chopper offers no capability of regenerative braking, field weakening, generator and resistive braking. The proposed FQDC chopper is designed to overcome these limitations. It offers seven modes of operation that include drive, reverse, field weakening, parallel mode, regenerative braking, resistive braking and generator [5-7]. The schematic of the FQDC chopper design is shown in Figure 1.

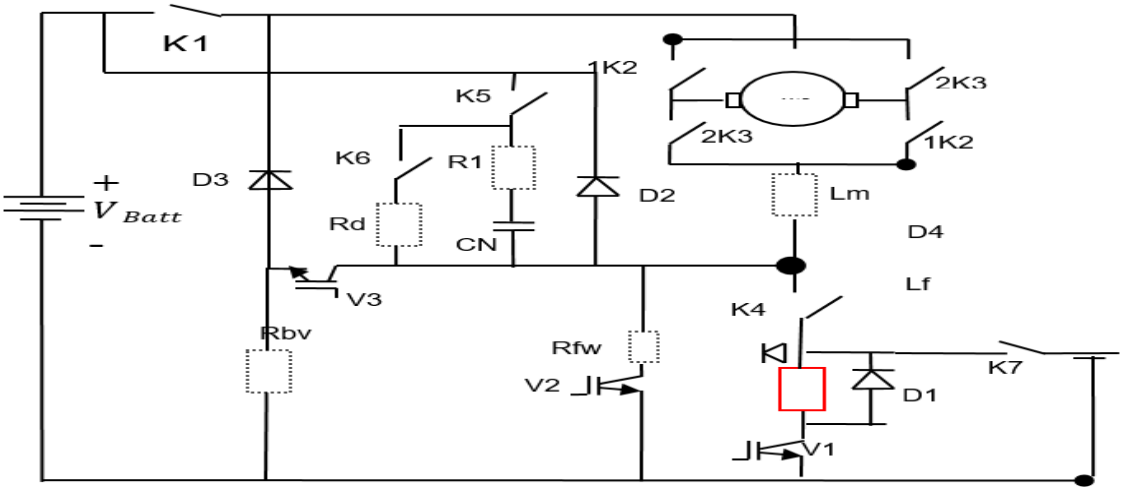

Figure1: Proposed four quadrants drive DC chopper

Electrical Vehicle Driving Pattern

There are three modes of driving in forward direction which are the drive mode for normal cruising, field weakening mode for fast driving with low load and parallel mode for climbing a steep hill. The reverse mode is meant for going backward when backing up the vehicle. The braking operation has two modes and they are the regenerative braking at high speed and resistive braking at low speed. Both braking modes slow down the EV while charging the batteries. The generatormode is solely used for charging the batteries like a conventional generator [1-3,5]. It is engaged when there is extra energy to be stored while the EV is moving or when the batteries need to be recharged while the EV is not moving.

In general, an EV will experience three driving conditions depending on the profile of the terrain it traverses on. The three driving conditions are cruising on a flat surface, moving downhill and climbing uphill as illustrated in Figure 2. The electric vehicle is also expected to carry a load which is low, medium or high. For a smooth operation, it is normal to consider the remaining battery power or battery State of Charge (SOC) and also the expected distance that can be covered with the remaining battery power. These two factors can be integrated in a single parameter called the ratio of the remaining SOC over the remaining distance traversed (RSOC/RDT).

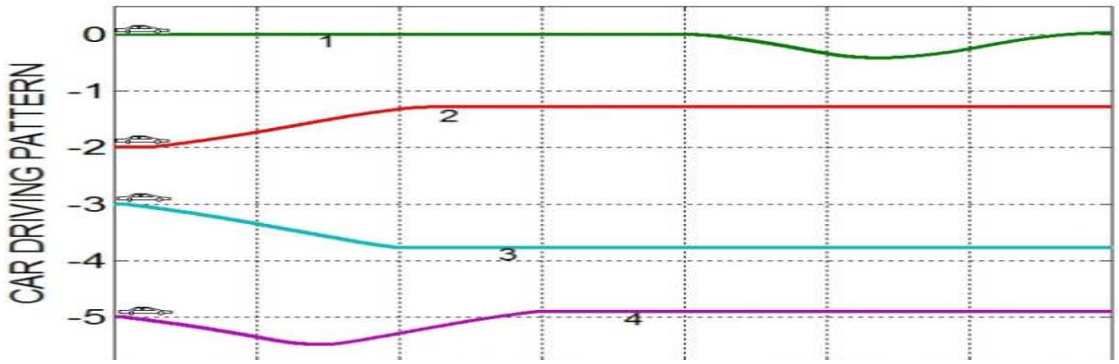

Figure2: different driving patterns

RESULTS AND DISCUSSION

A model depicted in Figure 3 is developed to simulate the operation of the FQDC. The simulation results are shown in Figure 4 to Figure 10. Various chopper operation modes were engaged and tested in this simulation.

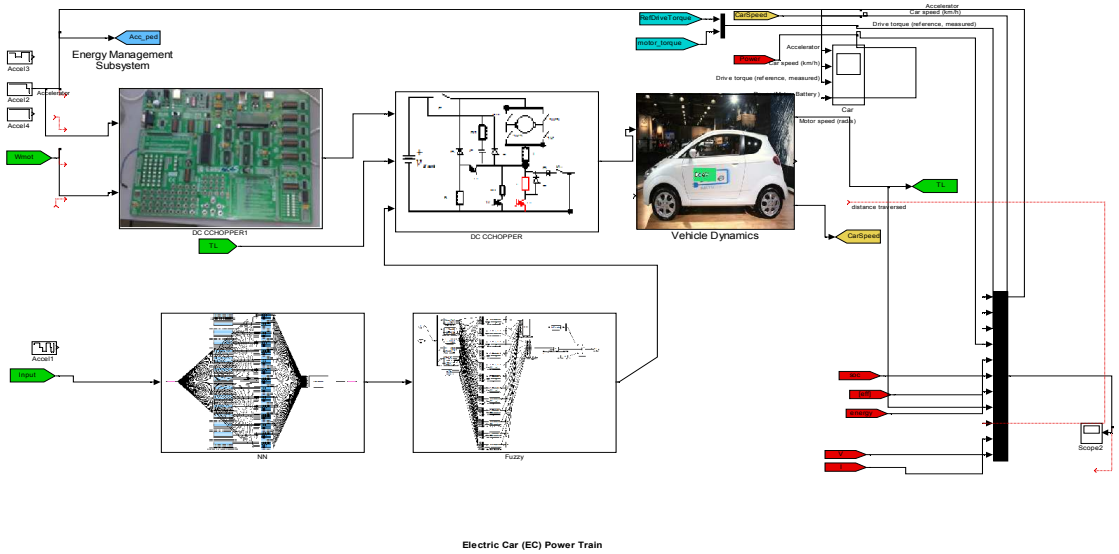

Figure 3: MATLAB/Simulink model

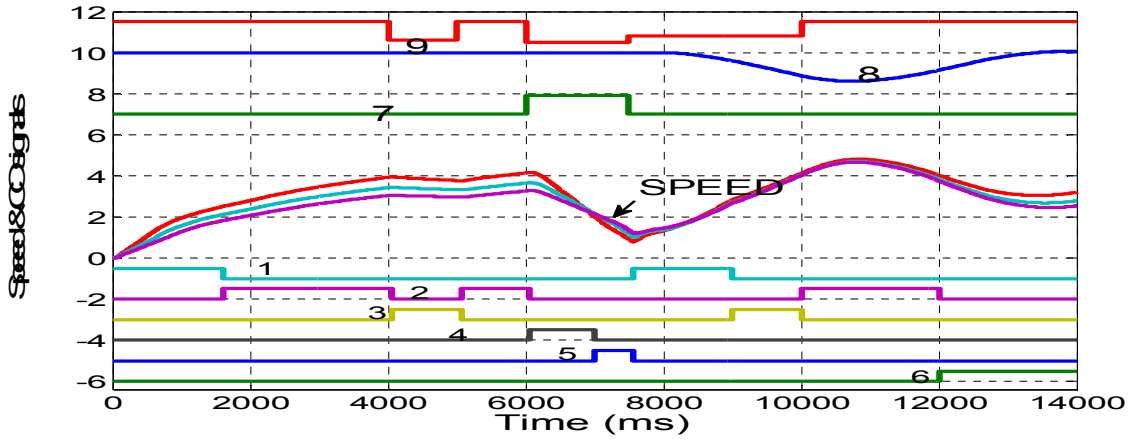

Figure 4: Modes, brake, accelerator and speed signals

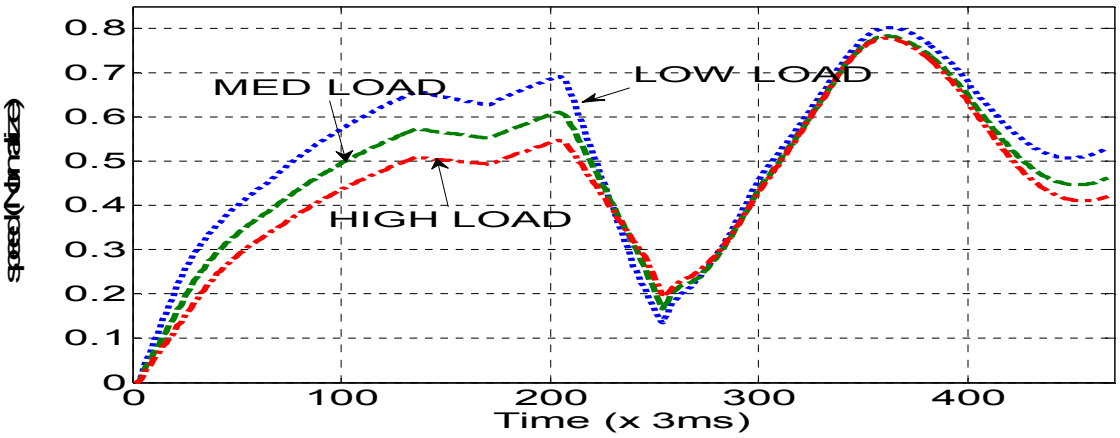

Figure 5: Speed with different loads

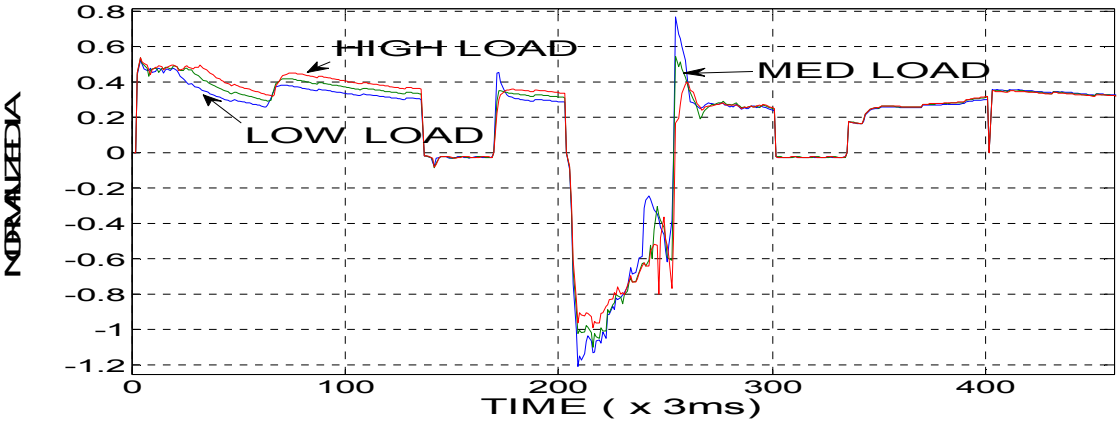

Figure 6: Armature current with different loads

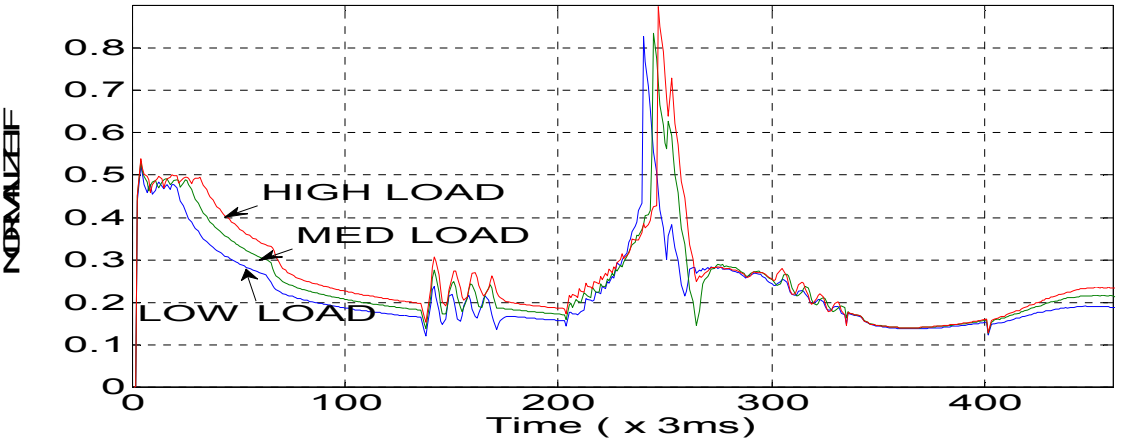

Figure 7: Field current with different loads

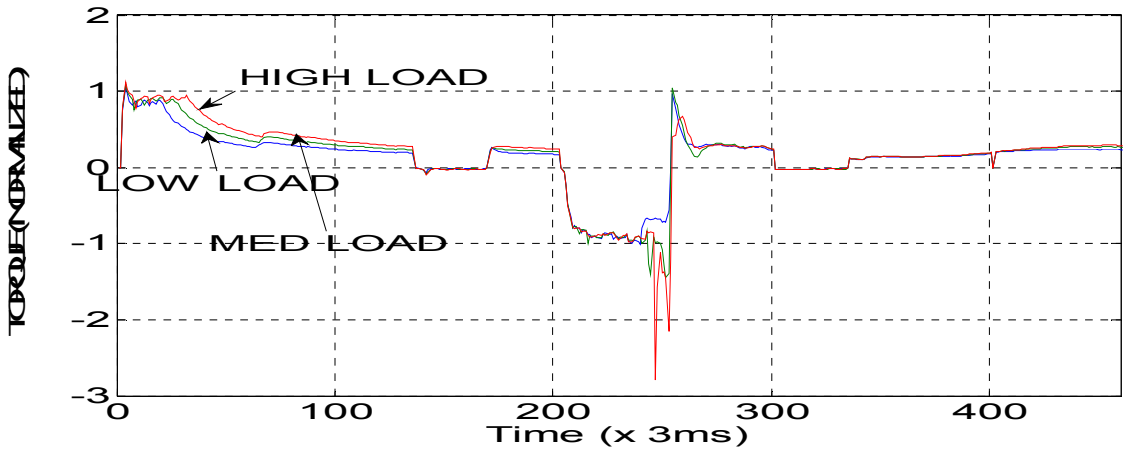

Figure 8: Motor torque with different loads

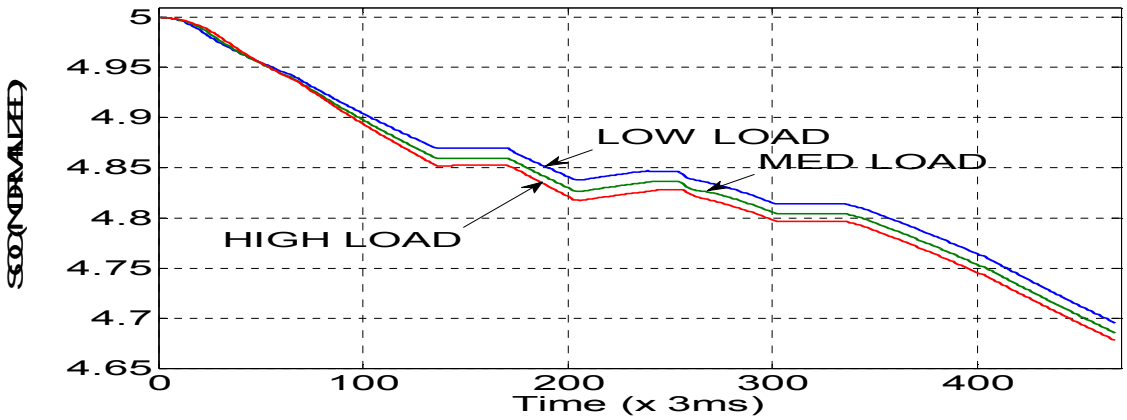

Figure 9: Battery SOC with different loads

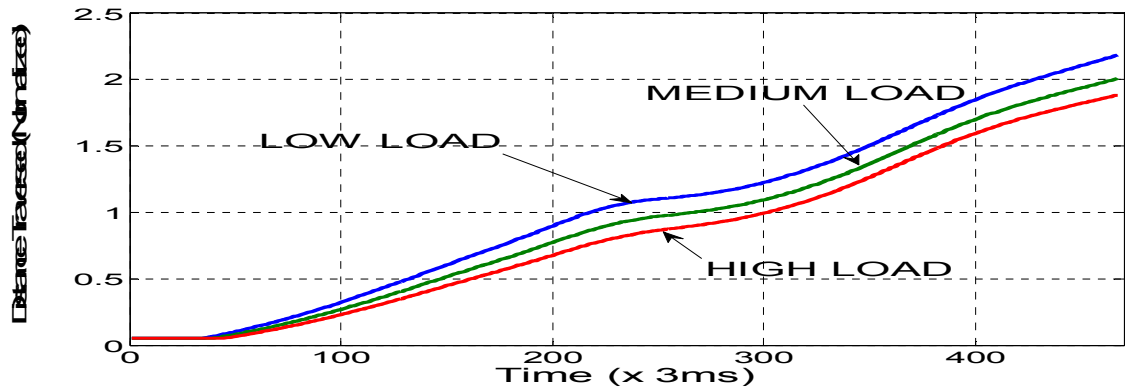

Figure 10: Distance traversed with different loads

In the simulation, the EV was subjected to a terrain profile represented by line 8 in Figure 4. The EV was made to carry three different load levels namely low, medium and high while traversing the terrain. Lines 1 to 6 represent the drive, field weakening, generator, regenerative braking, resistive braking and parallel mode respectively. For each mode, when the line level is high the mode is turned on by the FQDC and when its level is low the mode is turned off. Lines 7 and 9 are the brake pedal and accelerator pedal signal respectively. When the signal level is high the pedal is pressed and when the signal is low the pedal is released. The three lines marked "speed" in the figure are the speed of the EV with low, medium and high load respectively. They can be observed more clearly in Figure 5. At the start, when the accelerator pedal is depressed the drive mode is

engaged to build up speed. This is followed by the field weakening mode to maximize speed. When the accelerator pedal is released which indicates that the speed attained is sufficient the generator mode is turned on to charge the batteries. Later, when the brake pedal signal is received at high speed, the regenerative braking mode is initiated to slow the EV down. This is followed by the resistive braking mode to slow it down further when the speed is low.

While going downhill, when the accelerator pedal is lightly pressed, the drive mode turns on. As the speed continues to increase and the driving load is considered low, the drive mode stops and the generator mode starts. And when the accelerator pedal is pressed in full, the generator mode ceases and the field weakening mode commences to build speed quickly. Finally, as the EV starts to climb the steep hill and the speed starts to dwindle the parallel mode is activated. Figures 5 to 10 show the values of several parameters throughout the simulation. Figure 11 shows the SoC, RoS and Dt signals under three types of performance modes which are eco, normal and power driving. The eco mode is activated to save the battery power when the battery SOC is low. The normal mode is engaged when the SOC is not critical and the power mode is for spirited driving when the SoC is high. It can be observed that the SoC is decreasing while the vehicle load stays fixed. The error is obtained from the difference between the accelerator pedal and the vehicle speed. While the distance traverse (DT) monotonically increases, the rate of speed (RoS) varies accordingly. All of these signals have been normalized and they are used in designing the control algorithm for the chopper operation controller using expert system, fuzzy logic, neural network and ANFIS [5-7]

In Figure 12, the DC series motor outputs are plotted. They are torque, back emf (denoted by armature voltage (Va)), armature current (Ia), field current (If) and motor speed. The motor torque varies according to the operation mode selected. The torque is positive in all forward driving mode (drive, field weakening and parallel mode) and it is negative in the generator, regenerative braking and resistive braking modes. The field current changes accordingly but is always positive. The armature current can be positive or negative. The motor speed increases and decreases depending on the operation mode (driving or braking). All the signals in the figure have been normalized for easy plotting.

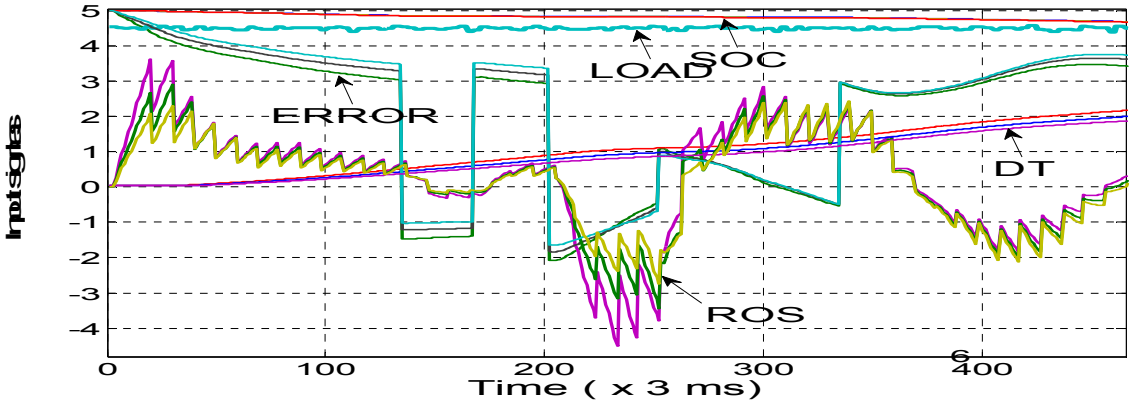

Figure 11: Signals error, RoS (rate of speed), Dt (distance traversed) with different loads

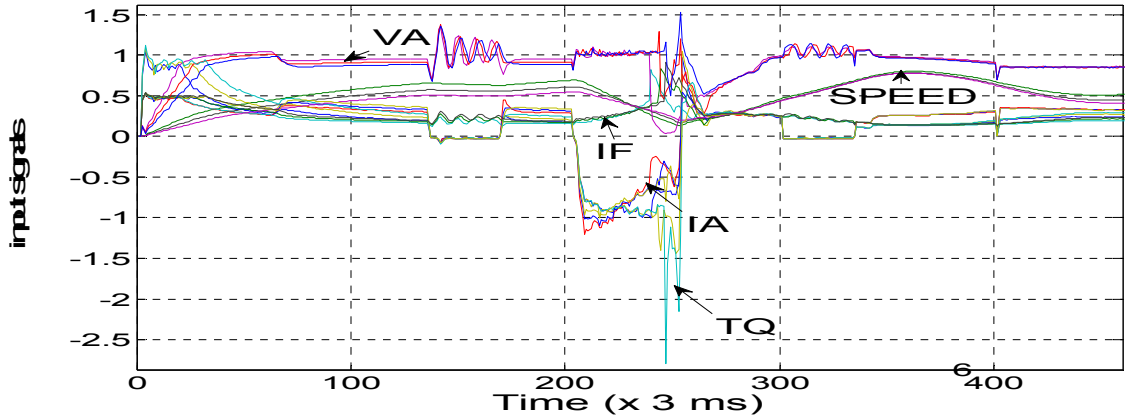

Figure.12: Signals VA (armature voltage), IA (field current), speed and motor torque with different loads

State of Charge (SOC) and Remaining Distance Traversed (RDT) Influence in Driving Pattern

The criteria for determining the chopper operation are also influenced by the SOC and RDT. For instance, if the state of charge is low and the remaining distance to travel is still high the controller should reduce the usage of battery power. The reduction percentage is influenced by the EV load. If the EV load is low, no drastic change is necessary to maintain the performance. Conversely, if the expected remaining distance to traverse is low but the SOC is high, the EV can run in power mode. The performance mode can be inferred from the ratio of the SOC and the expected remaining distance to traverse. If the SoC is critically low, the battery power can be further conserved by not operating the field weakening and the parallel mode because they use a lot of energy. Prolonging the generator mode can extend recharging time and increase the SOC. As a result the distance to traverse could be further extended. Figures 13 shows the operation of the same EV with low load traversing the same terrain.It can be observed that the parallel mode is absent and the drive mode is extended before the field weakening mode is engaged. Figure 14 shows that the eco mode has better SOC than that of the normal mode. Figure 15 confirms that the speed in eco mode is much lower than the one in normal mode and as a result the distance traversed over time is shorter as depicted in Figure 16.

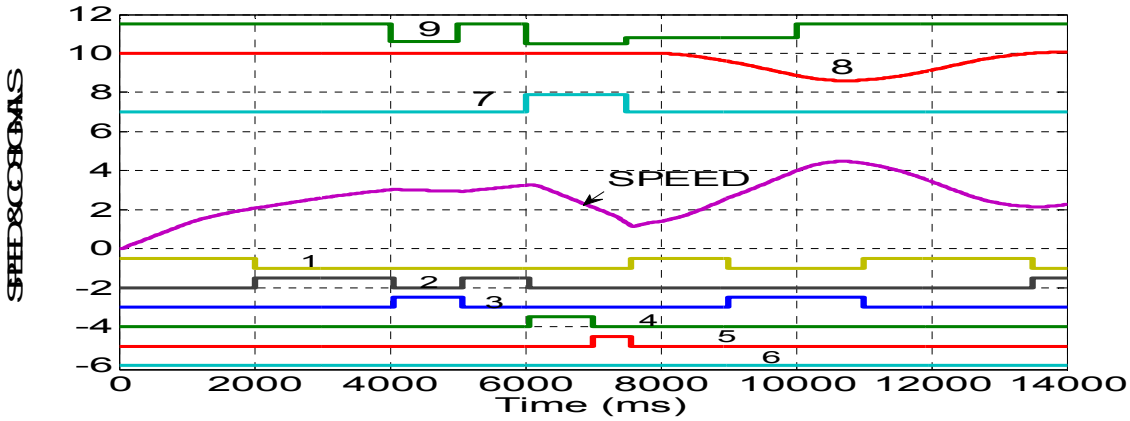

Figure13: Driving in saving power mode without parallel mode

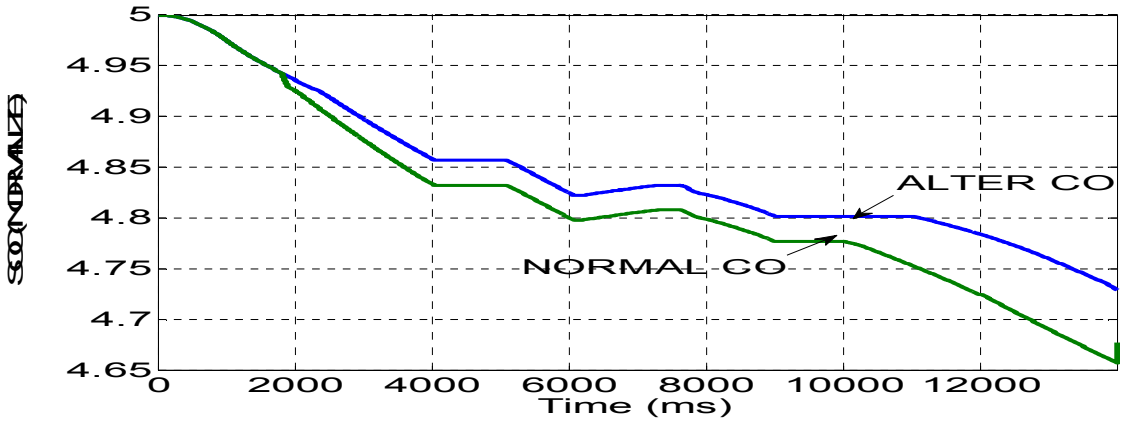

Figure 14: Battery SOC compared normal and saved mode

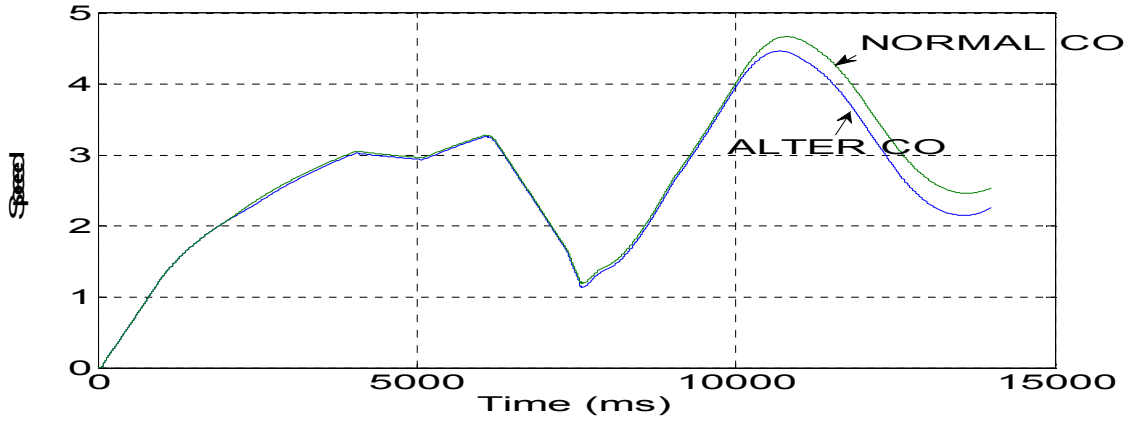

Figure 15: Speed compared normal and saved mode

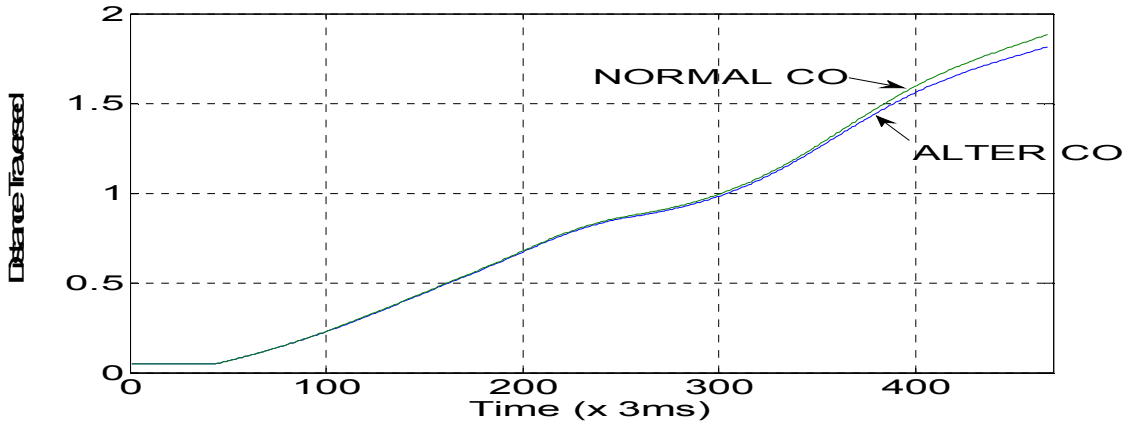

Figure 16: Distance traversed compared normal and saving mode

CONCLUSION

The FQDC chopper can handle several modes of chopper operation in response to different types of driving conditions, battery SOC and load levels. The parameters of the chopper can be adjusted to provide three types of performance modes which are normal, power and eco mode. The load has a definite influence in the driving performance and the SOC is a major factor to consider in designing the chopper operation and the control algorithm.

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