Simulation of Optimized Controller for a Propulion Drive PEV Based on SynRM

Shah Zanan Ali Kadhim

Abstract—**The global warming phenomenon increasing risks and the decrease of the available natural resources are two of the rezones that makes the need for electric vehicles (EVs). This paper present simulation and control for pure electric vehicle (PEV) components. The suggested PEV consist of two electric motors the been placed on the vehicle rear wheels without any reduction gears, rechargeable energy source, voltage source inverter, control interface system that controls each motor speed in the multi machine/ multi converter system and the electronic differential controller (EDC). Two synchronous reluctance motors (SynRMs) represents the propulsion system to the PEV. Space vector pulse width modulation (SVPWM) scheme proposed to control the motor by using variable input voltage. The Particle Swarm Optimization (PSO) is used to find the optimal parameters of the cascaded PID controller that controls the speed of the SynRM. A driving cycle has been designed to test the vehicle validity under different operation conditions and the resultant shows that PEV system gives a stable and suitable performance along the proposed driving cycle. The vehicle system is simulated and tested in the Matlab/ Simulink software package.**

Keywords*—*PEV, EDC, Driving Cycle, PSO, SVPWM

I. INTRODUCTION

The two main goals that aimed by many vehicles manufactures in all around the world are fuel economy and clean environment, so a new generation of vehicles has been to be environment friend and tried to meet these goals. PEV are completely differ from traditional vehicles, a PEV uses electric motors as propulsion or traction system and instead of using gear box the electronic differential controller (EDC) is used to control the linear speed of the vehicle. As expected in near future the market demand on electric vehicles (EVs) will increased [1, 2]. EVs are used as taxis and as personal cars to travel around in city because the presence of trains and planes to move for the long distant places. In this paper a propulsion type pure electric vehicle (PEV) is suggested. The drive system for the proposed PEV consist of two synchronous reluctance motors (SynRM). which does not need any winding or magnetic material on the rotor structure which make the motor rugged, simple in structure, lowest cost of manufacturing, high torque per unit volume, operating at very high speeds capability. SynRM have attractive features and make it famous choice for numerous industrial and applications. According to the previous features SynRM is the perfect choice for PEVs because the PEV may work in hard road environment such as hot, wet and may be full of chemicals and mud environment [3, 4]. The two SynRM are connected to the rear wheels of the vehicle. Fig. 1 shows EV propulsion chain. In this context variable speed operation or adjustable speed drives "ASD" of ac machines are majorly developed in the years and considered as a way to convert electric energy to mechanical work in a wide range of industrial applications, so to achieve high performance of speed control for the SynRM, Sensorless speed controller is typically required because of space and cost saving. The most popular sensorless control method is vector control method [5]. Vector control method have been used to control SynRM speed. In this control scheme the motor parameters are constants, the direct axis current in this control scheme is chosen to be constant and tried to make this current as small as possible. The speed control by the outer loop and the quadrature axis current controlled by inner loop. So mainly there are three loops that control both of motor speed and torque [6]. Each of the three loops are controlled by controller differ from the other controller. So cascaded PID controller is used to control the SynRM speed. PSO algorithm is used to find the optimum parameters for the cascaded controller. The results show that the optimized cascade PID controller is effective and efficient control over motor speed. In order to characterize the proposed PEV system performance, a topology is made which is called "driving cycle" which is carried out by using Matlab/Simulink environment. The driving cycle is applied to show the validity of the EV system under several speed and resistive torque variation. In the driving cycle many phases are applied each phase may have different speed and resistive force from the other.

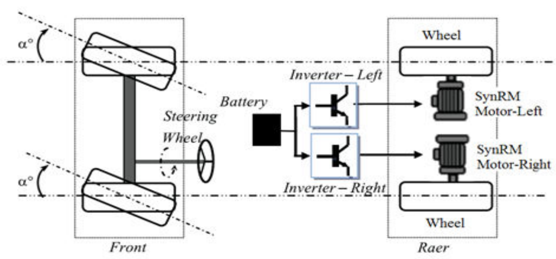

Fig. 1 EV propulsion chain

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II. PROPULSION MOTOR MODEL

Three phase SynRM model is good for analyzing motor under different operation conditions, but for appropriate control action three phase analysis are rarely used. So, the two axis SynRM model are mainly used for the control synthesis

$$V_d = R_s I_d + \frac{d\lambda_d}{dt} - \omega_r \lambda_q \qquad (1)$$

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$$V_q = R_s I_q + \frac{d\lambda_q}{dt} + \omega_r \lambda_d \quad (2)$$

$$\lambda_d = L_d I_d \quad (3)$$

$$\lambda_q = L_q I_q \quad (4)$$

Where L_d and L_q are the direct and quadratic axis winding self-inductance and measured in henri (H), R_s represent the stator winding resistance in ohm (Ω) and ω_r is the rotor angular speed in radian per second (rad/sec), the flux rate of change can be obtained as will be shown in equation (5) and (6) as follow.

$$\frac{d\lambda_d}{dt} = V_d - R_s I_d + \omega_r \lambda_q \quad (5)$$

$$\frac{d\lambda_q}{dt} = V_q - R_s I_q - \omega_r \lambda_d \quad (6)$$

And from equation (5) the rate of change of direct axis current can obtained in equation (7).

$$\frac{dI_d}{dt} = \frac{1}{L_d}(V_d - R_s I_d + \omega_r L_q I_q) \quad (7)$$

And from equation (6) the rate of change of quadratic axis current can obtained in equation (8).

$$\frac{dI_q}{dt} = \frac{1}{L_q}(V_q - R_s I_q + \omega_r L_d I_d) \quad (8)$$

The electromagnetic torque equation for SynRM can be obtained as follow in equation (9).

$$T_e = \frac{3}{4}\frac{P}{2}(L_d - L_q) I_d I_q \quad (9)$$

Where T_e represent the electromagnetic torque of the SynRM in Newton meter (N.M). The total torque equation is given below in equation (10).

$$T = \frac{3}{2} P(L_d - L_q) i_d i_q - \left(B\omega_r + J\frac{d\omega r}{dt}\right) - T_L \quad (10)$$

Where P the number of poles is pairs of the motor and load, J represent the moment of inertia coefficient of motor in kilogram square meter ($K_g M^2$), and T_L is the load torque to the motor in newton meter(N.M) and B is the viscous friction coefficient of the motor. Table I shows the motor parameters, tables data taken from the ABB motors company data sheet and Fig.(2) shows the Simulink model for the proposed SynRM [7, 8].

TABLE I
SYNRM PARAMETERS

Parameter	Parameter Value	Unite
Ld	6.0653	mH
Lq	0.9009	mH
Rs	0.269	Ohm
J	0.236	Kgm^2
B	0.00089	N.m.s
P	2	poles

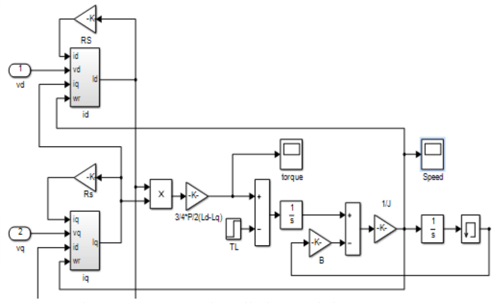

Fig. 2 SynRM Simulink Model

III. THREE PHASE VOLTAGE SOURCE INVERTER

The power electronic devices which are used to convert the DC voltage taken from any DC source (battery) into AC voltage (single phase, two phases, etc.). An inverter that feed synchronous motors are primarily used in variable v/f for the high-performance that required variable speed, such as fans, elevators and EVs. The space vector pulse width modulation (SVPWM) technique is the most popular pulse width modulation (PWM) technique because of its large output voltage, less harmonic distortion and better performance as compared with the other type of inverters, so the proposed inverter in this paper is SVPWM inverter. The switching status and the output voltage vectors depending on the SVM values are shown in Table II [9].

TABLE II

SWITCHING STATUS AND OUTPUT VECTORS

Voltage Vectors	Switching Vectors			Line to Neutral Voltages			Line to line Voltages		
	A	B	C	V_{an}	V_{bn}	V_{cn}	V_{ab}	V_{bc}	V_o
V_0	0	0	0	0	0	0	0	0	0
V_1	1	0	0	2/3	-1/3	-1/3	1	0	-1
V_2	1	1	0	1/3	1/3	-2/3	0	1	-1
V_3	0	1	0	-1/3	2/3	-1/3	-1	1	0
V_4	0	1	1	-2/3	1/3	1/3	-1	0	1
V_5	0	0	1	-1/3	1/3	2/3	0	-1	1
V_6	1	0	1	1/3	-2/3	1/3	1	-1	0
V_7	1	1	1	0	0	0	0	0	0

III. CASCADE CONTROL SYSTEM

The processes that have multiple variables in the input and output should be controlled are well-known as multi-input,multi-output (MIMO) or multivariable processes.

This type of control process is shown in fig. 3. Interactions usually exist or sometimes not exist between the control loops of multivariable processes, which is famed by difficulties in control when compare it with the control of single-input, single output (SISO) processes. The disadvantages of this type of control an exiguity of flexibility for interaction adjustment and when compare it with general multivariable control it has a few powerful tools for its design. SISO PID controller are tuned by control engineers, there is one simple way to tune a multi-loop PID controller by first tuning each individual loop one by one, and totally discarding the loop interactions and that is done by tune the (i) loop of cascade controller for the plant transfer. Then re-tuning all the loops together so that the overall system has stable performance and gives an acceptable load disturbance response [8].

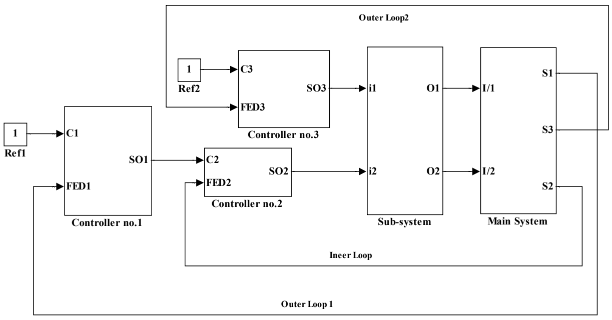

Fig. (3) Multi-Input\Multi-Output Control System

IV. PARTICLE SWARM OPTIMIZATION TUNING PID CONTROLLER PARAMETER

Particle swarm optimization (PSO) is a population depend on computational schemes that the main concept came from the simulation of social behavior (social-psychological methods) fish schooling, bird flocking and swarm theory [10, 11]. This theory has been made to be powerful in solving problems exhibiting the non-linearity and the non-differentiability. The scheme is obtained from research on swarm such as bird flocking and fish schooling. Accommodation to the results of research for a flock of birds, find that birds food by flocking (not by each individual). The fitness function is casted to maximize the constrains domain or to minimize the preference constrains [12, 13]. The criteria selection is depend on the system and the controller. In this paper the fitness functions are used depend on the Integral of Squared Error (ISE) criterion and overshoot (M_p) criterion as follow:

$$\text{Fitness function} = \min(\text{ISE}) + \min(M_p) \quad (11)$$

Where

$$\text{ISE} = \int e^2(t)dt \quad (12)$$

$$M_p = \max(n) - (n_{ref}) \quad (13)$$

$$e(i) = D(i) - y(i) \quad (14)$$

Where y(i) is the model output, and D(i) is the wanted output. While n is the actual speed, and n_{ref} is the reference speed. The velocity $v_i(t)$ and the current position $x_i(t)$ updating for each particle in the swarm are done in equations (15, 16). The velocity of each agent can be updated by the following equation.

$$v_i^{k+1} = w * v_i^k + c_1 * R_1 * (lbest_i - x_i^k) + c_2 * R_2 * (gbest_i - x_i^k) \quad (15)$$

And, the current position can be updated by the following equation:

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (16)$$

Where x_i^k is the current position of particle i at iteration k, v_i^k is the velocity of particle i at iteration k, w is the inertia weight which can be shown in equation(17), c_1, c_2 represent positive acceleration constants and R_1, R_2 are random variables distributed uniformly in the range [0; 1].

$$w = w_{max} - \frac{(w_{max} - w_{min})}{iter_{max}} \quad (17)$$

Where, w_{min} is the inital weight, w_{max} is the final weight $iter_{max}$ is the maximum iteration number. Table III shows the PSO parameter values[8].

TABLE III
THE VALUES OF PSO PARAMETERS

PSO_ Parameters	Value
Maximum iteration number	50
Size of the swarm " no of birds "	50
Dimension	20
PSO parameter c_1	1.2
PSO parameter c_2	1.2
Wmax	0.9
Wmin	0.2

V. ELECTRONIC DIFFERENTIAL CONTROLLER

The electronic device that ensure deliver a maximum torque value and it can control independently the two-driving wheel so that each wheel can turn at different speeds in any curve or at the same speed in the straight-line road is called EDC. According to the steering angle, EDC distribute the power to each motor [14]. The main beholding in the design of these EVs is to ensure that the vehicle is stabile when cornering and under slippery road conditions. The reference speed computation is the EDC task and depend mainly on the driver, vehicle dimension and the road condition. The linear speed and the steering angle that been given from the driver, which mean that these two inputs considered as the desired input or the reference to the EV system. At the beginning of a curve, the driver applies the curve steering angle on the steering, the EDC responded immediately and calculate the reference speed of each motor "each wheel" that should be running at, which is suited to ensure the stability of the EV performance inside the curve road by increasing the speed of outer motor and decreasing the speed of the inner motor [15,16]. The EDC calculates the exact reference speed that each motor should be rotating in and the amount of the power should be delivered to each motor independently. The mathematical model of the EDC can be represented as follows [17].

$$V_L = \omega_v \left(R + \frac{d_\omega}{2}\right) \quad (18)$$

$$V_R = \omega_v \left(R - \frac{d_\omega}{2}\right) \quad (19)$$

Where,

V_L is the left wheel linear speed.

V_R is the right wheel linear speed.

ω_v is the vehicle linear speed.

d_ω is the width of EV in meter.

R is the curve radius of the road and can be obtained as follows:

$$R = \frac{L_\omega}{\tan\delta} \quad (20)$$

Where, L_ω is the length of the EV, δ is the steering angle of the road. So, the angular speed in a curve road of each wheel can be obtained as follows:

$$\omega_L = \frac{L_\omega + \frac{d_\omega}{2}\tan\delta}{L_\omega}\omega_v \quad (21)$$

$$\omega_R = \frac{L_\omega - \frac{d_\omega}{2}\tan\delta}{L_\omega}\omega_v \quad (22)$$

The speed difference between the left and right wheels can be described as follows:

$$\Delta\omega = \omega_L - \omega_R = \frac{d_\omega\ .\tan\delta}{L_\omega}\omega_v \quad (23)$$

So the reference speed of each wheel motor can be obtained as follows:

$$\omega_{Lr} = \omega_v + \frac{\Delta\omega}{2} \quad (24)$$

$$\omega_{Rr} = \omega_v - \frac{\Delta\omega}{2} \quad (25)$$

The steering angle conditions under straight or curve road are shown below, Table IV shows the proposed EV parameters.

$$\delta > 0 \rightarrow Turn\ right$$
$$\delta = 0 \rightarrow stright\ a\ head$$
$$\delta < 0 \rightarrow Turn\ left$$

TABLE IV

ELECTRICAL VEHICLE ID PARAMETERS

d_ω	Width of Electric Vehicle	1.5 m
R_w	Wheel Radius	0.23 m
f_r	Rolling Resistance Force Constant	0.01
m	Vehicle Total Mass	$1000K_g$
ρ_{air}	Air Density	$1.2K_g/m^3$
A_f	Frontal Surface Area	$2.6m^2$
C_d	aerodynamic drag coefficient	0.32

VI. ELECTRIC VEHICLE RESISTIVE TORQUE

The EV is considered as a series loads described by many torques mainly "resistive torque". The resistive torque mainly consist of three resistive torques which are the rolling resistance, the aerodynamic resistance and the slope resistance. Fig. 4 show the forces acting on EV moving along a slope road [18].

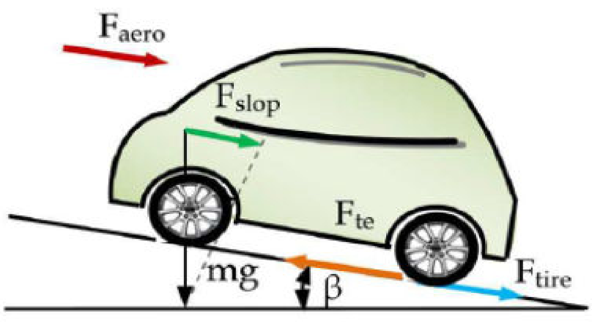

Fig. 4 The acting forces applied on EV moves along a slope road

The total resistive torques that act on EV system can be described as follows:

$$T_r = T_{tire} + T_{aero} + T_{slope} \quad (26)$$

VII. SYSTEM SIMULATION AND RESULTS

This section presents simulation and results for the EV system. The two motors drive system with vector control method, EDC, battery model and the vehicle load has been simulated. The drive system and the cascaded controller system are shown in fig.5. Table V shows the cascaded controller parameters that been tuned by PSO algorithm. Fig.6 shows the Simulink model of the EDC depending on equations (24 and 25). Fig. 7 sows the Simulink model of the resistive torques acting on EV system depending on equations (26 to 29). In Fig. 8 the driving cycle that been applied to the EV that consist of four phases applied, first phase with straight ahead with 80 Km/h, phase two steering with 80 Km/h at 5 sec with 1.5 steering degree, phase three uphill with 80 Km/h and 10 degree slope angle a at 10 sec time and fourth phase deceleration with 60Km/h at time 15 sec. The resistive force distribution is differ from one phase to the other. Fig. 9 shows the vehicle linear speed at second cycle. Fig. 10 shows the left wheel linear speed at first cycle. Fig. 11 the right wheel linear speed at first cycle. Figs. 12 and 13 shows the right and left wheels torque. The resistive torques that been applied in each phase are the resultant of the total forces applied to the vehicle and all the detailed given in table VI.

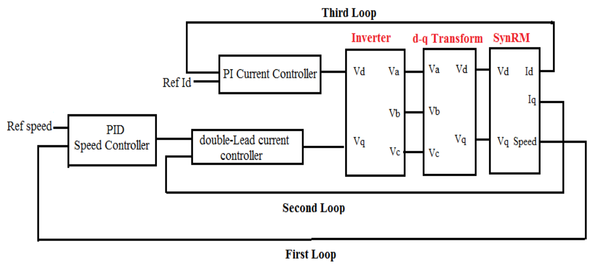

Fig. 5 The drive system and the cascaded controller

TABLE V

THE CASCADED PARAMETERS TUNED BY USING PSO

Controller type	Speed Controller Parameters			q-axis Current Controller Parameter	d- axis Current Controller Parameter	
Parameters	K_P	K_I	K_d	K_3	K_P	K_I
Values	200	8.8	0.749	20.879	2130	9.8

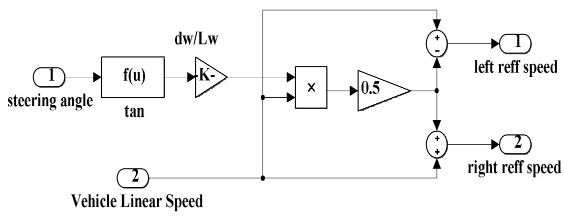

Fig. 6. Simulink model of EDC

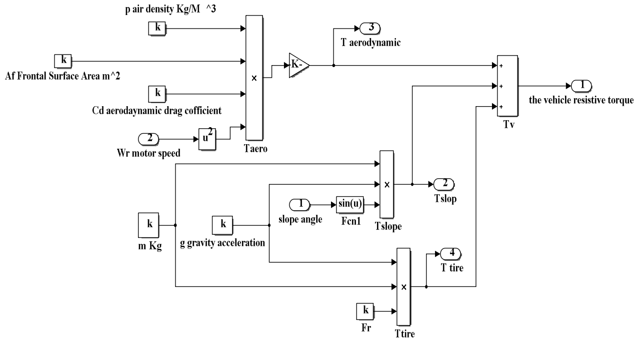

Fig. 7 Simulink model of the resistive torque acting on EV

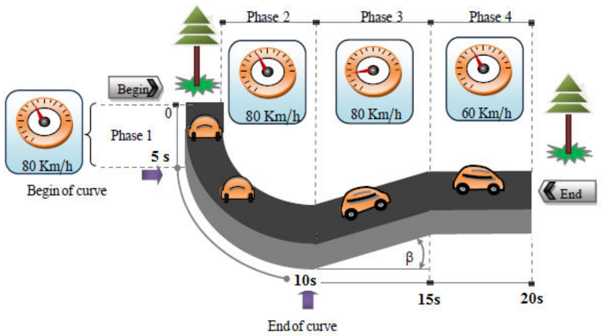

Fig.8 EV driving cycle

TABLE VI

DRIVING CYCLE RESISTIVE TORQUE DISTERPANCE

Phase 1	*Phase 2*	*Phase 3*	*Phase 4*
0-5 sec	*5-10 sec*	*10-15 sec*	*15-20 sec*
32.51 N.m Load	*32.51 N.m Load*	*32.51 N.m Load*	*29.14 N.m Load*

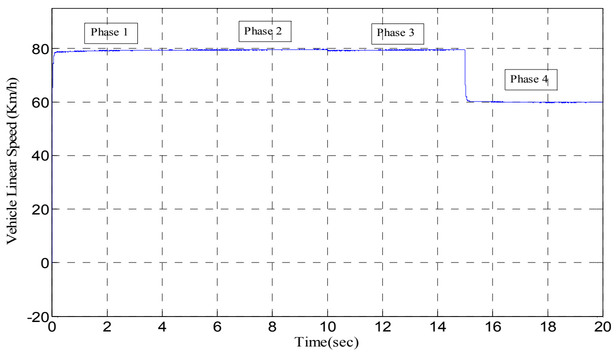

Fig. 9 Vehicle linear speed

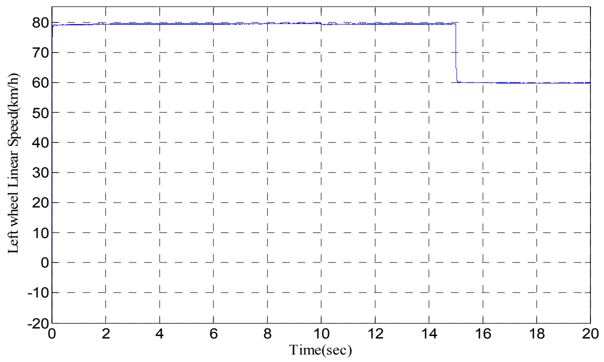

Fig. 10 Left wheel linear speed

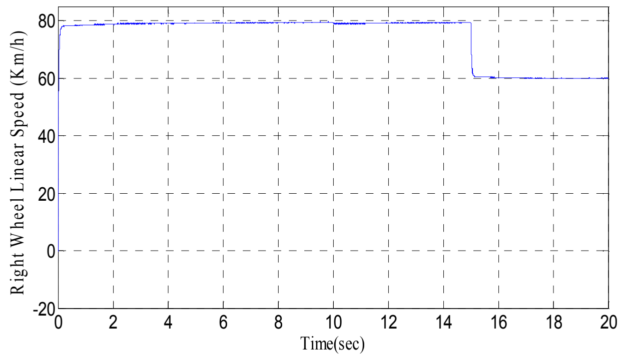

Fig. 11 Right wheel linear speed

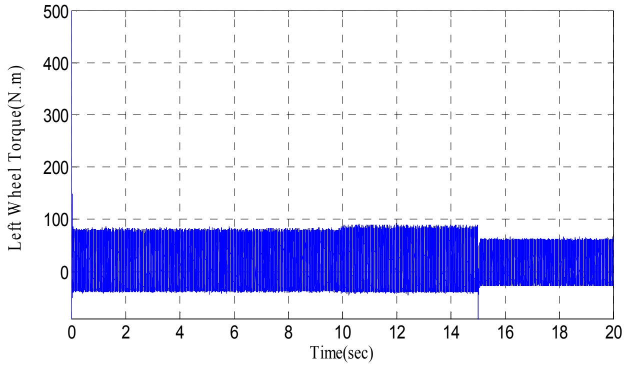

Fig. 12 Left wheel torque

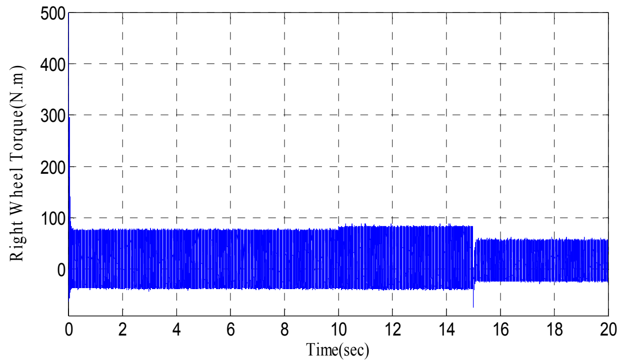

Fig. 13 Right wheel torque

VIII. CONCLUSION

This paper has concerned the simulation and control of the EV system by using Matlab/Simulink environment. The main motivation was due to the environmental and economic causes. In this paper the vector control method by depending on space vector pulse width modulation is used to control the two motors speed depending on multi-machine/ multi-converter system. The cascade controller is very difficult to tune manually and the loop intersection is the main cause of that difficulty, So particle swarm optimization is very suitable algorithm to tune the controller parameters. The linear speed of the vehicle is the resultant of average left and right wheels linear speeds. The EDC are used to control the vehicle stability. The EDC compute the required reference speed of each wheel depending on the road condition so that the vehicle have a suitable and stable performance. According to the results the proposed EV system have stable and efficient characteristics. The EV system is implemented and tested under various operation conditions. The proposed EV system give a suitable and stable performance along the road. The driving cycle was applied and the vehicle, the driving cycle show that the proposed vehicle is stable along the complete cycle tell the end of cycle.

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